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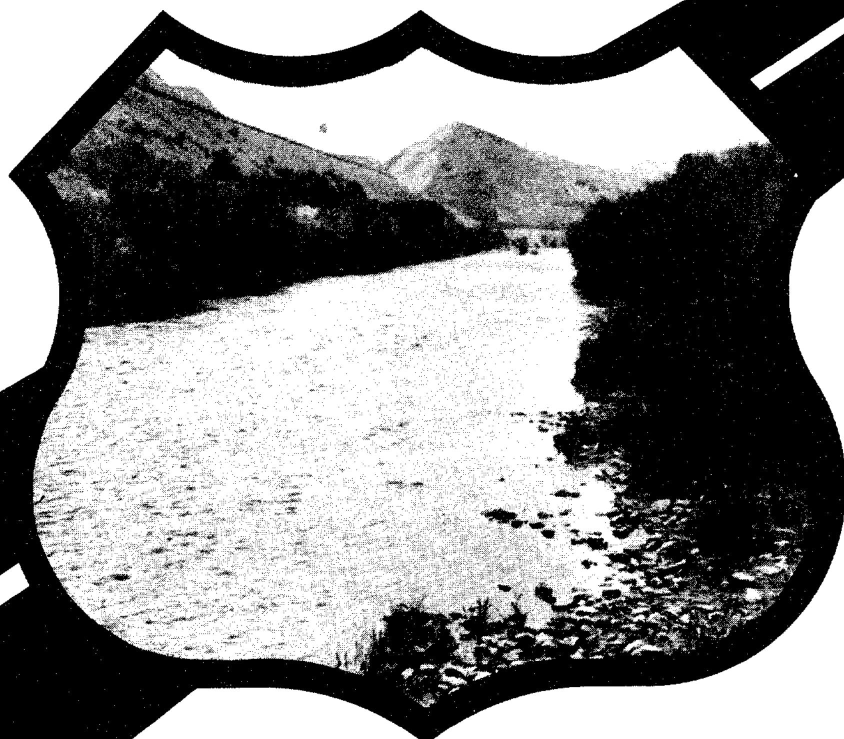
STABILITY OF RELOCATED STREAM CHANNELS

March 1981
Final Report



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FEDERAL HIGHWAY ADMINISTRATION
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Environmental Division
Washington, D.C. 20590

FOREWORD

This report describes the stability of streams that have been relocated for the purposes of highway construction. The study is an outgrowth of a previous research contract "Countermeasures for Hydraulic Problems at Bridges" (Research Report Number: FHWA/RD-78/162). Channel relocations serve as countermeasures by improving flow alignment at stream crossings or by otherwise reducing flood hazards.

Research in highway drainage and stream crossing design is included in Federally Coordinated Program of Highway Research and Development in Project 5H "Protection of the Highway System from Hazards Attributed to Flooding." Roy E. Trent is the Project Manager and Stephen A. Gilje is the Contract Manager.

Sufficient copies of the report are being distributed to provide a minimum of one copy to each FHWA regional office, division office, and State highway agency. Direct distribution is being made to the division offices.

Charles F. Scheffey
Director, Office of Research

NOTICE

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16. Abstract

Data gathered to document the stability of streams at 103 sites in different regions of the United States where stream channels were relocated for the purposes of highway construction indicate varied responses. In comparison with prior stream stability, bank erosion of the relocated channel was the same at 45 sites, better at 28 sites, and worse at 14 sites. Channel degradation, mostly minor, was discerned at 17 sites. Length of relocation contributed significantly to channel stability only at sites where its value exceeded 250 channel widths; below 100 channel widths, the effects were dominated by other factors. Among the factors identified as critical to the stability of relocated channels are: growth of vegetation on banks (40 sites); bank revetment (33 sites); and stability of prior channel (19 sites). Factors identifed as critical to instability are: bends in the channel (21 sites); erodibility of bed-bank materials (16 sites); and instability of prior channel (8 sites). Documented case histories of stream relocation projects on the scale done by highway agencies do not indicate the disastrous effects commonly associated with much larger scale river channelization projects.

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PREFACE

This study is an outgrowth of the project Countermeasures for Hydraulic Problems at Bridges (Brice and Blodgett, 1978). Channel relocation may serve as a countermeasure by improving the alinement of flow beneath the bridge or by reducing flood levels. The main purposes of relocation are to improve channel alinement at a crossing, to accommodate a planned roadway location, or to avoid one or more crossings. Because of regulations by various governmental agencies, engineers in many state highway agencies are now hesitant to recommend any relocation of a stream channel, even where minor changes would result in substantial savings in cost or probable increase in safety. However, the performances of past relocations, with particular regard to stability of the relocated channel and adjacent segments of the natural channel, have been investigated for few sites. The conclusions herein are based on case histories of 103 sites where channel relocations, or other alterations, were carried out by highway agencies mostly during the period 1960-70. This report has been prepared by the U.S. Geological Survey under an interagency agreement with the Federal Highway Administration.

Preliminary identification of many potential sites was obtained through Regional Administrators of the Federal Highway Administration, who reached engineers in their own organization and in state agencies. Particular thanks are due the members of state highway agencies who identified sites and furnished plans, aerial photographs, and information. This research was done under the general direction of Harry H. Barnes, Jr., Chief, Surface Water Branch, U.S. Geological Survey. District Chiefs of the Water Resources Division in Alabama, Montana, North Dakota, Minnesota, and Kentucky cooperated by obtaining ground photographs and field observations at ten sites.

Most of the plan sketches of channel relocations in this report are based on engineering drawings obtained from state highway agencies. In order to be presented in the format of this report, many of the drawings had to be reduced and generalized. An effort has been made to present the essential features accurately, but specific sources have not been attributed because of possible inaccuracies or misinterpretations. All photographs obtained from persons or agencies outside the Geological Survey are acknowledged in the appropriate figure captions.

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INTRODUCTION

Scope and objectives--The objectives of this study are to document with case histories the performance of a representative variety of natural stream channels that have been relocated or otherwise altered for purposes of bridge or highway construction; and to identify the critical factors associated with stability or lack of stability of altered channels. Streams altered by non-highway agencies, even though they may be crossed by a highway, are excluded. Also excluded is an evaluation of the biological and esthetic effects of alteration, except insofar as the removal and regrowth of vegetation may relate to stability. The physical effects of erosion-control measures, fish habitat structures, and structures such as bridges and culverts are within the scope of the study.

Site selection--According to general criteria, study sites were selected to represent major channel types and geographical regions of the United States, the kinds of alteration practiced by highway agencies, and practices in erosion control and stream rehabilitation. Specific criteria for site selection were (1) a minimum age (performance period) of about 10 years, (2) absence of extraneous man-induced influences, such as gravel mining or large-scale channelization by non-highway agencies, and (3) the occurrence of a flood of 10-yr or larger recurrence interval during the performance period.

In the final selection of the group of study sites, some of the specific criteria had to be modified in order to obtain a representative group of sites. In particular, the flood requirement was difficult to apply because many of the streams are ungaged and some are distant from the nearest gaged stream. In these cases, reliance was placed on regional flood histories or on field evidence of high-water marks. A few sites having short histories are included because of the effects of a major flood or changes even in the absence of a flood. In regions where most streams are channelized to some degree, as in parts of Iowa and Nebraska, a few sites are on streams that have been locally channelized by non-highway agencies.

From some states, notably Pennsylvania and Michigan, responses regarding sites where channel alterations had been made were obtained from all highway districts, and the list of potential sites was probably comprehensive. From others, only a few potential sites were obtained. Inasmuch as lists of potential sites were obtained from 22 states, it seems unlikely that the compilation of these represents any consistent bias; however, major alterations are more likely to be remembered by a respondent than are minor alterations, which may be under-represented. The geographical distribution of the 103 sites selected for study is shown in figure 1. Humid-region streams are well represented, both in mountainous terrain and in plains; but few sites suitable for study were obtained for arid and semiarid regions.

The representative nature of the group of study sites with regard to performance, whether good or poor, is difficult to ascertain, but the sites were drawn from a variety of sources in an effort to avoid bias against sites of poor performance: (1) Seven sites in Alabama are from a study by Jefferson (1965), written before most were adequately tested by time and flood. (2) All the streams altered along two interstate routes in Mississippi are included. (3) Eight sites in Oregon are from a study by McClellan (1974), done in consultation with Oregon State Game Commission biologists. (4) Four sites in Iowa are from a study of the effects of stream channelization on fish (Bulkley, 1975). (5) Twelve sites (sites 10, 11, 24, 26, 28, 39, 40, 45, 89, 93, 98, 99) came to attention specifically because of hydraulic problems at bridges or along the channel. Conversely, no sites came to attention specifically because of good performance.

Organization and collection of data--To standardize data collection and analysis, factors most relevant to channel stability were divided into three sets, called (1) site factors, (2) alteration factors, and (3) post-alteration factors. The factors in each set are listed and discussed more fully in separate chapters of this report.

Site factors include geomorphic and hydrologic information about the site, such as drainage area, discharge, channel slope, stream type, and vegetal cover along the streambank. Hydrologic data were compiled from reports and from District Offices of the Geological Survey. Geomorphic data are from topographic quadrangle maps of the Geological Survey, from airphotos, and from field study. For most sites, time-sequential airphotos were acquired from the U.S. Department of Agriculture, from the U.S. Geological Survey, or from the state highway agency.

Alteration factors include the type and purpose of alteration, and the changes in channel length and cross-section consequent upon alteration. Only cross sections of the channel as designed or "typical" cross sections of the channel as built were available for comparison with the cross sections as subsequently modified by natural processes. Actual surveys of the altered channel, if made at the time of completion, are evidently not kept on file by highway agencies. Hydraulic design factors, such as design discharge and velocity, were not available for most sites.

Post-alteration factors include length of performance period, number and recurrence intervals of floods, and growth of vegetation along the streambank.

Previous work--Few publications on the physical performance of stream channels altered by highway agencies were found in the literature. Jefferson (1965) reported on nine sites in Alabama where channel alterations had been made

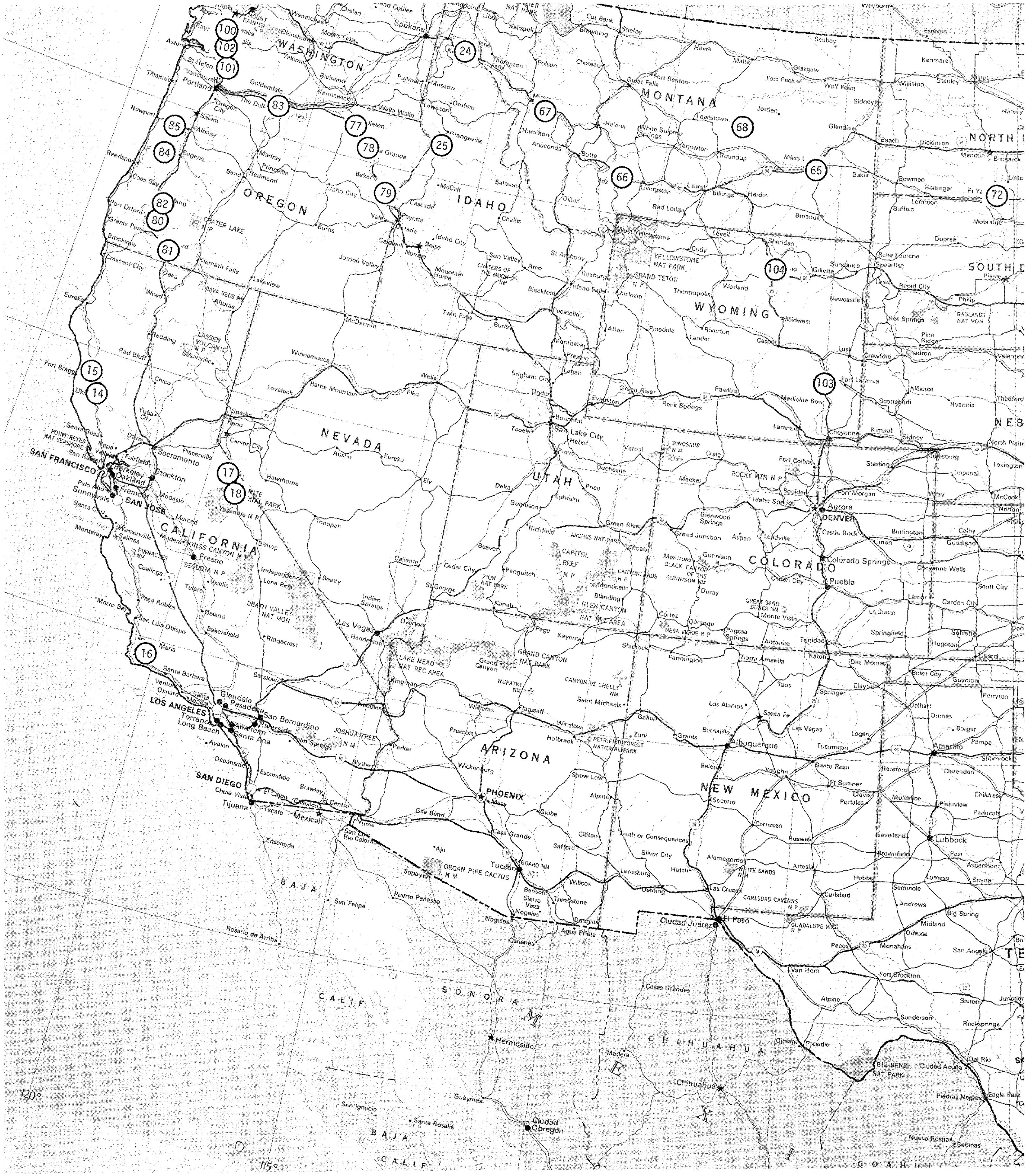
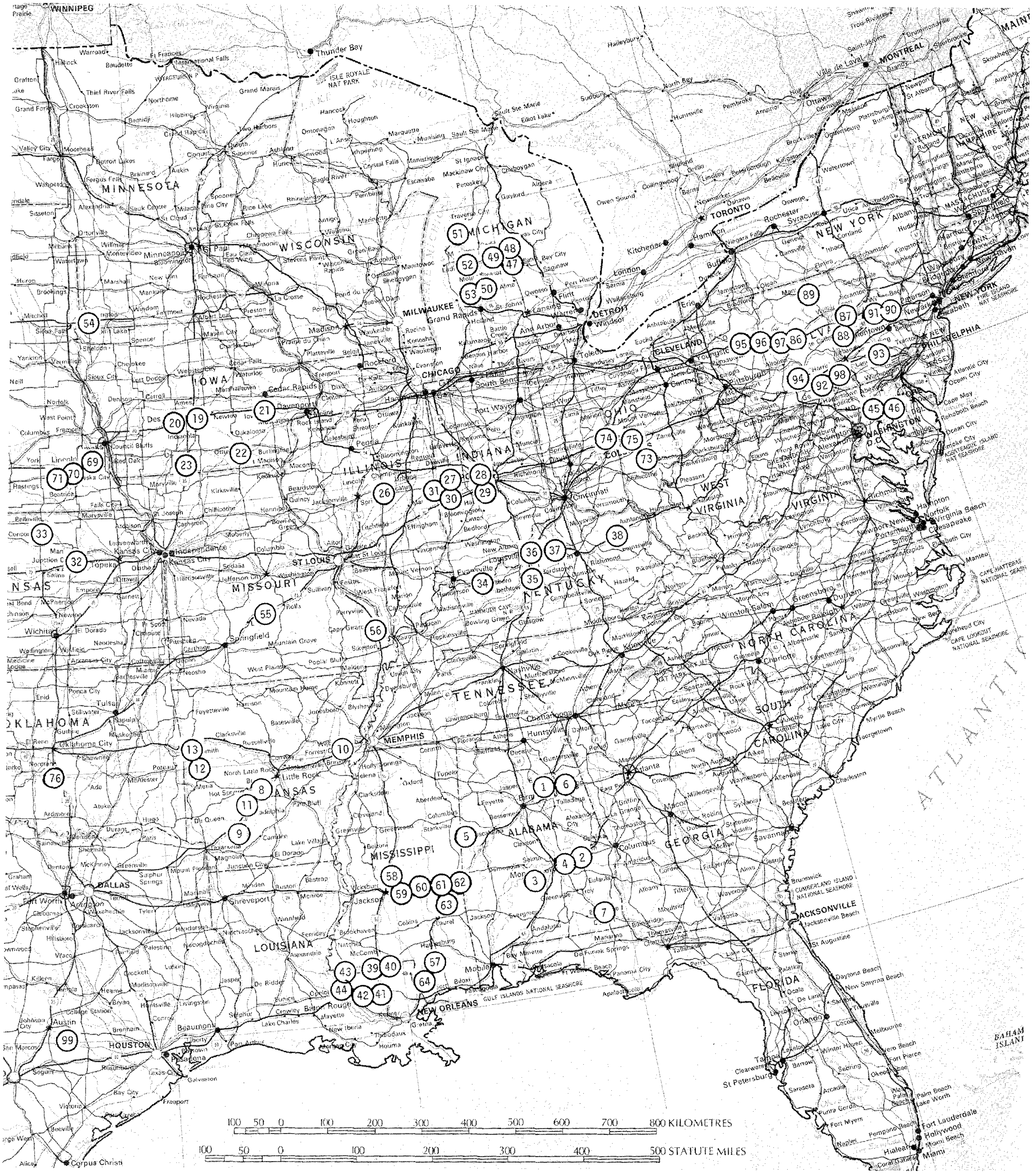


Figure 1. Geographical distribution



of study sites.

during the period 1951-63. The altered channels were either functioning as planned or were too new for valid evaluation of performance. Yearke (1971) measured erosional effects consequent upon relocation of Peabody River in New Hampshire, which amounted to a maximum local degradation of 3.6 m and a maximum local increase in channel width by a factor of four. McClellan (1974) investigated 18 highway-related channel alterations in Oregon. His main purpose was to evaluate the natural recovery of fish and game habitat, but some of his observations apply to channel stability. In a study of countermeasures for hydraulic problems at bridges, Brice and Blodgett (1978) found channel alterations at 11 or the 224 sites investigated. At most of these altered channels, problems occurred during floods exceeding the design flood. Three of the 11 sites are included in the present report.

Stream channelization refers to the straightening, enlarging, or snagging of channels for flood control or drainage purposes. The length of channel involved in a single project is much greater than in a typical highway-related project. The physical and biological effects of stream channelization (modification) have been assessed in a report prepared for the Council on Environmental Quality by the Arthur D. Little Company of Cambridge, Mass. (1973) and, under subcontract, by the Academy of Natural Sciences of Philadelphia, Pa. The report is based on literature research and on a field study of 42 channelization projects. The following aspects of, or issues relating to, channelization are assessed: (1) wetland drainage, (2) clear-cutting of hardwood trees, (3) elimination of oxbows and straightening of meandering channels, (4) changes in water table levels and stream recharge, (5) downstream effects, (6) erosion and sedimentation, and (7) channel maintenance. The physical assessment was made by members of the Arthur D. Little Company and the biological assessment was made by the Academy. For the 42 projects, the length of natural stream channel affected by modification ranged from 161 m to 954 km, and the median length was 26 km. By comparison, at the 103 highway-related channel relocations reported herein, the length of natural channel ranged from 0.07 to 4.2 km and the median length was 0.65 km.

Among the statements in the Arthur D. Little report that are relevant to the present study are the following:

> "It may serve to illuminate the overriding issue to suggest that the degree of physical effect seems strongly correlated with size of channel works . . . minor effects on small projects, relatively modest or uncertain effects of intermediate-size projects, pronounced effect on large projects." (p. 192)

> "The first listing that follows describes projects with low actual or potential contributions to erosion and sedimentation problems within the project areas. The conditions favoring this classification are: (1) short channelized reach relative to land-water system, (2) slight design gradient, (3) moderate design velocities, (4) moderate channel bank design slope, (5) limited excavation, (6) limited realignment, (7) riprapping or concrete lining of critical areas, (8) seemingly stable channel beds, (9) banks stabilized by revegetation, and (10) mitigation measures such as drop structures or sediment traps in upstream reservoirs to reduce sediment transport." (p. 182)

> "Channel maintenance offsets stream recovery and lack of channel maintenance permits gradual stream recovery. However, Academy studies indicated that no stream that had been channelized had completely recovered its natural species diversity and productivity, even if it was not maintained." (p. 267)

The environmental, geomorphic, and engineering aspects of channelization were briefly summarized by Keller (1976), who discussed new engineering design trends and recommended that future necessary channelization be confined to the shortest possible length of channel and provide the least amount of artificial control necessary to meet the desired objectives of the project. Among the few channelized streams for which detailed case histories have been published are the Blackwater River in Missouri (Emerson, 1971); the Willow Drainage Ditch in Iowa (Daniels, 1960); the Big Pine Creek Ditch in Indiana (Barnard, 1977); and the Homochitto River in Mississippi (Wilson, 1979).

In general, the number of published works on the biological effects of channelization far exceed those on the physical effects. The biological effects, particularly with regard to fish, are perhaps of more general interest and are immediately evident, whereas the stability (or instability) of a relocated channel may not become evident for many years.

CHANNEL STABILITY AND INSTABILITY

DEFINITION

Ideally, a stable channel is one that does not change in size or position through time. All alluvial channels change in size or position to some degree and therefore have some degree of instability. A stream that has attained equilibrium (grade, regime) is not necessarily stable in the practical engineering sense: It may migrate laterally, at a rate hazardous to engineering structures or other property, while maintaining its equilibrium slope and cross section.

Equilibrium is a useful concept for predicting qualitatively the probable response of a channel to a change in one of the variables that control its form and behavior, but there are no objective observational criteria for deciding whether or not a given channel has attained a state of equilibrium. A natural alluvial channel is commonly assumed to have attained, or approached, a state of equilibrium unless there is clear evidence for recent degradation or aggradation. Stability, on the other hand, needs to be assessed by observational criteria or indicators.

In stream morphology, a much-quoted definition of a graded stream is that of Mackin (1948, p. 471): "A graded stream is one in which, over a period of years, slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin. The graded stream is a system in equilibrium; its diagnostic characteristic is that any change in any of the controlling factors will cause a displacement of the equilibrium in a direction that will tend to absorb the effect of the change." Leopold, Wolman, and Miller (1964, p. 266) suggested that Mackin overemphasized the role of slope, and Rubey (1952, p. 129-134) has shown the importance of adjustments in channel cross section. Thus, if a relocated channel has a steeper slope than the prior (natural) channel, it should theoretically be possible to offset the slope increase and attain a new equilibrium by constructing the new channel with a wider, less efficient cross section.

KINDS OF CHANNEL INSTABILITY

The kinds of channel instability are classified as follows (fig. 2):

- Lateral instability
  - Change in channel width
  - Change in position by lateral erosion and accretion
  - Change in position by avulsion
- Vertical instability
  - Degradation
  - Aggradation

In figure 2A, lateral erosion of both channel banks resulted in an increase in channel width. In figure 2B, the rate of erosion of one bank at a bend is matched by rate of lateral accretion at the other, such that the position of the channel changes while its cross section remains the same. In figure 2C, a meandering thalweg within a wide channel has eroded the banks laterally at points of impingement. Change in channel position by avulsion is not illustrated in figure 2. Avulsion refers to a sudden change in channel course, as would be brought about by the breaking through of natural or artificial levees during flood, or by flow that breaks through the banks at one point and reenters the channel at another point downstream. In a sense, abandonment of a relocated channel by a stream, and reoccupation of the prior channel, might be regarded as avulsion. No examples of this were found among the study sites.

Vertical instability is illustrated in figure 2D and E. Degradation (fig. 2D) is defined as the general and progressive lowering of the longitudinal profile of a channel by erosion. It is commonly regarded as a probable, if not inevitable, consequence of the shortening of channel length by relocation, but few examples of it could be documented. Aggradation (fig. 2E) is defined as the general and progressive upbuilding of the longitudinal profile of a channel by deposition of sediment. It may occur in an overly wide relocated channel or in a natural channel downstream from an unstable relocated channel. However, few examples of aggradation could be documented. The formation of berms by accretion or slumping along the banks of an altered channel, cited as detrimental to habitat in the Arthur D. Little report (1973, p. 265), is not regarded here as aggradation.

ASSESSMENT OF STABILITY

Precision in the assessment of stability, and in the placement of a relocated channel into a particular stability category, is not likely to be attained because erosion varies in degree through space and time. For example, bank erosion may affect all or any part of the bankline and it may range in degree from barely perceptible to severe in a short distance. In addition, banks that are unstable soon after construction may become stable in a few years, or banks that are initially stable may become unstable. Nevertheless, the placement of channels into stability categories seems necessary for the objectives of the project, and a scheme was developed for this purpose. A channel is placed into one of four categories (designated A-D) according to an evaluation of the recent stability of its banks (fig. 3); and also into

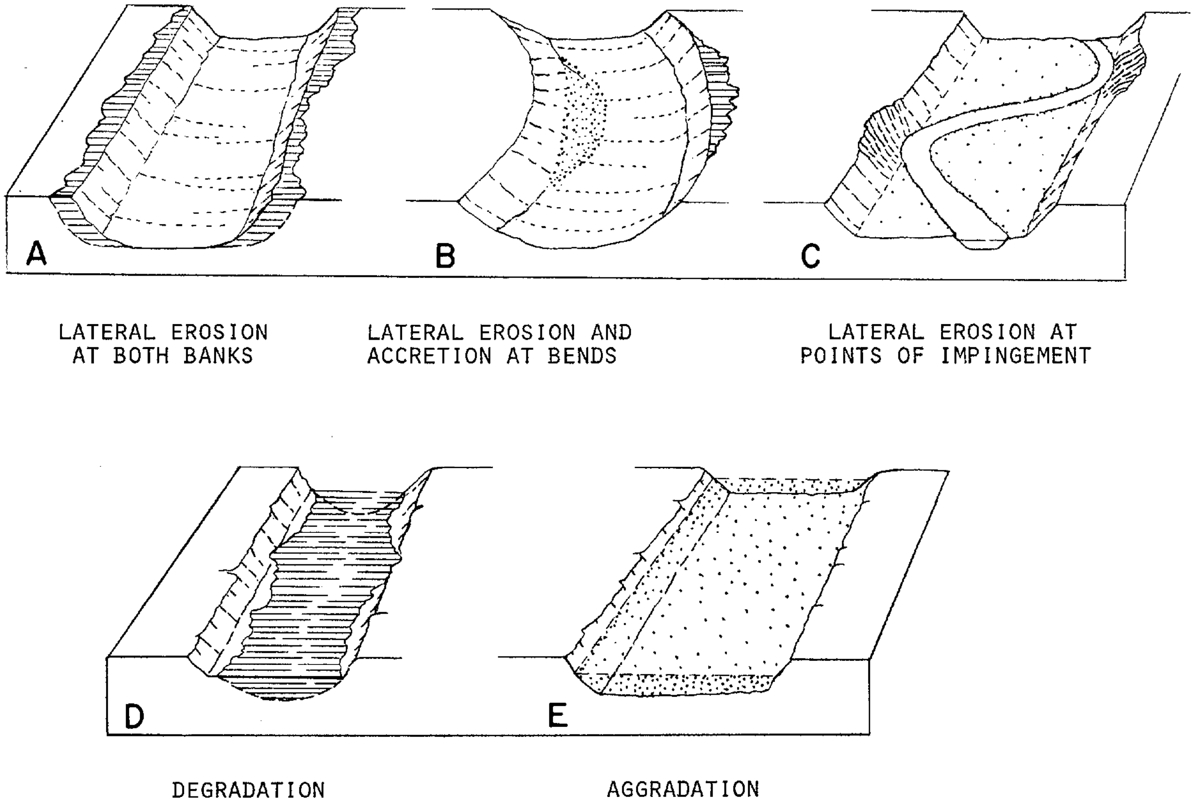


Figure 2. Kinds of channel instability. Eroded areas are indicated by horizontal ruled lines.

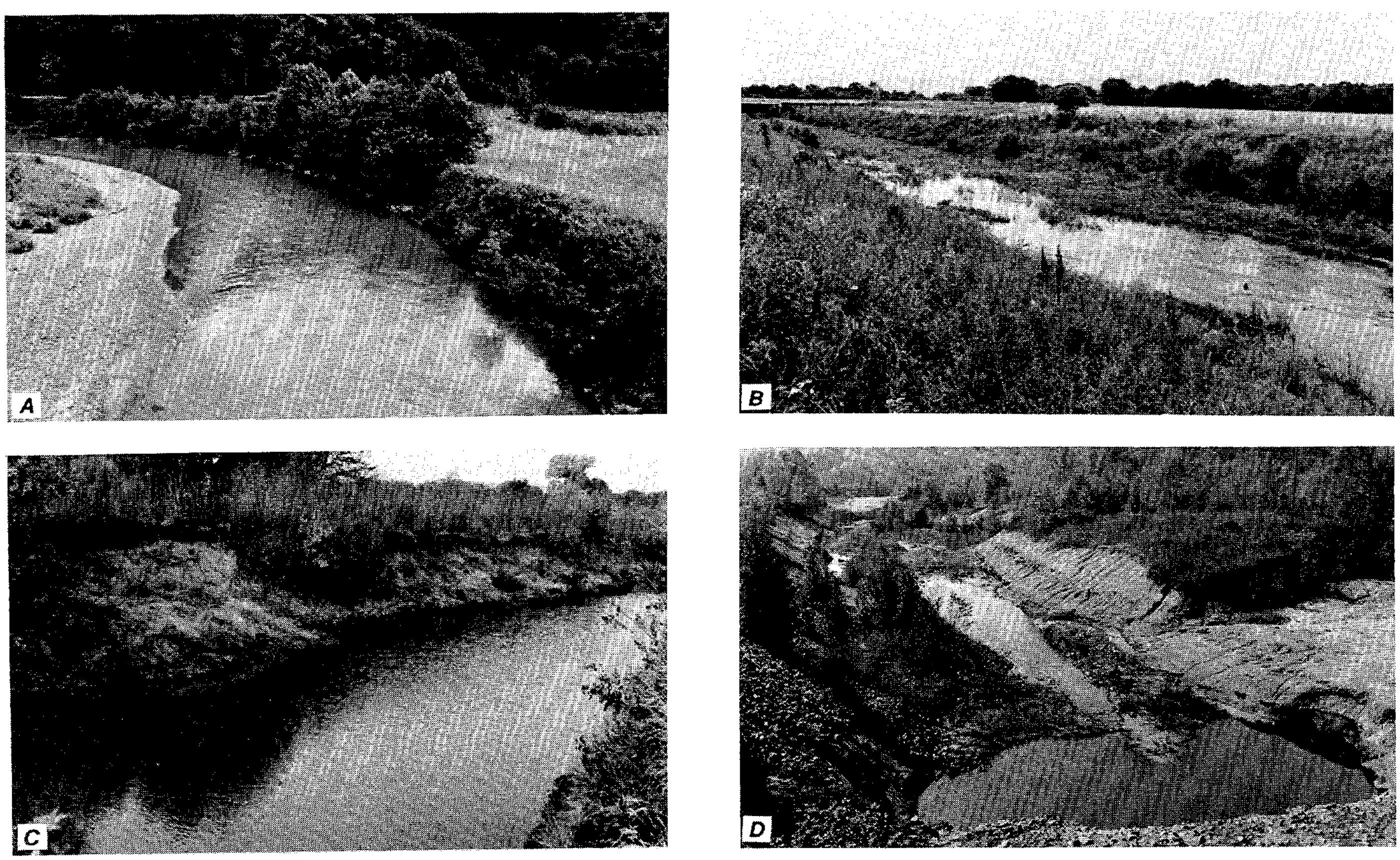


Figure 3. Photographs illustrating bank stability classes. Class A, cut banks rare or absent, Hocking River, Ohio. Class B, cut banks local and not severely cut, Poteau River, Ark. Class C, cut banks local but severely cut or slumped, Big Blue River, Nebr. Class D, banks generally cut or slumped, Crow Creek, Ark.

one of four categories (designated 1-4) according to its dimensional changes during the performance period. In outline form, the scheme is as follows:

<u>Cut or slumped banks along channel at end of performance period</u>

A. Rare or absent
B. Local only, and not severely cut or slumped
C. Local only, but severe
D. Generally cut or slumped

<u>Dimensional changes during performance period</u>

1. No significant change in width or depth (less than 5 percent of initial value)
2. Minor changes (in range of 5-20 percent)
3. Major local changes (greater than 20 percent)
4. Major general changes (greater than 20 percent)

Deficiencies in the scheme, apart from the practical difficulties of making the required measurements and judgments, are readily apparent. With regard to recent stability, only banks are considered, and any degradation or aggradation that may be in progress is neglected because it cannot be detected for any particular moment or short span of time. In addition, some combinations of severity (severe, not severe) and distribution (local, general) are deleted in order to simplify the scheme. With regard to dimensional changes, the percentage values given are arbitrary. If a natural channel were to change in dimensions by 20 percent over a 15-yr period, and continue to change at this rate, it would be regarded as decidedly unstable. However, a reasonable amount of evidence indicates that any dimensional changes in an altered channel are likely to be most rapid in the first few years after construction and to decrease thereafter. Most of the changes in width and depth reported in the case histories are increases. A decrease in width is not regarded as indicative of instability (although it may reduce channel conveyance below a desired value); but a decrease in depth indicates aggradation.

The occurrence and severity of bank cutting was judged from field observation supplemented, for most sites, by study of the most recent airphoto. Bank cutting can be difficult to observe in the field or on airphotos, for channels having densely vegetated banks and, in particular, overhanging trees. Densely vegetated banks were usually assumed to be stable unless fallen trees were observed. Changes in width were determined by comparison of bottom width on design cross section with bottom width as measured in the field or on airphotos.

Change in depth was assessed by comparison of bank height as observed in the field with bank height on design cross sections. This is admittedly approximate, and minor changes in depth (minor aggradation or degradation) have not been detected. However, refined field measurements are not warranted because accurate cross sections or longitudinal profiles of the channel as built are rarely available for comparison. In Alabama, an attempt was made to resurvey channel cross sections that were initially surveyed in the mid-1960's; the results of this were not conclusive, either because original survey markers could not be found or because the as-built channel dimensions were not accurately known.

All field observations of channels were made at periods of low or "normal" flow, because most field trips were scheduled for the fall. At high stages, bank height and bottom width are not easily measured and other observations relating to channel stability are not feasible.

<u>Stability of relocated channels at study sites</u>--The number of relocated channels in each assigned stability class, as well as the kind of instability identified at specific sites, is shown in table 1. Channels lined with concrete pavement (sites 45, 91, and 99) are not included in the tabulation. In the few cases where the relocated channel was evidently intended as a pilot channel (sites 7, 19, 23, 76), widening was not regarded as an indication of instability. At most of the sites listed under "degradation", the amount of degradation was minor and the identification somewhat tentative; however, the degradation at site 89 is definite, and major degradation is being controlled by check dams at sites 10 and 11. No major aggradation was observed at any site. Development of bars in a channel is not necessarily evidence for aggradation, nor is the presence of vegetation on the channel bottom, although vegetation may induce aggradation. Channel bottoms covered by non-woody vegetation were observed at sites 12, 26, 27, and 42.

<u>Stability of natural channels at study sites</u>--Where possible, the natural channel at a study site was assigned two stability ratings, one applying to its condition prior to alteration and another to its condition at the end of the performance period. The rating after alteration applies to the natural channel segments at either end of the relocated segment and extending upstream and downstream for about one or two km, depending on stream size.

Some effect of the relocated segment on adjacent segments of natural channel was discerned at 21 of the 87 sites for which prior stability was assessed (table 2). In general, the effects discerned were within a distance of 10-20 channel lengths from the ends of the relocated segment. At site 22 (Soap Creek, Iowa), rapid lateral erosion at two meander loops about 30 channel lengthsdownstream is tentatively attributed to the effects of a straight relocated segment.

Bank erosion upstream or downstream from a relocated channel is usually at bends and is attributed either to alinement of the channel junction, to degradation, or to the local increase in slope consequent upon relocation.

Table 1. Kinds of instability at relocated channels, tabulated according to stability class of channel

Stability class	Number of sites in class	Kind of instability at specific site		
		Bank erosion	Degradation	Aggradation
A1	31		--	--
A2	4	Sites 49,51,90	Site 101	
A3	1	Site 8		
B1	15	Sites 12,17,23,27,32,36,43,54,57,69, 73,75,81,94,104	Site 75	Site 54
B2	20	Sites 1,7,9,25,30,31,35,44,56,66,68, 71,83,84,86,87,88,93,95,96	Sites 1,56	
B3	3	Sites 26,40,41	Sites 26,40	
B4	3	Sites 3,33,58	Site 3	
C2	6	Sites 13,20,24,61,70,97	Sites 70,20,97	
C3	7	Sites 11,21,28,62,67,72,96	Sites 11,72,96	
C4	2	Sites 2,4		
D2	2	Sites 55,79	Site 55	
D3	3	Site 76,85	Sites 10,85	
D4	3	Sites 39,89	Site 89	

Table 2. Sites at which instability of natural channel segments is attributed to the relocated segment

Table 2. Sites at which instability of natural channel segments is attributed to the relocated segment.

Site No.	Stability class of relocated segment	Stability class of natural segments		Kind of instability attributed to the relocated segment		
		Before construction	In 1978-9	Bank erosion	Degradation	Aggradation
2...	C......	B.....	B....	(up-&-downstream)	-----------	-----------
10...	D......	D.....	D....	--------------	(upstream)	-----------
11...	B......	B.....	B....	(minor)	(upstream)	-----------
19...	B......	C.....	C....	(upstream)	-----------	-----------
22...	A......	B.....	C....	(downstream)	-----------	-----------
23...	B......	B.....	C....	(upstream)	-----------	-----------
26...	B......	B.....	B....	(upstream)	(upstream)	-----------
28...	C......	C.....	C....	(downstream)	-----------	-----------
30...	B......	B.....	C....	(downstream)	-----------	-----------
39...	D......	D.....	D....	(downstream)	-----------	-----------
40...	B......	B.....	B....	(near bridge)	-----------	-----------
45...	C......	---....	B....	-------------	-----------	(downstream)
60...	A......	B.....	C....	(downstream)	-----------	-----------
62...	C......	B.....	C....	(downstream)	-----------	-----------
64...	A......	A.....	B....	(upstream)	-----------	-----------
65...	A......	D.....	D....	(downstream)	-----------	-----------
69...	B......	C.....	C....	(downstream)	-----------	-----------
70...	C......	D.....	D.....	(upstream)	(upstream)	-----------
83...	B......	B-D....	D.....	(downstream)		
99...	A......	---....	B.....	(up-&-downstream)	-----------	-----------
101...	A......	B.....	B.....	(upstream)	(minor)	

SITE FACTORS

A site factor is defined as a characteristic of the site where a channel alteration is made, that existed before the alteration and may be relevant to channel stability after alteration. Some site factors, such as vegetation, are likely to be affected by alteration and others, such as drainage area, are not. The method used for determination of each of the following site factors, which are reported in the case histories (Appendix) is given below.

Stream flow habit--A stream is described as perennial if it flows continuously throughout the year, as ephemeral if it does not flow continuously during periods of as much as one month, and as intermittent if its flow ranges between ephemeral and permanent. The streams at many study sites are small and ungaged, and their flow could not be reliably categorized. Streams at seven sites were judged to be intermittent and the rest perennial.

Drainage area--Drainage area of streams at study sites was taken from gaging station descriptions, or from bridge or culvert design plans, or it was measured on quadrangle maps. For a few sites, the drainage area was measured approximately on state topographic index maps of 1:1,000,000 scale. The drainage areas of streams at study sites are plotted in figure 4. The range is from about 1 km^2 (site 45) to 51,540 km^2 (site 32), and values within this range are adequately represented.

Water discharge--For sites at or near a gaging station, values for average discharge are given. For ungaged sites, estimates of peak flow for floods of a specified recurrence interval are given if these are available from bridge or culvert design plans.

Channel width--Values given for channel width apply to channel bottom width, which is taken to be the same as unvegetated channel width. Along straight reaches, the unvegetated channel width of most streams corresponds to water-surface width at "normal" stage. Width was measured along straight reaches, where it is reasonably consistent for most streams, and modal values as measured on airphotos or by tape in the field are reported in the case histories. Channel bottom width, rather than bankfull width, is used here because it can be more consistently observed and measured on airphotos and also because it can be more readily compared with the design width of altered channels. Nearly all the altered channels at study sites were designed to be trapezoidal in cross section; the bottom width and side slope are specified, but the top width varies with surface irregularities of the ground through which the channel is cut.

Airphotos taken near bankfull stage or at flood stage are not suitable for bottom width measurements. According to probability, however, airphotos are likely to be taken during the stage that occurs oftenest, sometimes called the "normal" stage. For most streams, normal stage is below the stage at average discharge and well below bankfull. Because streambanks tend to be steep, and low relative to channel width, measurements at normal stage are approximations to channel bottom width. The scale of airphotos on which channel bottom width measurements were made is nominally 1:20,000; and measurements were made to the nearest 0.05 mm, which represents 1 m on the ground at this scale.

Bottom width for streams at study sites ranged from 2 m (site 45) to 90 m (site 100), as shown in figure 4. If either bottom width or drainage area is taken to be a measure of stream size, the incidence of instability after alteration is about as great for small streams as for large. According to the curve approximated in figure 4, channel bottom width increases as the 0.33 power of drainage area. Among the factors causing scatter of plotted points is the wide range of climates represented by the study sites, and also the wide range of channel types.

Bank height--Field measurement of bank height was made by hand level, measuring rod, or tape at places along the natural channel where a representative value could be obtained. Values apply to the vertical distance between the low-water surface and the top of the bank at the elevation of the "active" flood plain. The main difficulty in the measurement of bank height lies in the identification of the flood plain. Nevertheless, the measurements do reflect the fact that some streams have higher banks than others. There is no consistent relation between bank height and channel stability, nor between bank height and stream size. Some of the more stable streams have high sloping banks well stabilized by trees (Rolling Fork, Ky., site 35; Big Blue River, Nebr., site 71), whereas others having low banks are stable (Tamarack Creek, Mich., site 53; Strong River, Miss., site 59). However, high vertical banks may erode rapidly, because the root mats of trees along the bankline may be undercut, and fallen trees tend to promote bank erosion.

Channel slope--For most sites, natural channel slope was taken from Geological Survey topographic quadrangle maps. More detailed maps made by highway agencies were used if available. Channel slope tends to decrease systematically with increasing stream size (discharge) and, for a given discharge, to increase with increasing size of bed material. No general relation between channel slope and the occurrence of instability was discerned. Among the most stable natural streams are high-gradient (greater than 8 m/km) mountain streams having coarse bed material, well-vegetated banks, high channel roughness, and low discharge variability, such as the group studied by Osterkamp (1979, p. 4). In the absence of one or another of these stabilizing factors, however, a high channel slope may contribute to rapid bed and bank erosion (site 89).

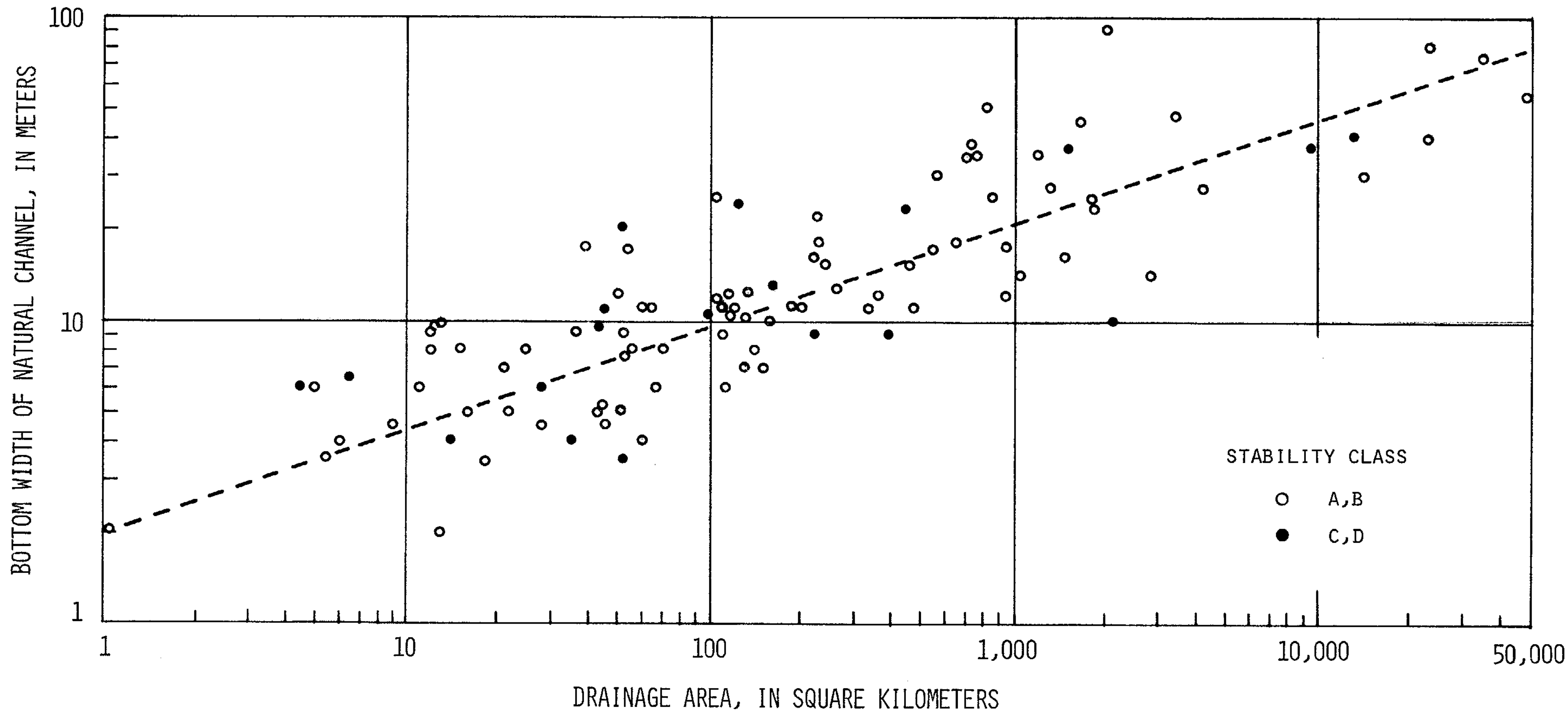


Figure 4. Channel bottom width in relation to drainage area for streams at study sites. Curve is fitted by eye.

Channel sinuosity--The sinuosity of a stream reach is the ratio of length as measured along the channel to length as measured along the valley centerline. Values of sinuosity reported for study sites range from 1.1 to 2.3. When a segment of sinuous channel is straightened, the slope of the straightened segment is increased by the same factor that the sinuosity was decreased. For a particular channel type, channel stability tends to decrease with increasing sinuosity because bank erosion is most active at bends.

Stream type--Most natural streams can be classified into four major types (fig. 5): equiwidth point-bar, wide-bend point-bar, braided point-bar, and braided without point bars. These types have been described and illustrated by Brice and Blodgett (1978). Stream properties grade continuously from one type to the next, but each type has a characteristic behavior and association of properties. In addition, channel stability is related to stream type.

A stream is considered to be of uniform width (equiwidth) if the average width of unvegetated channel at the widest places (usually at bends) is not greater than 1.5 times the average width at the narrowest places (usually in straight reaches). Equiwidth point-bar streams have narrow point bars and the banks tend to be well vegetated. A particular reach may be straight, sinuous, or highly meandering. They tend to be the most stable of all stream types, although the meander loops gradually migrate. The Pere Marquette River in Michigan (site 50) provides an example of the stability of a highly meandering equiwidth point-bar stream, where crossed at a meander without relocation of the channel.

Wide-bend point-bar streams have an average width at bends that is greater than 1.5 times the width in straight reaches. Unvegetated point bars tend to be conspicuous at normal stage, and the channel may be locally braided. Cutbanks are typical at the outside of bends. The rate of lateral migration at bends is potentially high, as compared with that of equiwidth streams; and the risk of instability upon relocation is correspondingly greater. The factors that contribute to instability of the natural stream may also operate along the relocated channel, unless suitable countermeasures are applied.

The transition to a braided point-bar stream (from wide-bend point-bar) is marked by the development of a braided but continuous thalweg that tends to meander within a broad sinuous channel. The point bars tend to be irregular and marked with a braided pattern. The thalweg may shift drastically in position during floods, eroding the banks at a rapid rate. Streams of this type commonly have sand beds and occur in semiarid regions; they are much less common than are wide-bend point-bar streams. Extensive countermeasures are likely to be required to maintain stream alinement, whether the channel is natural or relocated.

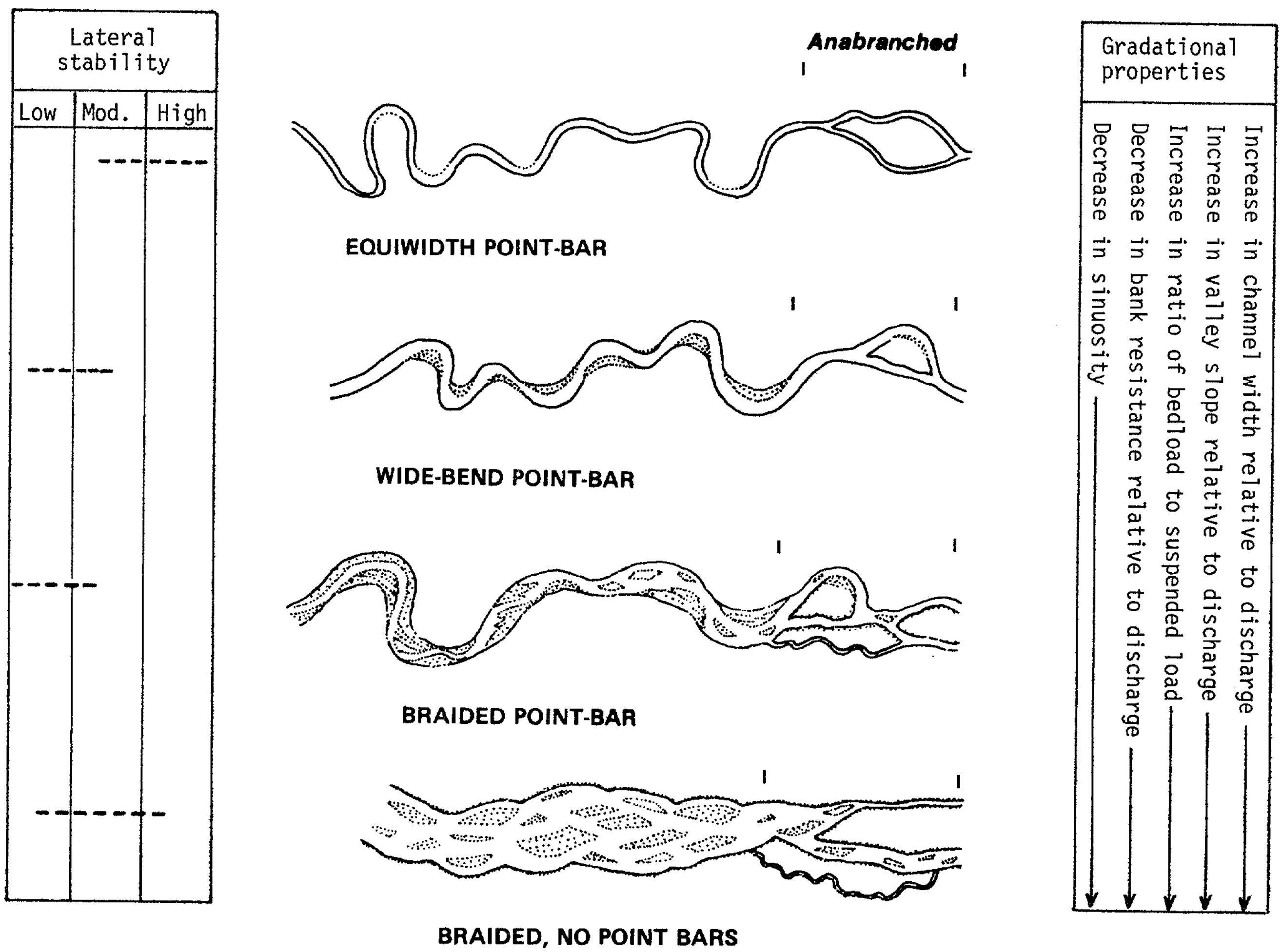


Figure 5. Major types of alluvial streams.

Braided streams without point bars typically have many midchannel and lateral bars (or islands), the flow is complexly divided, and the thalweg is not continuous. Some braided streams have sand beds, but bed material of gravel, cobbles, or boulders is more common. The channel tends to be broad and shallow, but the bars or islands lie within the well-defined banklines of a single channel. Although the braids may shift rapidly, the stability of the main-channel bankline is typically within the moderate range. Because of the broad channel, changes in alinement can usually be achieved by a reduction in channel width rather than a shift in position, and stability can be maintained with suitable countermeasures. Small braided streams in mountainous regions tend to be stable because of roughness and resistance imparted by a bed of cobbles and boulders. However, the relocation of two such streams--the Peabody River in New Hampshire and Wilson Creek in Pennsylvania--has resulted in serious instability.

A stream whose flow is distinctly divided into channels separated by large islands is anabranched, and any of the major stream types may be locally or generally anabranched. The individual anabranches may be of the same type as the parent stream, or they may belong to one of the other types. No examples of the alteration of an anabranched stream are included among the case histories, but examples are given in Brice, Blodgett, and others (1978, p. 103). In addition, the anabranched Calcasieu River at SR-489 near Simpson, La., was altered in 1974. In most cases, alteration involves the combining of multiple channels into a single channel.

Small streams, usually called creeks rather than rivers and having average discharges less than about 2.5 m^3/s (88 ft^3/s), are more difficult to classify than large streams. This difficulty is probably due to a more pronounced effect on stream form by vegetation, by erosional resistance of bank materials, and by coarseness of bed material. In addition, the channel form of small streams is commonly obscured by vegetation, both in the field and on airphotos. Although values for average discharge are not available for most streams at study sites, about half have bottom widths of 10 m or less and are regarded as small streams. Among these and for the study sites in general, a disproportionate number of equiwidth point-bar streams was identified, as compared with an equivalent population of large and medium-sized rivers.

The stability class of streams at study sites, prior to alteration, is shown in relation to stream type in table 3. Equiwidth point-bar streams in classes C and D have drainage basins mostly cleared for agricultural purposes, and their instability is almost certainly man induced; the instability of most in class B is probably man induced. A change in controlling factors is not immediately reflected by a change in stream type, particularly for small incised streams. The instability of wide-bend point-bar streams is mainly manifested by bank erosion at bends, the rate of which varies from one stream to the next and from place to place along the same stream.

Table 3. Stability class of streams at study sites in relation to stream type. Stability class A, cut banks rare or absent; class B, cut banks local and not severely cut; class C, cut banks local and severely cut; class D, banks generally cut or slumped.

STREAM TYPE	STABILITY CLASS PRIOR TO ALTERATION			
	A	B	C	D
Equiwidth point bar	Sites 5, 6, 9, 35, 36, 37, 38, 47, 48, 53, 58, 59, 64, 73, 74, 103	Sites 1, 7, 11, 12, 20, 21, 26, 27, 29, 40, 41, 42, 49, 50, 57, 60, 61, 62, 71, 72, 83, 88, 104	Sites 13, 43, 69	Site 70
(Locally anabranched)		Sites 2, 86, 87, 94		
Wide-bend point bar		Sites 22, 23, 30, 31, 46, 56, 75, 79, 80, 84	Sites 3, 4, 19	Sites 10, 32, 39, 54, 68
(Locally braided or anabranched)		Sites 8, 101	Site 33	Sites 65, 66, 67, 76
Braided point-bar		Site 78	Sites 16, 24	
Braided	Sites 18, 77	Site 81		Site 55

Channel boundary class--An alluvial channel is in alluvium, a non-alluvial channel is in bedrock, and a semialluvial channel has both bedrock and alluvium in its boundaries. Bedrock is not necessarily more resistant to erosion than is alluvium (see, for example, site 10) and is therefore further described as resistant or not resistant. Instability is obviously improbable for a channel wholly in resistant bedrock, and no such channels are included among the study sites. At several sites, outcrops of bedrock in the channel bottom have apparently served as controls to limit degradation (sites 6, 12, 13, 14, 15, 25, 32, 36, 77), but degradation may readily occur downstream from an outcrop (site 89). Outcrops of resistant bedrock in the channel do not prevent lateral erosion of alluvial banks (sites 4, 8, 88). At site 68, a resistant bluff upstream from the crossing contributed to the maintenance of alinement on an otherwise laterally unstable stream.

Valley relief--This factor applies to the vertical distance between a valley bottom and the crest of the highest adjacent divide. In a general way, it tells whether the site is in mountainous, hilly, or flat terrain.

Width of flood plain--Flood plains whose width is greater than about 10 times channel width are considered to be wide, and widths in the range of 2-10 times channel width are narrow. No relation was discerned between channel stability and width of flood plain.

Incision of channel--Channels whose bank height is 25 percent or more of channel width are considered to be incised. Lateral erosion rates tend to be slow if the banks are sloping, but high, steep banks fail by slumping. Most stable incised channels have responded satisfactorily to alteration (sites 12, 35, 36, 37, 38, 57, 59, 71), although high banks of the relocated channel are difficult and expensive to protect. On the other hand, the relocation of unstable incised channels is risky (sites 10, 70), because channel degradation may be in progress.

Vegetal cover along channel--The extent of woody vegetation along a channel is expressed as a percentage of the bankline (both banks) occupied by the vegetation. The three classes used here are (1) less than 50 percent, (2) 50-90 percent, and (3) greater than 90 percent. The extent of grass or other nonwoody vegetation is described qualitatively for sites where it is evidently important in bank stability.

The importance of vegetation in slope stability is generally known and adequate attention has been given to it in connection with the lining of drainage channels (Normann, 1975). The role of vegetation in streambank stability has not received much investigation, probably because its effects are very difficult to quantify. Vegetation protects banks by providing a root mat that increases resistance to erosion and also by increasing roughness, thereby reducing water velocity along the bank. The effectiveness of brush (as opposed to grass or other short vegetation) in reducing water velocity along a bank has been demonstrated by Klingeman and Bradley (1976), and Nunnally and Keller (1979, p. 23) measured for one stream the percentage of bankline protected by the root mats of hardwood trees. Zimmerman and others (1976) demonstrated that the mean width of small streams was significantly affected by vegetal cover, such that reaches bordered by trees were more narrow than reaches bordered by grass.

Among the sites of the present study, the most stable natural channels are bordered by a continuous cover of trees. However, tree cover along a bankline does not insure stability, particularly if the banks are high and formed of weakly coherent materials.

Bed-bank materials--For noncoherent materials of sand size or larger, resistance to erosion increases with increasing particle size. For coherent materials, which contain clay or some other binding agent, resistance depends on a complex of variables that include the type and quantity of clay and the orientation of clay particles (Partheniades, 1971, p. 30). The sampling of bed and banks is difficult because of the general lack of homogeneity. Loose sandy banks, or banks that grade downward to loose sand or fine gravel, are obviously susceptible to erosion. The armoring effect of materials in the size range of gravel to boulders depends on their size and sorting, and on the velocities to which they will be subjected.

The particle size of bed and bank materials is described as silt-clay, sand, gravel, cobble, or boulder according to the grade scale in Vanoni (1975, p. 20). No particle-size analyses were made. The size range of particles of sand size and smaller was estimated, and particles of gravel size and larger were compared with a scale in the field.

Bank materials are further described as coherent, moderately coherent, or weakly coherent. A coherent material is defined as one that, when dry, forms hard lumps that are not easily crushed with the hands. No general relation was found between the coherence of bank materials, as described, and stream stability. Streams at many of the sites in Mississippi and Michigan have weakly coherent sandy banks but a high degree of stability. In Mississippi, stability is probably due to a dense growth of vegetation; in Michigan, to vegetation and to a natural regulation of discharge by lakes and swamps.

An attempt was made to characterize streams as sand bed, gravel bed, or cobble-boulder bed according to the dominant (by volume) size range of material constituting the bed material. The bed material of some streams characterized as "sand bed" contains a substantial volume of gravel (for example, the Amite River in Louisiana, site 39).

Prior channel stability--As a potential factor relating to the stability of an altered channel, the stability of the natural channel prior to alteration was assessed according to the scheme previously described. Time-sequential airphotos taken at two times prior to alteration were obtained for many sites, and comparison of these airphotos was made to determine changes in width, position, or the occurrence of cut banks. For most sites, airphotos taken at least one time prior to alteration were obtained and studied for an assessment of prior bank stability.

The stability of relocated channels in relation to prior channel stability is shown in table 4, for the 87 sites at which an assessment of prior stability could be made. Sites listed within the diagonal row of outlined boxes correspond in "before" and "after" stability class. Prior channel stability depends on a complex of more primary factors contributing to stability, but many of these are more difficult to measure and their interaction is difficult to predict.

The correspondence of "before" and "after" stability is affected by such factors as the design of the relocated channel and the use of erosion-control measures. Nevertheless, the degree of correspondence is sufficiently good to be useful in decisions regarding a proposed relocation, and it has a rational basis: A stable natural channel is likely to have enough resilience to absorb the effects of a minor relocation, but an unstable channel may not have such resilience.

If only bank stability (as designated by letter) is considered, the relocated channel falls within the same class as the prior natural channel at 45 sites, a higher class at 28 sites, and a lower class at 14 sites. For those relocated channels in a higher class, the improved bank stability is probably due in most cases, either to straightness or to the use of countermeasures.

Works of man--Although sites subjected to obvious and nearby disturbance by man, such as gravel mining, were not chosen for study, most streams in the conterminous United States have probably been affected to some degree by man. Man-induced instability is reflected in the assessment of prior channel stability, and the probable causes of the instability are noted in case histories. Several study sites are downstream (but not immediately downstream) from dams, but at no site was instability attributed to a dam.

Table 4. Stability of relocated channels in relation to channel stability before relocation. Numbers refer to sites, and asterisks refer to sites where stability of the relocated channel is attributed, at least in part, to countermeasures.

STABILITY CLASS OF RELOCATED CHANNEL		A	B	C	D
A	1	5,6,15*,18*,37,38,47,48, 51,53,59,64,74*,77*,103	22,29*,42,46*,60,78*,80*	16*	65*
	2	90	49,51,101*		
	3		8*		
	4				
B	1	36*,73*	12,17,23,27,57,75*,94 104*	43,69	32,54*
	2	9,35	1,7,30,31,56,71,83*,84* 86,87*,88	19	68*66*
	3	40	26*,41		
	4	58		3,33	
C	1				
	2		20*,61	13,24*	70
	3		11*,21,62,72	28	67*
	4		2	4	
D	1				
	2		79		55
	3				76
	4				10*,39

STABILITY CLASS OF CHANNEL BEFORE RELOCATION

ALTERATION FACTORS

KINDS AND PURPOSES OF ALTERATION

The main kinds of alteration are relocation, encroachment, and reshaping. Relocation usually involves the cutting off of a segment of natural channel and its replacement with a shorter segment of artificial channel. Any change in position of a natural channel is regarded as relocation, even if the channel is transposed laterally by only a few meters and not changed in direction. Encroachment on a channel involves either a reduction in its width or the placement of obstructions in the path of its flow. A roadway embankment may encroach laterally on a channel in a narrow valley, or the channel may be narrowed by encroachment of an embankment end-slope at a bridge. Among the obstructions to flow that may be placed in a channel are spurs, check dams, and various structures (or boulders) intended to improve fish habitat. The reshaping of a channel usually involves an enlargement of cross section and is done to make the channel conform with the bridge waterway, to increase flow conveyance, or to allow placement of bank protection.

A stream channel at a bridge crossing is likely to undergo some reshaping during bridge construction, whether this is specified in the plans or not. Similarly, any highway that follows a stream in a narrow mountain valley is likely to encroach to some degree on the channel from place to place. These examples represent alterations in the strict sense, but such alterations were omitted from this study for the following reasons: (1) The effects of alterations and encroachments in the immediate vicinity of a bridge have already been documented (Brice and Blodgett, 1978). No effects on channel stability beyond the vicinity of the bridge were discerned. (2) Minor lateral encroachments of highway embankments on stream channels were observed at many localities during the course of field work for the present study. The effects of these on channel stability, if any, could not be assessed. The streams involved typically have bedrock channels and are narrowed by confinement between a riprapped highway embankment and a steep valley side of resistant bedrock.

Except at site 31, where only widening was done, alteration at the study sites involved some amount of relocation. At sites 6 and 78, the channel was relocated in one reach and widened in another. At sites 81 and 82, alteration involved both relocation and encroachment. Thus, this report is mainly on channel relocations, for which the length of natural channel cut off by relocation ranges from 70 to 4,200 m.

The purposes of channel alterations (diversions) by highway agencies are enumerated as follows in Neill (1973, p. 138): (1) to divert the channel away from approach embankments, (2) to eliminate or reduce a skew angle of the bridge, (3) to provide a more stable channel alinement, in lieu of expensive training works, (4) to remove the crossing from the base of a steep hill, thereby allowing a lower grade line for the structure, (5) to allow a single structure instead of a series of structures separated by embankments, and (6) to reduce flood levels or prevent them being raised by road and bridge works. According to the California Department of Transportation (1975, p. 7-861.8), the reasons for channel changes are as follows: (1) permit better highway alinement, (2) permit better culvert alinement, (3) economize by eliminating culverts or bridges where a stream recrosses a highway, (4) improve flow conditions in channels, (5) protect highway from flood damage, and (6) right-of-way considerations.

The purpose of alteration is not stated on design plans, but the major purpose is usually apparent from the situation as depicted on the plans. Supplementary information on purpose was obtained from state highway agencies for about a fourth of the sites. At many sites, alteration serves more than one purpose. As shown in table 5, the most common purpose was to improve the channel alinement at a bridge or culvert crossing. Avoidance of crossings and the accommodation of planned roadway location are about equally common. The building of a bridge on dry ground, and the subsequent relocation of the stream beneath the bridge, facilitates bridge construction and management of traffic during construction. This is probably not a common primary reason for relocation, but it may be a fairly common secondary one.

LENGTH OF RELOCATION

The length of natural channel that was cut off or otherwise altered was measured on plans or airphotos with dividers. The use of dividers for measurement of distance on sinuous channels is recommended by the U.S. Water Resources Council (1968), and it is an accurate and satisfactory method. The frequency distribution of natural channel length in meters at study sites is shown in figure 6, at bottom; the median length is about 650 m, and the distribution is strongly skewed toward the shorter lengths. For purposes of stability assessment, the absolute length of natural channel is probably less important than the length relative to stream size. For example, a length of 500 m is insignificant for a stream whose width is 500 m, but significant for a stream whose width is 10 m. The frequency distribution of natural channel length in multiples of channel width is shown in figure 6, at top; the median length is 50 channel widths and, again, the distribution is strongly skewed toward the lower values.

The change in channel length resulting from relocation is expressed by a length-change factor, which is the ratio of length of relocated channel to length of prior channel: Thus, a length-change factor of 0.9 indicates a slight shortening of the stream segment involved in relocation. The lower the length-change factor, the greater the degree of shortening.

Table 5. Purposes of channel alteration at study sites.

Purpose	Number of site
Improve channel alinement at crossing	1, 2, 4, 5, 6, 8, 10, 12, 13, 14, 21, 22, 23, 27(?), 28, 29, 34, 35, 37, 39, 40, 41, 42, 43, 44, 45, 47, 48, 51, 53, 54, 55, 56, 57, 58, 60, 61, 62, 63, 64, 65, 66, 68, 69, 70, 71, 72, 80, 83, 86, 87, 91, 92, 95, 98, 102, 103, 104
Accommodate planned roadway location	13, 14, 15, 16, 17, 18, 22, 24, 25, 26, 29, 36, 46, 58, 59, 60, 64, 66, 67, 69, 70, 71, 73, 74, 75, 78, 80, 81, 82, 83, 84, 85, 88, 94, 95, 97, 99, 102
Avoid one or more crossings	2, 6, 11, 15, 16, 19, 20, 26, 32, 36, 38, 46, 52, 54, 56, 75, 77, 79, 84, 87, 89, 90, 96, 97, 98, 100, 101, 104
Prevent lateral erosion of roadway by channel migration	3, 9, 10, 23, 30, 33, 39, 49, 65, 76, 93
Reduce flood levels	5, 9, 30(?), 40, 41, 47(?)
Combine multiple channels into a single channel	48, 66, 96, 98
Facilitate construction of new bridge	3(?), 27(?)
Provide fill for embankment	32

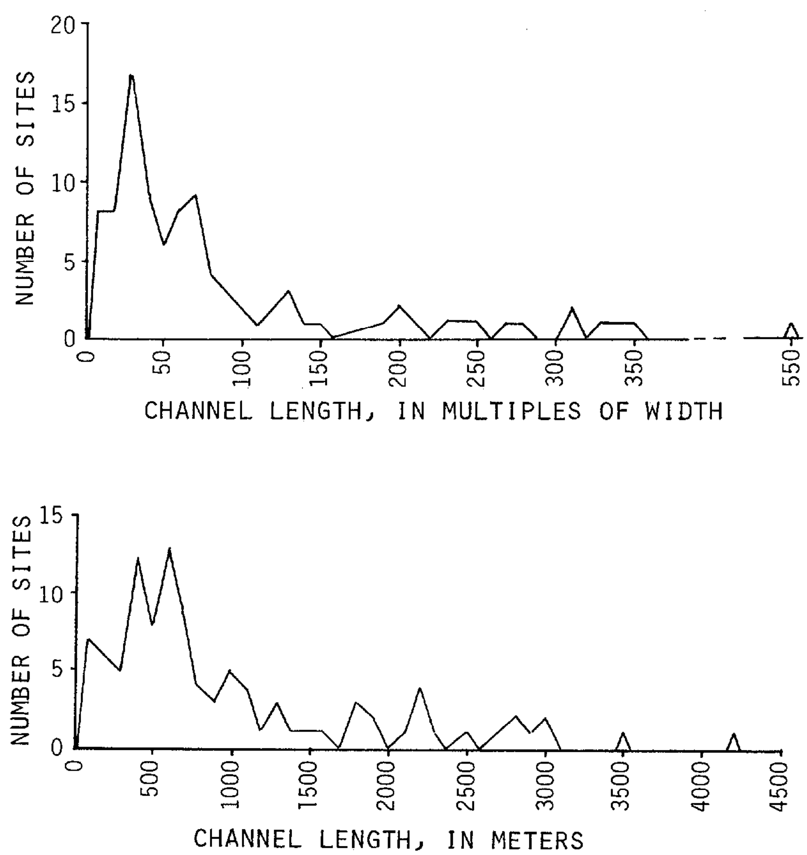


Figure 6. Frequency polygons showing length of natural channel relocated at study sites, as expressed in multiples of channel width, top, and in meters, bottom.

In figure 7, values of length-change factor at study sites are plotted against length of prior channel, in multiples of channel width; and the bank stability class of each site is indicated by a symbol. Sites at which erosion control measures, either riprapped banks or check dams (drop structures), have evidently contributed to stability are marked with an asterisk. If length-change factor is a critical factor in channel stability, the stability of sites should decrease toward the bottom in figure 7, for a particular value of prior channel length. If length of prior channel is a critical factor, stability should decrease toward the right, for a particular value of the length-change factor.

No general decrease in stability toward the right nor toward the bottom in figure 7 is discernible, which apparently indicates that neither the length-change factor nor length of relocation are critical factors in channel stability. Before this conclusion is drawn, other factors contributing to instability at specific sites should be examined. Inasmuch as the widest range of data points for length of prior channel lie within the range of 0.4-0.6 for length-change factor, the stability trend from left to right within this range will be examined. Of the sites at left, less than 100 channel widths in length, sites 4, 11, 39, 61, 70, and 79 have class C or D stability and the others have A or B stability. At sites 4, 39, and 70 the prior channel had such a high degree of instability that stability of the relocated channel was improbable. Bank erosion at site 61 was due to flow constriction at a bridge, and bank slumping at site 79 was due to high steep side slopes. At site 11, the mouth of a small stream was shifted and its length shortened substantially in relation to its total length. Thus, instability at these sites is due to factors other than length of prior channel.

All the longer relocations (greater than 250 channel widths in length) have class B or C stability, despite the fact that most are protected by erosion-control measures. At site 20 (Bear Creek, Iowa), site 26 (Stevens Creek, Ill.), site 36 (Beargrass Creek, Ky.), and site 54 (Kanaranzi Creek, Minn.), channel degradation has probably been prevented by check dams. At site 45 (Maiden Choice Branch, Md.), the relocated channel is lined with concrete. At the longest relocation in terms of channel width (site 97, Five Mile Run, Pa.; not shown in figure 7), the length of prior channel is 550 channel widths. Degradation has been inhibited by outcrops of bedrock in the channel; banks are stable along some parts of the channel and unstable along others.

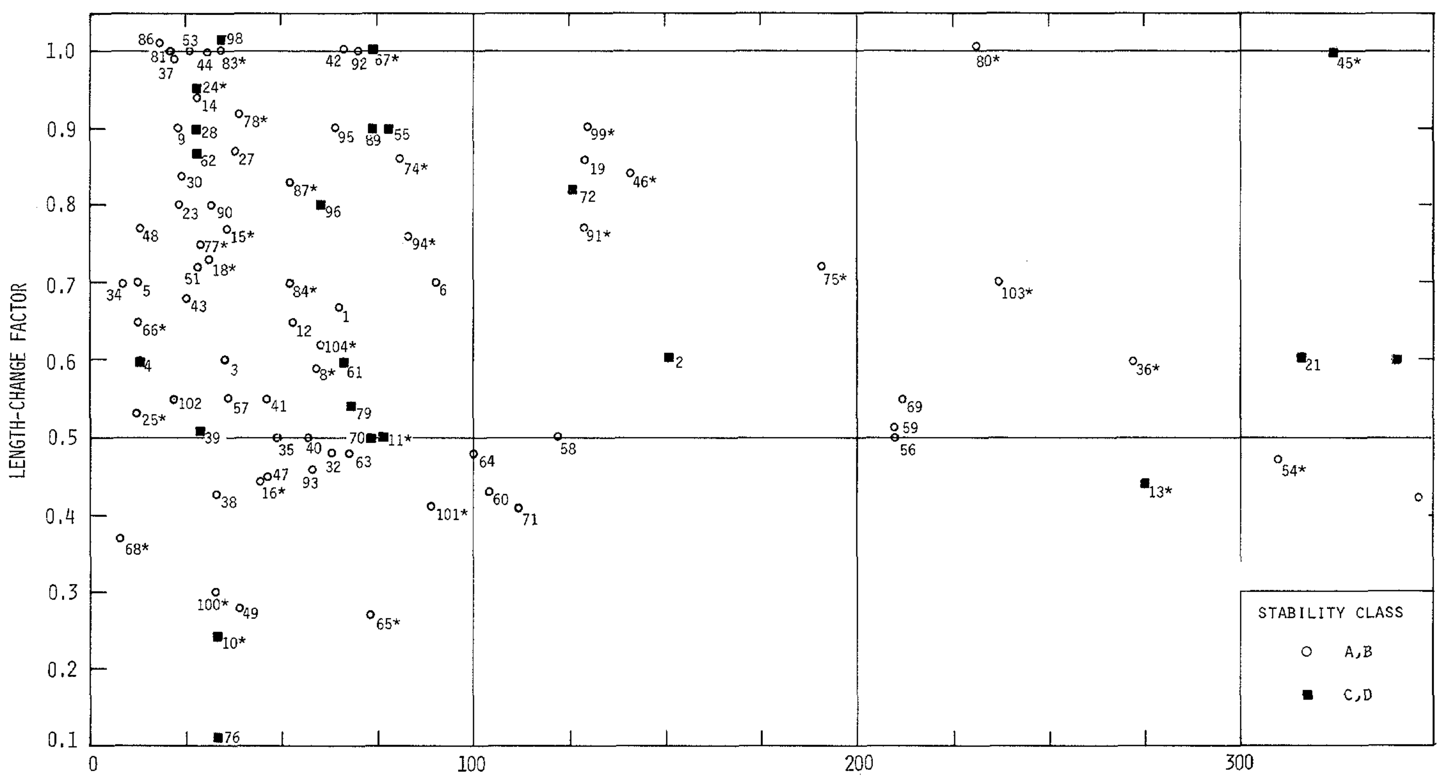


Figure 7. Scatter diagram showing stability class of relocated channel in relation to length-change factor and length of prior channel. Numbers refer to sites, and asterisks indicate sites where countermeasures have been effective. Stability class A, cut banks rare or absent; class B, cut banks local and not severely cut; class C, cut banks local and severely cut; class D, banks generally cut or slumped.

Examination of the reasons for instability at the sites plotted in figure 7 leads to the following tentative conclusions with regard to length of relocation and the length-change factor: (1) Length of relocation contributed significantly to channel instability at sites where its value exceeded 250 channel widths. At sites where the value was below 100 channel widths, the effects of length of relocation were dominated by other factors. (2) No consistent relation between degree of channel shortening (length-change factor) and channel stability was discerned. However, severe shortening probably contributed to instability at some sites, and the effects of shortening probably increase with length of reach relocated.

The risk of instability would, hypothetically, be expected to increase with increasing length of reach relocated. For a given change in slope, the amount of vertical fall between adjacent segments of natural channel increases with increase in length of relocated reach (fig. 8). If the relocated reach is short, the longitudinal profile probably adjusts locally by minor upstream degradation and downstream aggradation. Adjustment to natural meander cutoffs probably occurs in this way, as well as by local increase in width. Failure to adjust locally may result in upstream migration of the steeper channel segment, manifested as channel degradation. If the relocated reach is long, greater vertical changes in the profile are required for local adjustment, and the probability of progressive upstream degradation is increased. For the typical long relocated reach in which the natural channel is sinuous and the relocated channel is straight, channel length will be substantially decreased (and slope increased) by relocation. The increase in slope can be diminished or avoided by the use of a check dam or by building a sinuous relocated channel. However, neither check dams nor equivalence in length insure stability.

The risk of instability is evidently diminished if the natural channel is stable prior to relocation. In figure 7, several sites of class A or B stability rating have apparently unfavorable lengths of reach relocated (in the range of 50-250 channel widths) and unfavorable width-change factors (less than 0.5). These are site 40 (Cool Creek, La.), site 59 (Strong River, Miss.), site 60 (Turkey Creek, Miss.), site 63 (Bogue Homo, Miss.), and site 64 (East Hobolochitto Creek, Miss.). At all these sites, the natural channel is stable, meandering, and has a dense forest cover along more than 90 percent of the bankline. The slopes of such streams may have become adjusted to the effects of periodic natural cutoffs, which are similar in length to the reaches relocated.

SLOPE OF RELOCATED CHANNEL

At 92 of 102 study sites, relocation resulted in a decrease in channel length, and (unless check dams or drop structures were installed) the relocated channel consequently has a greater slope than did the corresponding segment of natural channel. If all variables other than slope (especially roughness and depth) remain constant, the increase in slope will result in an increase in velocity and a consequent increase in potential for bed and bank erosion. For the study sites, the reciprocal of the length-change factor is an adequate approximation of the slope-change factor; that is, if length is decreased by a factor of 0.5, slope is increased by a factor of two. Slope was increased by a factor of two or more at 25 study sites. As indicated by the foregoing discussion relating to figure 8, the risk of instability for a given increase in slope probably

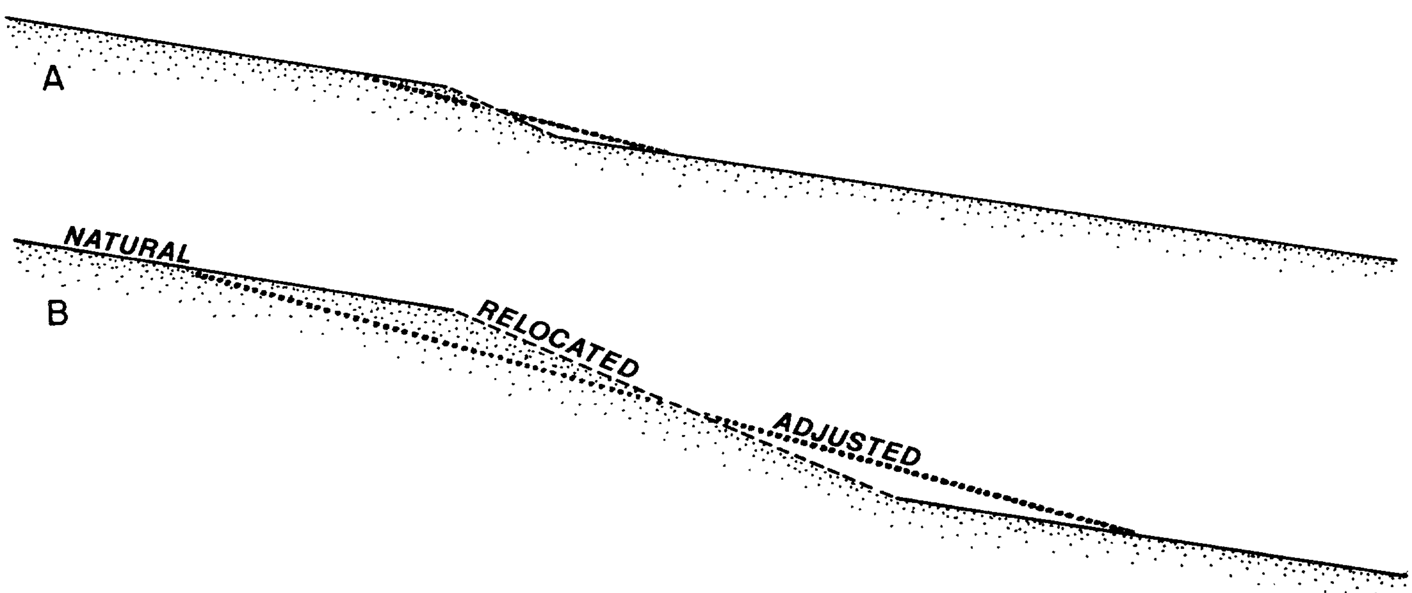


Figure 8. Hypothetical response, by local slope adjustment, of a natural channel profile to increase in slope consequent upon relocation. A, Short relocation, about 50 channel widths in length. B, Longer relocation, about 250 channel widths in length. Longitudinal profile of natural channel is shown in solid line; of relocated channel, in dashed line; of adjusted channel, in dotted line.

increases with length of reach relocated.

In figure 9, slope of relocated channel at study sites is plotted against area of drainage basin. The curve is not fitted by eye or by statistical methods; its slope is drawn at a value of -0.25 which, according to Lane (1957), represents the rate of decrease in slope with increasing discharge for natural streams. Its position (intercept) was selected to separate the sites according to the coarseness of their bed material. Coarse bed material is clearly associated with the higher values of slope.

For a particular value of drainage area, the slopes of stable relocated channels may differ by a factor of 10 or more (fig. 10). The differences in slope are accounted for by differences in water and sediment discharge, in size of bed material, and in channel width. A weak tendency for channels of class A stability to lie at the lower range of slope values can perhaps be discerned, but some channels of high slope are also stable.

CROSS SECTION OF RELOCATED CHANNELS

Information on design specifications of the channel cross section was obtained from state highway agencies for 71 sites. Little or no information was obtained for the other 32 sites. At all sites for which adequate information on cross-sectional shape was obtained, the design plans specified a trapezoidal shape. At some sites, the bottom of the trapezoid was modified to slope slightly toward a centerline, presumably to provide initial guidance of flow down the center of the channel. For unlined channels in alluvium (excluding pilot channels), the side slopes range from 1:1 to 2:1 (x units of horizontal distance: 1 unit of vertical rise). Side slopes of 1:1 were specified at 2 sites, 1.5:1 slopes at 13 sites, and 2:1 slopes at 37 sites. Where banks were continuously revetted with riprap or concrete pavement, a slope of 1.5:1 or 2:1 was specified, except at site 72 (3:1 slope) and site 77 (4:1 slope).

According to guidelines published by the AASHTO (American Association of State Highway and Transportation Officials, 1979, p. 223), "Channels which do not require a rigid lining at the time of construction are usually of a trapezoidal shape . . . . Unlined channels are seldom constructed with side slopes steeper than 2-horizontal to 1-vertical . . . . The natural processes of erosion and siltation will usually shape an unlined trapezoidal channel to an approximate parabolic shape."

Relocation by use of a pilot channel, which is intended to be enlarged by streamflow, is scarcely represented by the study sites. Relocation at site 76 (Washita River, Okla.) was by pilot channel, and the bank erosion there is probably not due to the use of this method. The relocated channel at site 7 (West Fork Choctawatchee River, Ala.), at site 19 (Beaver Creek, Iowa), and at site 23 (Thompson River, Iowa) may have been intended as a pilot, as suggested by the narrow width, but this is not clear from the design plans. Neill, (1973, p. 140), considered pilot channels as an alternative method for the part of a relocation not adjacent to the bridge, if the consequences of downstream transport of river-excavated sediment are acceptable. In general, the width of a relocated channel should be in the range of 1-1.4 times the width of the prior channel, and an effort should be made to stabilize the bank at the design width. Bank erosion, once initiated, may be progressive beyond desired limits.

Observations were made on the changes with time in the side slopes of relocated channels. Performance periods during which the changes occurred ranged from 2 to 50 yr, the modal period is 15 yr. Side slopes that were originally 2:1 (26.5°) generally steepened to angles in the range of 35°-60°. Changes at three sites in Alabama, where cross sections were surveyed by transit in 1978, are typical, and plotted sections are given in the case histories. Performance periods for these three sites are in the range of 15-17 yr. At site 1 (Big Canoe Creek), side slopes tended to steepen from an original value of 1.5:1 (34°) to values in the range of 60°-70°. At site 2 (Calebee Creek), side slopes that were originally 2:1 steepened to values in the range of 29°-36°. At site 3 (Cedar Creek), side slopes that were originally 1:1 (45°) were in the range of 30°-50° at the end of the performance period.

Typical changes with time in the cross section of a trapezoidal relocated channel, having 2:1 side slopes, are shown in figure 11. In addition, the steepening of side slopes by erosion at the toe is well shown by a photograph of the Poteau River in Arkansas (fig. 3B), where the slopes steepened during a period of 9 yr from an original value of 26.5° to values in the range of 30°-40°. Observed values for the side slopes of relocated channels are within the range of values observed for natural creeks and small rivers, and it is therefore unlikely that the angles will recline as the performance periods are lengthened. Nevertheless, construction of initial side slopes not steeper than 2:1 is a good practice. The steeper the slope, the greater the difficulty in establishing vegetation on it and the more subject it is to failure by slumping. If the growth of vegetation were encouraged by a suitable mulching technique (Normann, 1975), and if no major floods occurred soon after construction, 2:1 slopes could probably be stabilized without much erosion at the toe.

The failure of banks by slumping becomes more serious, although not necessarily more probable, as bank height increases. High steep banks are difficult to stabilize, and large slumps may transport enough material to divert flow toward the opposite bank. Site 20 provides an example of such diversion. Deep cuts through unconsolidated materials are especially hazardous, and site 79 provides an example of incipient slump blocks sufficiently large to block the channel. Terracing of such deep cuts (sites 15, 20) is advisable.

Dual channels, in which a low-flow channel is inset within a larger flood channel, were

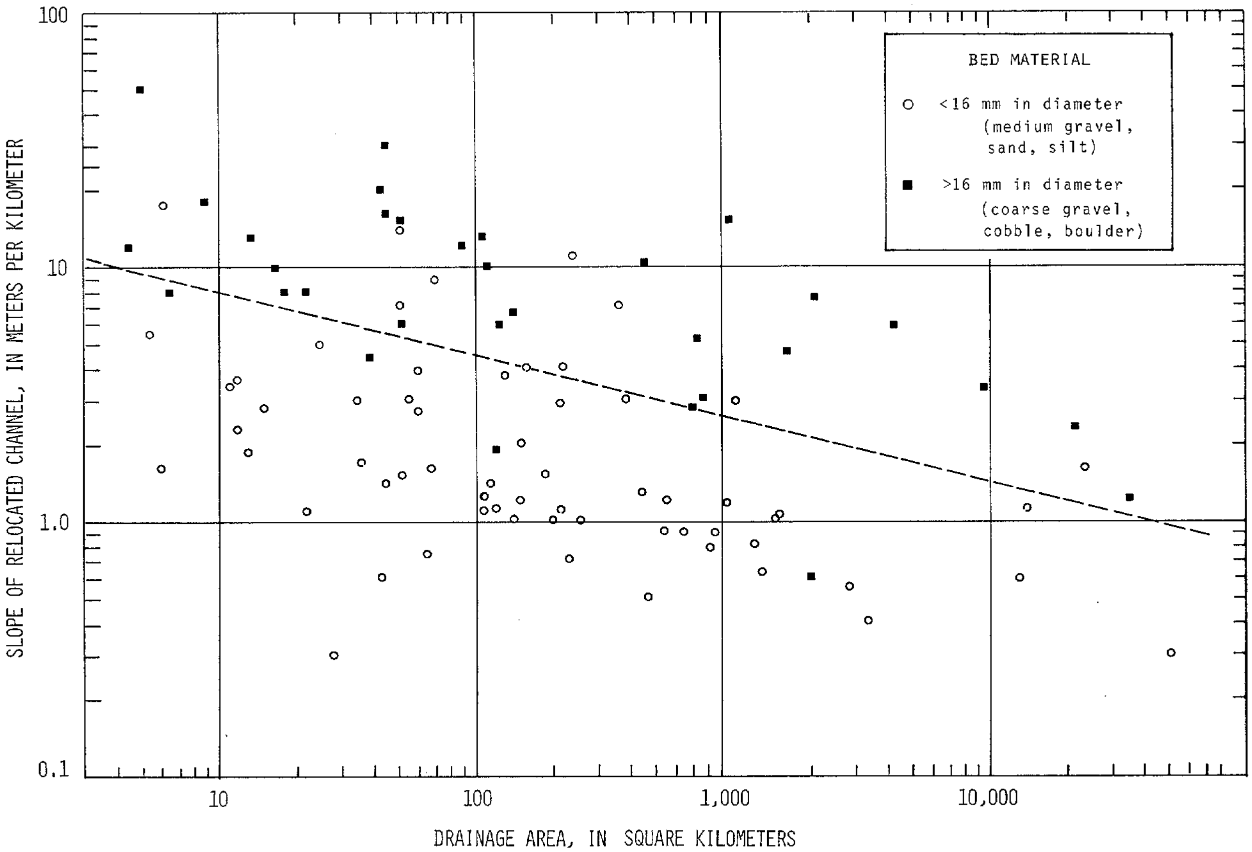


Figure 9. Slope of relocated channels in relation to drainage area and size of bed material.

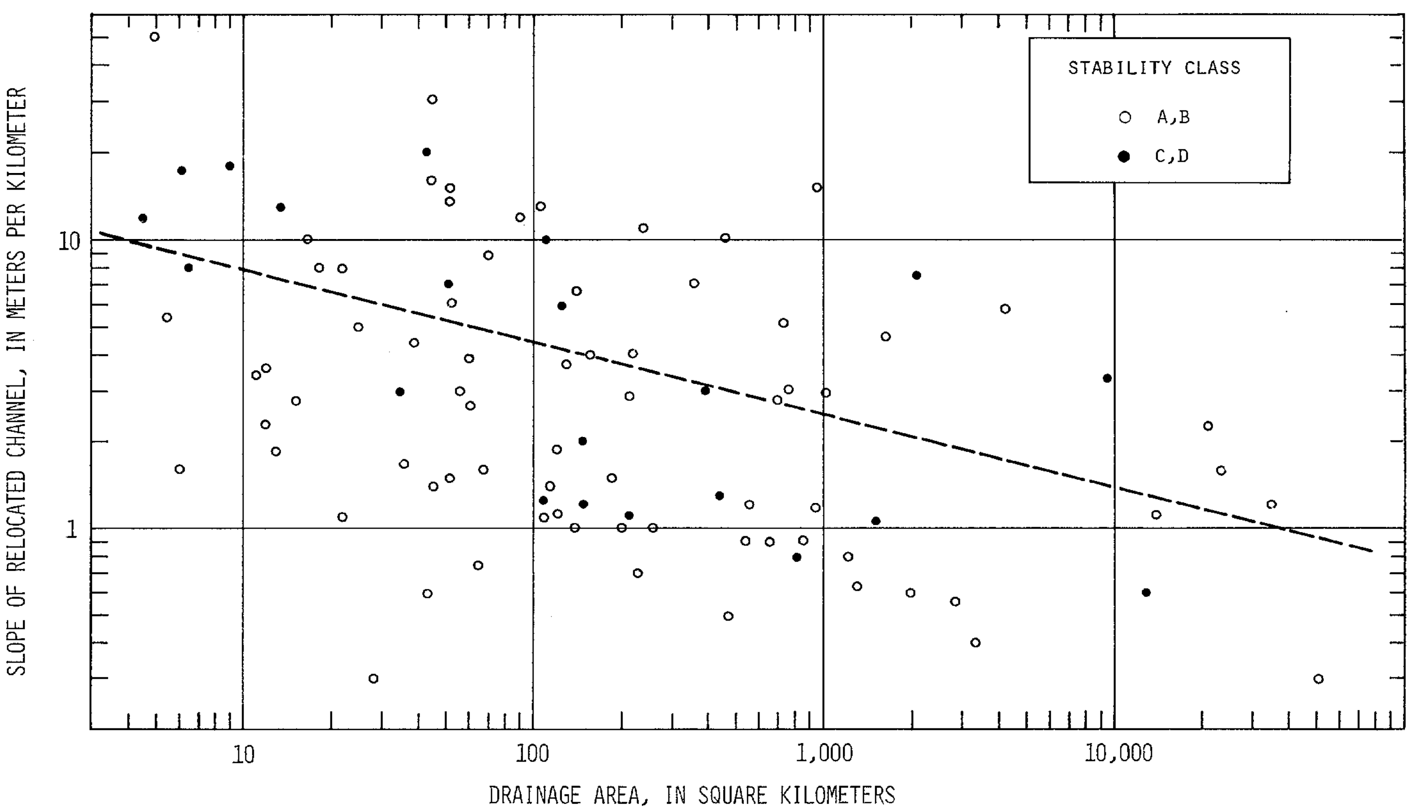


Figure 10. Slope of relocated channels in relation to drainage area and stability class of channel.

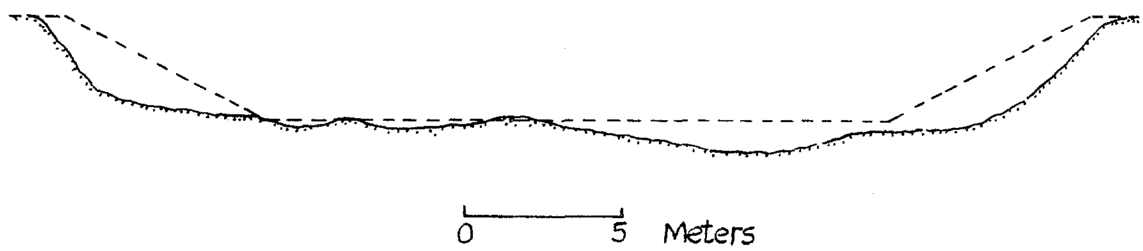


Figure 11. Typical change with time in the cross section of a trapezoidal channel (dashed line) having 2:1 side slopes and no bank revetment. No vertical exaggeration.

constructed at sites 36, 74, 87, and 103. Although the low-flow channel at site 87 was obliterated by an extreme flood, dual channels are a desirable alternative in some situations, as suggested in Vanoni (1975, p. 53) and AASHTO (1979, p. 216). For "flashy" streams of highly variable discharge, a single channel of adequate width to transmit the larger flows is too wide for low flows, which either spread out over the channel bottom (braid) or develop a meandering thalweg. A dual channel may also be desirable for situations in which the flood plain is not available for conveyance of flood flows. At sites 74 and 87, the stream is bordered on one side by a highway embankment and on the other by the valley side-slope.

The bottom width of relocated channels is expressed in meters and by the width-change factor, which represents design width in multiples of natural channel width as measured on airphotos taken prior to relocation. For example, a width-change factor of 1.5 means that the design bottom width is 1.5 times the bottom width of the natural channel at the site. Width-change factors at study sites range from 0.6 (sites 3, 4) to 5 (site 26), excluding pilot channels and concrete-lined channels. According to the concept of channel equilibrium, an increase in channel slope can be offset by an increase in width.

On a plot of width-change factor against length-change factor (fig. 12), the distribution of points does not indicate any general tendency for designers to increase the width-change factor with decreasing values of the length-change factor. Some tendency is apparent toward use of a width-change factor of 1 (duplicating natural stream width), without regard to length-change factor; but a wide range of combinations of width-change factor and length-change factor is represented by the study sites. Despite this range, the distribution of points according to stability class does not support the hypothesis that greater stability is achieved by moderate increases in channel width, nor that large or small values of the width-change factor induce instability. At most of the sites where class C or D instability is reported, width-change is probably not a major contributing factor.

Of the 83 relocated channels plotted in figure 12, 8 have width-change factors less than 1, 46 have width-change factors in the range of 1-1.5, and 29 have width-change factors greater than 1.5. Within each of these categories, class C or D stability ratings are probably due to the following factors:

Sites having width-change factors less than 1

- Site 4 (Line Creek, Ala.)--Channel apparently too narrow
- 24 (Pine Creek, Idaho--Extreme flood; bend in channel

Sites having width-change factors of 1-1.5

- 11 (trib. to Caddo River, Ark.)--Turbulence at check dam; low length-change factor
- 20 (Bear Creek, Iowa)--High channel side-slopes
- 61 (Oakahatta Creek, Miss.)--Flow constriction at bridge
- 67 (Clark Fork, Mont.)--Prior channel instability; anabranching and braided channel pattern
- 89 (Wilson Creek, Pa.)--Steep valley slope; removal of bed armor and bordering vegetation; severe floods soon after construction

Sites having width-change factors greater than 1.5

- 2 (Calebee Creek, Ala.)--Flood soon after construction; weak coherence of bank materials
- 39 (Amite River, La.)--Prior channel instability; weak coherence of bank materials
- 72 (One Mile Creek, N. Dak.)--Bend in channel; outfall from culvert
- 13 (Flat Rock Creek, Ark.)--Turbulence at check dam; transition from narrow to wide section
- 97 (Five Mile Run, Pa.)--High channel side-slopes
- 98 (Hunters Run, Pa.)--Bend in channel

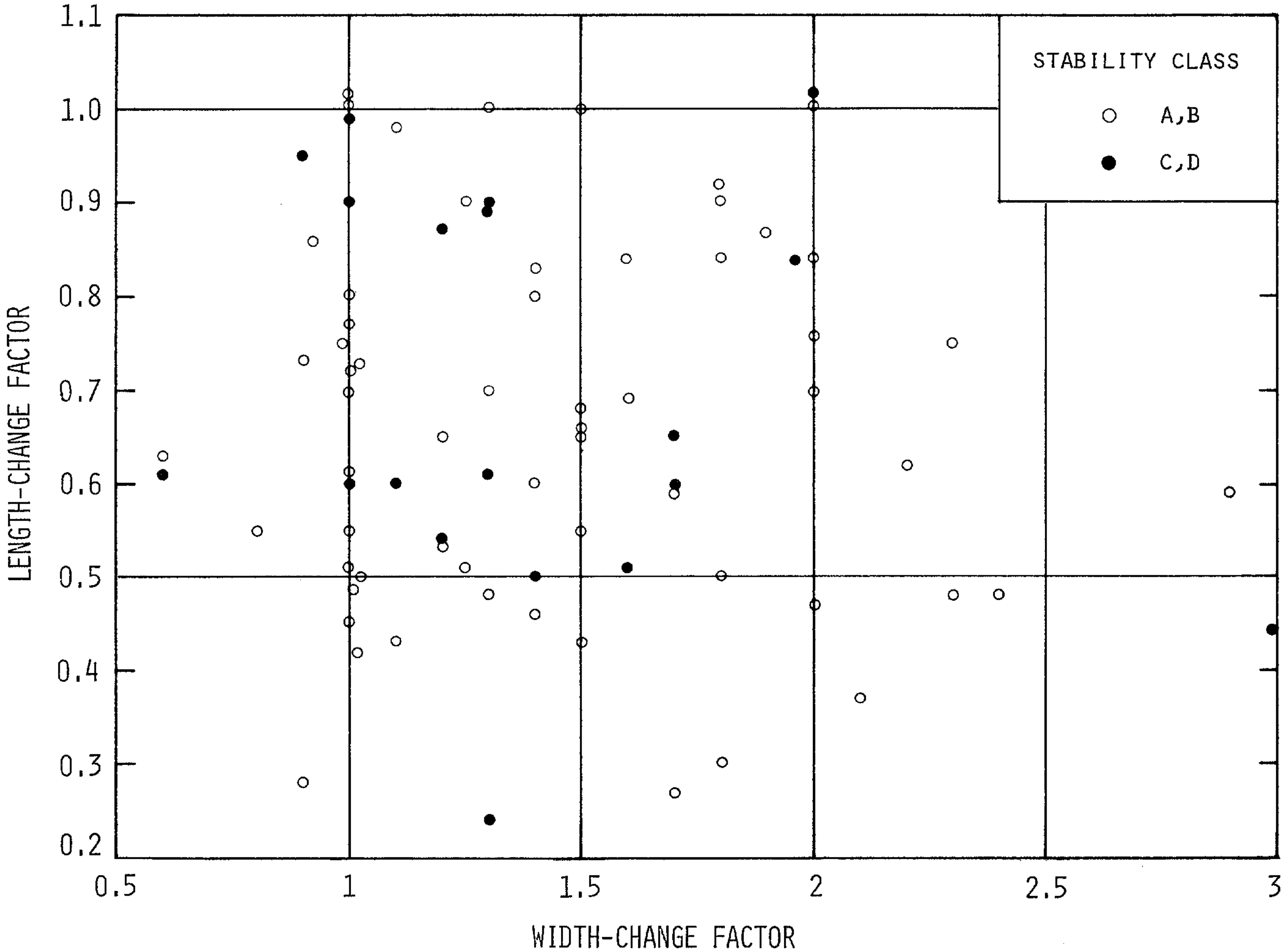


Figure 12. Scatter diagram showing stability class of relocated channels in relation to length-change and width-change factors.

The apparent lack of influence of the width-change factor in channel stability is probably due to the tendency for natural adjustment of channel width subsequent to relocation. If the relocated channel is too narrow, it will widen; if too wide, it may become more narrow. Increases in channel width among the study sites provide no insight into the adjustment process because width may increase for many reasons other than adjustment to an equilibrium value. On the other hand, decreases in channel width are more likely to represent adjustment. Among the sites at which decreases in channel width were observed are site 13, where the width-change factor (WCF) was 3; site 32 (WCF 2.4); site 59 (WCF 1.8); site 60 (WCF 1.5); site 63 (WCF 2.3); and site 80 (WCF 2).

Other relocated channels whose width-change factors were within the upper range had not narrowed, but excessive width was indicated by growth of vegetation on the channel bottom or by the development of alternate bars. These are at site 12 (WCF 1.5), site 26 (WCF 5), site 27 (WCF 1.9), site 30 (WCF 2), site 31 (WCF 3.8), site 42 (WCF 3.8), and site 54 (WCF 2). The performance periods at study sites are probably too short for the undesirable consequences of an overly wide channel to develop fully. A width-change factor in the range of 1-1.4 is probably adequate for most relocations, and a width-change factor that exceeds 2 is probably excessive, although it may not contribute to instability.

The main risk in building a channel too narrow is that widening by bank erosion may be progressive and difficult to control. Also, sediment produced by bank erosion may cause aggradation in the natural channel downstream from the relocation. The main risk in building a channel too wide is that vegetation may obstruct the channel or a wandering low-water channel may develop. Also, the upstream transition with the more narrow natural channel may become a site of bank erosion owing to eddy action accompanying expansion of flood flow.

CHANNEL ALINEMENT

Aspects of alinement that relate to the assessment of channel stability are categorized as follows: (1) Alinement along the relocated channel. The relocated channel may be straight (fig. 13A), have one or more curves along its course (fig. 13B), be curved at one end (fig. 13C) or both ends, or have the configuration of a broad arc (fig. 13E). (2) Alinement at channel junctions. Examples of different degrees of curvature (or angularity) at the junctions of natural and relocated channel are shown in figure 13. (3) Bends in the natural channel immediately upstream or downstream from the junction (fig. 13D).

Curves (bends) in channels are regarded for descriptive purposes as arcs of circles. The "sharpness" of a bend, and its potential for inducing bank erosion, depends on its radius (in relation to stream width) and its angle of turn, which is the number of degrees of azimuth that the stream changes course at the bend. A channel that is flowing north as it enters a bend, but flowing east as it leaves, has a turn angle of 90°.

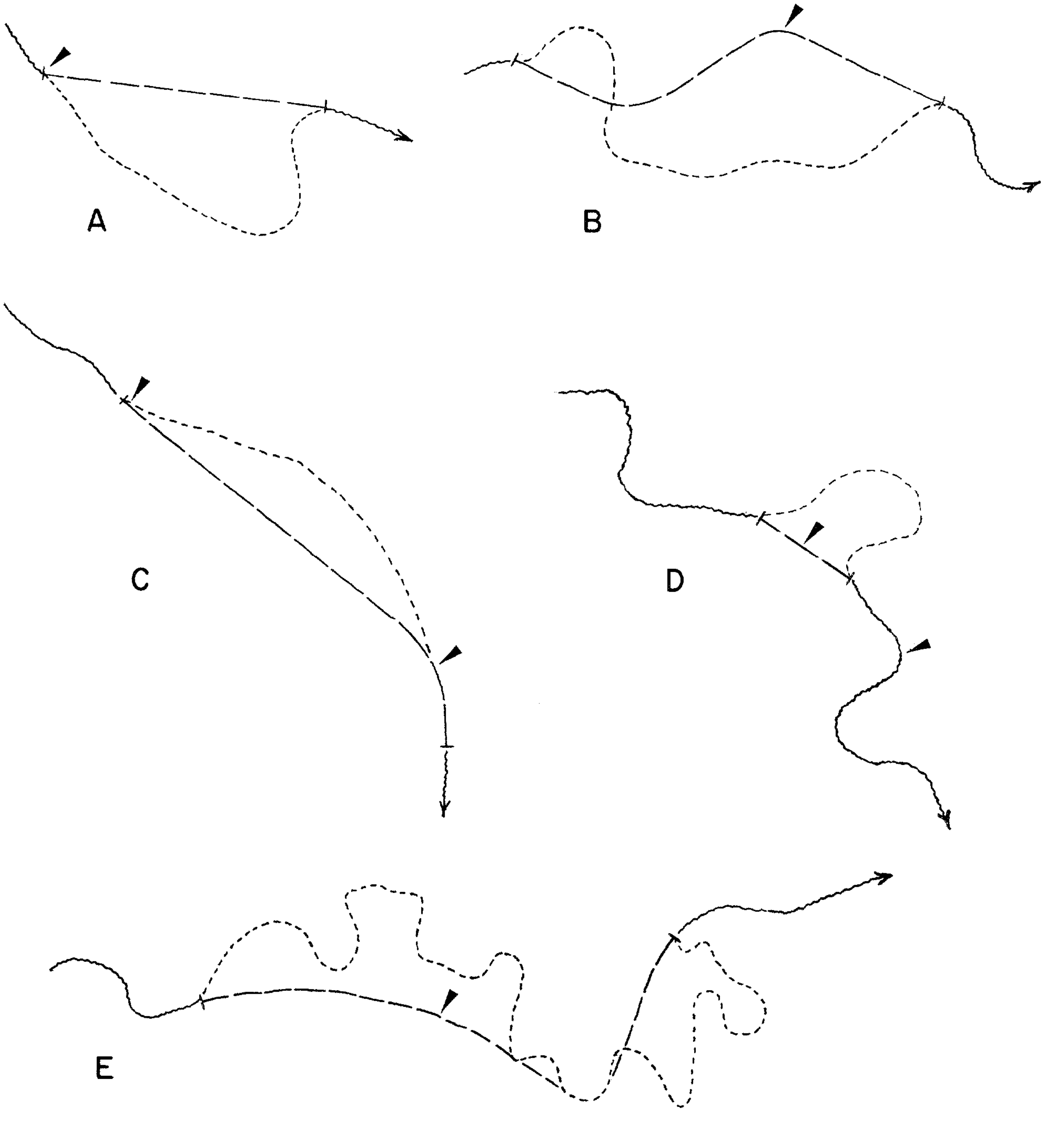


Figure 13. Examples of channel alinement. Prior channel is shown in dotted line, relocated channel in dashed line, and adjacent segments of natural channel in solid line. Arrows indicate points at which bank erosion occurred.

Alinement along relocated channels--At the study sites, 52 of 100 channels were either straight, had bends of less than 5°, or had the configuration of an arc of very large radius. Of the bends along relocated channels, turn angles were in the range of 5°-30° for 14 bends, 31°-60° for 36 bends, 61°-90° for 14 bends, and 91°-120° for 2 bends. At most bends, the outside bank was protected either with riprap or, less commonly, with concrete slope pavement. Nevertheless, bends are associated with channel instability at 21 sites, a larger number than for any other of the factors to which instability is attributed. Conversely, channel stability is attributed to straightness at 19 sites, mainly on the grounds that the straight relocated channel is more stable than are sinuous reaches of the natural channel.

Although bends in a relocated channel are detrimental to its stability, they give the channel a more natural aspect and contribute to fish habitat by providing greater channel length and more varied depths of flow. One site at which meanders were deliberately constructed for environmental purposes is included among the case histories (site 85, Gellatly Creek, Oreg.) and one other site was visited in the field (Clark Fork near Drummond, Mont.). The work at Gellatly Creek was completed in 1976. By 1979 the channel had deteriorated by degradation and bank erosion. This is attributed to the lack of woody vegetation, which plays a particularly critical role in the behavior of very small streams by increasing roughness and bank resistance. The degradation occurred in spite of the fact that the length of relocated channel equals or exceeds the length of prior channel. Artificial meanders on Clark Fork (fig. 14) have been studied in detail with regard to fish habitat by Hunt and Graham (1972), who concluded that the hydraulic, topographic, and fish habitat characteristics were similar to those found in natural meanders. Field observation in 1979 showed that the meanders were stable, but the appearance was not natural because of the large riprap placed continuously along both banks. The designer of artificial meanders is faced with a dilemma: In order to avoid deterioration of the channel while woody vegetation is becoming established, bank protection measures must be applied and these are likely to look unnatural. In addition, equalling or even exceeding the length of prior channel does not necessarily prevent degradation.

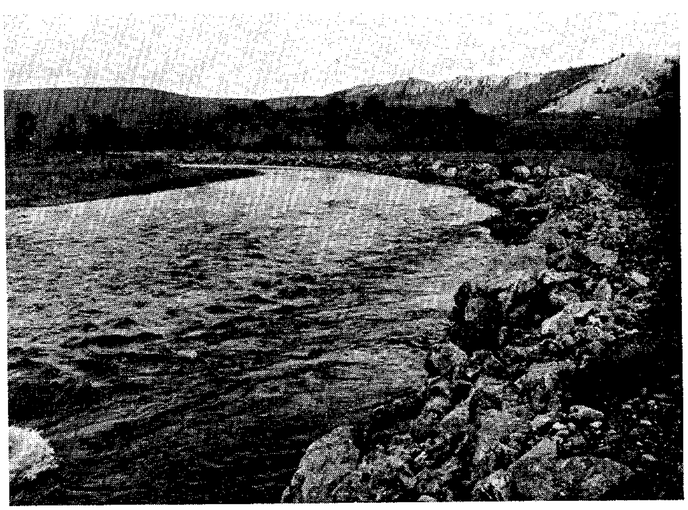


Figure 14. Relocated channel of Clark Fork at artificial meander near Drummond, Mont.

Alinement at channel junctions--The angle of turn at the upstream and downstream junction of natural and relocated channel was measured at 90 sites (180 junctions). The angle of turn was less than 5° at 104 junctions, in the range of 5°-30° at 34 junctions, of 31°-60° at 32 junctions, and of 61°-90° at 10 junctions. The prevalence of low angles of turn at junctions indicates that designers are well aware of the potential for instability at angular junctions, and the higher angles occur mainly in difficult situations. Channel instability was attributed to angularity of junction at only three sites.

Bends in natural channel immediately upstream or downstream from junction--Migration of an upstream bend may induce bank erosion along a relocated channel by changing the alinement of entering flow. Conversely, a relocated channel may induce bank erosion at a sharp bend downstream by directing flow against a bankline. Both of these effects occurred at site 39 (fig. 13D), where lateral migration rates on the Amite River were high prior to relocation. The effects are less apparent on more stable channels and were documented for only one other stream (site 69).

MEASURES FOR EROSION CONTROL AND ENVIRONMENTAL PURPOSES

Preservation of original vegetation--No evidence was found for the preservation of original vegetation along any of the relocated channels: a channel of trapezoidal cross section and 2:1 side slopes can scarcely be excavated and graded without the removal of vegetation. At many sites, however, the strip of cleared ground along the channel, as observed on airphotos, seemed unnecessarily wide. At site 56 (fig. 13E), a sharp bend in the natural channel was incorporated into the relocated channel. The original trees at the bend were preserved and are probably responsible for its stability. At site 38, the stability of two sharply angular channel junctions is probably due to the preservation of trees. On naturally stable mountain streams having boulder and cobble beds, the preservation of trees by minor course deviations of a relocated channel is feasible. On less stable streams having sand beds and erodible banks, the preservation of trees along a relocation may not be feasible unless part of the natural channel can be incorporated into the relocation. At site 53, a part of the natural channel was left undisturbed in the median area of a divided highway.

Planting of vegetation--The sowing of grass or other nonwoody vegetation is specified on the design plans for a few of the study sites and may have been carried out for many. However, at none of the sites was any evidence found for a deliberate effort to establish trees or other woody vegetation. The raw bankline of a relocated channel is admittedly a difficult place on which to grow trees, but the importance of trees both in appearance and in erosion control would seem to justify a serious and possibly sustained effort. Planting of stakes of willow and poplar has been widely used for bank protection in New Zealand, and several methods of planting stakes are described in Acheson (1968, p. 72-83). Such planting is described as "the simplest and sometimes the cheapest way of establishing protection, but damage and mortality are often high and considerable patience and judgment are required". Stake planting is usually most effective on small-to-moderate sized rivers whose load includes fine sediment.

Bank revetment and channel lining--Revetment at bridges has been assessed in a previous report (Brice and Blodgett, 1978) and is not described at study sites unless it extends for a substantial distance along the channel. Types of revetment used along relocated channels at study sites are as follows:

(1) Dumped rock riprap (sites 6, 8, 12, 13, 14, 15, 18, 24, 25, 27, 28, 30, 37, 47, 54, 59, 65, 66, 67, 68, 72, 73, 74, 75, 77, 78, 80, 81, 82, 83, 84, 85, 87, 88, 90, 92, 94, 100, 103, 104). In general, riprap was used selectively, at bends and along roadway embankments, rather than along both banks. The size, quality, and quantity used was best in states where it was more readily available, as in Oregon, Washington, Idaho, and California. At most sites where used, riprap is assessed as a critical factor in channel stability. A few failures of riprap occurred. At site 72, riprap of "fieldstone" (glacial boulders) failed at a bend downstream from a culvert, at which a stilling basin and drop structure were subsequently installed. At site 90, riprap failed on a high embankment during a severe flood. At site 66, local failure of riprap was observed at an embankment, against which flow was directly impinging.

(2) Concrete grouted riprap (site 51). At this site, the riprap was performing well despite the fact that it was set against a sandy bank. However, floods are very rare along the stream and water velocities are generally low.

(3) Rock-and-wire mattress (site 104). This type of revetment consists of a mat of wire-enclosed riprap and is usually less than 0.3 m in thickness. It is best suited to arid and semiarid regions. The example here is from Wyoming, at a site where the revetment has mostly, but not entirely, prevented erosion at a bend.

(4) Gabions (sites 46, 90). At site 46, where the gabions are placed on plastic filter cloth, some undercutting at the toe was observed. At site 90, the gabions are on a high embankment, where riprap had previously failed during a flood.

(5) Concrete slope pavement (sites 26, 28, 29, 53, 88). Rigid revetment is subject to failure from undermining at the toe or ends. Failure occurred at site 28, local subsidence was observed at site 29, and a 30-m length of pavement was destroyed by flood at site 88.

(6) Concrete channel lining (sites 45, 91, 99). The bottom of the lining failed locally, probably from hydrostatic pressure, at sites 45 and 99; no weep holes in the lining were provided at these sites. No problems were observed at site 91.

(7) Articulated concrete blocks (site 29). Effectiveness of the blocks at this site was generally good, and vegetation has become established in the crevices between blocks.

Flow-control structures--Included in this category are spurs, spur dikes, retards, and check dams or drop structures, all of which are intended to prevent erosion by controlling the direction, velocity, or depth of flowing water.

(1) Spurs (site 89). Short riprap spurs at site 89, for which no design specifications were obtained, failed to prevent bank erosion and have been destroyed by erosion. Spurs were installed at one other site (site 77), but these are set against a heavily riprapped bank and are intended for environmental purposes.

(2) Spur dikes (site 68). At this site, riprap placed along one bank of a relocated channel has been removed by erosion, and a spur dike is maintaining channel alinement at the bridge.

(3) Retards (sites 8, 67, 79, 81). All the retards at study sites are of rock riprap, placed at the bankline to deflect flow at bends or channel junctions. Performance is satisfactory except at site 81, where the retard is inadequate.

(4) Check dams or drop structures (sites 10, 11, 13, 20, 26, 29, 36, 46, 54, 69, 72, 74, 75, 83, 87, 101, 104). Concrete, gabions, rock riprap, or steel sheet piling have been used at study sites for these structures, whose height above streambed at different sites ranges from about 0.5 m to 2.5 m. Check dams have evidently served to prevent degradation at most of the sites but have induced bank erosion or bed scour at four sites. Apparently, the probability that a check dam will cause erosion increases with increasing height above the channel bottom.

(5) Culvert wingwalls (sites 34, 63). Extended concrete wingwalls at culverts have contributed to channel stability at these two sites.

Measures intended mainly for environmental purposes--At site 27, two "fish and sediment ponds", consisting mainly of low riprap check dams, were built but had badly deteriorated within two years after completion. At site 77, riprap spurs were built to induce limited sinuosity within a straight riprapped bankline and thereby to improve fish habitat and to give the channel a more natural appearance. Although the spurs have been eroded, the objective has been attained. At site 78, the longitudinal profile of the channel was so constructed that sections of 1 m/km slope alternate with flat sections at 90 m intervals. This feature was evidently intended to provide alternating rapids and pools, which were apparent at normal stage in 1979. In addition, "fish boulders" were placed in the channel. At site 83, gabion check dams were placed at intervals across the channel to provide pools. Turbulence at the check dams has evidently induced bank erosion. The low check dams at site 74 were probably placed, at least in part, for environmental purposes and the rapids they create add visual interest to the straight channel. At site 51, spurs built of small logs, held together with spikes, were installed at some time after construction, probably by the state fish and game agency. Because of their weak construction, these spurs make little or no contribution to channel stability.

POST-ALTERATION FACTORS

Length of performance period--As given in the case histories, performance period begins with the year of completion of the channel alteration and ends with the date of field inspection, for purposes of this report. Conditions as observed on airphotos taken within a few years of the date of inspection were considered applicable to that date unless there was reason to believe otherwise. Performance periods range from 2 to 50 years; the modal period is distinctly peaked at 15 years (fig. 15). Sites on the interstate highway system, which was under intensive construction during the period 1960-70, were emphasized in the letter of inquiry regarding sites, sent by the Contract Manager to regional offices of the Federal Highway Administration.

Tendencies toward instability at a site are likely to become apparent soon after construction and to diminish in 10-15 years. For example, Yearke (1971) established bench marks along the relocated channel of the Peabody River during construction in 1961 and made subsequent surveys in 1963, 1964, 1965, and 1968. He reported that "Its adjustment was a continuing process with the major change occurring within the first year and adjustments of decreasing significance occurring each year thereafter". Cross sections at five sites in Alabama (sites 1, 2, 3, 4, 6), at which relocation was completed during the period 1961-63, were surveyed in 1965 and again in 1978. Although substantial changes occurred at some sections during the period 1965-78, comparison of the cross sections indicates that the major changes occurred soon after construction. The early onset of erosion is attributed to floods at two of the sites in Alabama, but it may also occur in the absence of floods (site 10).

Streamflow during performance period--The relation of bank erosion to stream stage differs from one stream to the next, but the general relation found for the Sacramento River by the Corps of Engineers (U.S. Congress, 1960) is a useful approximation. Significant bank erosion begins when the mean water velocity in the channel reaches a certain value (about 1.3 m/s for the Sacramento River). Bank erosion was found to be roughly related to stage duration, in foot-days per year, for the time that the velocity exceeds this value. Thus, bank erosion occurs mainly during floods because the stream stays above a certain stage for a sustained period of time. Sustained flow just below bankfull stage could also cause rapid bank erosion. On some streams, bank failure by slumping is most likely to occur during or after falling stream stage. Floods provide the severest test of a relocated channel, but the severity of the test is not necessarily proportional to the magnitude of the flood; and some testing is provided by flows near but below bankfull stage.

District offices of the U.S. Geological Survey (Water Resources Division) were consulted with regard to the occurrence of floods at study sites. About one-third of the sites are on gaged streams, and tables of annual peak discharges were obtained for these. For most of the other sites, occurrence of floods was based on the probability that regional storms, as recorded on nearby gaged streams, also affected the stream at the site. For a few sites, no flood records were applicable, and reliance was placed on field observation of high-water marks.

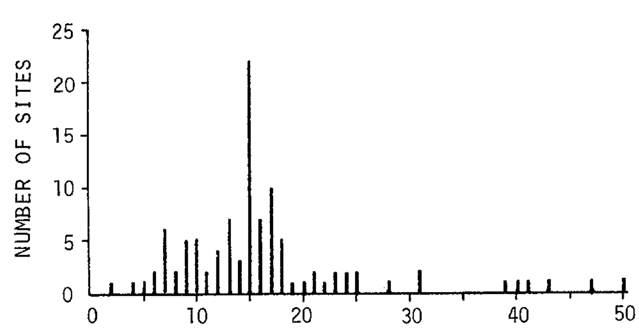


Figure 15. Histogram of performance periods at study sites.

A flood that occurs soon after construction, while the banks are raw and before vegetation has become established, probably causes much more bank erosion than would a later flood of the same magnitude and duration. For example, Jefferson (1965, p. 6) documented severe bank erosion resulting from floods that occurred at site 2 soon after completion. In addition, the stage and timing of floods is important in the establishment of riparian vegetation (Sigafoos, 1964, p. A27).

Post-construction maintenance and addition of countermeasures--In general, the post-construction clearing of vegetation along altered channels was restricted to the highway right-of-way, which is regularly mowed in many states. At two sites (sites 24, 72), curves in the relocated channel were modified after bank erosion had occurred. Check dams or drop structures were added at sites 11, 26, and 72 after degradation had occurred. Riprap was replaced or added at sites 8, 10, 11, 26, 39, 54, 65, 87, 88, and 89.

Growth of vegetation along channel--Comments on the natural recovery of vegetation along relocated channels are provided for most sites in the case histories. In general, recovery was good in naturally forested regions where climatic conditions were favorable and fair to poor in other regions. At several sites, damage to trees by beavers was apparent, and beaver dams in the relocated channel were observed at sites 5, 17, 19, and 59.

CRITICAL FACTORS CONTRIBUTING TO STABILITY AND INSTABILITY

At each study site, the factors that probably made the most critical contribution to stability or instability were inferred from available evidence. Because of the many factors involved and their complex interrelations, no completely objective way of isolating the critical factors is apparent. In the listings that follow, the factors are arranged according to their frequency of occurrence at study sites; and the sites are arranged according to channel stability class. The significance of each factor has been previously discussed.

In a sense, the factors listed represent the attributes of stable and of unstable channels and the circumstances associated with stability, some of which are within the control of the highway agency and some are not.

FACTORS CONTRIBUTING TO STABILITY OF RELOCATED CHANNELS

(1) Growth of vegetation on banks (41 sites)
- Class A1: Sites 5, 18, 22, 37, 42, 46, 47, 48, 52, 53, 59, 63, 64, 80, 82, 102, 103
- A2: Sites 49, 51, 101
- B1: Sites 12, 36, 43, 57, 69, 73
- B2: Sites 1, 7, 30, 35, 84, 93
- B4: Sites 3, 33, 58
- C2: Sites 13, 61, 97
- C3: Sites 21, 62
- C4: Site 2

(2) Bank revetment (33 sites)
- Class A1: Sites 14, 15, 29, 46, 53, 65, 74, 77, 80, 82, 91, 100, 103
- A3: Site 8
- B1: Site 45, 54, 73, 75, 81, 94, 99, 104
- B2: Sites 25, 66, 68, 83, 84, 87
- B3: Site 26
- C2: Sites 13, 24, 67
- C3: Site 72

(3) Stability of prior channel (20 sites)
- Class A1: Sites 5, 6, 18, 37, 38, 47, 48, 53, 59, 64, 74, 77
- B2: Sites 7, 9, 35, 66, 71, 86
- B3: Site 40
- B4: Site 58

(4) Straightness of channel (20 sites)
- Class A1: Sites 16, 18, 60, 65
- A2: Sites 49, 51, 90, 101
- A3: Site 8
- B1: Sites 12, 23, 32, 36, 57, 73, 75
- B2: Sites 19, 71
- B4: Site 3
- D3: Site 76

(5) Low channel slope, for size and type of stream (16 sites)
- Class A1: Sites 5, 42, 48, 52, 59, 60, 63, 64, 100, 102
- A2: Sites 49, 51
- B2: Sites 9, 44, 71
- C2: Site 61

(6) Erosional resistance of bed or bank material (15 sites)
- Class A1: Sites 6, 18, 60, 77, 80
- A2: Site 90
- B1: Sites 17, 36, 81, 94
- B2: Sites 19, 25, 86, 93, 96

(7) Conservative length-change factor (15 sites)
- Class A1: Sites 16, 37, 74, 80, 92, 103
- B1: Sites 17, 81
- B2: Sites 9, 35, 86, 87, 95
- C2: Site 24
- C3: Site 21

(8) Bedrock control in or along channel (13 sites)
- Class A1: Sites 6, 14, 15, 77, 82
- A2: Site 90
- A3: Site 8
- B1: Site 12
- B2: Sites 25, 56, 68
- C2: Site 97
- D2: Site 55

(9) Check dam or drop structure (11 sites)
Class A1: Site 29
A2: Site 101
B1: Sites 36, 54, 75, 104
B2: Sites 83, 87
B3: Site 26
C2: Site 20
C3: Site 72

(10) Natural or artificial regulation of discharge (10 sites)
Class A1: Sites 47, 48, 52, 53, 92, 100
A2: Sites 49, 51, 101
B4: Site 33

(11) No floods in first few years after construction (6 sites)
Class A1: Site 6
B1: Sites 23, 57, 69
B2: Sites 30, 56

(12) Preservation of original vegetation (3 sites)
Class A1: Sites 34, 38
B2: Site 56

(13) Dual channel (3 sites)
Class A1: Sites 74, 103
B1: Site 36

FACTORS CONTRIBUTING TO INSTABILITY OF RELOCATED CHANNELS

In addition to the factors listed below, the removal of vegetation along relocated channels during construction is regarded as a major factor contributing to instability. Because such removal was done at all study sites, and because it seems unavoidable at most sites for practical reasons, it is not listed as a contributing factor.

(1) Bends in relocated channel (21 sites)
Class B1: Sites 17, 81, 104
B2: Sites 1, 30, 44, 66, 68, 86, 87, 88, 93, 95, 96
B3: Site 41
C2: Site 24
C3: Site 21, 28, 72, 96
D3: Site 85

(2) Flood of large recurrence interval (17 sites)
Class A2: Site 90
A3: Site 8
B1: Sites 94, 95
B2: Sites 9, 25, 87, 88, 93, 95, 96
B3: Sites 26, 40
B4: Site 58
C2: Site 24
C3: Sites 63, 96

(3) Erodibility of bed or bank materials (16 sites)
Class A2: Sites 49, 51
A3: Site 8
B1: Site 104
B2: Sites9, 83
B4: Sites 3, 33
C2: Site 61
C3: Sites 28, 67, 72
C4: Site 4
D2: Site 55
D4: sites 10, 89

(4) High channel side, susceptible to slumping (9 sites)
Class B1: Sites 69, 75
B2: Sites 56, 88, 95
C2: Sites 70, 20, 97
D2: Site 79

(5) Instability of prior channel (8 sites)
Class B2: Site 83
C2: Site 70
C3: Sites 28, 67
C4: Site 4
D2: Site 55
D3: Site 10
D4: Site 39

(6) Sharp decrease in channel length (8 sites)
Class A2: Site 101
B2: Sites 1, 56
B3: Site 26
B4: Site 58
C2: Site 97
C3: Site 11
D4: Site 10

(7) Failure of revetment (7 sites)
Class A2: Site 90
B: Sites 45, 68, 99
C3: Sites 11, 72
D4: Site 89

(8) Width-change factor too high or too low (6 sites)
Class B1: Sites 27, 32, 54
B2: Site 31
B4: Site 3
C4: Site 4

(9) Cleared field at bankline (5 sites)
Class B1: Sites 12, 73
B2: Sites 35, 44, 56

(10) Flood soon after construction (5 sites)
Class B2: Site 35
B4: Sites 3, 33
C4: Site 2
D4: Site 89

(11) Lack of continuity in vegetal cover along banks (5 sites)
Class B1: Site 36
B2: Sites 84, 86
C2: Site 70
D3: Site 85

(12) Turbulence at check dam or drop structure (4 sites)
Class B2: Site 83
C2: Site 13
C3: Site 11
D4: Site 10

(13) Flow constriction at bridge (4 sites)
Class B2: Site 9
B3: Sites 40, 41
C2: Site 61

(14) Non-linear junction with natural channel (3 sites)
Class A3: Site 8
C2: Site 24
D3: Site 76

(15) Steep channel slope, for size and type of stream (2 sites)
Class D4: Sites 10, 89

INDUCED INSTABILITY OF NATURAL CHANNELS

Of 79 sites at which the stability of the natural channel prior to relocation was assessed, some effect of the relocated segment on adjacent segments of natural channel was discerned at 21 sites. An increased rate of bank erosion, mostly at bends, was discerned at 19 sites, degradation at 5 sites, and aggradation at 1 site. Factors that contributed to the induced instability of the natural channel segments are listed below.

(1) Increased channel slope due to relocation
Sites 10, 11, 19, 22, 23, 60, 64, 65, 70, 101
(2) Prior instability of natural channel
Sites 10, 11, 23, 28, 39, 65, 69, 70
(3) Erodibility of bed-bank materials
Sites 62, 64, 69, 83
(4) Locally high sinuosity of natural channel
Sites 2, 19, 22, 30, 65
(5) Flood of large recurrence interval
Sites 26, 40, 45, 62
(6) Degradation at relocated channel
Sites 10, 11, 26, 101
(7) Cleared field at bankline
Sites 22, 26, 60
(8) Nonlinear junction with relocated channel
Sites 23, 28
(9) Bend immediately downstream from junction
Sites 39, 69
(10) Flow contraction at bridge
Site 40
(11) Hydraulic properties of transition
Site 99
(12) Clearing and grading for highway construction
Site 45
(13) Turbulence at check dam
Site 83

SUMMARY

1. Case histories are presented for 103 stream channels, in different regions of the United States, that were altered for purposes of road or bridge construction, mostly during the period 1960-70. Each case history includes data on the factors considered to be potentially important in channel stability. These factors are organized into three sets: site factors, alteration factors, and post-alteration factors. From an assessment of the information as given and from field study, the factors critical to channel stability at the site are identified.

2. A completely stable channel is one that does not change in size or position with time, but all alluvial channels have some degree of instability. The stability of a channel is described according to a dual letter-number system in which four classes apply to the present degree of bank stability and four apply to the amount of dimensional change with time. Stability of the relocated channel was rated as good (classes A1-A3) at 36 sites, as fair to good (classes B1-B4) at 42 sites, as fair (classes C2-C4) at 15 sites, and as poor (classes D2-D4) at 7 sites. In comparison with bank stability of the prior channel, bank stability of the relocated channel was about the same at 45 sites, better at 28 sites, and worse at 14 sites. Channel degradation, mostly minor, was discerned at 17 sites. Degradation serious enough to jeopardize a bridge was observed at only three sites.

3. Alteration was by channel relocation at almost all the study sites; the other kinds of alteration--encroachment and reshaping--are represented by only a few sites. The main purposes of alteration are to improve channel alinement at a crossing, to accommodate a planned roadway location, and to avoid one or more crossings.

4. The length of natural channel involved in relocation ranges from 70 to 4,200 m, and the median length is 650 m; as expressed in multiples of channel width, the range is from 8 to 550, and the median is 50 channel widths. Length of relocation contributed significantly to channel instability at sites where its value exceeded 250 channel widths. At sites where the value was below 100 channel widths, the effects of length of relocation were dominated by other factors.

5. The change in channel length resulting from relocation is expressed by the length-change factor, which is the ratio of length of relocated channel to length of prior channel. The change in slope is inversely proportional to the length-change factor. The width-change factor is the ratio of width of relocated channel to width of prior channel. Length-change factors at study sites ranged from 0.24 to 1.2, and width-change factors ranged from 0.6 to 5. Despite this wide range and the hypothetical importance of these factors, they showed no general relation to the stability class of channels: their effects at many sites were evidently dominated by

other factors. However, severe shortening probably contributed to instability at some sites, and the effects of shortening probably increased with length of relocation.

6. Factors identified as critical to the stability of relocated channels at study sites are: growth of vegetation on banks (40 sites); bank revetment (33 sites); stability of prior channel (19 sites); and erosional resistance of bed-bank materials (15 sites).

7. Factors identified as critical to the instability of relocated channels at study sites are: bends in channel (21 sites); erodibility of bed-bank materials (16 sites); floods of large recurrence interval (16 sites); high channel side, susceptible to slumping (9 sites); and instability of prior channel (8 sites).

8. Of 87 sites at which prior stability was assessed, some effect of the relocated segment on adjacent segments of natural channel was discerned at 21 sites. The most common effect was an increased rate of bank erosion at bends, which was not discerned at a distance greater than 20-30 channel widths from the ends of the relocated segment.

RECOMMENDATIONS AND CONCLUSIONS

The recommendations and conclusions presented here apply to specific aspects of the planning and construction of channel relocation and are intended for assessment of the risk of instability and for reduction of the degree of instability connected with relocation. Serious instability resulting from relocation was observed at few study sites. At some of these, the probability of instability was high because the prior natural channel was unstable. At others, the probability seemed low, but floods of high recurrence interval occurred during or soon after construction. Although there is an element of chance in channel stability, the experience represented by the study sites should provide some useful guidelines for improvement in the performance of channels relocated by highway agencies.

Channel stability prior to relocation--Assessment of the stability of a channel prior to relocation provides valuable information on the need for erosion-control measures and the risk of instability. An unstable channel is likely to respond unfavorably to relocation. Bank stability is assessed by field study and the stereoscopic examination of airphotos. The most useful indicators of bank instability are cut or slumped banks, fallen trees along the bankline, and wide point bars exposed at normal stream stage. Bank recession rates are measured by comparison of time-sequential airphotos. Vertical instability is equally important but more difficult to determine. It is indicated by changes in channel elevation at bridges and gaging stations. Serious degradation is usually accompanied by generally cut or slumped banks along a channel.

Classification of a channel according to the scheme presented herein will provide some insight into its probable stability. The scheme is more useful for channels wider than about 10 m than for smaller channels.

Erosional resistance of channel boundary materials--The stability of a channel, whether natural or relocated, is partly determined by the erosional resistance of materials that form the perimeter of the channel. Assessment of erosional resistance provides useful information on the potential stability of a proposed relocation, on the need for countermeasures, and on the need for the deliberate establishment of vegetal cover along the banks.

Resistant bedrock that crops out in the channel bottom or that lies at shallow depth will provide protection against degradation. Not all bedrock is resistant. Erosion of shale, or of other sedimentary rock types interbedded with shale, was observed at three sites. Degradation was slight or undetected at most sites where bed material was of cobble and boulder size. However, serious degradation resulted from relocation at two such sites. Degradation may result from the relocation of any alluvial channel, whatever the size of bed material, but the incidence of serious degradation of channels relocated by highway agencies is slight.

The coherence and erosional resistance of banks tend to increase with increase in clay content. Banks of weakly coherent sand or silt are clearly subject to rapid erosion, but stable channels at several sites have weakly coherent banks well protected with vegetation. No consistent relation was found between channel stability and the coherence of bank materials, probably because of the effects of vegetation.

Length of relocation--As measured by the length of prior channel cut off by relocation, length of relocation contributed significantly to channel instability at sites where its value exceeded 250 channel widths. At sites where the value was below 100 channel widths, the effects of length of relocation were dominated by other factors. The probability of local bank erosion at some point along a channel increases with the length of the channel.

Degree of channel shortening--No consistent relation between degree of channel shortening by relocation (length-change factor) and channel stability was discerned. However, severe shortening probably contributed to instability at some sites, and the effects of shortening probably increase with length of relocation.

If a segment of sinuous channel is straightened, the slope of the straightened segment is increased by the same factor that the sinuosity was decreased. Shortening and the consequent increase in slope can be avoided by constructing an artificially meandering channel that has the same sinuosity as the prior natural channel. The performance of artificial meanders was observed at only two sites. At one of these, the banks were continuously revetted with heavy riprap; at the other, bank erosion and degradation were occurring. Evidence from the general population of sites indicates that equivalence in length does not insure stability and that bank erosion is more probable at bends than in straight reaches.

Bank revetment is likely to be required at artificial meanders to attain a reasonable degree of bank stability, and the required length of revetted bank will increase with increase in induced sinuosity. Although gentle curves in a channel do not add significantly to its length, they are more easily stabilized and they tend to relieve the visual monotony of a straight channel.

Width of relocated channel--The width-change factor is the ratio of bottom width of relocated channel to bottom width of natural channel. According to the concept of channel equilibrium, an increase in channel slope by relocation can be offset by an increase in the width-change factor. However, the study sites show no general tendency of designers to increase the width-change factor to offset an increase in slope. Some tendency is apparent toward duplicating natural stream width without regard to increase in slope. No consistent effect of the width-change factor on stability could be demonstrated. From an examination of relocated channels that are evidently too wide, it was concluded that width-change factor of 1-1.4 is probably adequate for most relocations. A width-change factor that exceeds 2 is probably excessive, although it may not contribute to instability.

Channel width tends to become adjusted to an equilibrium value. The main risk in building a channel too narrow is that widening by bank erosion may be progressive and difficult to control. Also, sediment produced by bank erosion may cause aggradation in the natural channel downstream from the relocation. The main risk in building a channel too wide is that vegetation may obstruct the channel or a wandering low-water channel may develop. Also, the upstream transition with the more narrow natural channel may become a site of bank erosion owing to eddy action accompanying expansion of flood flow.

Cross-sectional shape of relocated channel--No shape other than trapezoidal was specified on design plans for unlined channel at study sites, and the side slopes specified were either 1.5:1 (13 sites) or 2:1 (37 sites). At all sites, subsequent erosion steepened the side slopes and modified the cross section toward a parabolic shape. Nevertheless, an initial side slope of 2-horizontal to 1-vertical (or less steep than 2:1) can be expected to contribute to bank stability by increasing the possibility of early establishment of vegetation, by either natural or artificial means.

Dual channels, in which a low-flow channel is inset within a larger flood channel, are a desirable alternative for "flashy" streams of highly variable discharge and for situations in which a flood plain is not available for conveyance of flood flow.

High banks or side slopes, which resulted from the relocation of a channel across high ground, failed by slumping at several sites. At two sites, incipient slump blocks were of sufficient size to entirely block the channel. The relocation of narrow, deeply incised channels presents a similar stability problem, which may require sufficient grading to reduce side slopes to a stable angle. At two sites, terracing of high side slopes has evidently contributed to slope stability.

Alinement along relocated channel and at junctions with natural channel--About half of the relocated channels were straight, and the rest had one or more bends. Turn angles were in the range of 5°-30° for 14 bends, 31°-60° for 36 bends, 61°-90° for 14 bends, and 91°-120° for 2 bends. At most bends, the outside bank was revetted; nevertheless, bank erosion is associated with bends at 21 sites. At channel junctions, the prevalence of low angles of turn indicates that designers are well aware of the potential for instability at angular junctions. Bank erosion was attributed to angularity of junction at only two sites. At one site, a relocated channel induced bank erosion at a sharp downstream bend in the natural channel by directing flow against the bankline.

Preservation of original vegetation--Although construction of a relocated channel with earth-moving equipment requires the removal of trees and other vegetation, there may be some latitude in the width of cleared ground along the sides of the relocation and at the junctions with the natural channel. At one site, trees left at a sharply angular junction have evidently contributed to its stability. At two sites, vegetation has been preserved by incorporating part of the natural channel into the relocation.

Planting of vegetation--At none of the study sites was any evidence found for a deliberate effort to establish trees or other woody vegetation. The importance of vegetation, both in appearance and in erosion control, would seem to justify a serious and possibly sustained effort to establish it as soon as possible on the graded banks.

Bank revetment--Revetment made a critical contribution to stability at many sites where it was placed at bends and along roadway embankments. Rock riprap was by far the most commonly used revetment, and its effectiveness was generally satisfactory. Concrete slope pavement failed to some degree at three of the five sites where it was used. Articulated concrete blocks were effective at the one site where used, and vegetation had become established in the interstices between blocks.

Check dams (drop structures)--Check dams were observed at 17 sites, and bed scour or bank erosion was attributed to these structures at four sites. The most serious erosion was at the highest structures (2.5-3 m in height). In general, the check dams have been effective in preventing channel degradation. The potential for erosion at a check dam depends on its design and construction, its height, and the use of revetment on adjoining banks. A series of low check dams, less than about 0.5 m in height, is probably preferable to a single higher structure, because the potential for erosion is less, as are the consequences of failure. By simulating rapids, low check dams may add visual interest to the flow in a channel.

Maintenance--Except for the clearing of vegetation within the highway right-of-way, no routine maintenance of relocated channels was apparent at study sites. At several sites, countermeasures were added as a consquence of erosion at bridges or highway embankments. The following problems, subject to improvement by maintenance, were observed along relocated channels: (1) growth of annual vegetation in channel, (2) reduction of channel conveyance by overhanging trees, (3) local bank cutting, and (4) bank slumping. At most sites, these problems were not serious. The expense of routine maintenance or inspection of relocated channels beyond the highway right-of-way is probably prohibitive. However, most of the serious problems could be detected by periodic inspection, perhaps by aerial photography, during the first 5 or 10 years after construction.

APPENDIX

CASE HISTORIES

SITE 1. BIG CANOE CREEK AT I-59 NEAR ASHVILLE, ALA.

SYNOPSIS--Channel segment was relocated and thereby shortened from a length of 605 m to 400 m, for purpose of improving channel alinement at bridge (fig. 16). Performance period, 17 yr (1961-78) during which the largest flood (in March of 1970) had a recurrence interval of about 10 yr. As built, the relocated channel was trapezoidal in cross section, with a bottom width of 15 m, 1½:1 side slopes, and a longitudinal slope of 3.5 m/km. No bank protection measures were applied. This site was reported on by Jefferson (1965), who observed minor bank erosion near the bend in the relocated channel but saw no evidence of instability elsewhere. Channel cross sections were surveyed by the U.S. Geological Survey in 1965, and these same sections were resurveyed in 1978 (fig. 17). The right bank at section 1 receded about 6 m during the period 1965-78, a lesser amount of bank erosion occurred in section 2, and none at section 4. The surveys also indicate about 0.6 m of degradation at sections 1 and 2, but aggradation at section 4. By 1978, the bankline had become densely vegetated (figs. 18A and 18B) and the cut banks, although present, seemed not to be receding. Grass had become established on alternate gravel bars in the channel (fig. 18C), and these may lead to development of sinuosity. Adjacent segments of the natural channel had cut banks at bends prior to relocation (as observed on a 1957 airphoto), and the incidence of cut banks was about the same in 1977.

Stability class B2 for relocated channel and for adjacent segments of natural channel. Bank erosion has evidently been controlled by the establishment of vegetation and the increase in channel width, which initially exceeded the width of the natural channel by a factor of 1.5.

SITE FACTORS--Lat 33°48', long 86°22', at I-59, 1.5 km southwest of Ashville, Ala., interchange, on Ashville 7½' map. Big Canoe Creek is perennial, with a drainage area of 130 km^2 and an average discharge of about 2.7 m^3/s. Wide-bend point-bar stream, alluvial, channel bottom width of 10 m, channel slope of 3.5 m/km, sinuosity of 1.5. Valley relief is 10-15 m, the flood plain is wide relative to stream width, and prior to relocation tree cover along the bankline was greater than 90 percent. Bed material is fine to medium gravel, and bank material is moderately coherent gravel, sand, and clay.

ALTERATION FACTORS, POST-ALTERATION FACTORS, DISCUSSION--(See "Synopsis")

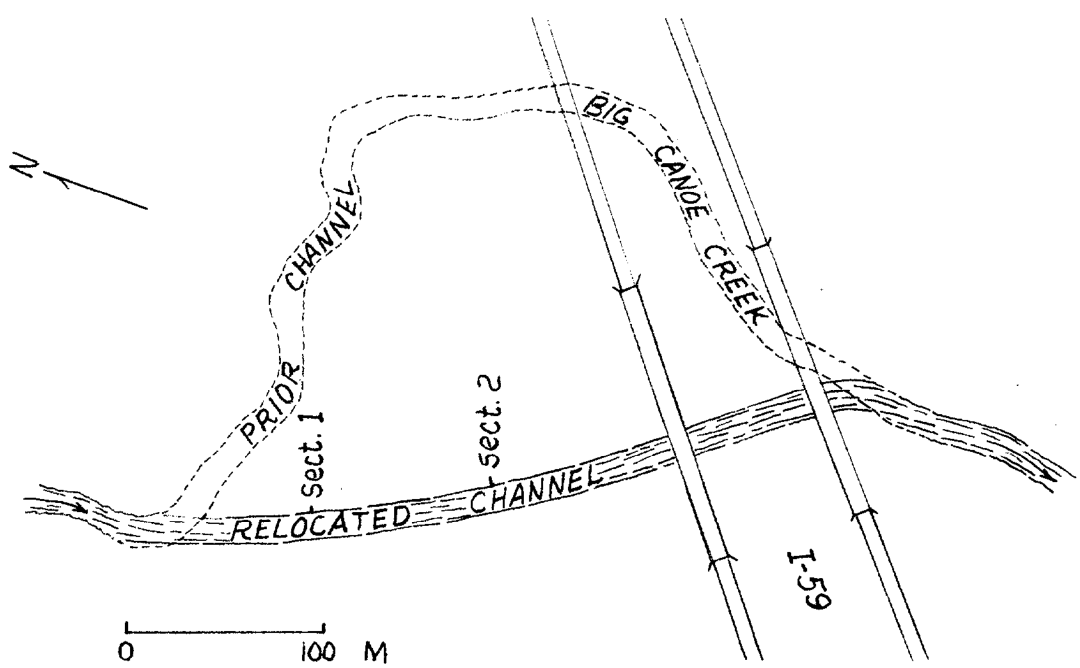


Figure 16. Plan sketch of channel relocation, Big Canoe Creek.

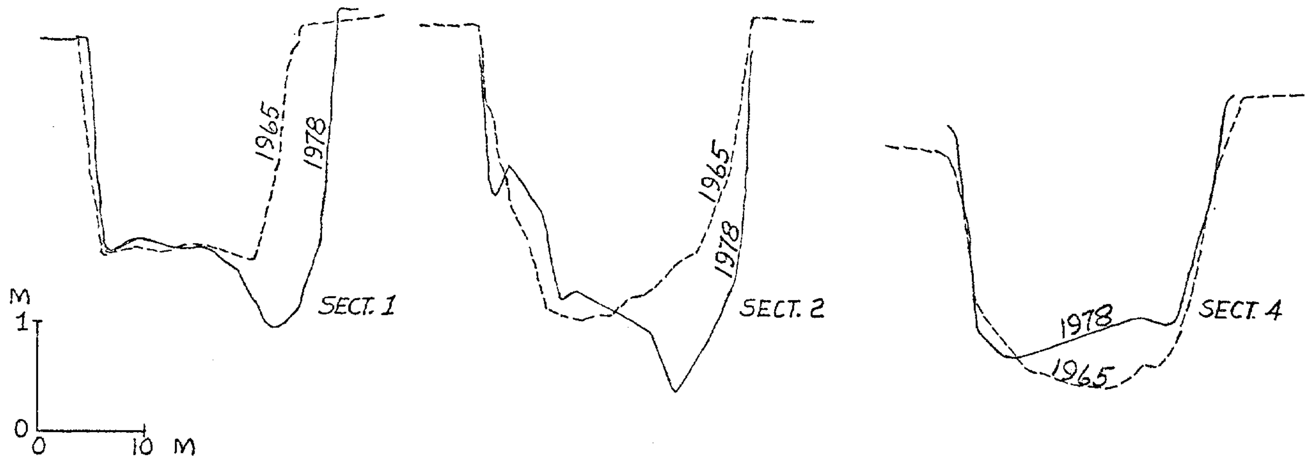
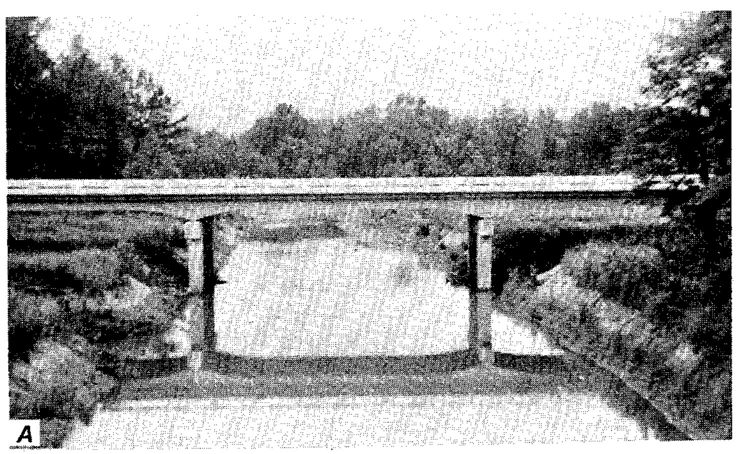


Figure 17. Cross sections of Big Canoe Creek as surveyed in 1965 and 1978. (See figure 16 for locations of sections 1 and 2; section 4 is at downstream bridge on I-59).



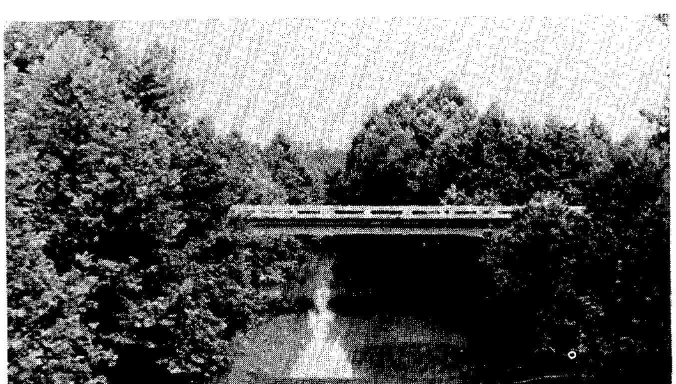


Figure 18. Big Canoe Creek at site 1. A, View upstream along relocated channel from downstream bridge, in 1965. B, View from same point as in A, in 1978. C, View upstream along relocated channel from section 1, in 1978.

SITE 2. CALEBEE CREEK AT I-85 NEAR MILSTEAD, ALA.

SYNOPSIS--Anabranching channel segment 1,365 m in length was relocated and thereby shortened to 805 m, to avoid multiple crossings and to improve channel alinement at bridge (fig. 19). Performance period, 1963-78 (15 yr), during which a flood of 25-yr recurrence interval occurred (in April of 1964). As built, the relocated channel had a trapezoidal cross section, with a bottom width of 15 m, 2:1 side slopes, and a longitudinal slope of 3 m/km. No bank protection measures were applied. When observed by Jefferson (1965) in January of 1964, the banks of the recently completed channel were generally stable (fig. 20A). When observed again in April of 1964 (after a major flood) the banks were badly slumped (fig. 20B), which was attributed by Jefferson to hydrostatic pressure in saturated bank materials. In 1978, bank erosion was active along one part of the relocated channel (fig. 20C), where the channel width had increased by about 15 m since construction (section 3, fig. 21). At other surveyed cross sections (fig. 21), width increases were in the range of 3 to 10 m. No significant amount of degradation or aggradation is indicated by the cross sections. Along adjacent segments of the natural channel, the flood plain is densely forested, and channel stability is therefore difficult to observe on airphotos. However, comparison of airphotos taken in 1958 and 1973 indicates that bank erosion at bends has been somewhat more active since relocation.

Stability class C4 for relocated channel. Instability of the relocated channel is attributed to the occurrence of a flood soon after construction, when the banks were entirely raw and unprotected by vegetation. Some of the steep eroding banks formed at this time have persisted to the present, because vegetation could not become established on them. In addition, the bank materials are not resistant to erosion.

SITE FACTORS--Lat. 32°25.5', long 85°54.5', at I-85, 2 km south of Milstead, Ala., on Shorter 7.5' map. Calebee Creek is perennial, drainage area of 390 km^2, average discharge of 5.3 m^3/s. Bottom width is 8-10 m, bank height is 3 m, and channel slope is about 1.4 m/km. Equiwidth point-bar stream, locally anabranched, alluvial, sinuosity of 1.75, valley relief of 45 m, wide flood plain, densely forested. Bed material is sand, and bank material is moderately coherent silt and fine sand.

ALTERATION AND POST-ALTERATION FACTORS--The bridge opening, and presumably the relocated channel, were designed to convey a 50-yr flood of 735 m^3/s at an average velocity of 1.1 m^3/s. By relocation, length of the channel segment was decreased by a factor of 0.6, and bottom width was increased by a factor of 1.7. By 1978, alternate bars had formed in the relocated channel, and these are likely to be the precursors of meandering.

DISCUSSION--The timing of floods in relation to channel relocation is a definite factor in channel stability, and the flood at this site occurred at an unfortunate time. Even if an attempt had been made to plant vegetation along the banks, it could scarcely have become well enough established to inhibit bank slumping. If further bank erosion is to be controlled under such circumstances, it would be necessary to regrade the banks after the flood and apply a vegetal lining or some other bank protection measure.

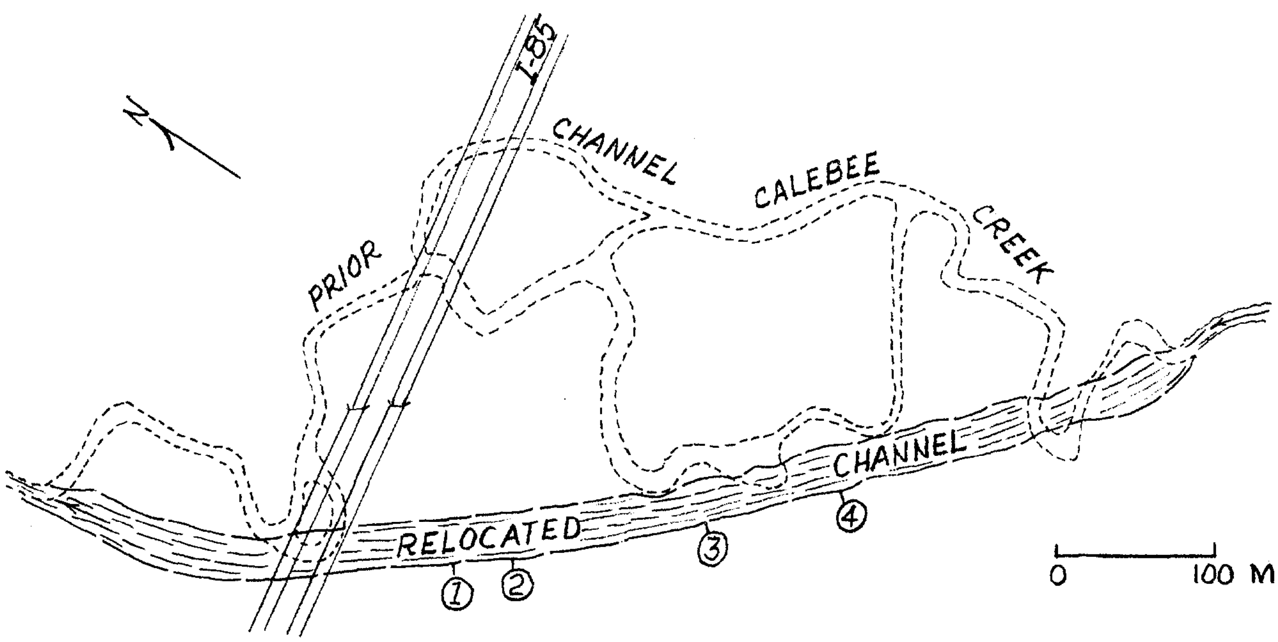


Figure 19. Plan sketch of channel relocation, Calebee Creek. Location of surveyed cross sections is indicated by circled numerals.

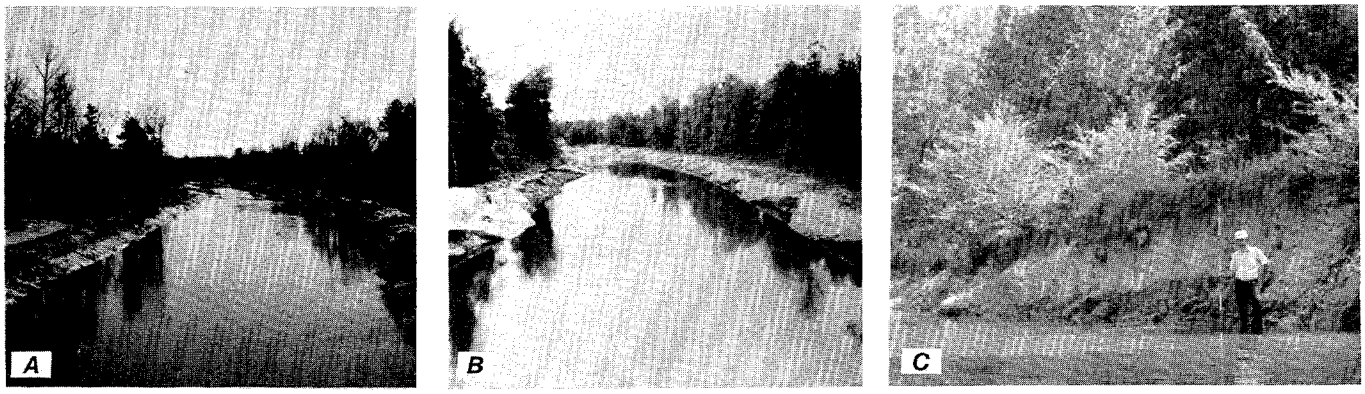


Figure 20. Calebee Creek at site 2. A, Relocated channel as viewed upstream from interstate bridge, on January 19, 1964. B, View from same point as in A, on April 22, 1964. C, Bank erosion at section 2, on August 28, 1978.

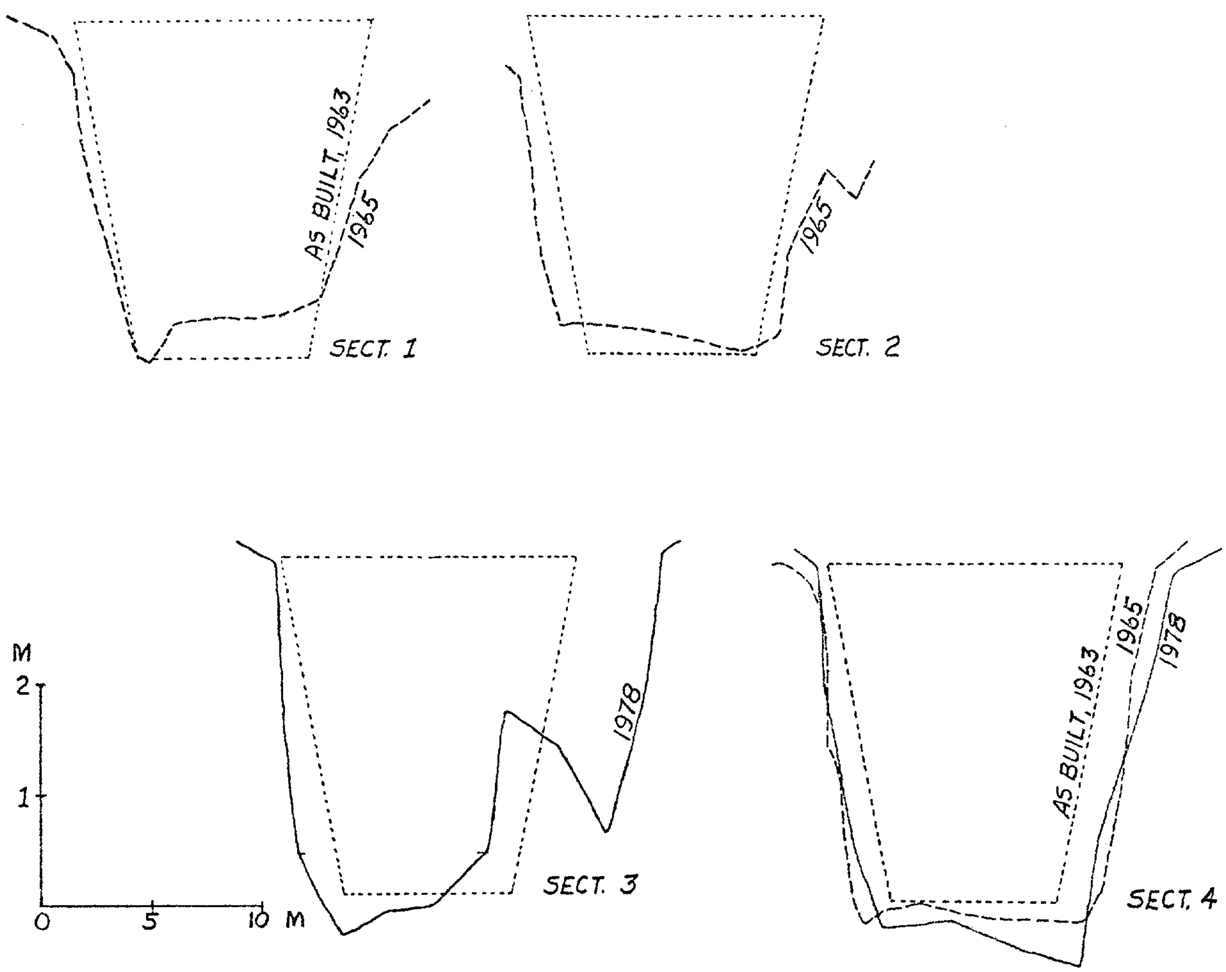


Figure 21. Surveyed cross sections of Calebee Creek, as compared with as-built cross section.

SITE 3. CEDAR CREEK AT COUNTY ROAD 18 AT MINTER, ALA.

SYNOPSIS--Channel was relocated and thereby shortened from a length of 1,040 m to a length of 655 m, for apparent purpose of preventing encroachment of meander loop on roadway and possibly for convenience in construction of the new bridge (fig. 22). Performance period, 17 yr (1961-78), during which a large flood occurred in 1961, soon after construction, and an extreme flood occurred in 1975. The relocated channel (fig. 23A) was trapezoidal in cross section, with a bottom width of 12 m, 1:1 side slopes, and a longitudinal slope of about 1.2 m/km. The bridge abutment fill-slopes were revetted with concrete pavement, but no bank protection measures were applied to the relocated channel. From observations made in January 1964, Jefferson (1965) reported that local indentations in the bankline had formed by lateral erosion; and that the channel had generally widened, particularly at a section 150 m downstream from the bridge, where an outcrop of resistant marl in the streambed dips gently toward the left bank (fig. 23B). In addition, a shift in the stage-discharge relation for the stream gage indicated about 0.15 m of channel degradation. Most of this erosion probably occurred during the 1961 flood. According to a cross section surveyed in 1965, the bottom width of the channel had increased to 30 m at the widest section (fig. 24 , section 3). Although this section was not resurveyed in 1978, channel width at other sections did not increase significantly during the period 1965-78, and in 1978 trees were well established along the bankline (fig. 23C). As observed on a 1955 airphoto, meandering reaches of the natural channel were decidedly unstable, as indicated by almost continuous cut banks and wide point bars. On a 1974 airphoto, the pattern of the natural channel is much changed because of many meander cutoffs, but the degree of instability is about the same as in 1955.

Stability class B4 for relocated channel and class C4 for adjacent segments of natural channel. Lateral instability of the relocated channel is attributed to its narrow width, to erodibility of the bank materials, and to the occurrence of a major flood almost immediately after construction.

SITE FACTORS--Lat 32°05', long 86°59', at Dallas County Road 18, 0.8 km east of Minter, Ala., on Braggs 15' map. Cedar Creek is perennial, with a drainage area of 562 km^2, a bottom width of 20 m, a bank height of 3 m, and a channel slope of 0.8 m/km. Wide-bend point-bar stream, semi-alluvial, sinuosity of 1.5, valley relief of 25 m, wide flood plain. Trees are continuous along the channel upstream from the bridge, but mainly cleared downstream, where the channel is most unstable. Bed material is fine to medium sand, and bank material is weakly coherent sand and silt-clay.

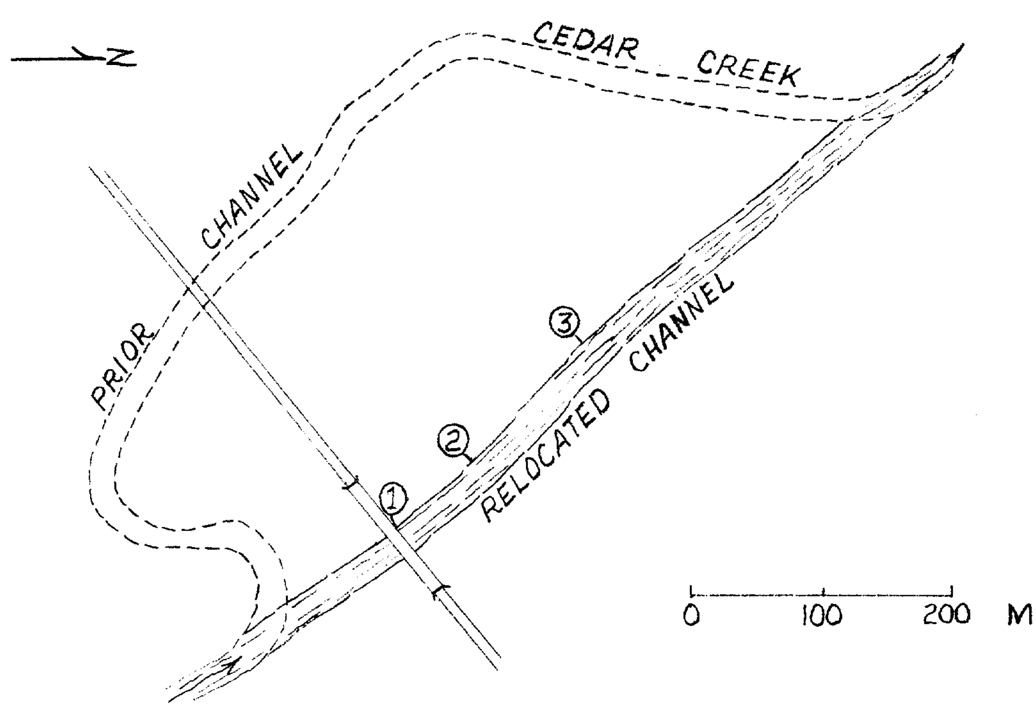


Figure 22. Plan sketch of Cedar Creek channel relocation. Location of surveyed cross sections is indicated by circled numerals.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--Although the relocated channel widened greatly as a consequence of the flood that occurred shortly after construction, its width in 1978 was no greater than that of the adjacent meandering reach downstream from the bridge and it had greater lateral stability than this reach. Furthermore, it was not much affected by the flood of 1975, for which a peak discharge of 2,800 m^3/s was recorded. Inasmuch as the as-built bottom width of the relocated channel (12 m) was much less than that of the natural channel (30 m), it may possibly have been intended as a pilot channel; although this is not indicated by placement of pile bents at the bridge, which have been exposed by lateral erosion. The site is unusual in that the prior channel was not filled and was separated from the relocated channel by only a narrow earth dike. However, flow seems not to have been diverted into the prior channel.

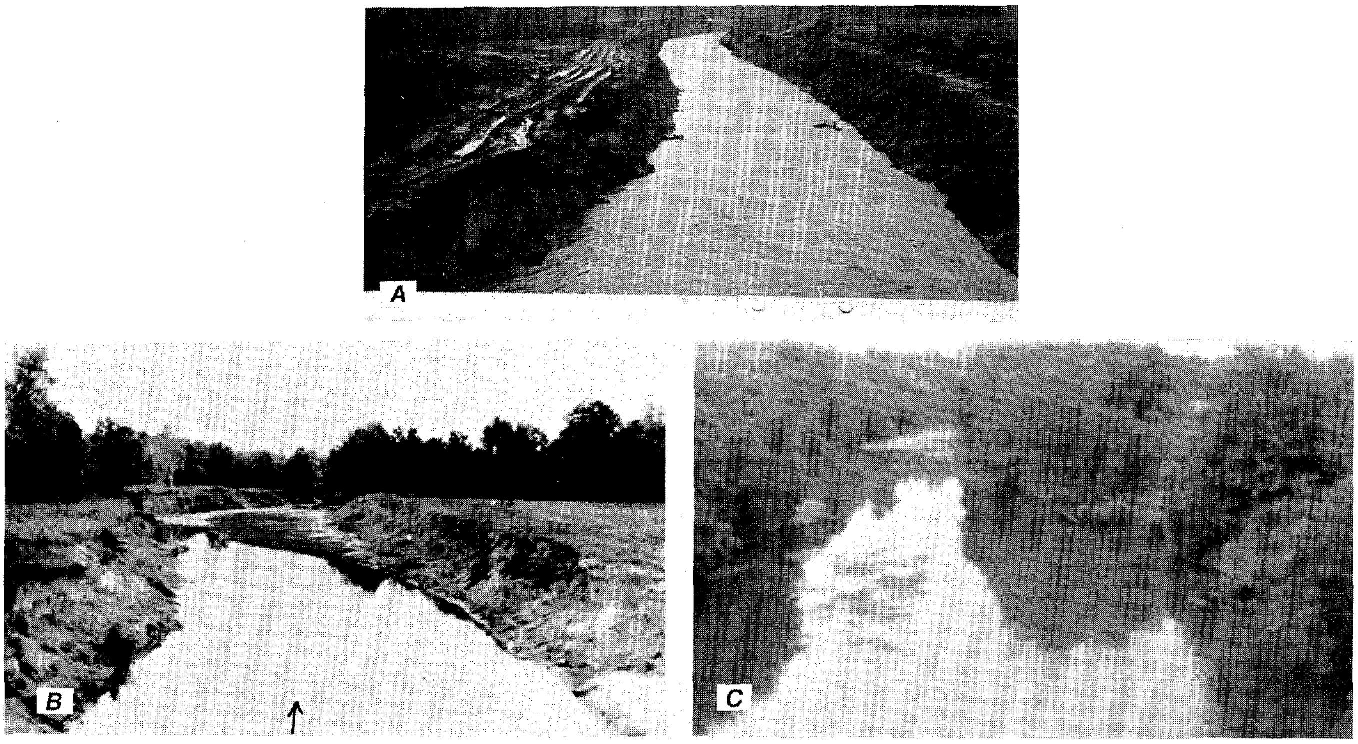


Figure 23. Cedar Creek at site 3. A, Relocated channel as viewed downstream from bridge, in January 1961. B, Same view as A, in June 1962. C, Same view as A, in August 1978.

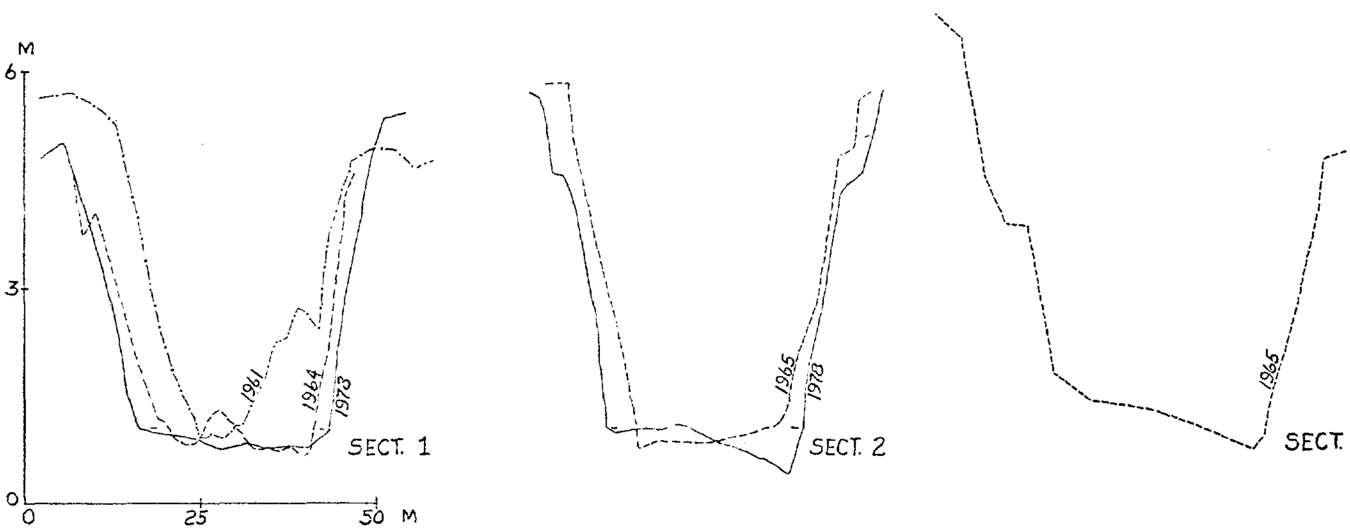


Figure 24. Surveyed cross sections of relocated channel, Cedar Creek.

SITE 4. LINE CREEK AT I-85 NEAR SHORTER, ALA.

SYNOPSIS--A channel segment was shortened from a length of 640 m to a length of 395 m, for purpose of improving channel alinement at bridge (fig. 25) and also to improve the spacing between the main bridges and relief bridges. Performance period, 18 yr (1960-78), during which floods occurred in 1961, 1964 (10-to 25-yr recurrence interval) and 1975 (25-yr recurrence interval). The relocated channel was trapezoidal in cross section, with a bottom width of 30 m, a top width of about 60 m, 1.5:1 side slopes, and a longitudinal slope of 0.8 m/km. No bank protection measures were applied at the bridge or along the channel. When observed by Jefferson (1965) in January 1964, the thalweg of the relocated channel had shifted toward the right bank, eroded the bridge abutment fill-slope, and exposed two pile bents (figs. 26A and B). In addition, the bankline was locally indented by lateral erosion. By April 1964, after a flood, bank erosion had progressed and an indentation extending landward 15 m from the original bankline had formed at the right bank 60 m upstream from the bridge. By 1978, the thalweg had shifted toward the left bank (fig. 26C). At surveyed cross sections (fig. fig. 27), bottom width of the channel had increased during the period 1960-78 from an original value of 30 m to values ranging from 50 to 70 m. However, the 1978 values are within the range measured for the natural channel on a 1958 airphoto, on which the channel has the wide point bars, wandering thalweg, and cut banks that indicate a high degree of lateral instability. There is no evidence of degradation, nor any evidence that the relocation has affected the previously unstable natural channel.

Stability class C4 for relocated channel and for adjacent segments of natural channel. The critical factors in channel performance are the prior instability of the natural channel (attributed to erodible banks) and the lack of bank protection measures.

SITE FACTORS--Lat 32°22.5', long 86°05', at I-85, 7.5 km southwest of Shorter, Ala., on Mount Meigs 15' map. Line Creek is perennial, with a drainage area of 818 km^2 and an average discharge of about 11 m^3/s. Channel width at site is in the range of 40-60 m, bank height is 3-4 m, and channel slope is about 0.5 m/km. Wide-bend point bar stream, with alluvial banks but local outcrops of resistant marl in bed; sinuousity is 1.5, valley relief is 5 m, and the flood plain is wide and densely forested. Bed material is gravel in the size range of 4 to 35 mm; bank material is weakly coherent silt and sand.

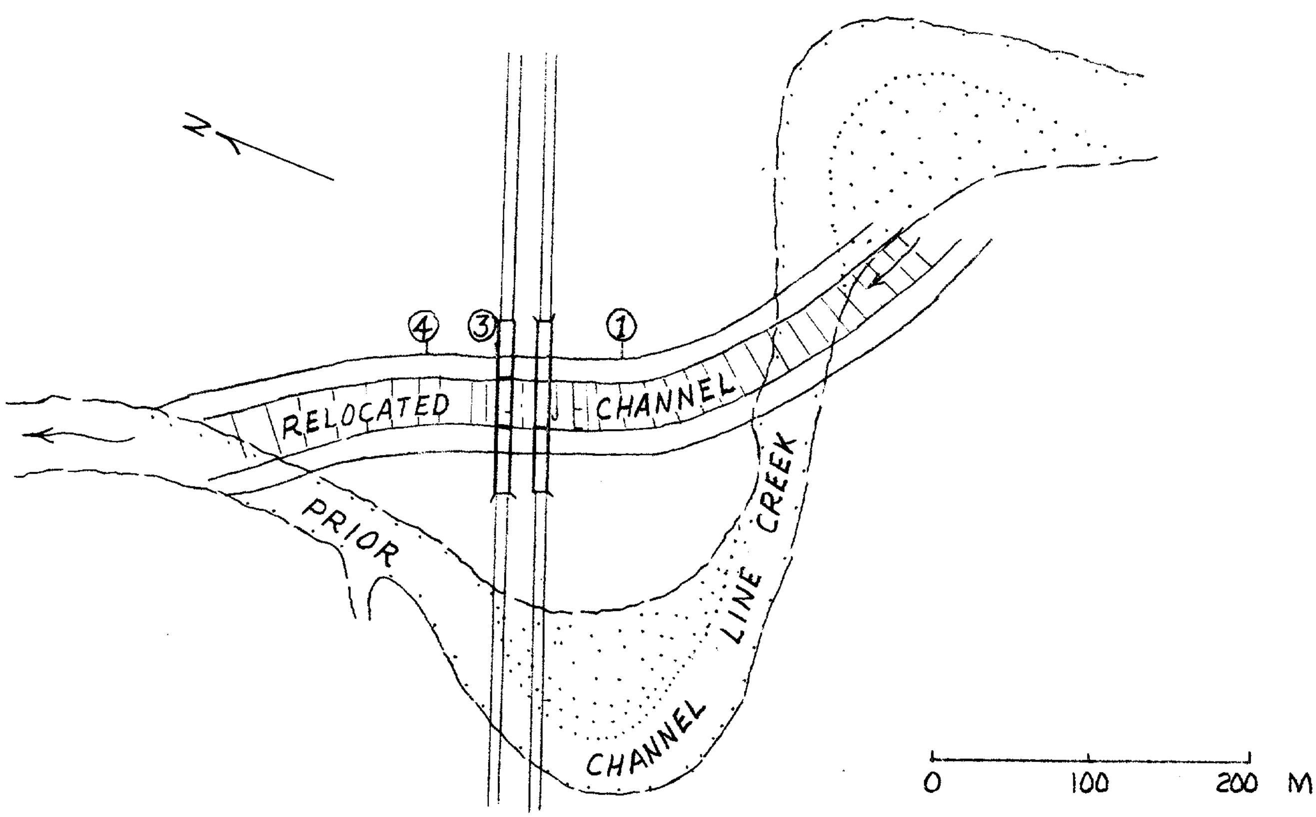


Figure 25. Plan sketch of channel relocation, Line Creek. Position of surveyed cross sections is indicated by circled numerals.

ALTERATION FACTORS--The bridge opening, together with the openings of two relief bridges, was designed to convey a 50-yr flood, but the stage of this flood would be about 3 m above the bank tops of the relocated channel, as designed. The designers may have anticipated widening of the relocated channel, but no provision for widening was made in the placement of pile bents on either side of the channel at the bridge, nor was any protection of abutment fill-slopes specified in the plans.

POST-ALTERATION FACTORS--After erosion of the abutment fill-slopes and severe local bank erosion upstream from the bridge in 1964-65, riprap was placed at the abutments and the eroded bank indentation was filled and revetted with riprap. Bank erosion at the surveyed cross sections has progressed little since 1965 (fig. 27), and trees have become well established along the bankline (fig. 26C).

DISCUSSION--Widening of the relocated channel, although severe, was predictable in view of the prior instability of the natural channel and the lack of countermeasures. The channel is not likely to increase much in width, but lateral erosion is probable as the thalweg shifts from side to side within the wide channel.

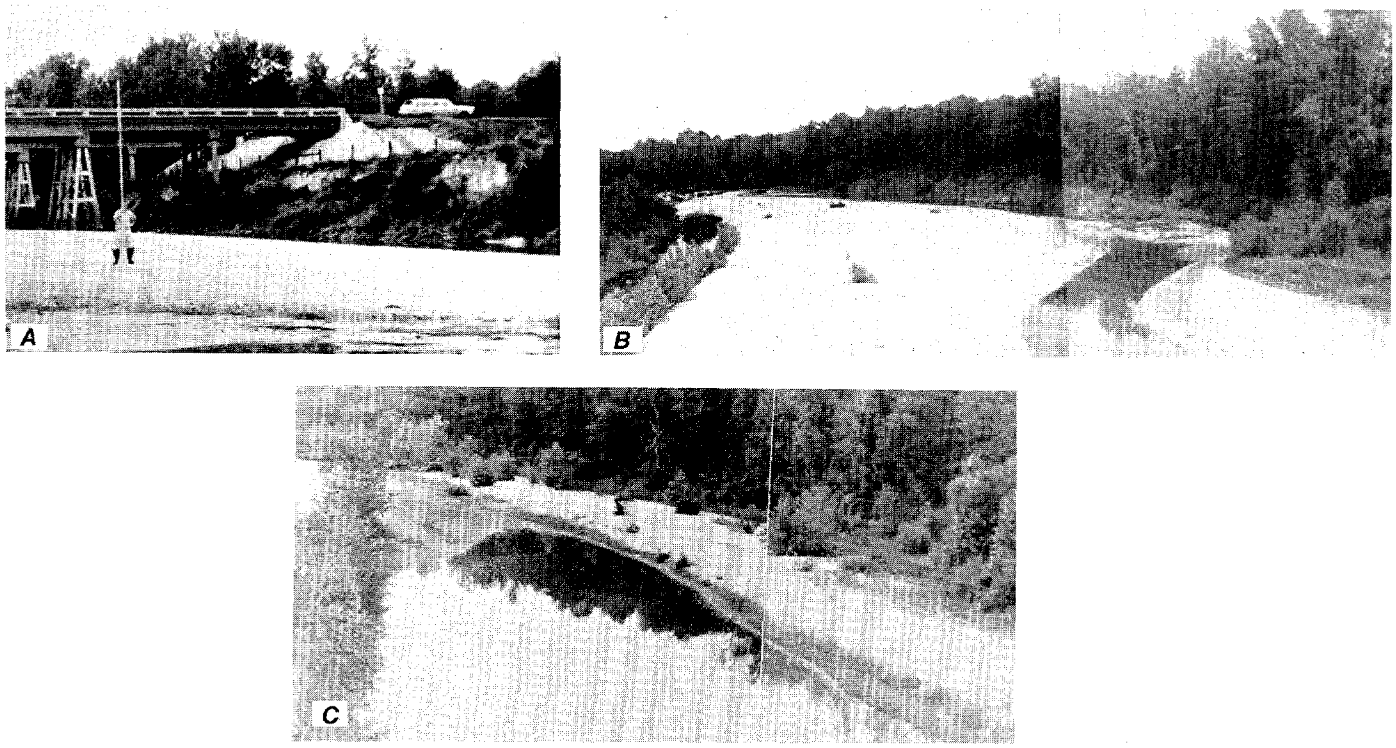


Figure 26. Line Creek at site 4. A, Lateral erosion at right abutment of interstate bridge, as photographed in 1965. Pile bent behind man was originally at toe of abutment fill slope. B, Relocated channel as seen downstream from interstate bridge, in 1966. C, Same view as B, as photographed in 1978. Channel has shifted to left.

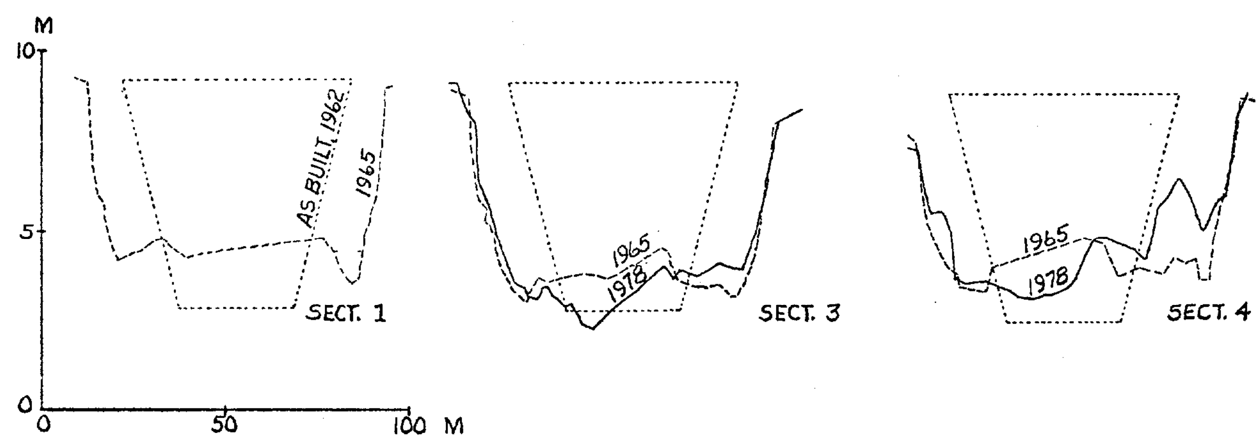


Figure 27. Surveyed cross sections of relocated channel of Line Creek, in comparison with channel dimensions as specified on plans.

SITE 5. LITTLE LUBBUB CREEK AT COUNTY ROAD NEAR CARROLLTON, ALA.

SYNOPSIS--Channel of stream flowing through swampy and densely forested flood plain was relocated to improve channel alinement and flow conveyance through bridge opening; a channel segment 145 m in length was straightened and shortened to 100 m (fig. 28). Performance period, 24 yr (1954-78), during which a 25-yr flood occurred in February 1961. Relocated channel was trapezoidal in cross section, with a bottom width of 6 m, 1.5:1 side slopes, and a channel slope of 1.5 m/km. No countermeasures were applied. In January 1964, the site was observed by Jefferson (1965), who reported no evidence of instability (fig. 29A) and noted that the natural low-water channel was inefficient at high water stages. However, minor bank erosion near the bridge, perhaps caused by drainage along the roadway embankment, was photographed in April 1964 by members of the U.S. Geological Survey. In June 1978, the site was revisited by the Geological Survey. Although cut banks in moderately coherent clayey sand were observed, the banks were vegetated (fig. 29B) and the channel had not enlarged. Water in the relocated channel was ponded by a beaver dam downstream.

Stability class A1 for relocated channel and for adjacent segments of the natural channel. Channel stability is attributed to low water velocities that result from the shallow depth of the channel and the swampy, densely forested nature of the terrain through which it flows.

SITE FACTORS--Lat 33°13', long 88°03', at Pickens County road 5.5 km southeast of Carrollton, Ala., on Cunningham 7.5' map. Little Lubbub Creek is perennial, with a drainage area of 52 km^2, and an average discharge of about 0.7 m^3/s. Channel width is 12 m, bank height is 1.5 m, and channel slope is 1.3 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.5; wide, swampy, densely forested flood plain. Bed material is silt-clay, and bank material is moderately coherent clayey sand.

ALTERATION FACTORS, POST-ALTERATION FACTORS, DISCUSSION--(See "Synopsis")

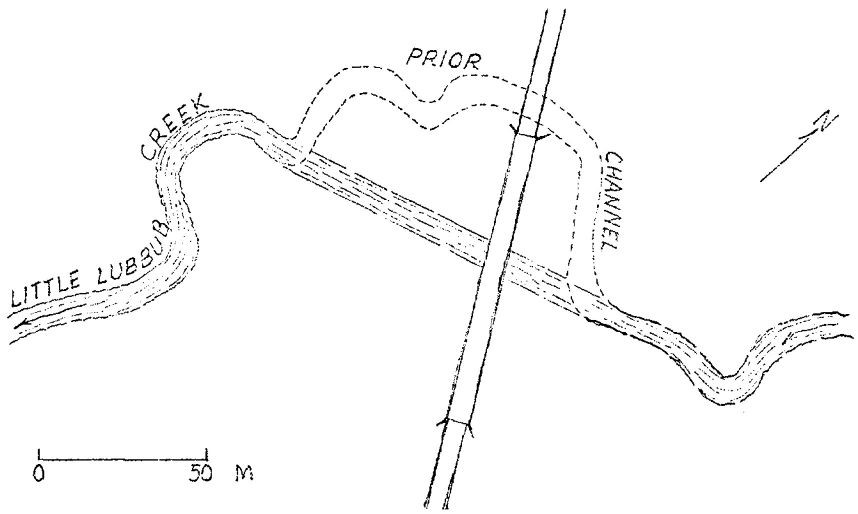


Figure 28. Plan sketch of Little Lubbub Creek channel relocation.

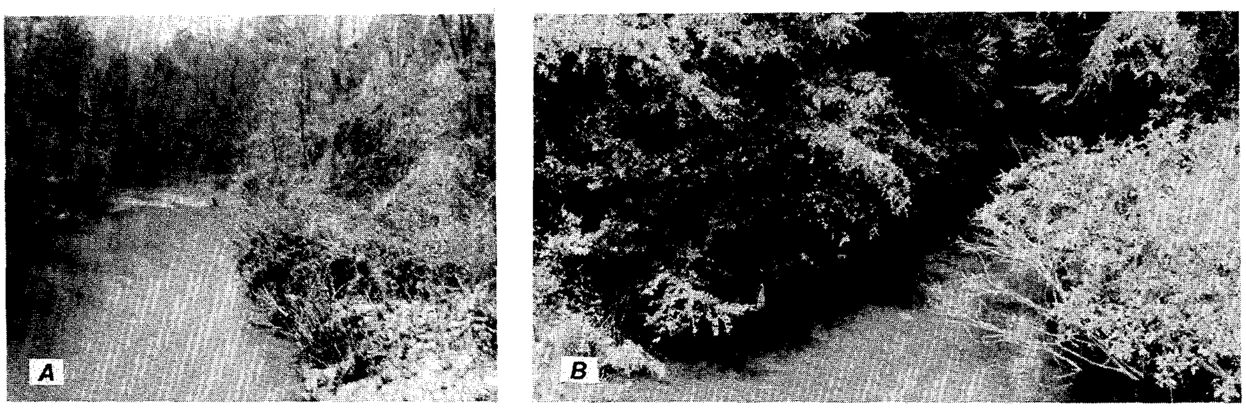


Figure 29. Little Lubbub Creek at site 5. A, View upstream from bridge along relocated channel in January 1964. B, Same view as in A, June 1978.

SITE 6. OHATCHEE CREEK AT US-431
NEAR WELLINGTON, ALA.

SYNOPSIS--Two kinds of channel alterations were made at this site: (1) A channel segment 990 m in length was relocated and shortened to 690 m, in order to avoid two bridge crossings (fig. 30). (2) Where the stream was bridged at a bend, the channel bottom width was increased from 13 m to 35 m, in order to improve channel alinement and increase flow conveyance (fig. 30 and 31). Performance period, 15 yr (1963-78), during which a flood of recurrence interval in the range of 10-25 yr occurred in March 1979. As built, a typical cross section of the relocated channel was trapezoidal in cross section, with a bottom width of 18 m, 1.5:1 side slopes, and a longitudinal slope of 1.1 m/km. The left bank was revetted with dumped limestone riprap, having a maximum diameter of 2 m, but not evenly spread along the bankline. The site was visited shortly after completion by Jefferson (1965), who speculated that bank erosion might occur at the bend in the relocated channel. Cross sections of the relocated channel were surveyed by the U.S. Geological Survey in 1965 (fig. 32) and photographs were taken periodically thereafter. By 1967 (fig. 33A), small trees were beginning to grow along the bankline, bars were forming in the channel, and the right bank, although raw, had not eroded significantly. In 1978, the site was revisited by the Geological Survey. Trees were well established along the bankline, and gravel bars in the channel were grassed (fig. 33B). Site inspection and a surveyed cross section indicated that no significant amount of bank erosion had occurred since 1965. Comparison of airphotos taken in 1969 and 1977 supports this conclusion and also indicates that the widened bridge cross section has remained stable. No instability of adjacent segments of the natural channel could be discerned.

Stability class A1 for relocated channel, for widened channel at bridge, and for adjacent segments of the natural channel. Stability is attributed to resistant bank materials, to lack of floods prior to establishment of vegetation, and (with regard to degradation) to outcrops of limestone in the channel.

SITE FACTORS--Lat 33°51.5', long 85°55', at US-431, 4.5 km north of Wellington, Ala., on Wellington 7.5' map. Ohatchee Creek is perennial, with a drainage area of 121 km^2. Channel width is 10-12 m, bank height is about 2.5 m, and channel slope is 0.7 m/km. Equiwidth point-bar stream, semialluvial, sinuosity of 1.2, valley relief of 75 m, wide flood plain, narrow strip of trees along more than 90 percent of the bankline. Bed material is in the sand-gravel range, with a maximum diameter of about 50 mm; bank material is coherent, consisting of sand and gravel in a clay matrix.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis").

DISCUSSION--The bottom width of the relocated channel was about 1.5 times that of the natural channel; consequently, bars have formed in the relocated channel and these may eventually induce sinuosity. The angular junctions of the relocated channel with the natural channel (fig. 30) might have been expected to induce bank erosion; but this has not occurred, evidently because of the resistance of the bank materials. However, a scour hole about 2.5 m deep has formed in the channel bed at the downstream junction.

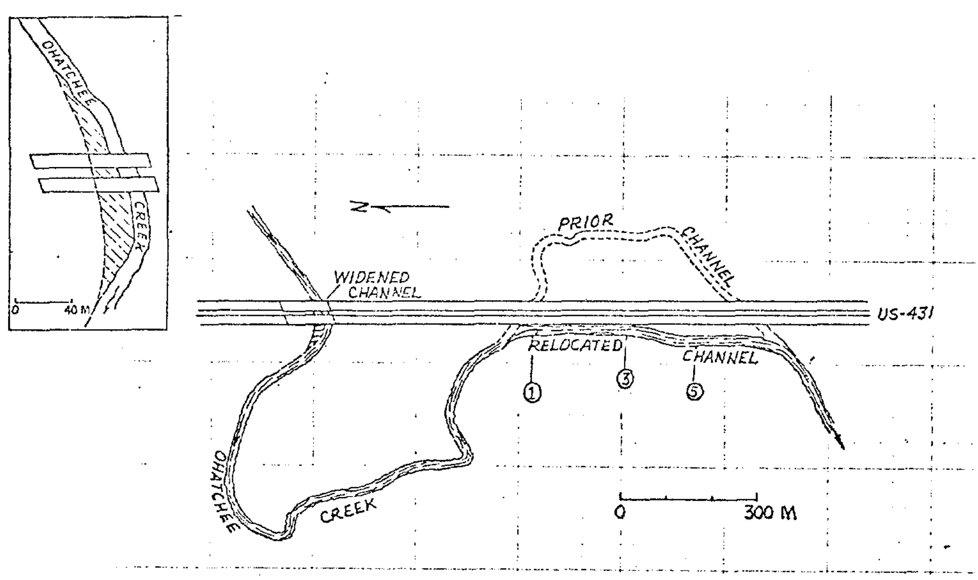


Figure 30. Plan sketch of Ohatchee Creek channel relocation and (inset) widening of channel at bridge. Circled numerals indicate location of surveyed cross sections.

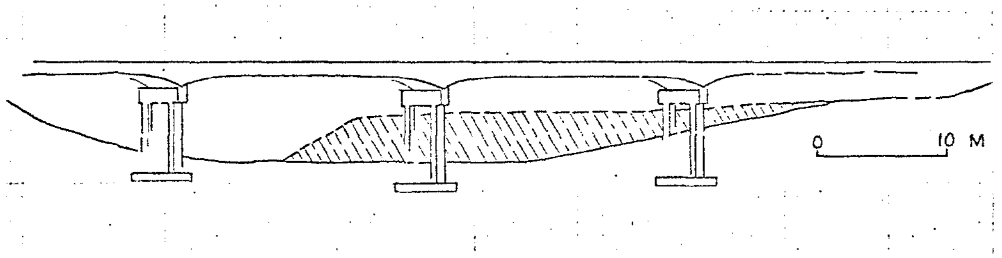


Figure 31. Cross section at US-431 bridge, Ohatchee Creek, showing area removed in channel widening (diagonally lined).

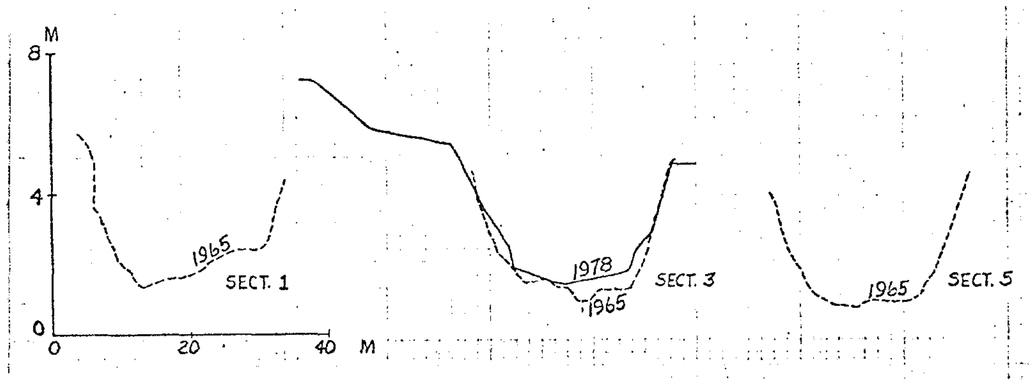


Figure 32. Surveyed cross sections of relocated channel, Ohatchee Creek. See figure 30 for location.

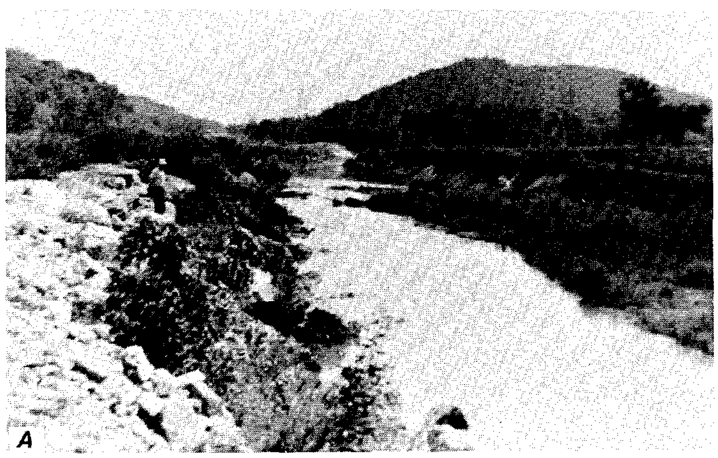


Figure 33. Ohatchee Creek at site 6. A, View downstream along relocated channel near station 3, in 1967. B, View downstream along relocated channel near station 3, in 1978.

SITE 7. WEST FORK CHOCTAWHATCHEE RIVER
AT COUNTY ROAD NEAR OZARK, ALA.

SYNOPSIS--A bypass channel was dredged across a meander loop to divert part of flood flow through a relief bridge (fig. 34), but the natural channel was not blocked and it continues to transmit about two-thirds of the flow during low and medium stages. Performance period, 25 yr (1953-78), during which a flood occurred in September 1956. The site was observed in 1964 by Jefferson (1965), who reported no channel widening; and none is indicated by periodic cross sections surveyed by the U.S. Geological Survey (fig. 35), nor by periodic photographs (fig. 36A and 36B). The dredged channel has increased in width since construction by a factor of about 2, but it remains more narrow than the natural channel. A depth increase of about 1 m at the relief bridge is attributed to local scour. The natural channel was stable prior to construction, and has remained stable subsequently. Dredging of the bypass channel entailed the risk that the stream would be diverted entirely, but this has not occurred.

Stability class B2 for bypass channel and for natural channel. Critical factors in stability and in maintenance of flow through the natural channel are: (1) The good degree of stability of the natural channel prior to dredging of the bypass channel. This stability is attributed to coherent bank material, dense growth of vegetation along the banks, and possibly to natural levees. (2) Orientation of the bypass channel, which intersects the natural channel at a large angle.

SITE FACTORS--Lat 31°29', long 85°32', on Dale county road about 9 km east of Ozark, Ala., on Ewell 7.5' map. West Fork Choctawhatchee River is perennial, drainage area 541 km^2 at site, flow ungaged at site but 25-yr flood estimated at 368 m^3/s from area/discharge relations for gaged streams in the Choctawhatchee River drainage basin. Channel width 16-18 m, bank height 1.5-2.5 m, valley slope 0.92 m/km, channel slope 0.6 m/km. Equiwidth point-bar stream, alluvial, sinuosity 1.5. Angular meanders and narrow elongate meanders are indicative of channel stability. Valley relief about 50 m, wide flood plain, about 900 m in width. Continuous forest cover along channel. Bed material sand, "hard marl" at depth of about 2.5 m below bed; bank material sand and sandy clay. No works of man that might contribute to channel instability are apparent, except for patchy clearing of flood plain and valley side-slopes.

ALTERATION FACTORS--The meander loop across which the bypass channel was dredged is 420 m in length, and the bypass channel is 150 m in length. As built, the bottom width of the natural channel was 6 m, and the slope was about 0.9 m/km. In constructing the bypass channel, one arm of an oxbow depression was connected to the stream by means of a channel dredged to the same depth as the stream; and the oxbow was deepened and straightened. A more shallow channel (light dashed line in figure 34) was cut across the next loop upstream, but this channel transmits water only during floods. Vegetation was cleared for a distance of about 30 m on either side of the main bypass channel. This vegetation had regenerated to form a nearly complete cover by 1969, and a complete cover by 1978. No countermeasures were installed along the dredged channel.

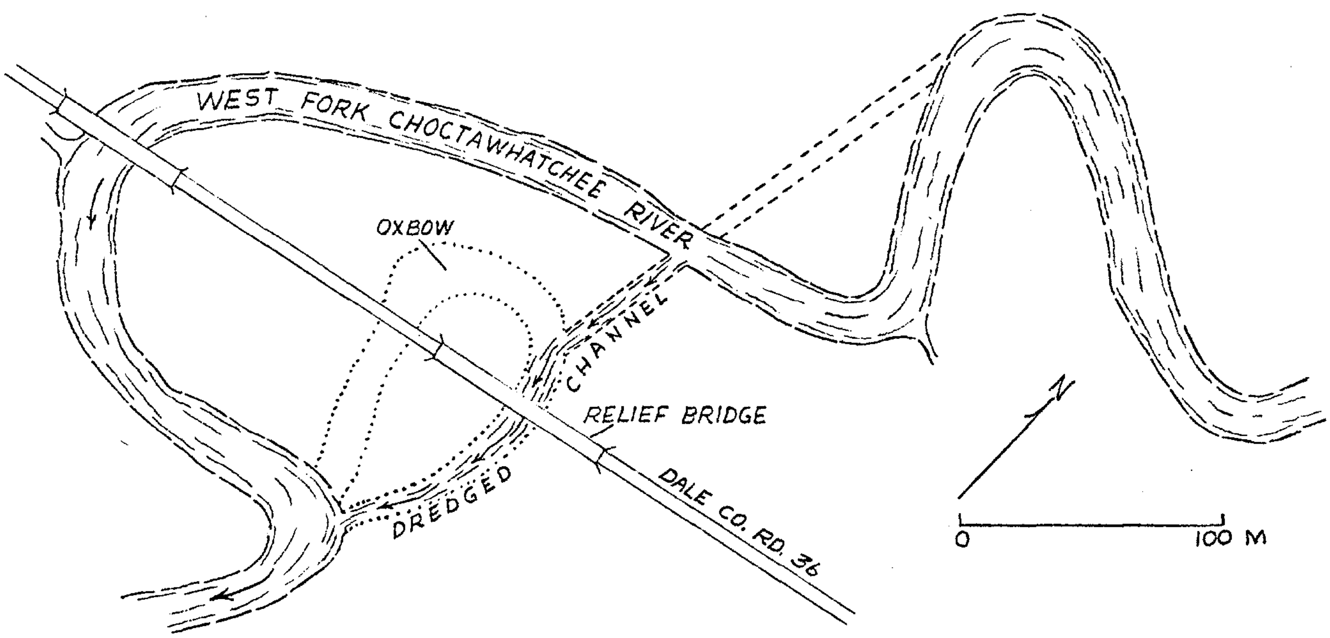


Figure 34. Plan sketch of bypass channel, West Fork Choctawhatchee River.

POST-ALTERATION FACTORS--According to flow measurements made by the U.S. Geological Survey, the peak discharge during a flood in September, 1956, was 254 m^3/s, of which 0.6 was transmitted through the dredged channel. The recurrence interval of this flood is in the range of 10-20 yr. There is no record of maintenance or installation of countermeasures along the dredged channel.

DISCUSSION--The dredged bypass channel has served the intended purpose of diverting flood flow through a relief bridge that would, in the absence of the channel, have been built longer to span both arms of the oxbow depression. The risk that the stream would be entirely diverted through the dredged channel seems not to have been considered in design, but such diversion has not occurred and seems unlikely now. Banks of the dredged channel have been stabilized by vegetation, and the natural channel remains stable.

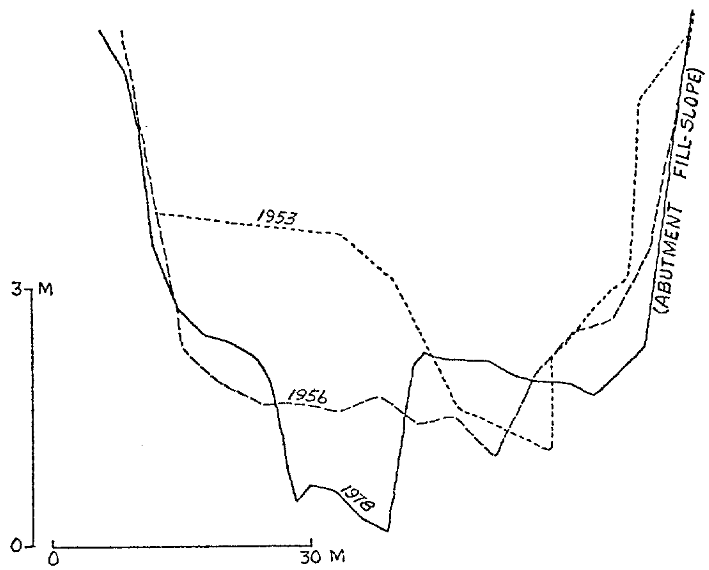


Figure 35. Surveyed cross sections at upstream side of bridge across bypass channel, West Fork Choctawatchee River.

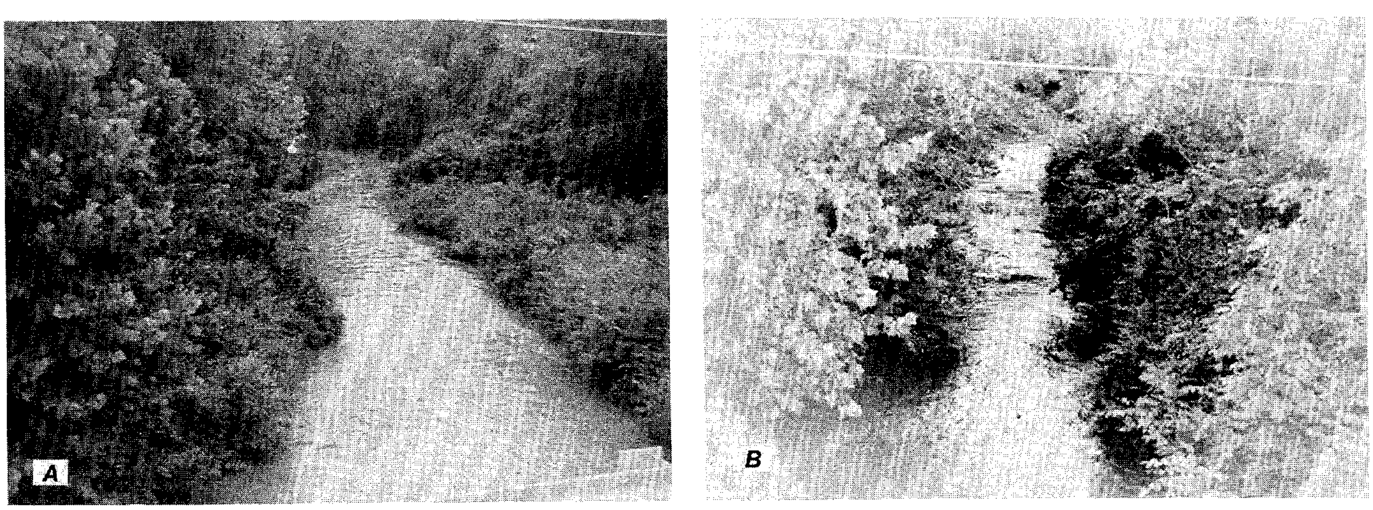


Figure 36. West Fork Choctawatchee River at site 7. A, View downstream along bypass from bridge, in 1965. B, View downstream along bypass channel from bridge, in 1978.

SITE 8. BLAKLEY CREEK AT I-30 AND AT SR-84 NEAR MALVERN, ARK.

SYNOPSIS--Channel was relocated by cutting off a meander bend, thereby reducing length of channel segment from 535 m to 315 m; for purpose of improving channel alinement at bridges (figs. 37 and 38A) Performance period, 13 yr (1966-79), during which a major flood, estimated to have a recurrence interval greater than 50 yr. occurred. The relocated channel was trapezoidal in cross section, with a bottom width ranging from 25 to 27 m, 2:1 side slopes, and a longitudinal slope of 6 m/km. Rock riprap was placed at the bridge abutments, but no countermeasures were installed along the relocated channel. As a result of the major flood, which occurred during the period 1966-68, the right bank of the relocated channel was eroded, upstream from the SR-84 bridge, and some riprap was eroded from the right bridge abutment. In 1968, a dike of dumped rock riprap (fig. 38B) was built along eroded area, and riprap was placed along both banks between the bridges. Downstream from the bridges, cut banks were more prominent at bends in 1979 than in 1965, but the flood may have contributed to this.

Stability class A3 for relocated channel and class B3 for downstream reach of the natural channel. Bank erosion along the relocated channel is attributed to its rather angular upstream junction with the natural channel, and the lack of countermeasures downstream from the junction.

SITE FACTORS--Lat 34°20', long 92°55', at I-30 and at SR-84, 7 km southwest of Malvern, Ark., on Malvern 15' map. Blakley Creek is perennial, with a drainage area of 52 km^2 and an estimated 50-yr flood discharge of 283 m^3/s. Channel width is 8-10 m, and channel slope is 6 m/km. Wide-bend point bar stream, locally braided, semi-alluvial, sinuosity of 1.3, valley relief of 30 m, narrow flood plain upstream from site and wide flood plain (or low terrace) downstream. Tree cover along bankline is in the range of 50-90 percent. Bed material is in the gravel-cobble range, bank material is weakly coherent gravel, silt, and clay.

ALTERATION FACTORS--(See "Synopsis")

POST-ALTERATION FACTORS--Upstream from the SR-84 bridge, near the junction of natural and relocated channel, the relocated channel has widened from an as-built width of 25 m to a width of 36 m in 1979. Channel degradation has been precluded by an outcrop of resistant bedrock in the channel upstream from the SR-84 bridge. No further floods have occurred since 1968, but the existing bank protection appears to be competent to resist further bank erosion.

DISCUSSION--The upstream junction of natural and relocated channel was sufficiently angular to require the use of bank protection measures, in view of the erodibility of the banks and the magnitude of the flood.

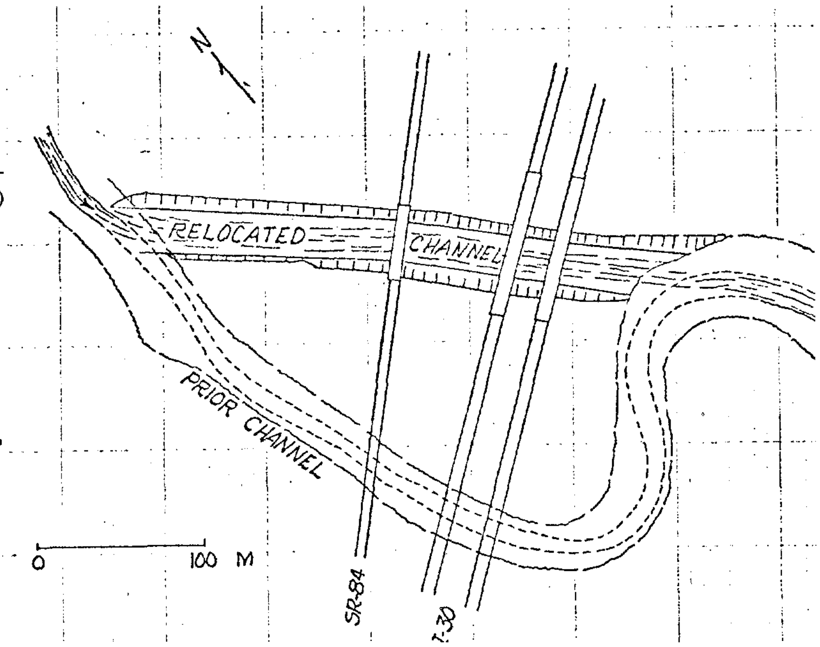


Figure 37. Plan sketch of Blakley Creek channel relocation.

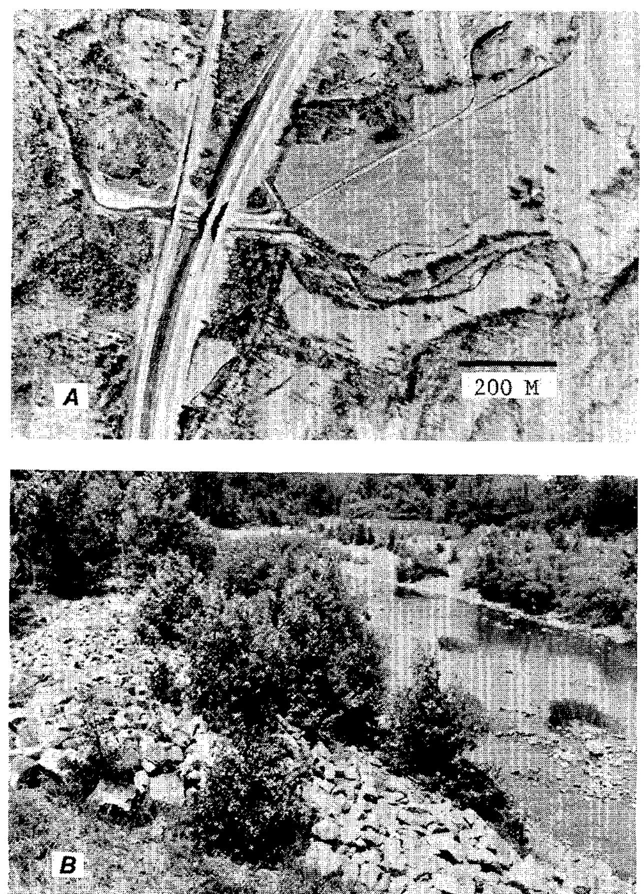


Figure 38. Blakley Creek at site 8. A, Airphoto of channel relocation, in 1976. (From Arkansas Dept. of Transportation) B, Upstream view of relocated channel in 1979, showing rock dike at right bank near SR-84 bridge.

SITE 9. SANDY CREEK AT SR-299 NEAR LANEBURG, ARK.

SYNOPSIS--Channel relocation, two meander loops cut off, channel length reduced from 210 m to 91 m, or by a factor of 0.43. Purpose of relocation was to prevent lateral migration of stream against roadway embankment and to improve flow conveyance through bridge (fig. 39). Performance period 8 yr, 1972-79; relocated channel subjected to 50-yr (estimated) flood in 1973 and to another severe flood in 1975. Abutment fill-slopes of bridge were eroded during both floods, and general scour occurred in the bridge waterway (fig. 40). Bottom width of the relocated channel was increased by erosion but top width remained about the same.

Stability class B2 for relocated channel, class A for natural channel. The critical factors in erosion of the relocated channel are: (1) Constriction of flood plain flow by the bridge during a flood larger than the design flood. (2) Erodibility of the sandy banks, which was increased by complete removal of vegetation. At the bridge, erosion of the abutment fill-slopes would probably have been prevented by riprap.

SITE FACTORS--Lat 33°42', long 93°20', on SR-299 about 1.5 km north of Laneburg, Ark., on Laneburg 7.5 map. Sandy Creek is perennial, drainage area of 36 km^2, 50-yr flood estimated at 145 m^3/s. Channel width is 8-10 m, bank height is 1-2 m to flood plain, channel slope at site is 1.5 m/km. Equiwidth point-bar stream, alluvial, sinuosity about 2.3 at site but generally much lower, about 1.2. Valley relief, about 30 m; flood plain wide, about 250 m in width. Dense forest cover along most of channel. Bed material is sand, bank material is moderately coherent clayey sand. Prior channel stability assessed as very good.

ALTERATION FACTORS--As built, the relocated channel was trapezoidal in cross section, with a bottom width of 16 m, a top width of 21 m, 2:1 side slopes, and a channel slope of 1.7 m/km. The relocated channel is straight and conformable in trend with the natural channel at both upstream and downstream ends. It was built with approximately twice the width and area as the natural channel, presumably to increase conveyance of flood flow through the bridge opening. All vegetation was cleared for a distance of about 30 m on either side of the relocated channel, and no protective measures were applied, either along the channel or at the bridge abutment fill-slopes.

POST-ALTERATION FACTORS--In 1973, shortly after construction was completed, a flood estimated at 50-yr or greater recurrence interval caused erosion of the bridge abutment fill slopes and roadway embankment, and general scour at the bridge opening; similar erosion, to a lesser degree, occurred in 1975. The eroded areas were filled in, but no riprap or other bank protection measures were applied. Establishment of vegetation along the channel was delayed by these floods, but by 1979 young trees were beginning to grow along the banks.

DISCUSSION--The relocated channel was widened and deepened by erosion at the bridge because of constriction of flood plain flow. Elsewhere, the relocated channel has not increased in top width, but its original configuration has been much changed by fill and scour. The erosion that occurred is attributed to the fact that the recently constructed channel was unvegetated and unprotected by countermeasures. No effect of the relocation on the natural channel, which is bordered by dense forest, could be discerned. The relocated channel seems well designed, and its width, greater by a factor of 2 than the natural channel, is probably justified ty the severe floods to which this area is subject. The pool at the bridge is analogous to scour pools that commonly form at relief bridges. This pool will probably remain and become stabilized by vegetal growth along the banks and the rest of the relocated channel will probably be stabilized and constricted by vegetation.

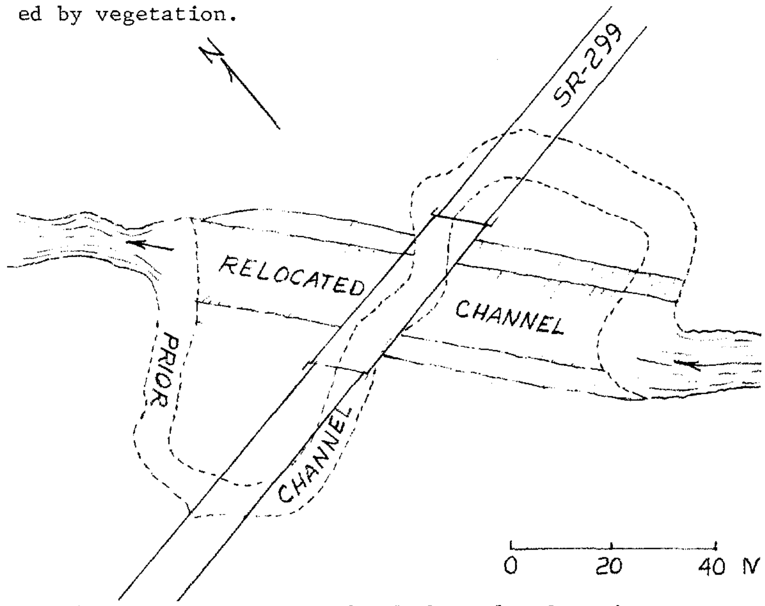


Figure 39. Plan sketch of channel relocation, Sandy Creek.

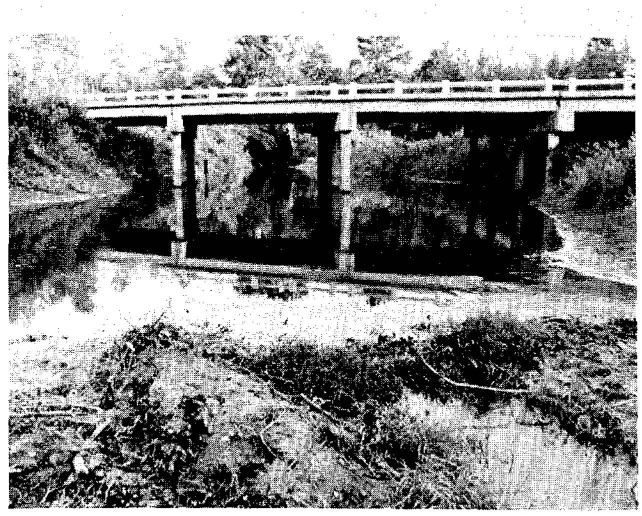


Figure 40. Sandy Creek at site 9. Upstream view toward bridge in 1979, showing area scoured during flood in 1975.

SITE 10. CROW CREEK AT I-40 NEAR FORREST CITY, ARK.

SYNOPSIS--Channel segment was relocated by cutting off a single large meander loop, thereby reducing the length of the segment from 660 m to 160 m; for purpose of improving channel alinement at bridge and preventing lateral erosion of roadway embankment (figs. 41A and B). Performance period, 15 yr (1964-78), during which no major floods occurred. As built, the relocated channel was trapezoidal in cross section, with a bottom width of 26 m, 2:1 side slopes, a depth of about 5 m. Degradation that occurred at pier footings during bridge construction was sufficiently serious that a check dam was built, although not originally planned. Prior to relocation, the channel was actively degrading and eroding laterally, and degradation was apparently increased by the relocation. By 1979, the check dam had been partially undermined and the channel was widened and deepened in the area of overfall (figs. 41C and D). Elsewhere, only minor changes in the relocated channel were observed and stability of the natural channel was about the same as in 1957, although lateral erosion was continuing. Critical factors contributing to instability of the relocated channel are: (1) Prior channel instability, attributed to steep channel slope and the deforestation of bankline and drainage basin. (2) Sharp local increase in channel slope by relocation. (3) Turbulence at the check dam.

Stability class D3 for relocated channel and for adjacent segments of natural channel. Because of the check dam, the amount of degradation induced by relocation cannot be measured, but it is probably on the order of 1 m.

SITE FACTORS--Lat 35°02', long 90°45', on I-40 about 3.5 km east of Forrest City, Ark., on border of Forrest City 7.5' and Madison 7.5' maps. Crow Creek is perennial, drainage area of 51 km^2 at site. Channel bottom width is 20 m, bank height is 3 m to flood plain, 5-8 m to bordering terraces, and channel slope is 0.0034 m/m. Wide-bend point-bar stream, semi-alluvial, sinuosity 1.2. Valley relief about 30 m, flood plain narrow to absent. Narrow strip of trees (willow, sycamore) along channel, locally discontinuous. Bed material, gravel and sand on shale; bank material, shale and coherent alluvium. Stream has a geomorphic history of degradation, as indicated by terraces and abandoned meander loops at different elevations. Works of man that may have contributed to channel instability are deforestation of land along stream and in about half of the drainage basin. A dam and reservoir have been built about 5 stream-kilometers upstream from the site.

ALTERATION FACTORS--The meander loop cut off by relocation was elongated, therefore the change in slope (from about 3.5 m/km to about 7 m/km) consequent on relocation was concentrated along a relatively short relocated channel. Rock riprap (median diameter about 0.4 m) was placed on the bridge abutment fill-slopes and extended along the left bank downstream from the bridge for a distance of about 80 m. Vegetation was cleared completely along the artificial channel and there is no evidence of replanting. The check dam, of concrete-grouted riprap, was built 20 m down downstream from the bridge. The dam is about 10 m in width from crest to toe, and the water surface behind the dam stands about 3 m above the pool at its base.

POST-ALTERATION FACTORS--Although no major floods have occurred since relocation, overfall at the check dam has resulted in local widening and deepening of the relocated channel and in partial failure of riprap on the right bank. Side slopes of the relocated channel are unvegetated except for young trees in the riprapped areas, but no major lateral erosion has occurred either downstream from the bridges (fig. 41C) or upstream (fig. 41F). In 1979, slumping of the riprapped left bank at the bridge was observed. Comparison of airphotos taken in 1957, 1968, and 1973 indicates little change, or perhaps some improvement, in the stability of the natural channel, but lateral erosion was still active in 1979. Degradation of the natural channel prior to relocation is indicated by the deep incision of minor side tributaries, as observed on the 1957 airphotos. The severity of lateral erosion tends to decrease downstream along the natural channel, which has a stable aspect in the vicinity of the US-70 crossing, 3 km downstream from the I-40 bridges (fig. 41E).

DISCUSSION--Instability, particularly with regard to degradation, of the natural channel was not taken into account in the design of pier foundations, and the check dam was added as a countermeasure. Although the check dam has prevented further degradation, it presents continuing problems of erosion and maintenance. If the bridges were located about 50 m upstream from the existing site, the danger of encroachment of the meander against the highway embankment would be removed and flow alinement at the bridges would be reasonably good without channel alteration. The high streambanks near the bridge could then have been stabilized by grading, placement of flexible revetment, and planting with vegetation.

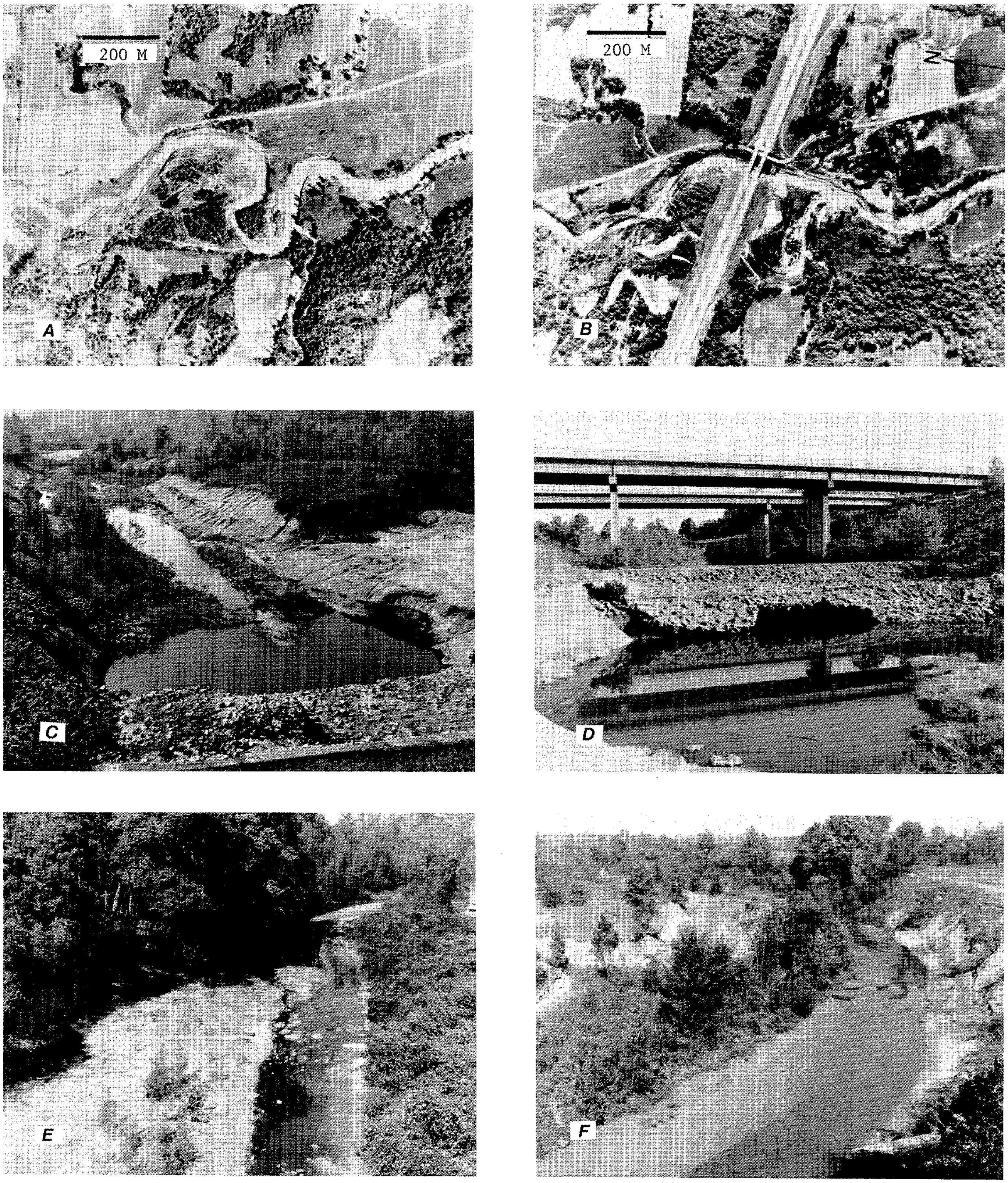


Figure 41. Crow Creek at site 10. A, Airphoto of site in 1957, prior to relocation. Position of relocated channel shown in dashed lines. (From U.S. Dept. of Agriculture). B, Airphoto in 1968, four years after relocation. (From U.S. Dept. of Agriculture). C, Relocated channel as viewed downstream from bridge, in 1978. Check dam is in foreground. D, Scour at check dam, as photographed in 1978. E, Natural channel 2.7 km downstream from relocation, in 1978. F, Channel as viewed upstream from bridge in 1978.

SITE 11. TRIBUTARY TO CADDO RIVER AT I-30 AT CADDO VALLEY, ARK.

SYNOPSIS--An unnamed tributary to the Caddo River was relocated so that it entered the river upstream from I-30, and the length of the channel segment was reduced from 460 m to 230 m, in order to avoid crossing the tributary (fig. 42). Performance period 15 yr (1965-79), during which a moderate flood of undetermined frequency occurred, in 1968. The relocated channel had a top width of about 20 m, a bottom width of about 6 m, and a slope of about 12 m/km. A gravel bar formed at the mouth of the relocated tributary, which deflected the flow of the Caddo River toward the right bank and caused local scour at piers on the flood plain, of the I-30 bridges. The gravel was evidently derived from degradation of the tributary and from lateral erosion at the tributary entrance. In 1970, the gravel bar at the mouth of the tributary was removed and a check dam constructed of concrete grouted riprap was built across the tributary mouth (fig. 43A). During the period 1971-76, the gravel bar formed again.

In 1979, a large scour hole having a depth of 1-2 m was observed below the check dam (figs. 43A and 43B), and the downstream end of the check dam was undermined. The top width of the relocated channel had not increased along most of its length but degradation estimated at 1-2 m had occurred prior to construction of the check dam and bank erosion had occurred at the upstream and downstream ends of the relocation (figs. 43A and 43C). About 1 m of degradation was observed on the natural channel upsteam from the relocation (fig. 43D).

Stability class C3 for relocated channel and class B3 for upstream reach of natural channel. The critical factor in channel degradation was the drastic shortening (by a factor of 0.5) of a substantial length of the tributary. Also, relocation of the mouth of a stream may entail a greater risk of degradation than relocation elsewhere along its course, because no local adjustment of the natural channel downstream from the relocation is possible.

SITE FACTORS--Lat 34°11', long 93°04', at I-30, 0.5 km south of Caddo Valley, Ark., on Caddo Valley 7.5' map. The unnamed tributary has a drainage area of 4.5 km^2, and its top width increased from 5 m at the upper end of the proposed relocation to about 12 m near its junction with the Caddo River. Equiwidth stream, somewhat incised (particularly near the mouth), channel slope of 6 m/km, alluvial, sinuosity of 1.2; tree cover along banks less than 50 percent. Bed material is gravel and cobble, bank material is coherent gravel cemented with clay and iron oxide.

ALTERATION FACTORS--No specific information was obtained on the as-built cross section of the relocated channel, and the top width was measured on an airphoto taken in 1964.

POST-ALTERATION FACTORS--Channel degradation was apparently a major reason for construction of the check dam, but there is no record of the actual amount of degradation at the time the dam was built. However, the gravel bar at the tributary entrance was mostly derived from bank erosion at the entrance and from bed scour at the check dam overfall. Rock riprap placed along the banks downstream from the check dam has been most removed by erosion (fig. 43B).

DISCUSSION--In 1979, the lip of the check dam stood 2.5 m above the surface of the plunge pool at its base. If the check dam fails, degradation will proceed upstream along the tributary, but it will be detained by the resistant cemented gravel in the streambed. The most serious erosion has been induced by overfall at the check dam. Overfall of this magnitude could probably have been prevented by a series of low, flexible check dams of rock riprap, rather than a single check dam.

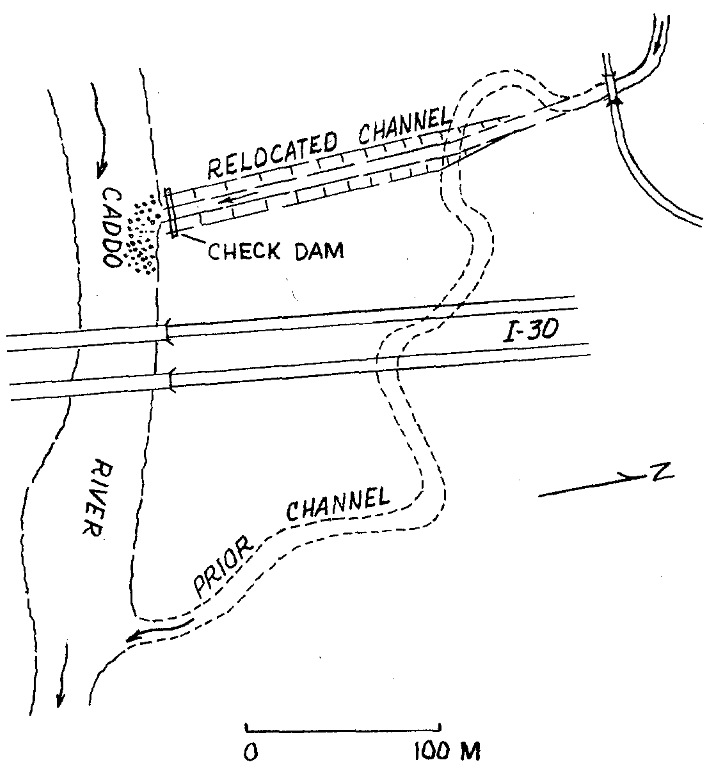


Figure 42. Plan sketch of channel relocation, tributary to Caddo River.

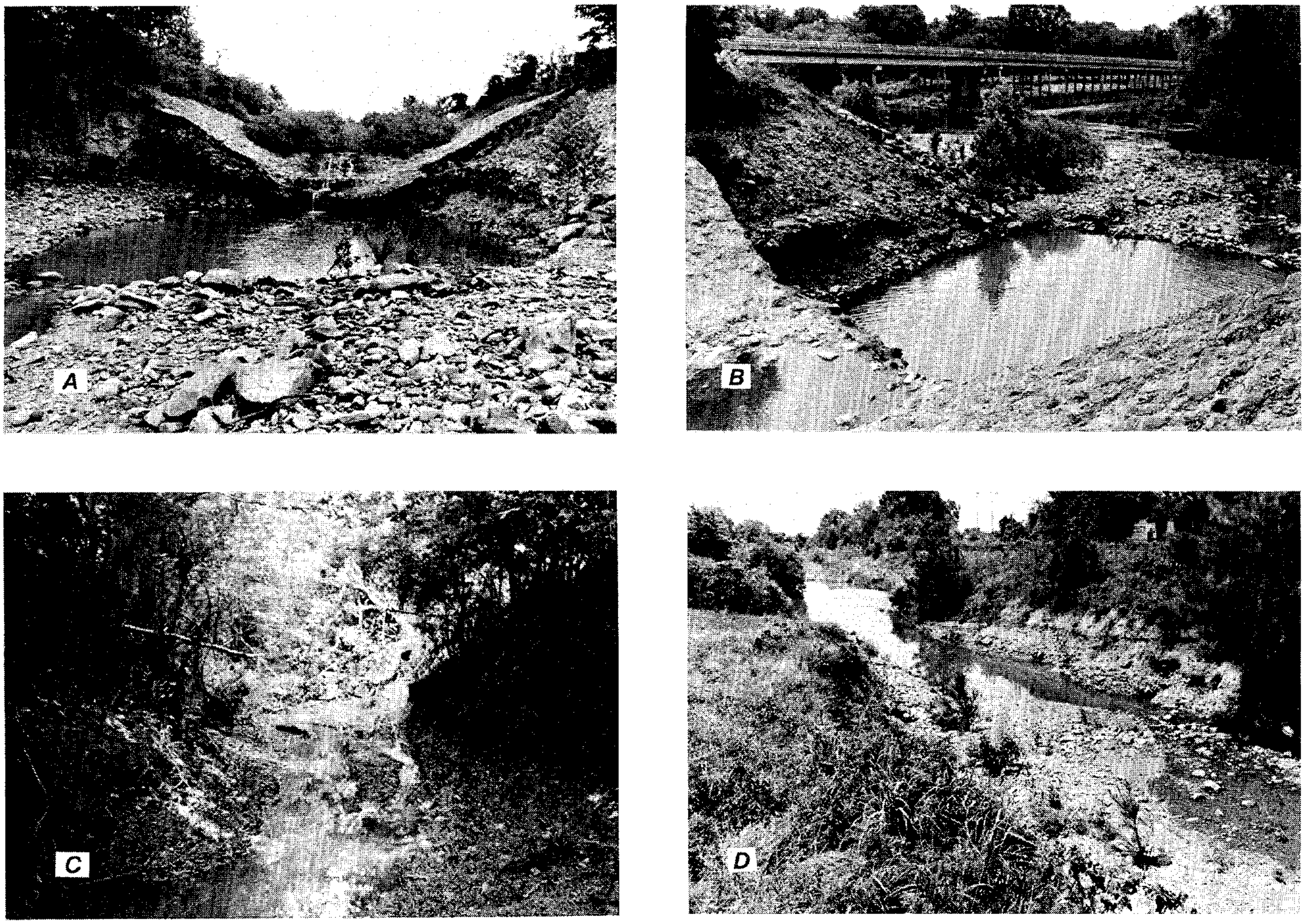


Figure 43. Tributary to Caddo River at site 11. A, Check dam at entrance of tributary to Caddo River in 1979. B, Scour hole at base of check dam, Caddo River and I-30 bridge in background, in 1979. C, Downstream view near upstream end of relocated channel, in 1979. D, Natural channel about 50 m upstream from relocated channel, in 1979.

SITE 12. POTEAU RIVER AT US-71 AT WALDRON, ARK.

SYNOPSIS--Channel relocation, reach 567 m in length shortened to 366 m, by factor of 0.65, for purpose of improving channel alinement at bridge (fig. 44). Performance period, about 9 yr, 1970-79. The relocated channel has been subjected to overbank flow but not to a major flood. Minor bank erosion has occurred at a few places along the relocated channel, but there has been no significant change in channel dimensions. Minor bank erosion was observed along the natural channel from place to place, but the degree of erosion seems about normal; no effect of relocation on the natural channel could be discerned.

Stability class B1 for relocated channel, class B for natural channel. Critical factors in channel stability are: (1) The "normal" stream discharge in the relocated channel is low in relation to bottom width, and water depth and velocity is insufficient for bank erosion. This excess of bottom width may eventually lead to meandering within the channel, but so far this has not occurred. (2) Degradation is prevented by resistant bedrock that forms a riffle at one place in the relocated channel. (3) The natural channel is rather stable, somewhat incised, and bordered by natural levees ranging in height from 1 to 2.5 m. (4) The relocated channel was not subjected to a major flood during the time that the banks were unvegetated.

SITE FACTORS--Lat 34°55', long 94°06', on US-71 0.5 km west of Waldron, Ark., on Waldron 7.5' map. Poteau River is perennial, drainage area of 114 km^2, 50-yr flood estimated at 374 m^3/s for purposes of bridge design. Channel bottom width is 12 m; bank height is 3.5 to 5.5 m, channel slope is 0.9 m/km. Equiwidth, point-bar stream, alluvial somewhat incised, natural levees well developed, sinuosity about 1.4. Valley relief about 75 m, flood plain wide, about km in width. Tree cover along 50-90 percent of bankline. Bank material is a moderately coherent mixture of clay, silt, and sand; bed material is sand and gravel.

ALTERATION FACTORS--As built, the relocated channel was trapezoidal in cross section, with a bottom width of 18 m, 2:1 side slopes, a top width of 35 m, and a longitudinal slope of 1.4 m/km. The relocated channel has a smooth transition with the natural channel at both upstream and downstream ends. Because the cut-off segment of natural channel received a minor tributary, it was left partially unfilled and was connected with the relocated channel by a ditch, which enters at almost a right angle. Flood water entering from the side ditch is a potential cause of eddy currents and consequent bank erosion, but so far erosion has been minor. No bank protection measures were applied along the relocated channel, but the banks of the natural channel have been riprapped at a point several hundred feet downstream from the bridge. Apparently, bank erosion was occurring here at the time the relocation was made.

POST-ALTERATION FACTORS--Although the site is ungaged for streamflow, lines of debris indicate that overbank flow has occurred at least once since channel relocation. There is no evidence of post-construction maintenance at the site. Young trees have become established at the toe of banks along the relocated channel (fig. 45).

DISCUSSION--Bank stability has probably been enhanced along the relocated channel by its greater bottom width (18 m as compared with 12 m for the natural channel), but this has led to a growth of vegetation in the channel bottom.

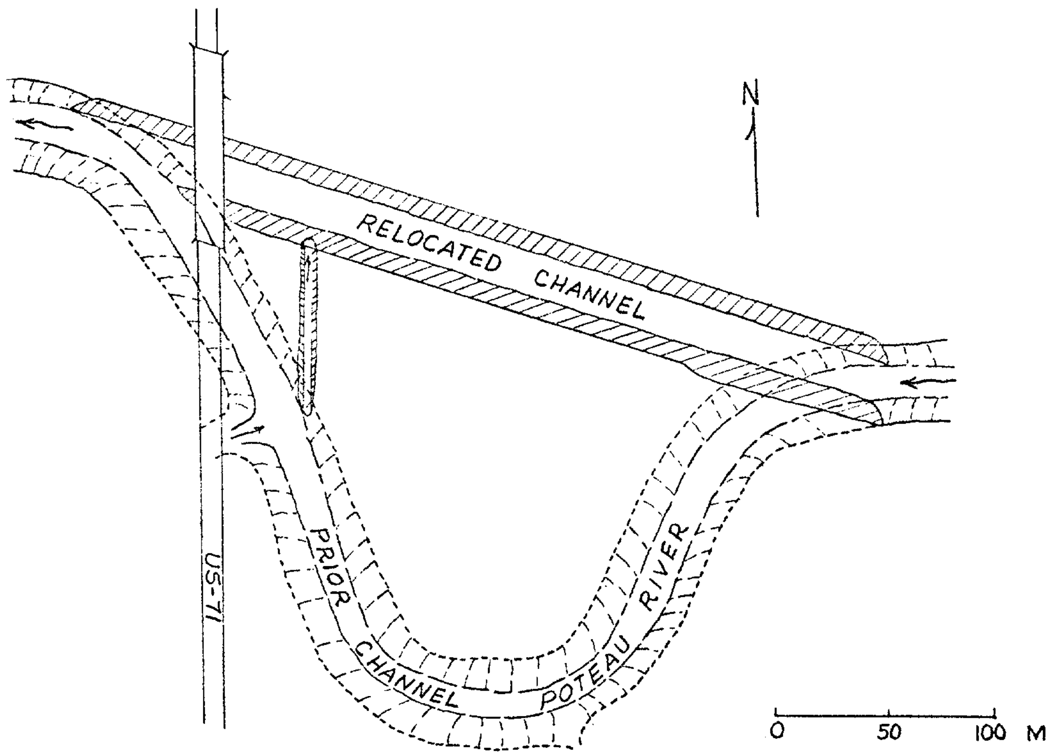


Figure 44. Plan sketch of Poteau River channel relocation.

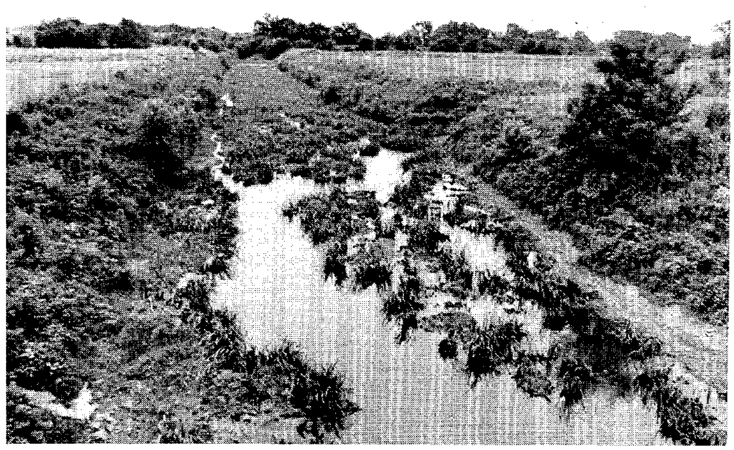


Figure 45. Relocated channel of Poteau River, upstream from US-71 bridge, in 1979.

SITE 13. FLAT ROCK CREEK AT I-540 AT VAN BUREN, ARK.

SYNOPSIS--A meandering channel segment 1,100 m in length was relocated and thereby shortened to 490 m, for purpose of accommodating roadway location and to improve channel alinement at bridge (fig. 46). Performance period, 13 yr (1966-78). The stream is ungaged, but field inspection in 1979 indicated that a recent moderate flood had reached a stage 2 m below "low steel" of the bridge beams, or about 1 m below the maximum stage used for bridge design. As built, the relocated channel was trapezoidal in cross section, with a bottom width of 12 m, a top width of 24.5 m, 2:1 side slopes, and a channel slope of 3 m/km. Rock riprap was placed at the curve in the relocated channel, and at the bridge abutments (fig. 46). In 1979, hand placed rock riprap on the abutment fill slopes had been partially removed by erosion. Bottom width of the channel had decreased immediately upstream from the bridge to about 8 m (fig. 47A) but had increased to 14 m at the upstream end of the relocated channel (fig. 47B). Comparison of airphotos made in 1954, 1961, and 1968 indicated that relocation had not significantly affected the stability of adjacent segments of the natural channel; although the channel was disturbed by another relocation at I-540, about 1 km upstream.

Stability class C2 for relocated channel and class B1 for adjacent segments of the natural channel. Although no bedrock outcrops were observed in the channel at this site, an outcrop in the channel was observed at the SR-162 crossing about 0.3 km upstream; and channel degradation has probably been inhibited by bedrock outcrops from place to place. Along most of the length of the relocated channel, where banks are stable, lateral erosion has been controlled by riprap and by vegetation. In addition, bottom width of the relocated channel exceeded that of the natural channel by a factor of 3.

SITE FACTORS--Lat 35°26', long 94°20', at I-540, near southeast boundary of Van Buren, Ark., on Van Buren 7.5' map. Flat Rock Creek is perennial, with a drainage area of 35 km^2, a bottom width of 4 m, and a slope of about 1.4 m/km. Equiwidth point-bar stream, incised, mainly alluvial but with outcrops of bedded siltstone in the channel from place to place; sinuosity of 1.5, valley relief of 20 m, wide flood plain, narrow strip of trees almost continuous along channel. Bed material in silt and sand, bank material is moderately coherent silt, sand, and clay. Cut banks were present along the channel prior to relocation, and channel incision is attributed to clearing of most of the drainage basin for agricultural purposes.

ALTERATION AND POST-ALTERATION FACTORS--Channel length was reduced by a factor of 0.45, with a consequent substantial increase in slope. At the upstream end of the relocation, the natural channel is crossed by a length of iron pipe and a low dam of siltstone riprap (fig. 47B) that evidently represents a check dam, although none is specified on the plans. Bank erosion has occurred downstream from this dam and is attributed to overfall at the dam. Elsewhere, the banks of the relocated channel were stable and well vegetated, and channel width has decreased upstream from the bridge.

DISCUSSION--A relocation involving rather drastic shortening, over a length of channel that is large in relation to stream size, would be expected to cause degradation; but little or none is evident. Degradation has probably been prevented by the check dam (whatever its origin) or by outcrops of bedrock in the channel.

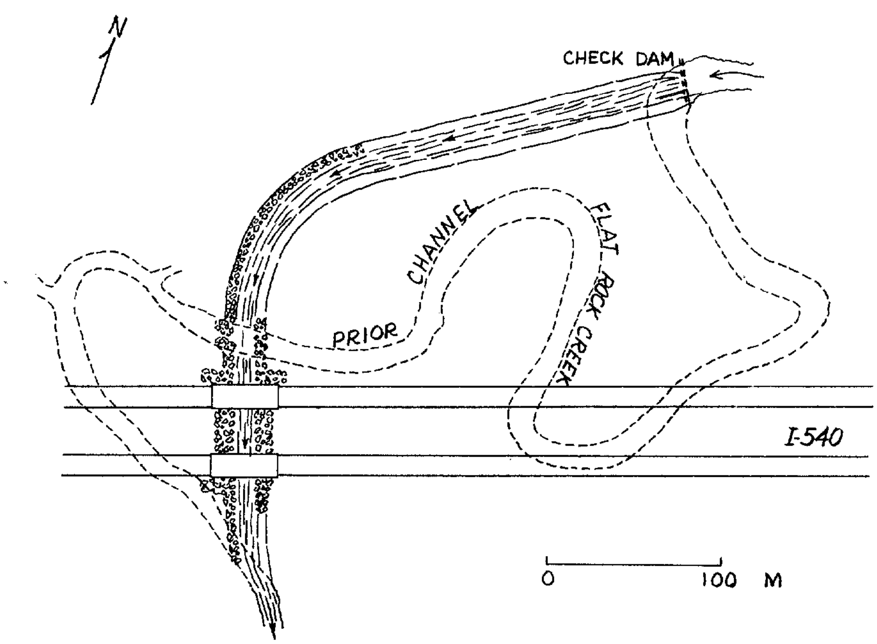
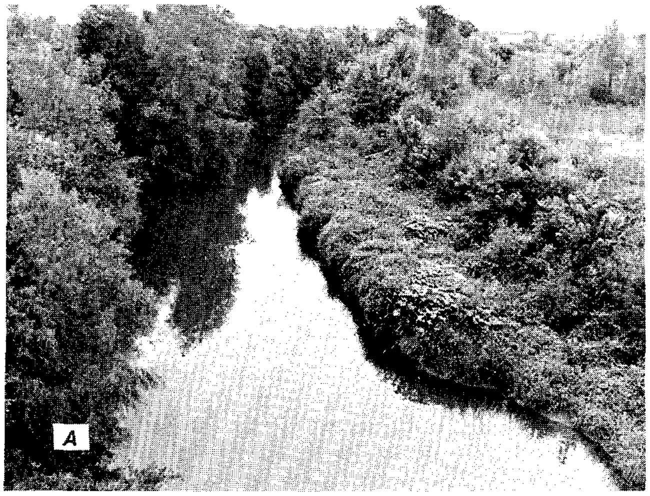


Figure 46. Plan sketch of channel relocation, Flat Rock Creek.



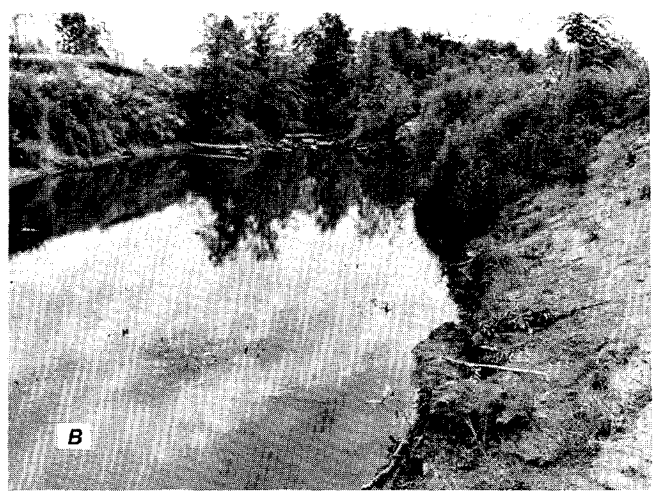


Figure 47. Flat Rock Creek at site 13. A, View upstream from I-405 bridge, in 1979. B, Upstream end of relocated channel, in 1979.

SITE 14. EAST FORK RUSSIAN RIVER NEAR UKIAH, CALIF.

SYNOPSIS--Channel relocation, reach 427 m in length shortened to 400 m and thereby moved laterally by about 38 m to make room for roadway in narrow valley (fig. 48). Performance period 12 yr, 1967-78, during which a major flood (peak flow of 208 m^3/s) occurred in 1970. Bed of relocated channel and lower 2 m of right bank are in resistant bedrock; left bank is fill-slope of roadway, protected with heavy rock riprap. Under these circumstances, potential instability is mainly restricted to slumping of the steep upper right bank, or erosion of the bank during flood. Neither of these kinds of instability has occurred.

Stability class A1 for relocated channel, and class A1 for natural channel. Critical factors in stability are the resistance of the upper right bank to slumping and lateral erosion, and the protection afforded the roadway fill by heavy rock riprap (fig. 49).

SITE FACTORS--Lat 39°15', long 123°08', on SR-20 about 17 km northeast of Ukiah, Calif., on Ukiah 7.5' map. East Fork Russian River is perennial, drainage area of 239 km^2, average discharge 9.4 m^3/s. Semi-alluvial stream, channel slope about 11 m/km, valley relief 400 m. Flood plain narrow or absent, bed material gravel, cobbles, and boulders.

ALTERATION FACTORS--Relocation resulted in a shortening of the channel by a factor of 0.94 over a distance of about 400 m, which, for a semi-alluvial mountain stream, has no significant effect on channel slope. Room for the relocated channel was made by cutting back the steep valley side, such that the right bank of the relocated channel has a 1:1 slope. Bottom width of the relocated channel is 18 m, which is slightly greater than the bottom width of the natural channel.

POST-ALTERATION FACTORS--There is no record of maintenance or installation of additional countermeasures at the site, and no slumping or bank erosion was evident when the site was inspected in September, 1978. Shrubs and small trees had become well established in the riprap along the left bank.

DISCUSSION--Slumping of the alluvium (or colluvium) in the upper part of the right bank may occur at some future time, and this could result in blockage of the relocated channel.

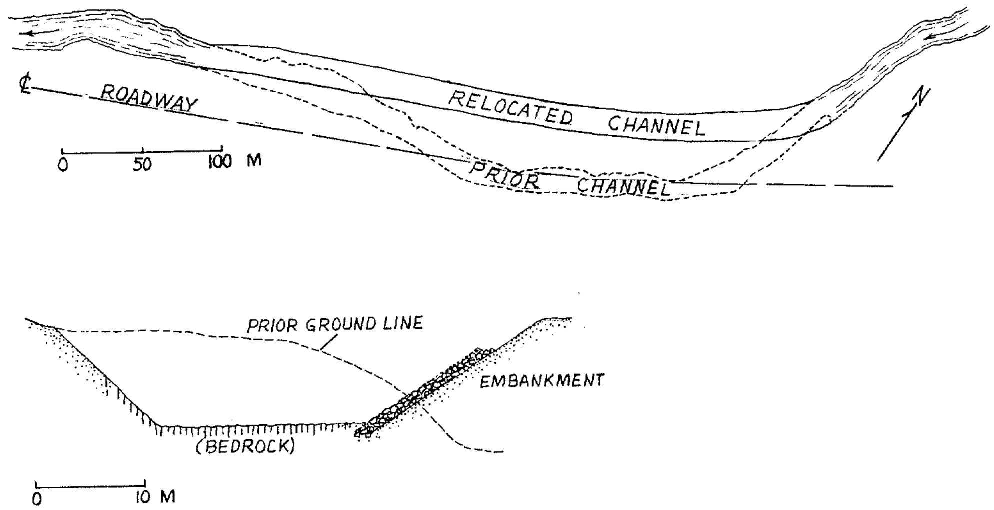


Figure 48. Plan sketch of channel relocation and cross section of relocated channel, East Fork Russian River

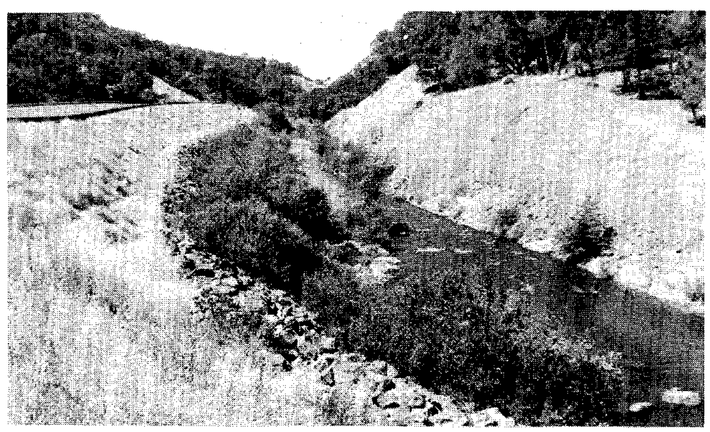


Figure 49. View downstream along channel relocation, East Fork Russian River, in 1978.

SITE 15. OUTLET CREEK AT US-101 NEAR LONGVALE, CALIF.

SYNOPSIS--Channel relocation, reach 435 m in length shortened to 335 m, to avoid two crossings on realined highway curve (fig. 50). Performance period, 22 yr (1957-1978). Extreme flood in 1964, daily mean discharge 1,485 m^3/s as compared with average discharge of 12 m^3/s. Stream is semi-alluvial, and resistant bedrock crops out in bottom of relocated channel. The highway embankment, which forms the right bank of the relocated channel, is heavily riprapped, and the main potential for instability is at the left bank, which is a steep (3/4:1) slope cut into colluvial material (figs. 50 and 51). However, no erosion or slumping was observed.

Stability class A1 for both relocated and natural channel. The critical factor in the stability of the cut slope is probably the shallow depth to bedrock, and the cutting of a bench or terrace on the slope may have contributed to stability.

SITE FACTORS--Lat 39°32', long 123°24', on US-101, 3.2 km south of Longvale, Calif., on Longvale 7.5' map. Outlet Creek is perennial, drainage area of about 360 km^2 at site, average discharge 12 m^3/s. Channel width is 9-15 m, channel slope is 3.6 m/km. Semi-alluvial stream, valley relief about 350 m, steep valley side-slopes, flood plain narrow or absent. Tree cover less than 50 percent along channel. Bed material is gravel and cobble, bank material is gravel and sand where alluvial.

ALTERATION FACTORS--The length of a curve in the natural channel was shortened by a factor of 0.77, and room for the relocated channel was made by grading back a steep valley side-slope. The relocated channel lies between this graded slope and the riprapped highway embankment. Riprap on the embankment includes rocks weighing several tons, and erosion of the embankment is unlikely.

POST-ALTERATION FACTORS--No maintenance work, following the extreme flood of 1964, is apparent. Small trees have become established on the rip-rapped highway embankment and along the base of the cut slope (fig. 51).

DISCUSSION--Landsliding, the major potential for instability along the relocated channel, is very common in some California terrains, but is not evident here along the valley of Outlet Creek. The lack of naturally occurring landslides, which is attributed to the resistance of the underlying bedrock, was an indication that the cut slope would not be particularly susceptible to failure by mass movement. Except for the bare upper part of the cut slope, the appearance of the relocated channel is not unnatural for a mountain stream in a narrow valley.

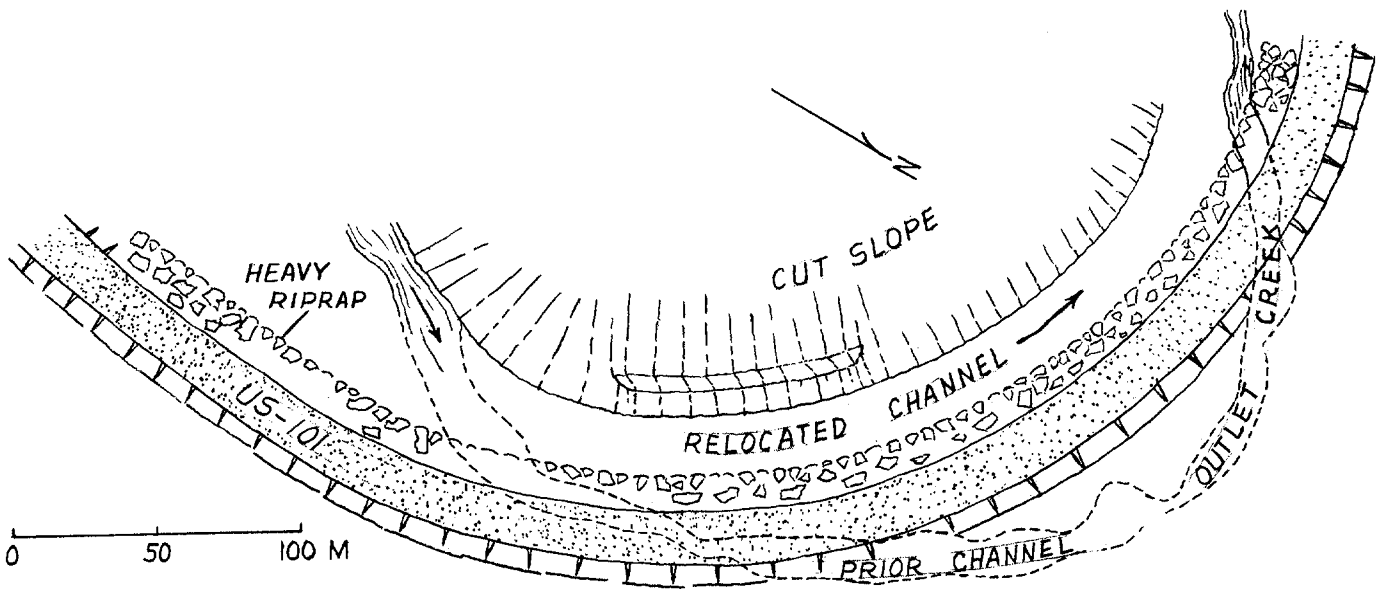


Figure 50. Plan sketch of channel relocation, Outlet Creek.

Figure 51. View upstream along relocated channel of Outlet Creek, in 1978.

SITE 16. NOJOQUI CREEK AT
US-101 AT BUELLTON, CALIF.

SYNOPSIS--Lowermost 760 m of creek was relocated to enter Santa Ynez River upstream from US-101 bridge, for purpose of avoiding a stream crossing at an interchange (fig. 52). Performance period, 16 yr (1964-1979), during which major floods occurred in 1969 and 1978. No evidence of degradation or lateral erosion in relocated channel, but a sinuous low-water channel has developed in the wide bottom of the relocated channel. Severe bank erosion occurred in natural channel at bend upstream from relocation during flood of 1978, but this is not attributed to the relocation.

Stability class A1 for relocated channel, class C3 for natural channel. Stability of the relocated channel is attributed to its width, which exceeds that of the natural channel by a factor of 1.5-2, and to the riprapped dikes along the channel sides. In addition, channel slope was not much changed by the relocation.

SITE FACTORS--Lat 34°36', long 127°11.5', on US-101 about 1.3 km south of Buellton, on Solvang 7.5' map. Nojoqui Creek is intermittent, drainage area about 39 km^2. Stream is ungaged, but adjacent gaged stream of similar drainage area (Alisal Creek) has average discharge of 0.15 m^3/s, with no flow 64 percent of the time. Channel width 15-20 m, bank height to flood plain, 1.5 m, channel slope at site 6.9 m/km. Point-bar braided stream, generally incised into terraces. Tree cover along channel, less than 50 percent. Channel at site is on flood plain of Santa Ynez River. Bed material is gravel, cobbles, and small boulders; bank material is moderately cohesive silt, clay, and gravel.

ALTERATION FACTORS--Lowermost 760 m of natural channel was relocated into a straight artificial channel 640 m in length, resulting in a length change factor of 0.84. The width of the natural channel was in the range of 15-20 m. The relocated channel has a top width of 42 m, a bottom width of 31 m, and is bounded by riprapped dikes that rise about 1.5 m above the flat bottom. Slope of the natural channel was 4.4 m/km; of the relocated channel, 5.3 m/km, decreasing to 2.5 m/km at the lower end. The dikes bounding the relocated channel are riprapped in part with large (1 m) rock and in part with 0.6 m rock, with toe of riprap extended to depth of 1.8 m below channel bottom.

POST-ALTERATION FACTORS--Floods having an estimated recurrence interval of greater than 25 yrs occurred in 1969 and 1978. The banks of the natural channel at a bend upstream from the relocation were severely eroded in 1978 (fig. 53A), and the channel was subsequently realined by the bulldozing of bed material against the banks. The flood apparently disrupted the riprap facing of dikes along the relocated channel, but there is no evidence that the dikes were broken. Young willows and other vegetation have become established along the dikes and, locally, in the channel bottom.

DISCUSSION--Because the bottom width of the relocated channel is more than twice that of the natural channel, a sinuous low-water channel has developed (fig. 53B), which may eventually erode laterally against the bounding dikes. In addition, the wide bottom may become overgrown with willows, which will impair its transmission of floods. As depicted on 1957 airphotos, the reach of natural channel subsequently to be relocated was nondescript in appearance, already disturbed by road construction, and not much more attractive in appearance than the present relocated channel.

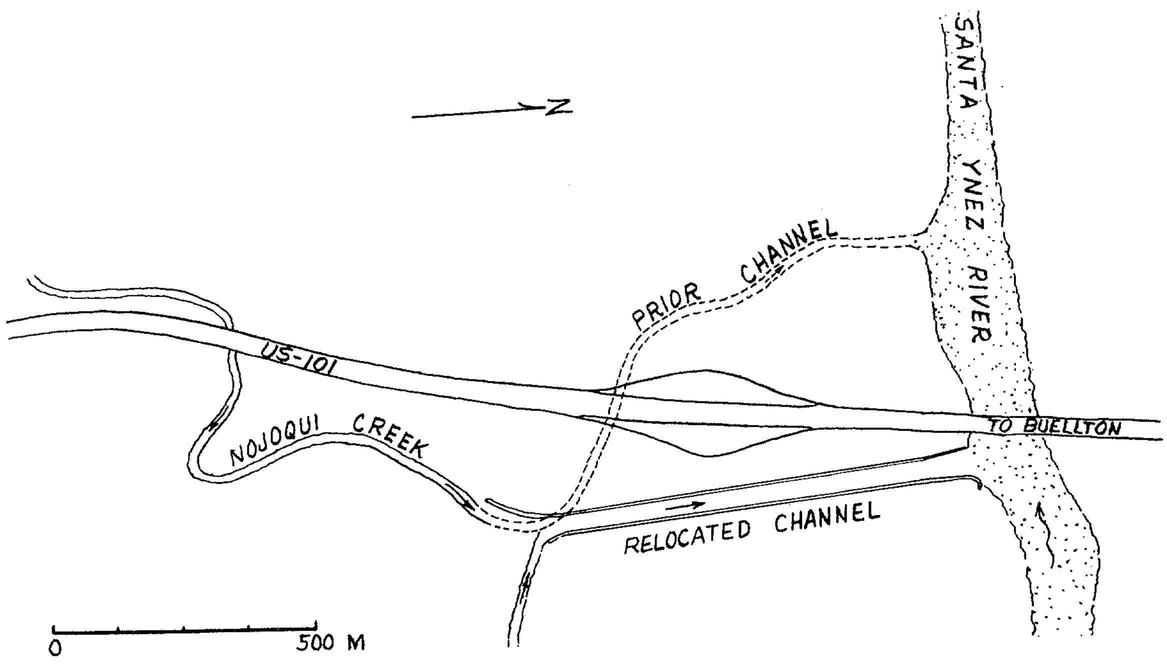


Figure 52. Plan sketch of Nojoqui Creek channel relocation.

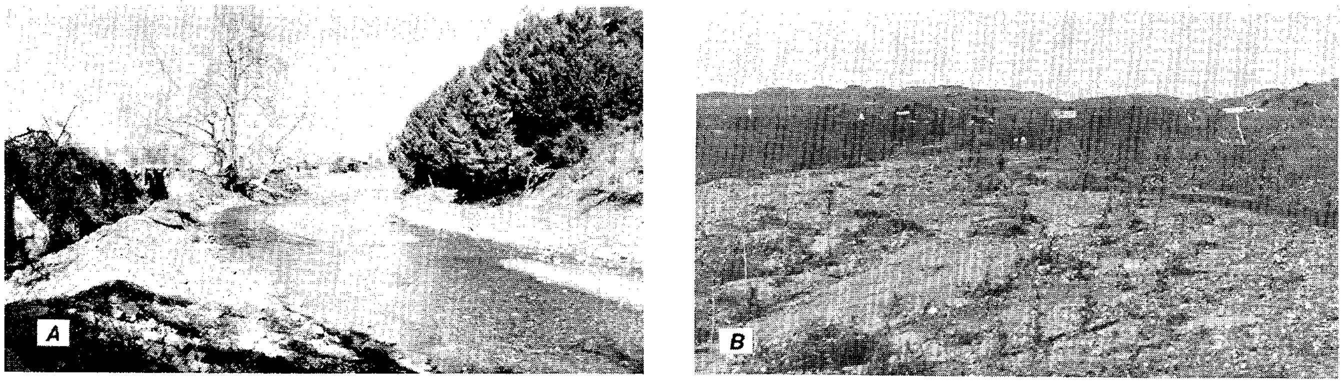


Figure 53. Nojoqui Creek at site 16. A, Bank erosion, extreme left, upstream from relocated channel, in 1979. B, Downstream view along relocated channel, in 1979.

SITE 17. SWAUGER CREEK AT US-395 NEAR FALES HOT SPRINGS, CALIF.

SYNOPSIS--Channel relocation, reach 113 m in length, was moved laterally about 10 m and shortened in order to make room for roadway (fig. 54 Performance period 12 yr (1967-78). Bottom width of the relocated channel has decreased from 3.5 m, as built, to about 2.5 m, probably because of slumping of the poorly sorted, unconsolidated bank materials. Bank-to-bank channel width had remained about the same, except for a local 20-30 percent increase at the outside of the downstream bend.

Stability class B1 for relocated channel. Relocation has had no apparent effect on the natural channel. General stability of the relocated channel is attributed to the minor change in channel slope resulting from relocation.

SITE FACTORS--Lat 38°20', long 119°19', on US-395, 6.5 km east of Fales Hot Springs, Calif., on Fales Hot Springs 15' map. Swauger Creek is perennial, drainage area of about 45 km^2 at site. No stream gage at site, but average discharge estimated at 0.1 m^3/s from records at downstream gage. Alluvial stream, low sinuosity, channel slope 28 m/km, valley relief 450 m. Sagebrush and scattered small trees along channel. Bed material ranges in size from gravel to small boulders; bank material is weakly coherent, poorly sorted gravelly alluvium.

ALTERATION FACTORS--Relocation resulted in shortening of reach from 113 m to 107 m or by a factor of 0.95. Relocated channel was constructed with top width of 9 m, bottom width 3.6 m, side slopes of 1.5:1 in weakly coherent alluvium, depth about 2 m. Channel slope was 30 m/km. No revetment or other countermeasures were applied to the relocated channel.

POST-ALTERATION FACTORS--There is no evidence of serious flooding or of maintenance at the site during the performance period, and drainage at the upper end of the relocated channel has been ponded by a beaver dam. Vegetation has become established along part of the channel (fig. 55).

DISCUSSION--At the site of the relocation, the natural channel has been crowded to the south side of the valley by the alluvial fan of a side tributary, and its trend is nearly straight. Recovery of natural vegetation is slow at this altitude (about 2,200 m) and in the arid climate. The relocated channel is not particularly attractive in appearance, but is not very different from the natural channel.

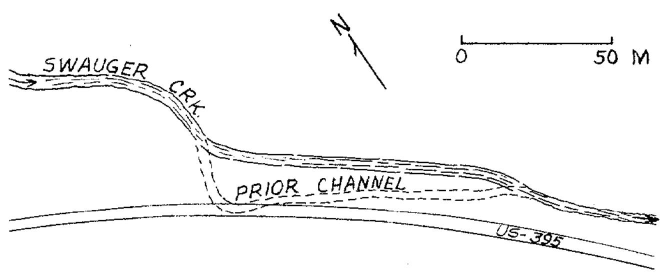


Figure 54. Plan sketch of Swauger Creek channel relocation.

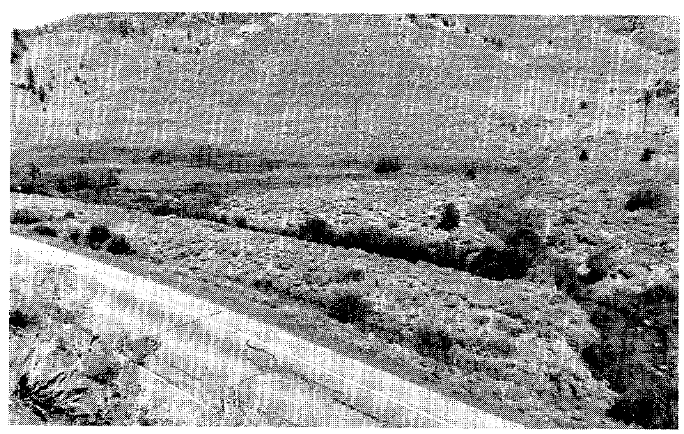


Figure 55. View of relocated channel of Swauger Creek in 1978. Flow is to right.

SITE 18. EAST WALKER RIVER AT SR-182 NEAR BRIDGEPORT, CALIF.

SYNOPSIS--Channel relocation, reach 370 m in length shortened and moved laterally by 70 m to avoid sharp curve in new roadway (fig. 56). Performance period 25 yr, 1954-1978. Streamflow is regulated by upstream reservoir, and no major floods occurred during performance period; although a peak flow of 39 m^3/s (ten times average discharge) occurred in 1963. Left bank of relocated channel is riprapped roadway embankment, right bank is in alluvium. Regeneration of vegetation, mainly willows, has occurred for about half the length of the right bank; the rest, although partially bare, is not actively eroding (fig. 57A). No effect of relocation on the natural channel could be discerned (fig. 57B).

Stability class A1 for relocated channel, and A1 for adjacent natural channel. Critical factors in channel stability are flow regulation by the upstream reservoir, and the natural stability of shallow channels with cobble-boulder bedloads and low, well vegetated banks.

SITE FACTORS--Lat 38°21', long 119°12.5', on SR-182, 10.5 km north of Bridgeport, Calif., on Bridgeport 15' map. East Walker River is perennial, drainage area of about 945 km at site, average discharge 3.7 m^3/s. Channel width 9-15 m, bank height 0.3-1 m, channel slope 10.8 m/km. Braided stream, semi-alluvial, sinuosity about 1.2. Valley relief about 800 m, flood plain narrow to absent. Narrow strip of small trees, mainly willow, along more than 90 percent of channel. Bed material cobbles and boulders, bank material coarse alluvium and poorly sorted colluvium. Flow is regulated by Bridgeport Reservoir, the dam for which is 4.1 km upstream from site.

ALTERATION FACTORS--Reach 370 m in length was shortened to 271 m, or by a factor of 0.73. Width of the natural channel, which is irregular, ranges from 9-15 m, and width of the relocated channel ranges from 9 m at the upstream end to 12 m at the downstream end. Slope of the relocated channel is about 15 m/km, and the bankfull depth is 1.5 m. Although the relocated channel has a smooth transition with the natural channel at the downstream intersection, the upstream intersection is nearly at 90° to the relocated channel and riprapped roadway embankment.

DISCUSSION--An abrupt intersection of a stream channel with a roadway embankment is a potential cause for erosion, but no problems have occurred here during the 25-yr performance period. The heavy riprap along the roadway embankment has contributed to stability, as has regulation by the reservoir. An additional factor is the natural stability, except in extreme floods, of shallow mountain streams having coarse bedloads.

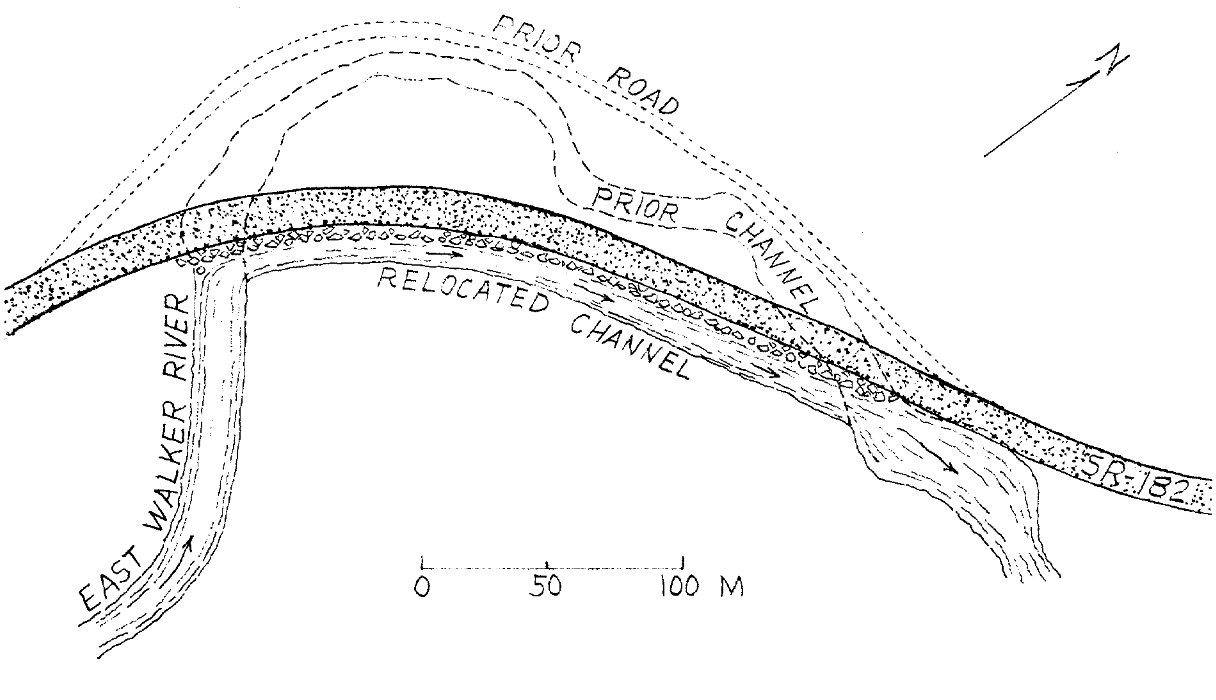
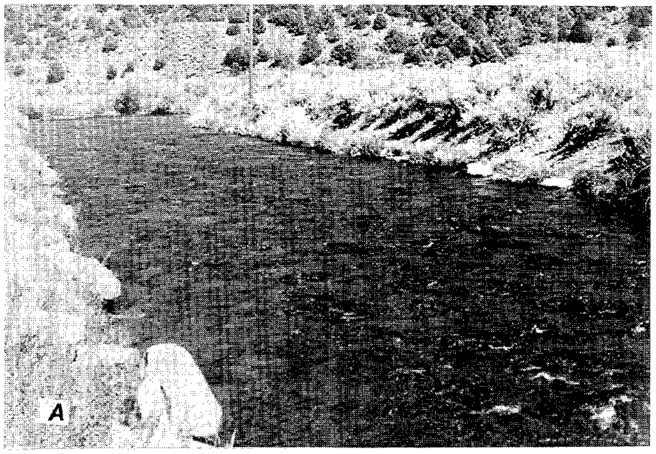


Figure 56. Plan sketch of channel relocation, East Walker River.



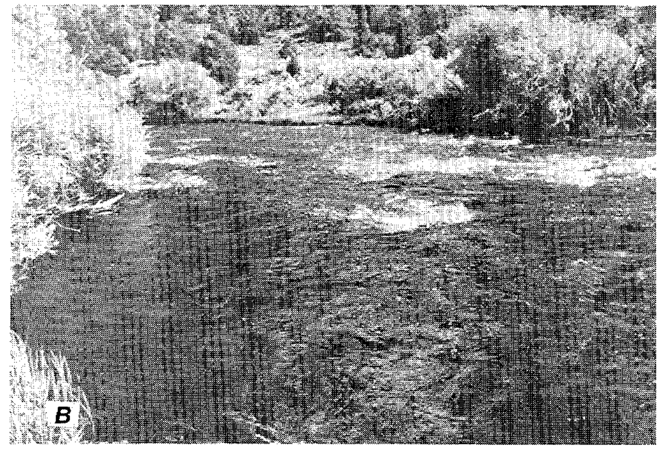


Figure 57. East Walker River at site 18. A, View downstream, about midway along relocated channel, in 1978. B, Natural channel about 30 m downstream from relocation.

SITE 19. BEAVER CREEK AND DES MOINES RIVER AT I-35-80 AT DES MOINES, IOWA

SYNOPSIS--A channel segment of Beaver Creek extending 2,200 m above its junction with Des Moines River was relocated and thereby shortened to 1,950 m; and the junction was moved upstream on the Des Moines River (fig 58). The purpose of the relocation was evidently to avoid a crossing of Beaver Creek. Performance period, 18 yr (1961-79), during which the highest flow in an 18-yr period of record occurred in 1974. Relocation was effected by diverting flow along a pilot channel having a bottom width of 12 m and a slope of 1.17 m/km. In 1979, bottom width of the relocated channel ranged from 30 to 40 m. About half of the bankline was bordered by trees, and the rest was bordered by grass. The streamward face of the banks was mostly unvegetated and small scale slumping was common (fig. 59A), but bank recession was judged to be slow. Upstream from the relocation, the natural channel was eroding rapidly at bends (fig. 59B).

Stability class B for relocated channel and class C for natural channel. As observed on a 1955 airphoto, the natural channel was more stable than in 1978; but the decrease in stability cannot be solely attributed to the relocation, because another channel segment, about 1 km upstream, has recently been channelized. Further widening of the relocated channel will probably be inhibited by the coherence of the clay-rich bank materials.

In connection with the relocation of Beaver Creek, a meander of the Des Moines River was cut off, with little change in channel length, to improve channel alinement at the interstate bridge (fig. 58). Subsequently, an island has formed in the channel upstream from the bridge (opposite the relocated mouth of Beaver Creek), and flow has been diverted toward the west bridge abutment (fig. 59C). Riprap has been placed along the bankline upstream from the bridge, but further recession of the banks, in the direction of the abutment, is probable.

SITE FACTORS--Lat 41°39', long 93°40', at I-35-80, near north boundary of Des Moines, Iowa, on Des Moines NW 7.5' map. Beaver Creek is perennial, with a drainage area of 950 km^2, and an average discharge of 5.5 m^3/s. Bottom width is 15-20 m and channel slope is 0.9 m/km. Wide bend point-bar stream, alluvial, sinuosity of 1.3, valley relief of 50 m, wide flood plain, tree cover along channel greater than 90 percent. Bed material is sand, and bank material is coherent clay, silt, and sand. The drainage basin is mostly cleared, and several channel segments upstream from the site have been straightened. In addition, part of the relocated segment had been straightened, prior to 1955.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--Bottom width of the relocated channel of Beaver Creek has increased from 12 m (pilot channel) in 1961 to 30-40 m in 1979. By comparison, the bottom width of the natural channel was in the range of 15-20 m in 1955. No sinuosity of the thalweg within the wide relocated channel was observed in 1979, but such sinuosity is likely to develop. The relocated channel is unattractive in aspect, although the area has potential for recreation.

Relocation of the Des Moines River has led to a bank erosion problem near the west bridge abutment because of the growth of an island in the channel. Islands are uncommon in the Des Moines River, and this one is probably due to sediment discharged into the Des Moines from Beaver Creek and derived from eroding banks of relocated Beaver Creek.

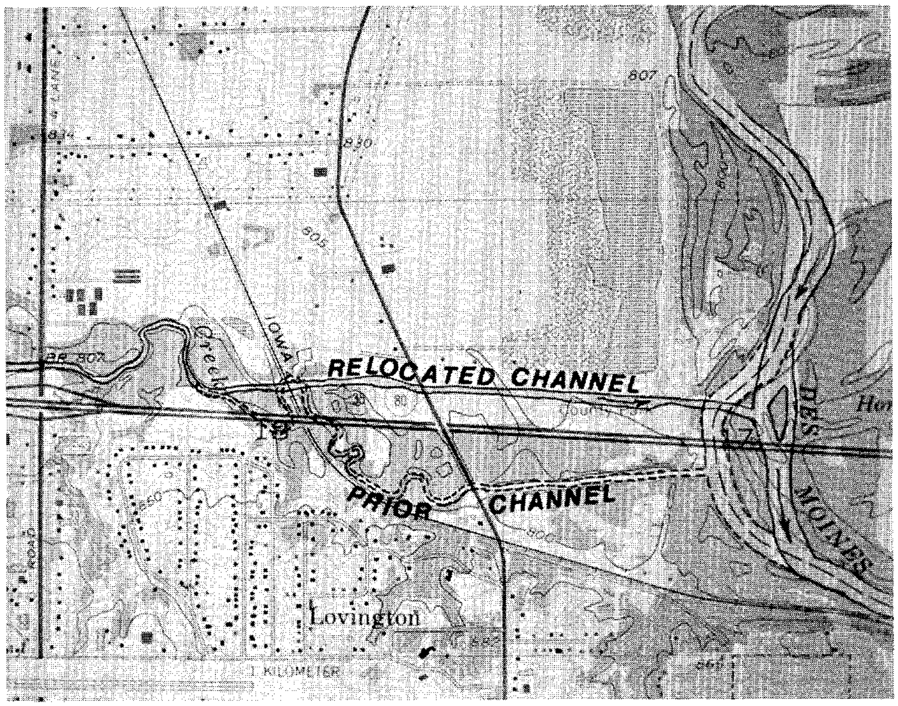


Figure 58. Topographic map showing relocation of Beaver Creek and Des Moines River. (From U.S. Geological Survey Des Moines NW 7.5' map)

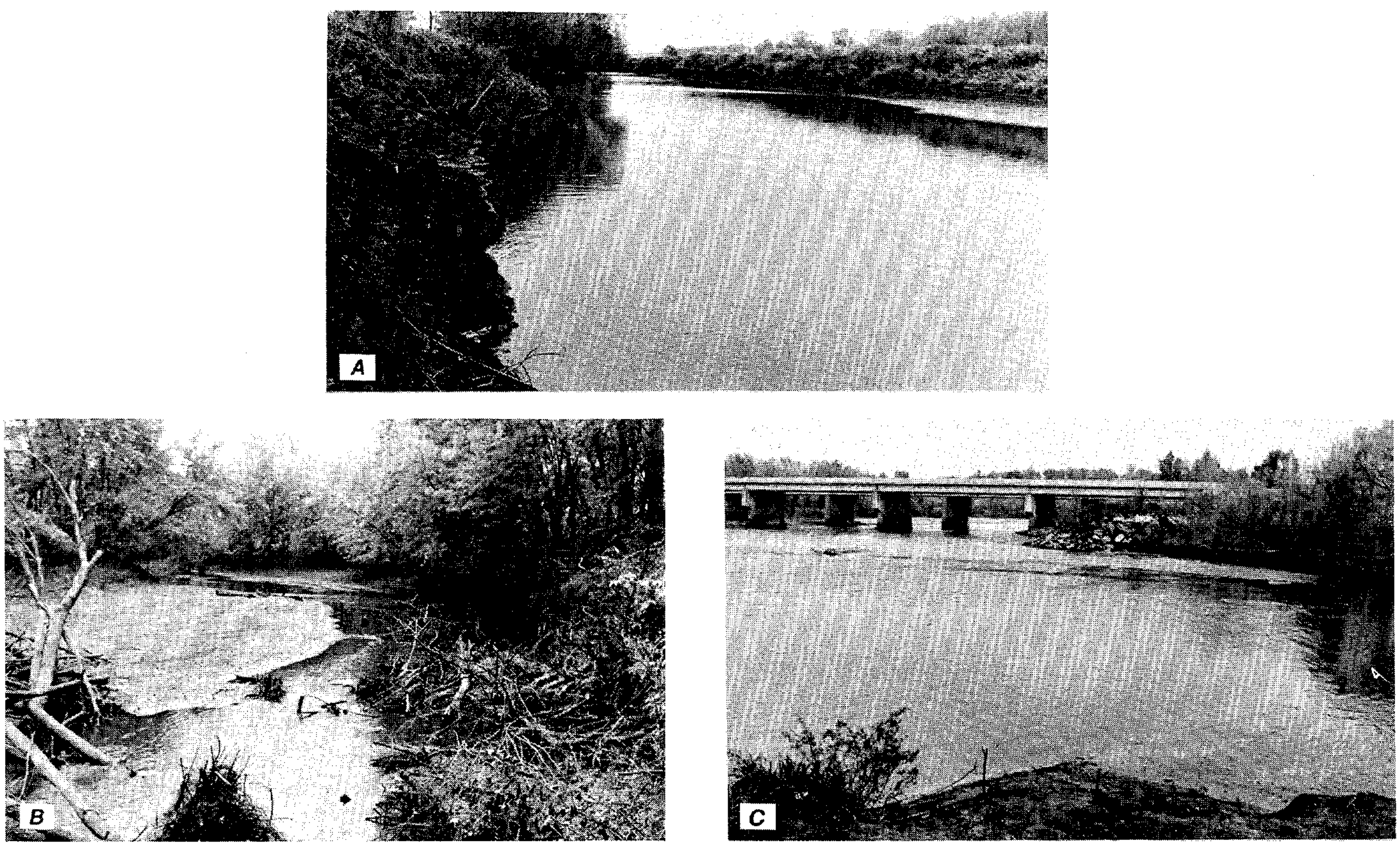


Figure 59. Beaver Creek at site 19. A, Downstream view of relocated channel, about midway of its length, in 1979. Note small scale slumping of cohesive clay in foreground. B, Natural channel of Beaver Creek, upstream from relocation, in 1979. C, Junction of Beaver Creek, right, and Des Moines River; interstate bridge across Des Moines River in background.

SITE 20. BEAR CREEK AT I-80
NEAR EARLHAM, IOWA

SYNOPSIS--A channel segment 2,050 m in length was relocated and thereby shortened to 1,200 m, in order to avoid two stream crossings (figs. 60 and 61A). Performance period, 13 yr (1966-79). Bear Creek is ungaged, but a general storm occurred in the area in July 1973, which caused a major flood on adjacent gaged streams. As built, the relocated channel was trapezoidal in cross section (fig. 60, inset), with a bottom width of 6 m, 2:1 side slopes, and a longitudinal slope that was reduced to 2 m/km by addition of a concrete drop structure (fig. 61B) having a fall of 2 m. No other counter measures were used, except for local application of jute mesh and sod on the cut (fig. 61C) north of the relocated channel. This cut was terraced (fig. 60, inset), and the terrace treads slope at 2 percent away from the risers. In 1979, the cut was heavily grassed, but the banks along the relocated channel had slumped in a few places (fig. 61D), and several gullies 2-3 m in depth had developed from side drainage. In addition, several large slumps were observed on the opposite (south) bank of the channel downstream from the culvert entrance. The banks of the relocated channel were otherwise generally stable, and the channel bottom width was within 1 or 2 m of the width as built. Two beaver dams were observed in the relocated channel, one about midway of its length and the other near the downstream end. Downstream from the relocation, the natural channel was generally stable (fig. 61E) except for cut banks at bends, and its condition was similar to that observed on a 1955 airphoto.

Stability class C2 for relocated channel and class B1 for adjacent segments of natural channel. Slumping along the relocated channel is attributed to the height and steepness of the channel side slopes and the lack of coherence of the slope materials. Gullying is attributed to the same factors. Degradation has probably been prevented by the concrete drop structure, although there is some evidence for 0.5-1 m of degradation along the relocated channel upstream from the structure.

SITE FACTORS--Lat 41°31', long 94°09', at I-80, 3 km north of Earlham, Iowa, on Adel 15' map. Bear Creek is intermittent, with a drainage area of about 28 km^2, bottom width of 6 m, bank height of 2-2.5 m, and channel slope of 2.3 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.5, valley relief of 30 m, wide flood plain, tree cover of 50-90 percent along bankline. Bed material is sand with minor amount of gravel, bank material is weakly coherent silt, clay, and fine sand. Most of the drainage basin has been cleared for agriculture.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis").

DISCUSSION--The length of the relocated segment was large in relation to stream size, and original channel length was reduced by a factor of 0.6. Serious channel degradation would probably have occurred without the drop structure. Terracing of the high cut has probably prevented more serious slumping and gullying.

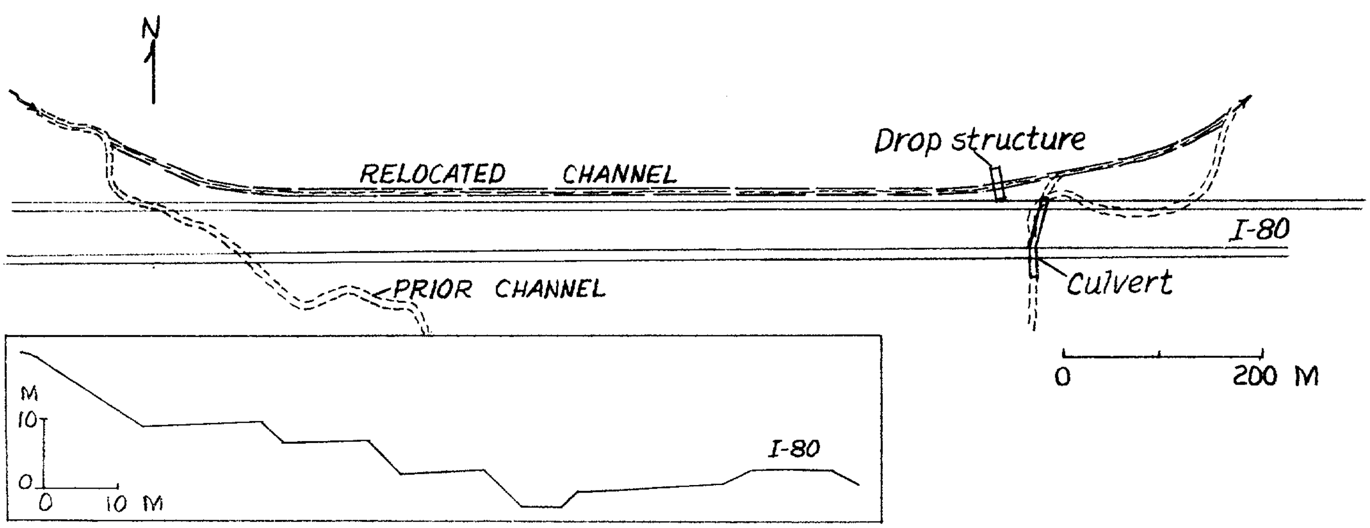


Figure 60. Plan sketch of Bear Creek channel relocation. Inset, typical cross section of relocated channel and adjacent slopes.

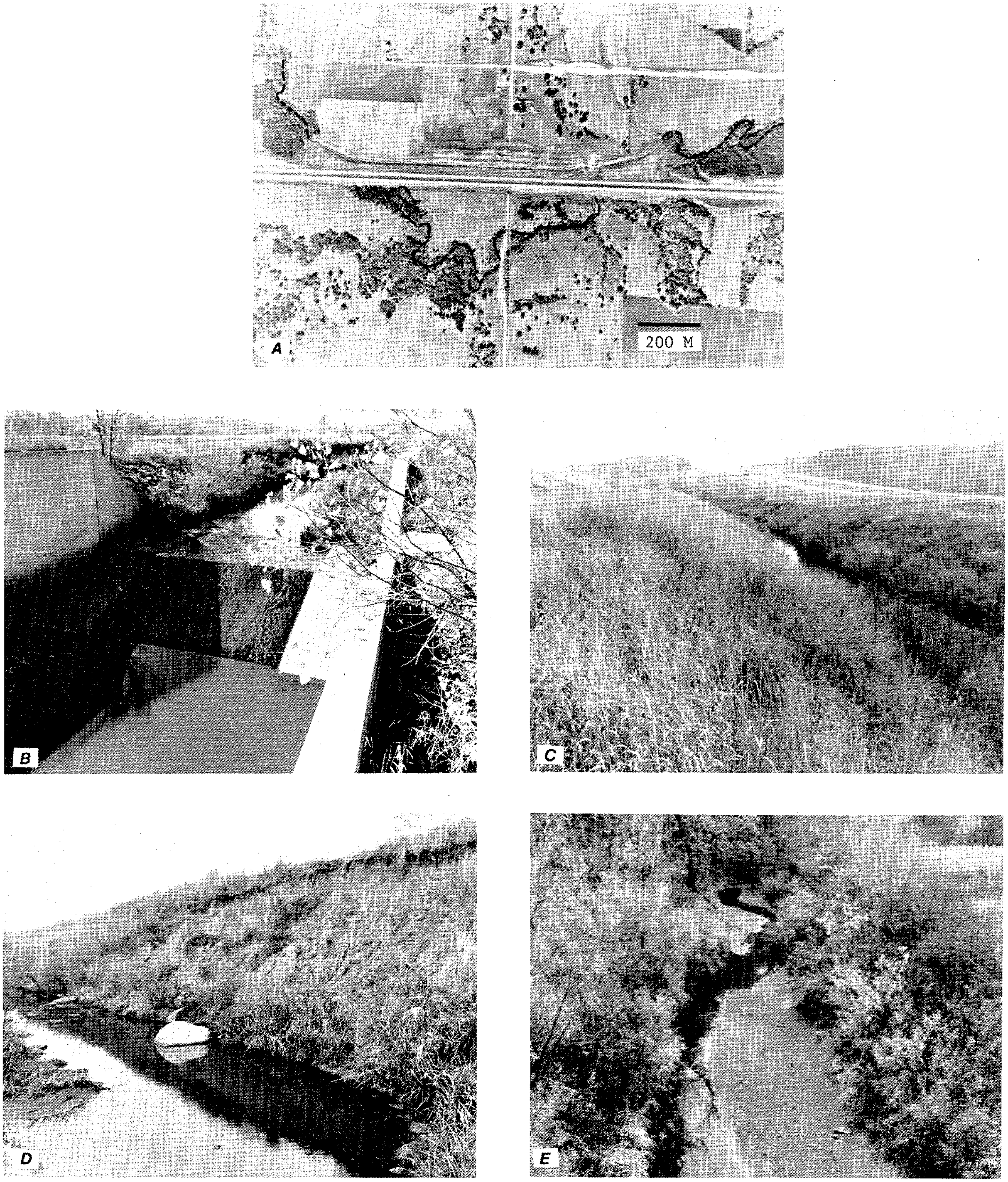


Figure 61. Bear Creek at site 20. A, Airphoto of channel relocation in 1967. B, Concrete drop structure on relocated channel. C, Downstream view along relocated channel, in 1979. D, Bank slumping along relocated channel, about midway of its length. E, Natural channel in 1979, at bridge 700 m downstream from relocation.

SITE 21. CLEAR CREEK AT I-380 AND I-80 NEAR IOWA CITY, IOWA

SYNOPSIS--A reach 2,850 m in length was relocated in segments during the period 1962-70 and shortened to 1,750 m, for the purpose of improving channel alinement at bridges on I-380 and I-80 (figs. 62A and 62B). The downstream part of the reach, 600 m in length, was relocated in 1962 for the I-80 crossing and the upstream part, in 1970 for the I-380 crossing. Maximum peak flow for a 36-yr period of record occurred on Clear Creek in May 1974. As-built bottom width of the relocated channel ranged from 8 to 15 m, and channel slope was 1.1 m/km. No bank protection measures or other countermeasures along the relocated channel were specified on the plans or observed in the field. In 1979, bank erosion was apparent at bends in the relocated channel between the two interstate crossings (figs. 62C and 62D), where the bottom width ranged from 11 to 14 m and the top width, from 17 to 25 m. Degradation could not be evaluated but no progressive degradation, as would be indicated by headcuts or rapid bank erosion, was apparent. Adjacent channel segments had already been disturbed by prior (non-highway) straightening, probably done 50 yr or more ago. The banks are generally stable (figs. 62E and F), and the degree of bank cutting is about the same as that observed on an airphoto taken in 1955.

Stability class C3 for relocated channel and class B1 for adjacent segments of natural channel. In view of the erodibility of bed and banks, the degree of shortening (factor of 0.6), the magnitude of the 1974 flood, and the lack of countermeasures, the stability of the channel is better than would be expected. Establishment of vegetation at the toe of the bank has evidently controlled progressive bank erosion.

SITE FACTORS--Lat 41°42', long 91°38', at I-380 and at I-80, 8 km west of Iowa City, Iowa, on Iowa City West 7.5' map. Clear Creek is perennial, with a drainage area of 217 km^2 and an average discharge of about 1.5 m^3/s. Channel bottom width is 8-10 m, bank height is 2.5-3 m, and channel slope is 1 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.3, valley relief of 30 m, wide flood plain, greater than 90 percent tree cover along bankline. Bed material is sand, bank material is moderately coherent sand, silt, and clay. As observed on a 1955 airphoto, the channel is moderately stable with cut banks at some bends. The channel appears to have been straightened upstream from the site, perhaps 50 yr or more ago, and it has been straightened downstream from the site.

POST-ALTERATION FACTORS--At bends in the relocated channel, the banks have slumped and the slumped blocks have formed a berm along the low-water channel. Establishment of trees, mainly willow but some birch and silver maple, on this berm has evidently controlled progressive bank erosion (figs. 62C and 62D). Because of this berm formation, the channel cross section has widened more at the top than at the bottom. The reach extending 600 m upstream from the I-80 crossing, which was relocated in 1962, has a dense growth of trees along most of the bankline. However, some point bars have formed (fig. 62D) and these are likely to be the precursors of meandering.

DISCUSSION--Establishment of vegetation along the berm at the toe of the bank is the only apparent factor in the halting of progressive bank erosion. The reason for little or no degradation is not apparent.

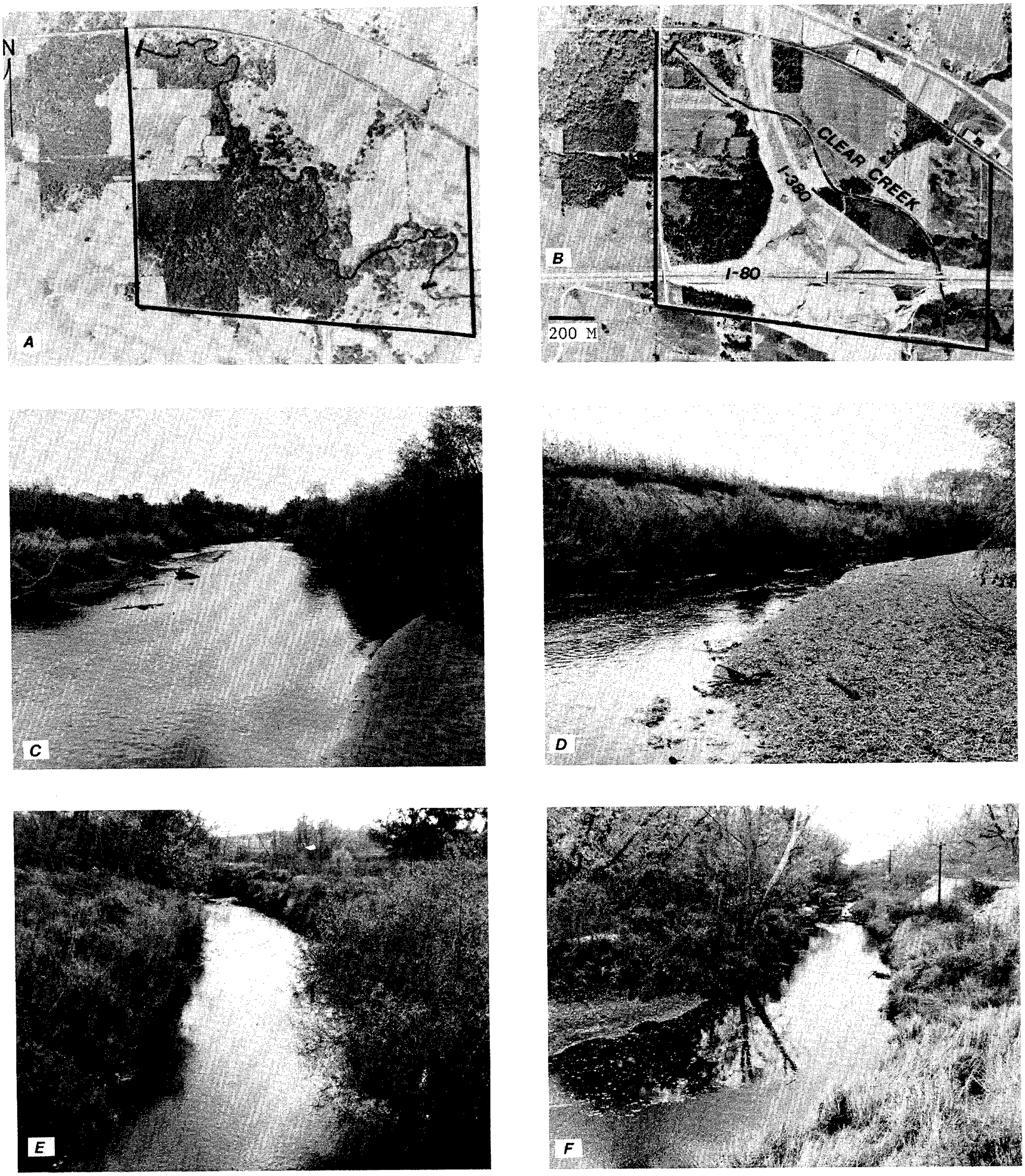


Figure 62. Clear Creek at site 21. A, Airphoto of site in 1956. Meandering course of Clear Creek is indicated by dotted line. Distance between vertical lines bounding area is 1,400 m. (From U.S. Dept. of Agriculture). B, Airphoto of Clear Creek site in 1970. Relocated course of creek is indicated by heavy dashed line. (From U.S. Dept. of Agriculture). D, Relocated channel at bend downstream from I-380 crossing, in 1979. D, Relocated channel at bend upstream from I-80 crossing, in 1979. E, Natural channel downstream from I-80 crossing, in 1979. F, Natural channel upstream from relocation, in 1979.

SITE 22. SOAP CREEK AT US-63
NEAR OTTUMWA, IOWA

SYNOPSIS--Channel segment was relocated and thereby shortened from a length of 975 m to 580 m, for purpose of improving channel alinement at bridge and to accommodate planned roadway alinement (fig. 63). Performance period, 16 yr ✓ (1963-79). No flow records for Soap Creek or adjacent comparable streams are available; however, at least one flow above bankfull stage is indicated by overbank deposits observed in 1979. Relocated channel, as built, was trapezoidal in cross section, with a bottom width of 18.5 m, 2:1 side slopes, and a channel slope of about 0.5 m/km. No bank protection measures were specified on the plans or observed in the field; and vegetation along the relocated channel was cleared and not replanted. In 1979, the relocated channel was stable, with vegetated banks, both downstream (fig. 64A) and upstream (fig. 64B) from the bridge, and the bottom width was within 1-2 m of as-built bottom width. Upstream from the relocation, the natural channel of Soap Creek had cut banks at some bends, and about the same degree of stability as observed on a 1957 airphoto. At the first bend downstream from the relocation, bank erosion was severe (fig. 64C) and bottom width had reached 40 m; severe bank erosion was also observed at the second bend. However, at the old US-63 bridge, 1.8 km downstream, the natural channel was generally stable (fig. 64D) except for some inactive bank slumping.

Stability class A1 for altered reach and class C3 for downstream reach of natural channel. Critical factors in stability of the relocated channel are its bottom width (greater than that of the natural channel by a factor of about 1.5), moderate coherence of bank materials, and probably the establishment of vegetation before a flood occurred. The increase in channel slope consequent upon relocation has not resulted in degradation but in an increased rate of growth of downstream meanders of the natural channel.

SITE FACTORS--Lat 40°53', long 92°25', at US-63, 12.5 km south of Ottumwa, Iowa, on Ottumwa South 7.5' map. Soap Creek is perennial, with a drainage area of 470 km^2, a channel width of 10-12 m, a bank height of 4 m, and a channel slope of 0.6 m/km. Wide-bend point-bar stream, alluvial, sinuosity of 1.4, wide flood plain, greater than 90 percent tree cover along bankline. Bed material is sand and fine gravel, bank material is moderately coherent sandy, clayey silt. As observed on a 1957 airphoto, the channel was stable except for cut banks at some bends; the drainage basin and flood plain were mostly cleared. At some time prior to 1957, an attempt had been made (probably by a landowner) to straighten the channel over a distance of about 1 km upstream from the relocation, but the attempt was unsuccessful.

DISCUSSION--Consequences of the relocation are similar to those of a natural meander cutoff, which commonly is followed by a period of rapid growth of adjacent meanders. It is noteworthy that the straight relocated channel is more stable than adjacent meandering reaches of the natural channel.

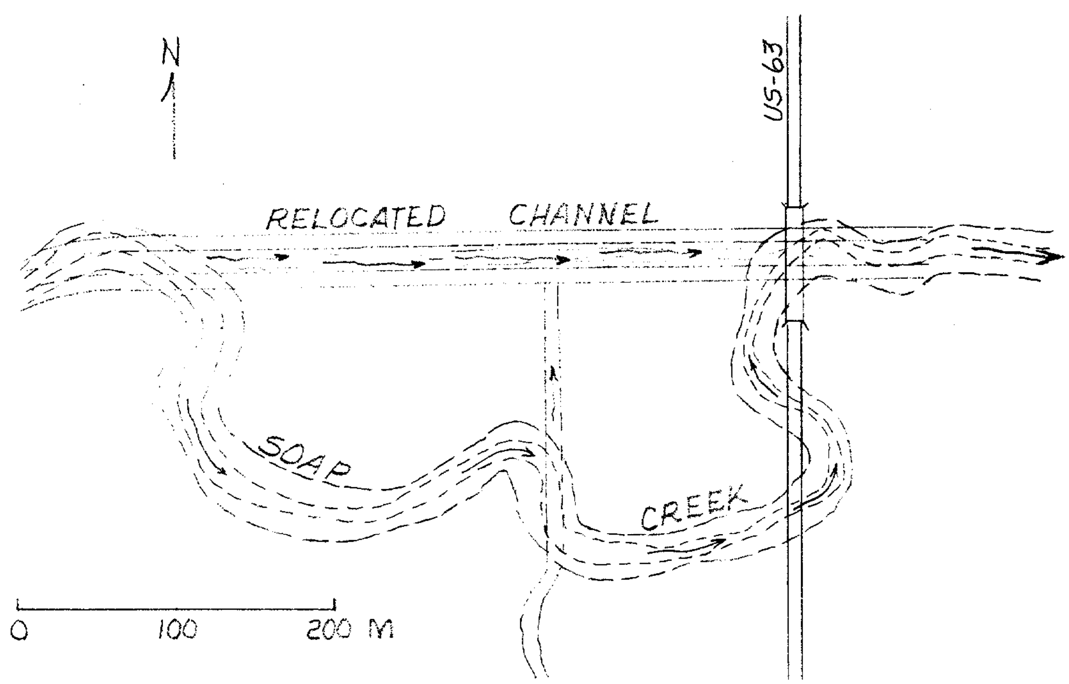


Figure 63. Plan sketch of Soap Creek channel relocation.

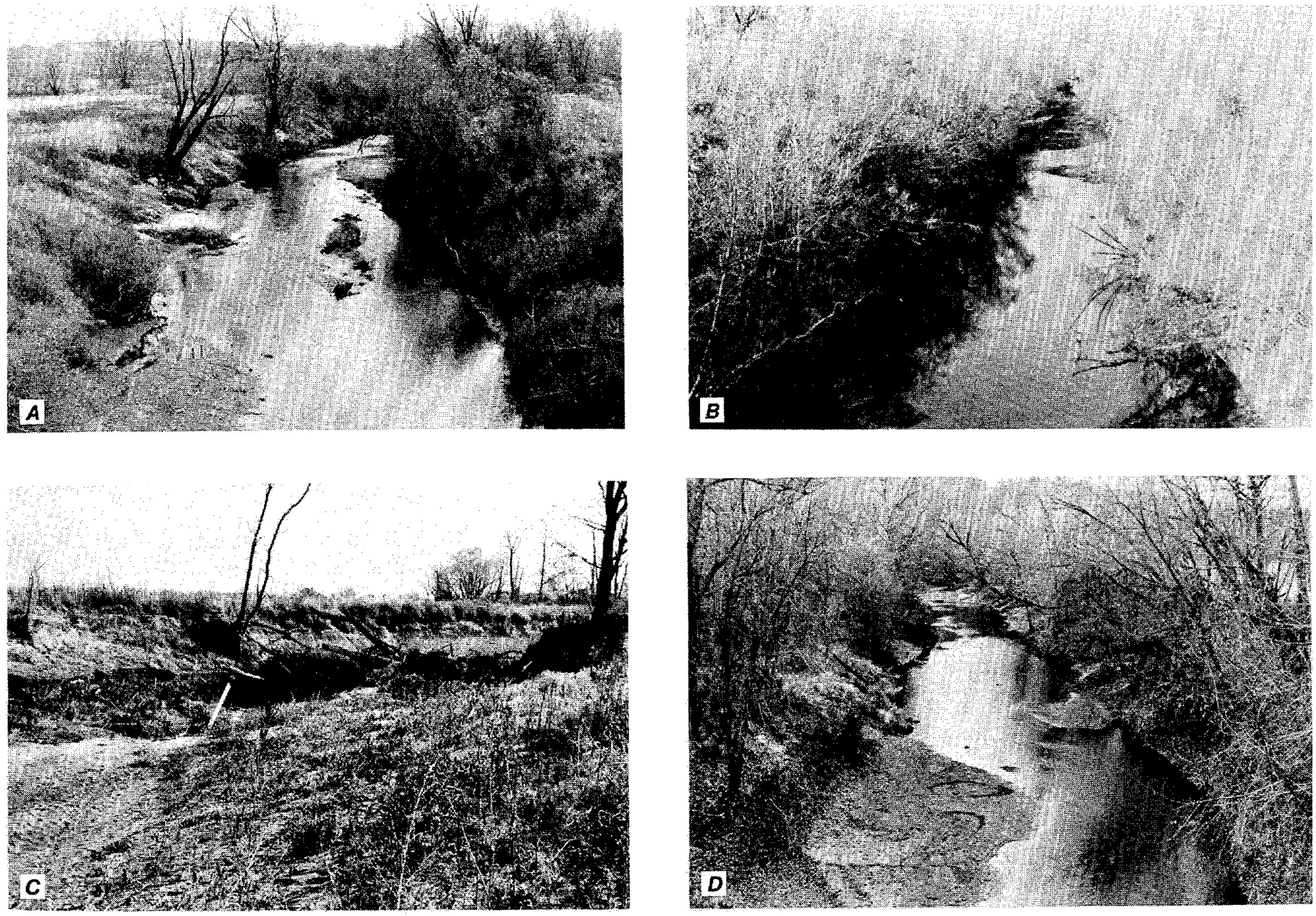


Figure 64. Soap Creek at site 22. A, Junction of natural and relocated channels (middle ground), as viewed downstream from US-63 bridge, in 1979. B, Relocated channel as viewed upstream from US-63 bridge. C, Bank erosion at first bend downstream from channel relocation. D, Natural channel upstream from old US-63 bridge.

SITE 23. THOMPSON RIVER AT I-35 NEAR DECATUR, IOWA

SYNOPSIS--Channel was relocated by cutting across a bend and thereby reducing length of a channel segment from 580 m to 460 m; for purpose of improving channel alinement at bridge and preventing encroachment of the meander on the roadway (figs. 65A and B). Performance period, 10 yr (1969-79), during which the maximum peak flow for a 43-yr period of record occurred in June 1974 (about 680 m^3/s). Relocated channel had a bottom width of 12 m, but no other information on its dimensions was obtained. The design discharge was 636 m^3/s, and no bank protection measures are specified in the plans. In 1979, bottom width of the relocated channel was 28-32 m and the banks were stabilized by vegetation (fig. 65C). At the first bend in the natural channel upstream from the bridge, banks were cut (fig. 65-D) and the bankline had receded about 10 m during the period 1967-77. Elsewhere, the stability of the natural channel was about the same as in 1967, when cut banks were at some bends and straight reaches were stable. As built, the width of the relocated channel was 12 m as compared with a width of 25 m for the natural channel, and it was probably intended as a pilot channel.

Stability class B1 for relocated channel and class C2 for adjacent reaches of natural channel Stability of the relocated channel is attributed to the growth of vegetation along the bankline, prior to the occurrence of a flood. The increase in slope consequent upon relocation probably contributed to bank erosion at the first bend downstream from the relocated channel; however, this bank was already unstable in 1967.

SITE FACTORS--Lat 40°41', long 93°51', at I-35, 8 km south of Decatur interchange. Thompson River is perennial, with a drainage area of 1,790 km^2, and an average discharge of 10.5 m^3/s. Channel bottom width is 25 m, and bank height is 3.5-4.5 m.

Wide bend point bar stream, alluvial, sinuosity of 1.2, wide flood plain cleared except for an almost continuous row of trees along channel. Bed material ranges in size from sand to small boulders, and bank material is moderately cohesive sand, silt, and clay.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--Although the relocated channel has widened since construction by a factor of 2-2.5, the stabilized bottom width attained in 1979 is within the range of bottom-width values for the natural channel.

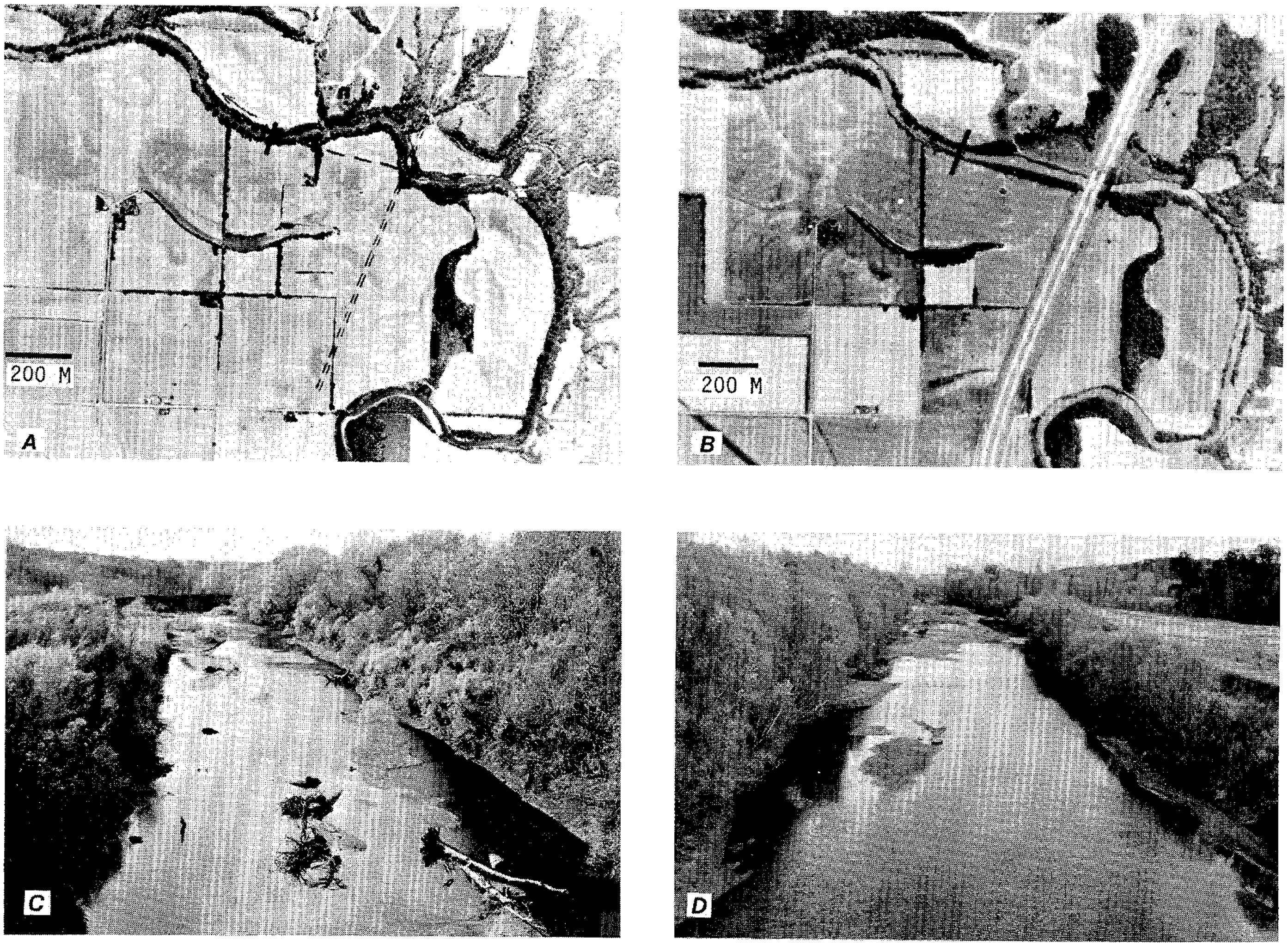


Figure 65. Thompson River at site 23. A, Airphoto of relocation site in 1967. Planned course of relocated channel is shown in single dashed line; of roadway, in double dashed line. (From U.S. Dept. of Agriculture). B, Airphoto of relocation site in 1977. Ends of relocation, which is 460 m in length, are shown by heavy bars across river. (From U.S. Dept. of Agriculture). C, View upstream from I-35 bridge along relocated channel, in 1979. D, View downstream from I-35 bridge along relocated channel, in 1979.

SITE 24. PINE CREEK AT I-90
AT PINEHURST, IDAHO

SYNOPSIS--Channel relocation, reach 675 m in length shortened to 645 m and moved laterally by about 100 m to make room for roadway. Performance period 10 yr, 1964-74. During an 85-yr flood in 1964, lateral erosion at an upstream bend in the relocated channel encroached on the I-90 roadway (fig. 66) and erosion and overflow also occurred at a downstream bend. The natural channel was already disturbed by mining operations and diking along one bank, and no effect on relocation on it could be discerned.

Stability class C2 for relocated channel, B for natural channel. In 1977, the relocated channel was modified by reducing the radius of curvature of bends, widening it locally, and placement of stronger bank revetment. The modified channel has not been tested by flood.

SITE FACTORS--Lat 47°33', long 116°13', on I-90 at Pinehurst, Idaho, on Kellogg 15' map. Pine Creek is perennial, drainage area about 125 km^2, 85-yr flood measured indirectly by U.S. Geological Survey at 238 m^3/s. Channel width is highly variable, about 24 m in straight reaches; bank height about 2 m to flood plain, channel slope about 6 m/km at site. Braided point-bar stream, alluvial, sinuosity 1.1-1.2. Valley relief 600 m, flood plain wide at site, tree cover along channel less than 50 percent. Bed material gravel and cobble.

ALTERATION FACTORS--Channel length was shortened by factor of 0.95 by relocation, which had a negligible effect on channel slope. Channel as relocated in 1964 had a typical top width of 43 m and a bottom width of 21 m, but the width narrowed upstream from the Ramp AB bridge (fig. 66). Side slopes of the relocated channel were 2:1, riprapped along both banks (fig. 67), and the right bank was raised by a dike to give a modal depth of about 3.5 m.

POST-ALTERATION FACTORS--During peak of the 1974 flood, the relocated channel upstream from the Ramp AB bridge had a cross-sectional flow area of 79 m^2 and an average velocity of 3 m/s. Lateral erosion is attributed to the sharpness of bends in the relocated channel.

In 1977, the relocated channel was modified to prevent a recurrence of flood erosion damage. The radius of the bend at the Main Street bridge was increased from 84 m to 349 m, and the radius of the bend above the Ramp AB bridge was increased from 81 m to 218 m. Riprap on the banks of the modified channel was placed to a depth of 1 m, and the toe of the riprap blanket was extended to 1.5 m below the channel bottom. Riprap on the outside of the curve above the Ramp AB bridge was concrete grouted. There has been little growth of vegetation along the channel since 1977.

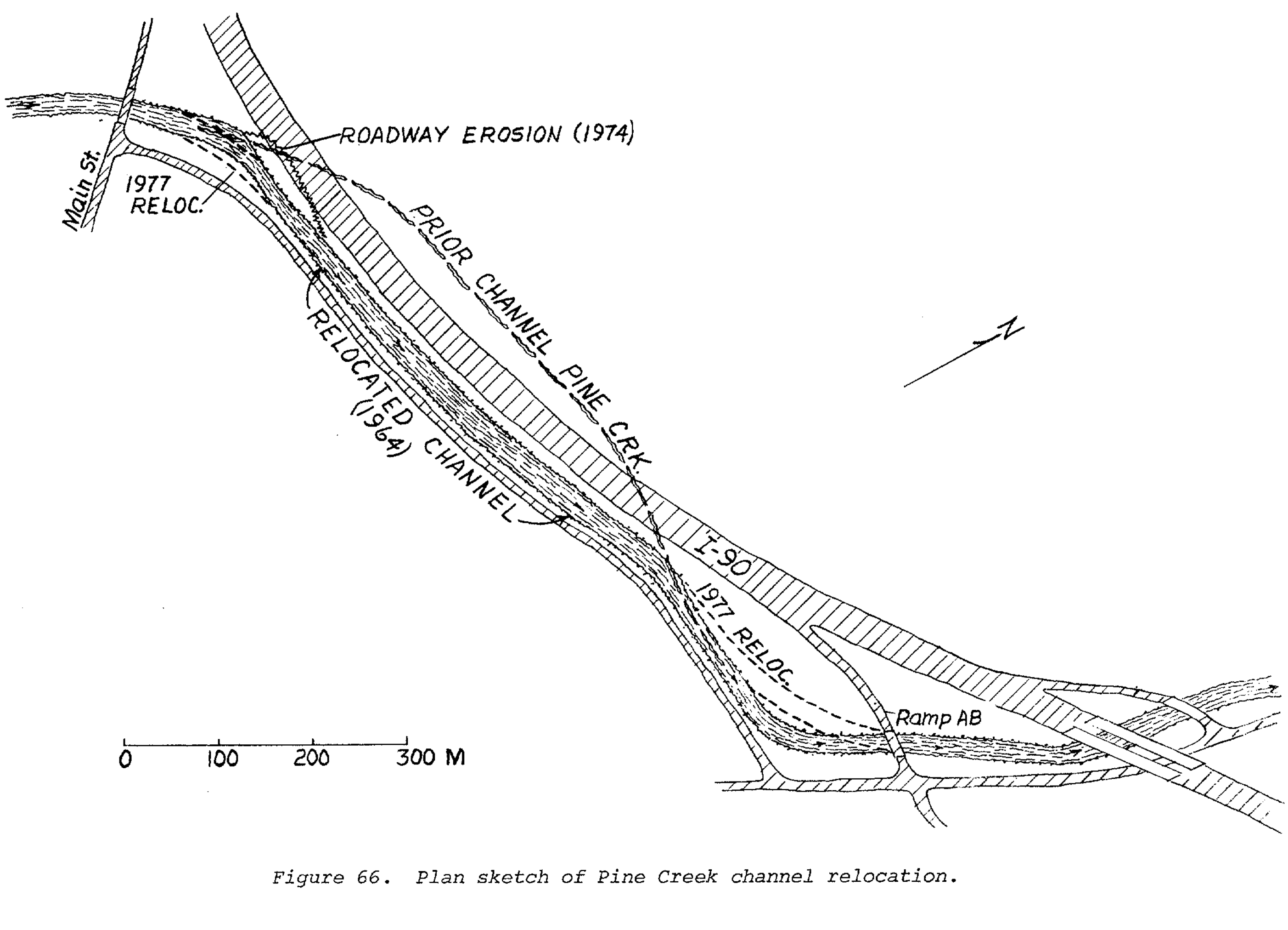


Figure 66. Plan sketch of Pine Creek channel relocation.

DISCUSSION--Inasmuch as the banks of the relocated channel were riprapped, the curves in the relocated channel would probably have caused no problems during floods of moderate intensity. During the 85-yr flood of 1974, in which the average water velocity in the relocated channel reached about 3 m/s, the curves proved to be too sharp. Substantial expense was involved in modifying the channel and in replacing the Ramp AB bridge, whose waterway opening proved to be inadequate. Some channel degradation, perhaps amounting to 0.6 m, has apparently occurred, as indicated by exposure of piers and a pipeline at the Main Street bridge; but this may not be caused by the channel relocation.

Figure 67. View downstream, from Main Street bridge, along relocated channel of Pine Creek. Erosion during 1974 flood occurred along bank in left background.

SITE 25. SALMON RIVER AT US-95 NEAR LUCILE, IDAHO

SYNOPSIS--Channel relocation, reach 915 m in length shortened to 488 m in order to avoid sharp curve in alinement of new roadway (fig. 68). Performance period 21 yr, 1959-79. In 1974, the relocated channel was subjected to the highest flood in the 62-yr period of record, which was measured at 3,680 m^3/s at White Bird (25 km downstream from site). According to the Idaho Department of Transportation, extensive erosion of riprap slope protection along the Salmon River occurred during this flood, in the 50-km reach downstream from White Bird, but none occurred along the relocated channel. However, the top width of the channel in 1979 was about 45 m wider than the width specified on the plans, and some lateral erosion of the left bank (fig. 69A) has probably occurred. No effect of relocation on adjacent segments of the natural channel could be discerned. Stability class B2 for relocated reach, class B for adjacent segments of natural channel. The critical factor in lateral stability of the channel is the heavy riprap revetment along the roadway embankment (figs. 68 and 69B). Degradation is prevented by outcrops of bedrock in the channel bottom.

SITE FACTORS--Lat 45°36.5', long 116°16.5', on US-95 about 10 km north of Lucile, Idaho. Salmon River is perennial, drainage area of about 34,500 km^2 at site, average discharge at White Bird is 317 m^3/s and about 285 m^3/s at site. Channel width is 75 m, bank height is 1.5 m to flood plain, and channel slope is 1.2 m/km as determined from 1955 high water profile. Stream is semi-alluvial, sinuosity of 1.1, valley relief of 800 m, flood plain narrow to absent. Tree cover sparse, less than 50 percent along channel. Bed material gravel, cobbles, minor content of boulders.

ALTERATION FACTORS--Reach 915 m in length, whose flow was divided by a large island (fig. 68), was shortened by factor of 0.53 by cutting off a large bend. A bottom width of 87 m was specified in plans for the relocated channel, but the "as-built" width is not on record. On a 1978 aerial photograph, the bottom width measures about 120 m. The roadway embankment was protected by a wide berm of heavy riprap (fig. 68 , inset) including quarry stones up to 1.7 m in length.

POST-ALTERATION FACTORS--According to the Idaho Department of Transportation, no maintenance or repair to the relocated channel has been required since construction, although bank revetment in the constricted section just downstream was damaged during the 1974 flood.

DISCUSSION--The channel cannot migrate very far laterally because the narrow alluvial valley bottom is bounded by bedrock. The main potential for instability is along the roadway embankment, which is at the outside of a broad curve. Here, the heavy riprap revetment maintained stability even during an extreme flood. No aerial photographs taken prior to relocation are available, so the natural channel cannot be assessed. However, in 1979 no cut banks were observed in the alluvial reach upstream from the relocation, and downstream the channel is in a rocky gorge.

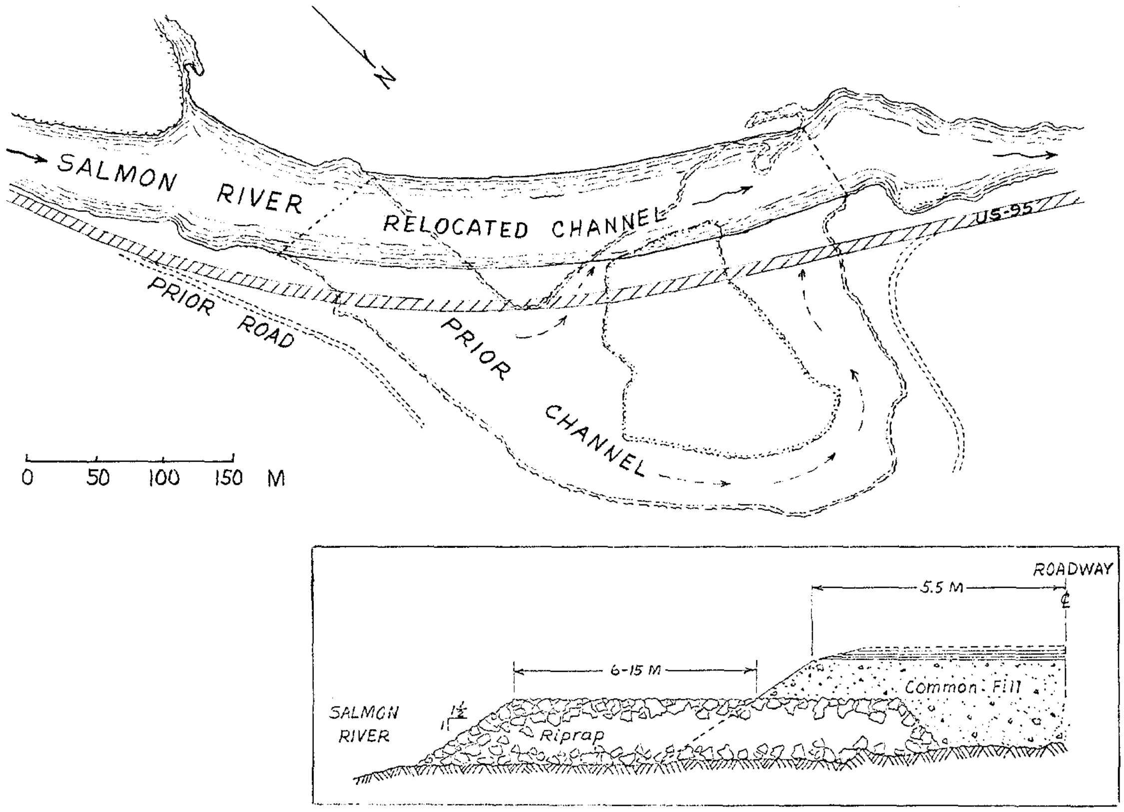


Figure 68. Top, plan sketch of Salmon River channel relocation. Inset, cross section of typical revetment along roadway embankment.

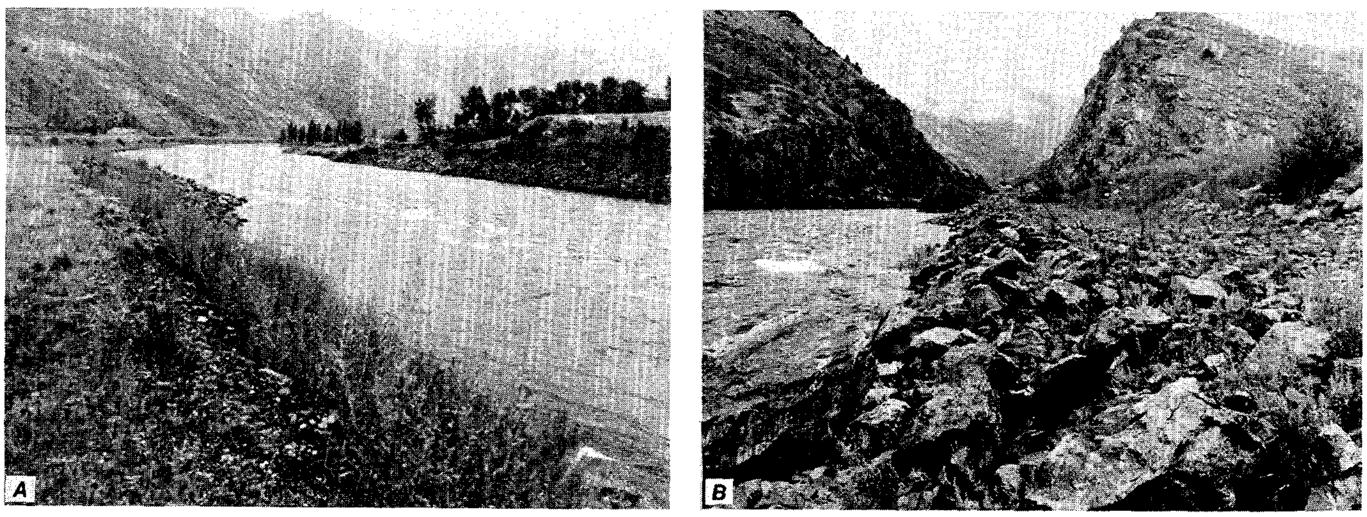


Figure 69. Salmon River at site 25. A, Upstream view along relocated channel in 1979. Wide riprap berm along roadway embankment is at left. B, Downstream view of rocky gorge downstream from relocation. Heavy riprap along right bank of relocated channel is in foreground.

SITE 26. STEVENS CREEK AT
I-72 AT DECATUR, ILL.

SYNOPSIS--Channel relocation, reach 2,250 m in length shortened to 990 m, or by a factor of 0.44, for purpose of reducing three potential crossings by I-72 to one crossing (fig. 70). Performance period 6 yr, 1973-78. The maximum stage of record occurred on Stevens Creek during a flood in 1974. Between stations 30.5 and 32, the left bank was eroded for a maximum lateral distance of 9 m, and bottom scour as measured after the flood, reached 1.2 m at one place (fig. 70). Channel degradation, amounting to about 0.6 m, extended upstream along the natural channel and downstream along the relocated channel as far as a concrete check dam. Lateral erosion also occurred at the toe of the concrete slope pavement just downstream from the bridge. Downstream from the relocation, the natural channel was apparently not much affected, as the extent of cut banks as observed in 1978 (fig. 71A) is not significantly different from that shown on a 1965 airphoto.

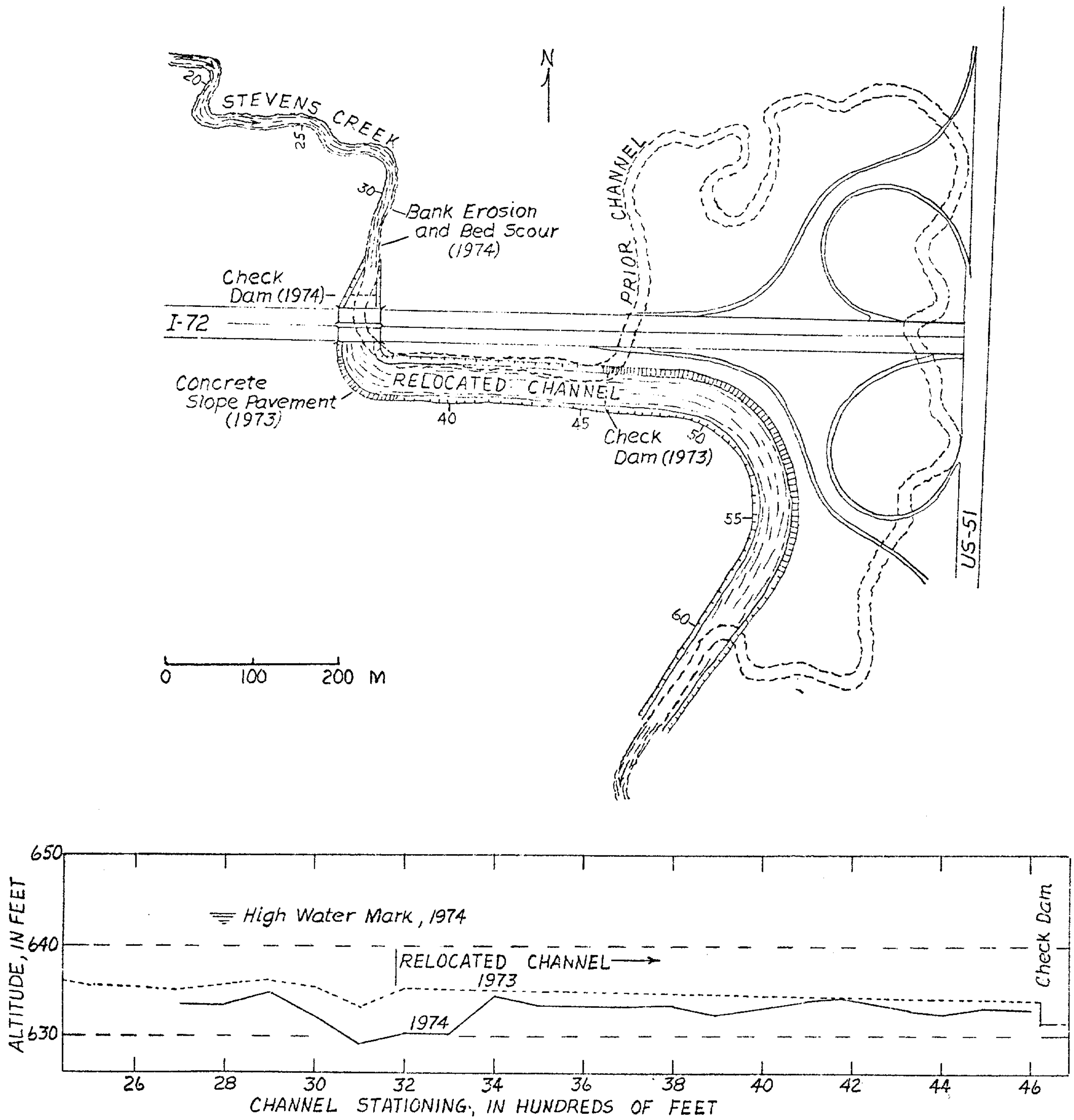


Figure 70. Top, plan sketch of Stevens Creek channel relocation. Bottom, longitudinal profiles of channel bottom before and after 1974 flood.

Stability class B3 for altered channel (local degradation); class B3 for natural channel upstream from relocation (lateral erosion and degradation, backfilled in 1974); class B1 for natural channel downstream from relocation. The critical factor in erosion of the natural and relocated channel between stations 30.5 and 32 during the 1974 flood is probably the increase in slope (from 0.6 m/km to 1.1 m/km) resulting from drastic shortening of channel length. In addition, the lateral stability of the natural channel had, prior to relocation, been adversely affected by clearing of vegetation for agricultural purposes. Lateral erosion of the relocated channel downstream from the I-72 bridge was minor, in spite of two bends, because of bank protection by concrete slope pavement and the very wide channel bottom.

SITE FACTORS--Lat 39°54.5', long 88°57.5', on I-72 at north city limits of Decatur, Ill., on Forsyth 7.5' map. Stevens Creek is perennial, drainage area of 113 km^2, 50-yr flood estimated at 167 m^3/s. Channel width is 5-8 m, bank height is 1.8-2 m, and channel slope is 0.6 m/km. Equiwidth point-bar stream, semi-alluvial, sinuosity of 1.4. Valley relief is 10 m, flood plain is about 200 m in width. Tree cover along channel, less than 50 percent. Bed material is gravel, bank material is clayey glacial till and alluvium. At some time during the period 1950-65, a large meander was cut off between stations 40 and 45 (fig. 70) for clearing of a golf course, shortening the channel by about 250 m.

ALTERATION FACTORS--The increase in channel slope resulting from channel shortening was partially offset by construction of a concrete check dam (drop structure), having an overfall of 0.6 m, at station 46. This reduced the potential channel slope from 2 m/km to 1.1 m/km, as compared with the natural channel slope of 0.6 m/km. The relocated channel, as well as the bridge opening, was constructed with a trapezoidal cross section and a bottom width of 33.5 m, as compared with a bottom width of 5-8 m for the natural channel. Both the bottom and top width of the relocated channel exceeded that of the natural channel by a factor of 4 or 5. This design was based on the premise that flow velocity at the 50-yr flood should not exceed 1.8 m/s; and that the bridge opening should be

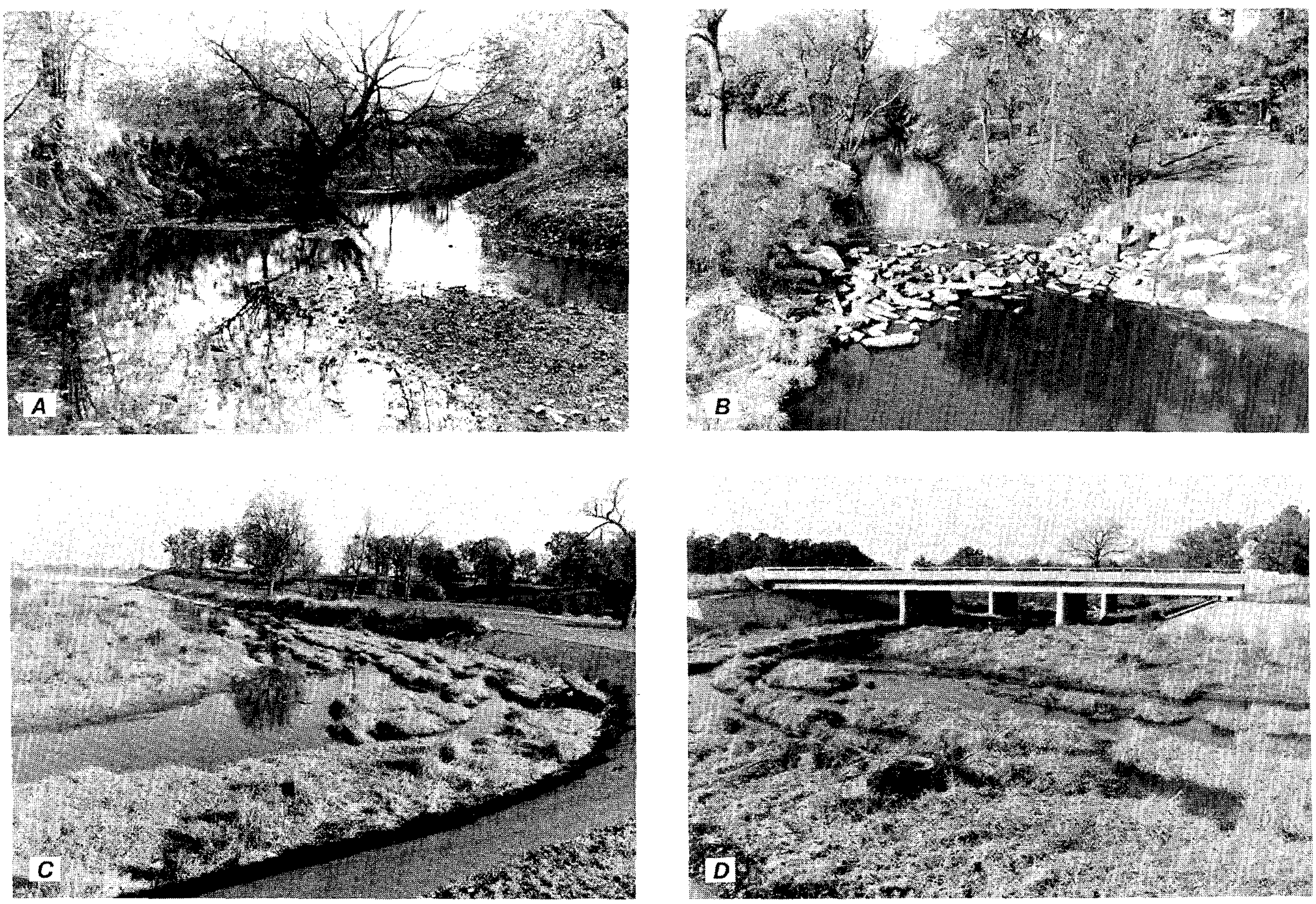


Figure 71. Stevens Creek at site 26. A, Natural channel in 1978, about 125 m downstream from relocated channel. B, Check dam, built after 1974 flood, upstream from I-72 bridge. Natural channel in background. C, View of relocated channel looking downstream from I-72 bridge, in 1978. D, View of relocated channel looking upstream toward I-72 bridge, in 1978.

the shortest possible with a trapezoidal cross section. (The bridge opening and channel were designed by a consultant in 1961, and represent practices no longer acceptable in Illinois.) The two bends in the relocated channel, one of which has a radius of 27.5 m and the other of 125 m, were protected at the outside bank by concrete slope pavement.

POST-ALTERATION FACTORS--In 1974, the year after completion of the relocated channel, a flood occurred that exceeded in stage by about 0.3 m the previous flood of record. To remedy the erosion damage between stations 30.5 and 32, and to prevent recurrence, the bank was filled in to its former position and riprapped. The transition section was eliminated and a check dam, consisting of a double row of timber pile faced with chain-link fence fabric and filled in with broken concrete riprap, was built just upstream from the I-72 bridge (fig. 71B). Riprap was also placed at local problem areas on the relocated channel downstream from the bridge (fig. 71C). During a second flood in April of 1979, an undulating hydraulic jump was observed at the check dam, a hole 3.5 m deep was scoured at the east pier of the bridge, and much of the riprap at the check dam was removed by erosion.

DISCUSSION--Although the relocated channel is overly wide, and a braided low-flow channel has developed within it (fig. 71D), the erosion that occurred between stations 30.5 and 32 is attributed to the increase in slope, which resulted from drastic channel shortening. At the transition between the natural and the relocated channel, the increase in slope (and consequent increase in water velocity) caused channel degradation and undercutting of banks, which contributed to the lateral erosion. Action of eddies at the expansion may also have been involved in the lateral erosion. Downstream from the bridge, the bottom of the overly-wide relocated channel is now largely overgrown with coarse grass (fig. 71D), which is likely to trap sediment. Infilling and consequent reduction of channel capacity will probably occur. In addition, a meandering low-flow channel can be expected, which may cut laterally against the banklines. Scour downstream from check dams is a common occurrence, and they must be regarded as risky countermeasures. Placement of riprap on the bed and banks through the eroded reach upstream from the bridge would probably have been a better remedy for degradation.

SITE 27. LEATHERWOOD CREEK AT US-36 NEAR MONTEZUMA, IND.

SYNOPSIS--Channel was relocated by cutting across a broad bend, thereby reducing the length of the channel segment from 418 m to 366 m, for the apparent purpose of improving channel alinement at the new US-36 bridge (fig. 72). Relocation may also have facilitated construction of the new bridge. Performance period, 2 yr (1976-78), during which no major floods occurred. The site nevertheless provides an example of the performance of fish habitat structures described as "fish and sediment ponds" on the plans, and it also demonstrates an early consequence of an overly wide relocated channel. The relocated channel was trapezoidal in cross section, with a bottom width of 21.5 m, 2:1 side slopes, and a channel slope that ranged from 2 m/km to 6 m/km. Riprap bank protection was placed at the bridge and at the downstream curve in the relocated channel. A "fish and sediment pond" consisted mainly of a riprap check dam extending across the stream, rising about 0.6 m above the streambed, but not keyed into the streambed or streambanks. Such a structure would not be expected to be permanent, and the structures at this site were mostly gone by 1979 (fig. 73A). Upstream from the bridge, alternate bars have formed along the sides of the channel, and these are inducing bank erosion and sinuosity. Downstream from the bridge, flow is divided by grassed bars (fig. 73B) on which willows are likely to become established. The relocation has had no apparent effect on adjacent segments of the natural channel.

Stability class B1 for relocated channel and class B1 for adjacent segments of natural channel. At this early stage, it appears that the relocated channel is overly wide (bottom width about twice that of the natural channel), and that this width may permit the development of sinuosity or a reduction of channel capacity by growth of vegetation in the channel.

SITE FACTORS--Lat 39°46.5', long 87°20', at US-36, 4 km east of Montezuma, Ind., on Montezuma 7.5' map. Leatherwood Creek is perennial, with a drainage area of about 45 km^2, a channel width of 10-12 m, and a channel slope of 2 m/km. Equiwidth point bar stream, alluvial, sinuosity of 1.2, valley relief of 30 m, wide flood plain, mostly cleared except for an almost continuous row of trees along the channel. Bed material is coarse sand and fine gravel, bank material is moderately coherent fine gravel, silt, and clay. As observed on a 1971 airphoto, the channel was stable except for minor bank erosion at bends.

ALTERATION FACTORS, POST-ALTERATION FACTORS, DISCUSSION--(See "Synopsis")

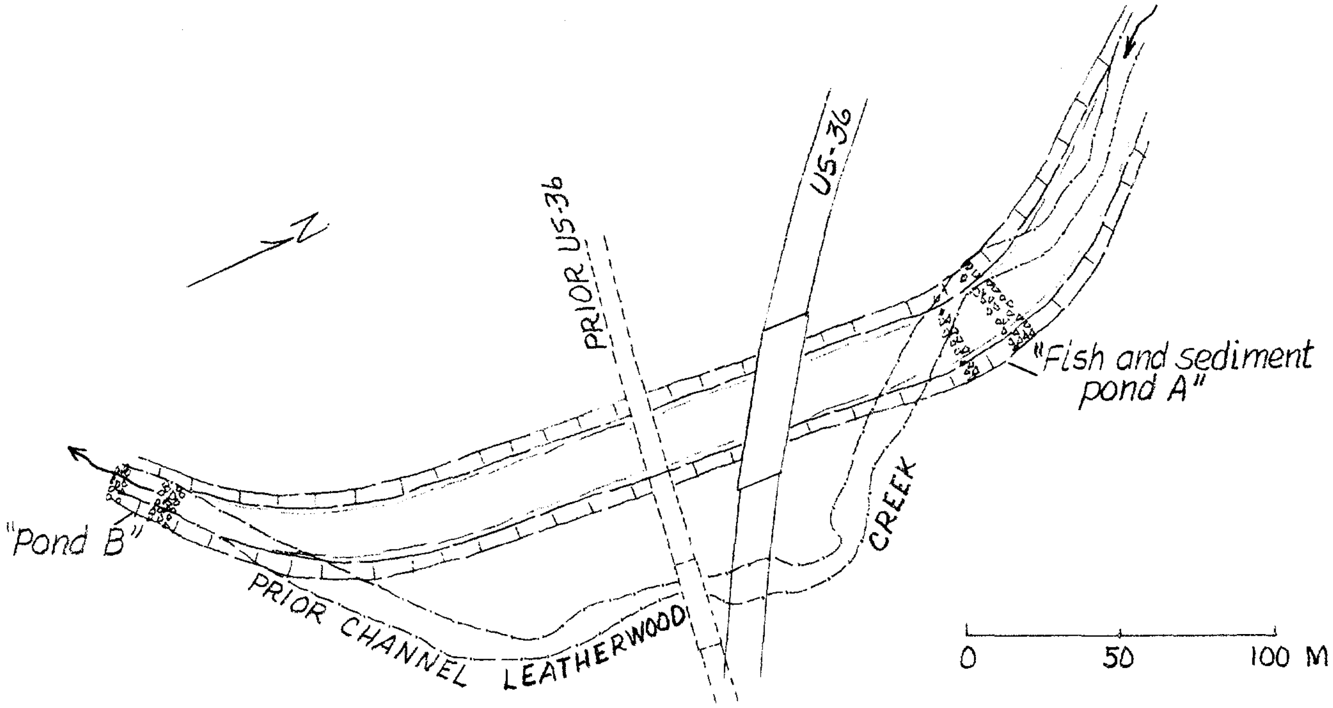


Figure 72. Plan sketch of Leatherwood Creek channel relocation.

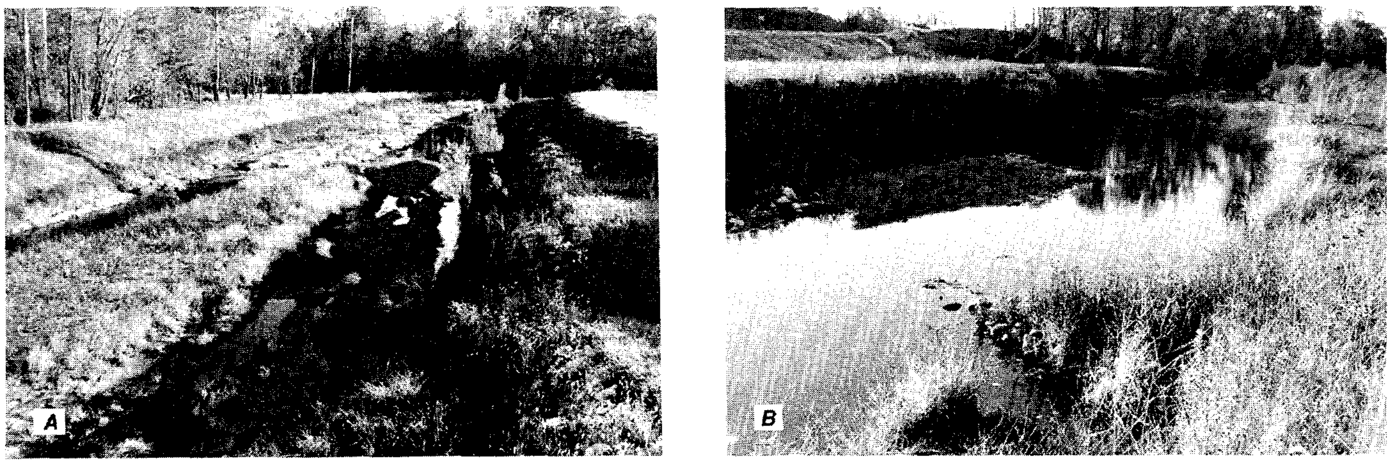


Figure 73. Leatherwood Creek at site 27. A, View upstream along relocated channel from US-36 bridge, in 1978. "Fish and sediment pond A" at left center. B, View downstream along relocated channel in 1978.

SITE 28. EAGLE CREEK AT I-465
AT INDIANAPOLIS, IND.

SYNOPSIS--Channel relocation, reach 645 m in length straightened to length of 580 m, to improve alinement of flow approaching bridge (fig. 74). Performance period 19 yr, 1960-1978. The relocated channel was subjected to moderate floods in 1970 (174 m^3s) and in 1976 (218 m^3s). The left bank of the relocated channel upstream from the bridge has eroded laterally by about 20 m, over a channel length of about 250 m, and a 90-m length of concrete slope pavement has been destroyed (figs. 75A and B). This left-bank erosion has deflected flow toward the right abutment affecting the original intent of the channel relocation. In addition, erosion has occurred at the downstream bend in the relocated channel (fig. 75C). Adjacent segments of the natural channel have raw and unstable banks in many places, but the general extent of these is similar to that observed on airphotos taken in 1953. Stability class C3 for relocated channel, C2 for adjacent segments of natural channel.

The critical factors in lateral erosion of the relocated channel are: (1) Erodibility of the right bank, which is composed of weakly coherent sand, silt, and gravel. (2) Curved alinement of the relocated channel with the natural channel, at both the upstream and downstream ends. Although the curve in the natural channel just upstream from the relocation is slight, it proved to be critical in view of the erodibility of the banks.

SITE FACTORS--Lat 39°48', long 86°16', on I-465 at Indianapolis, on Clermont, Ind., 7.5' map. Eagle Creek is perennial, drainage area of 440 km^2, average discharge 4.1 m^3/s. Channel bottom width is 22-25 m, bank height is 3 m to floodplain, and channel slope is about 0.9 m/km. Equiwidth point bar stream, semi-alluvial (glacial drift and outwash gravels crop out locally along the banks), and somewhat incised. Valley relief is 15 m, sinuosity is about 1.1, flood plain is about 750 m in width. Tree cover along banks, 50-90 percent. Bed material is sand, gravel, and glacial boulders. Bank material, where alluvial, is silt and sand overlying gravel; where non-alluvial, glacial till or outwash. A reservoir is located 3.5 km upstream from the site; and a check dam, discernible on 1953 airphotos, is located 900 m upstream from the site. The natural channel has been disturbed at several places by gravel mining and channelization, and the natural vegetation has been cleared from place to place along the banks. Cut banks are discernible on 1953 and 1956 airphotos. In particular, at the site of relocation a bend in the stream had migrated laterally almost to the railway embankment in 1953 (fig. 74), and by 1956 an apparent attempt had been made to divert it by cutting a channel across the point bar.

ALTERATION FACTORS--Straightening led to shortening of channel by factor of 0.9. Top width of natural channel is about 45 m; of relocated channel, about 52 m. Bottom width of relocated channel is 30 m, side slope is 2:1, and longitudinal slope is 1.33 m/km. Relocated channel joins natural channel with a slight bend at upstream end, but forms a bend of 140 m radius at downstream end. The abutment fill-slopes of the bridge were revetted with concrete slope pavement, which was also extended as bank protection for a distance of 138 m upstream from the bridge on the left bank, and 30 m on the right bank.

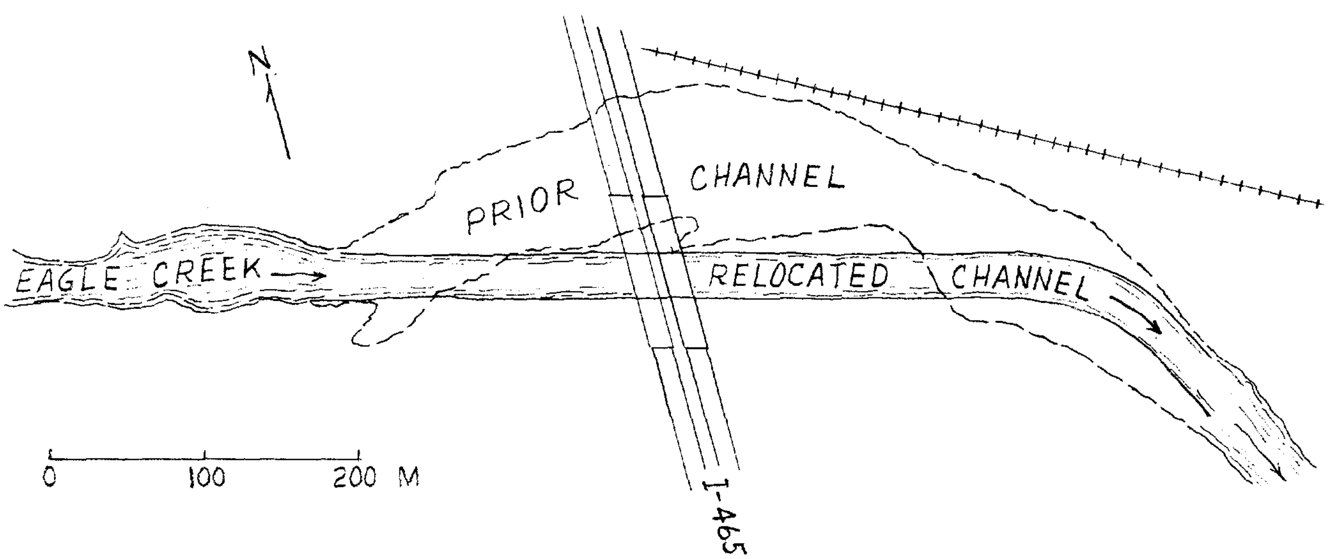


Figure 74. Plan sketch of Eagle Creek channel relocation.

POST-ALTERATION FACTORS--Most of the bank erosion in the relocated reach, as observed in 1978, has occurred since 1972, and the concrete slope pavement was almost intact in that year. No countermeasures to replace the damaged left-bank pavement are evident, but riprap and a sheet-pile cutoff wall have been placed at the upstream end of the right-bank pavement. The straight reach of relocated channel downstream from the bridge has not increased in width and appears stable, with a good growth of young willow, sycamore, and cottonwood along the bankline.

DISCUSSION--The instability of the left bank of the natural channel, prior to relocation, was an indication of potential problems with lateral erosion of the relocated channel. In hindsight, it seems probable that the lateral erosion may have been prevented by the placement of flexible revetment, such as riprap, along the left bank at the junction of natural and relocated channel. Rigid revetment, such as concrete slope pavement, is particularly susceptible to destruction by outflanking. Upstream from the relocation, the right bank is composed of resistant glacial till, which apparently deflects flow toward the less resistant left bank. The present situation is difficult, because the meander may continue to grow and migrate to the left, worsening the alinement of flow approaching the bridge. As a countermeasure, the left bank could be straightened and protected with flexible revetment for a distance of about 75 m upstream from the bridge. Special care would have to be taken to prevent outflanking of the upstream end of this revetment.

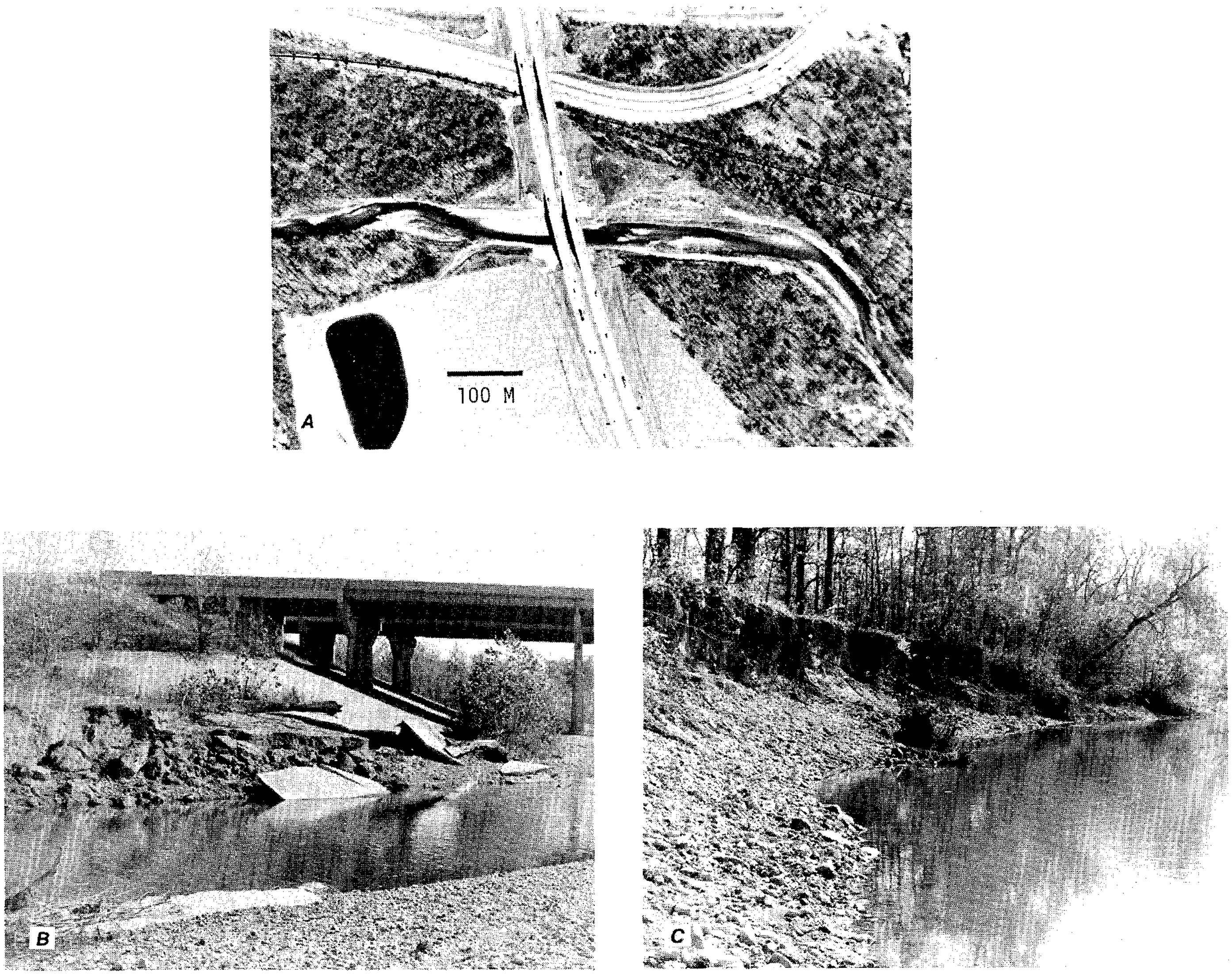


Figure 75. Eagle Creek at site 28. A, Airphoto of channel relocation, in 1972. (From Indiana Dept. of Transportation). B, Eroded concrete slope pavement at left bank upstream from bridge, in 1978. C, Eroded left bank at downstream bend in relocated channel, in 1978.

SITE 29. LICK CREEK AT I-465 AT INDIANAPOLIS, IND.

SYNOPSIS--In the construction of I-465, Lick creek was relocated for a channel length of about 1 km, of which only the upstream 600 m were studied for this report (fig. 76A). As with most streams in urban areas, the natural channel has been disturbed over a long period of time by various kinds of construction; therefore, only the performance of the relocated channel will be considered. Performance period 16 yr (1962-78) during which a severe flood occurred in 1974, and the maximum flood for the period of record, in June 1978. As built, the relocated channel was trapezoidal in cross section, with a bottom width of 9 m, 2:1 side slopes, and a channel slope of about 3 m/km. The channel bottom is crossed at intervals by low concrete check dams, for which no design specifications were obtained. Banks were revetted with concrete slope pavement at curves, and elsewhere with articulated concrete blocks set above a concrete toe wall. In 1979, vegetation had become well established in the concrete blocks (fig. 76B) which were intact except at two places, one at a culvert and the other at a side drain. Partial failure of the concrete slope pavement, over a much greater lateral distance, was also observed at a side drain (fig. 76C). Upstream from the relocation, the natural channel (fig. 76D) is closely bordered by houses, and the steep banks are cut from place to place.

SITE FACTORS--Lat 39°42', long 86°08.5', at I-465, near the western boundary of Indianapolis, Ind., on Maywood 7.5' map. Lick Creek is perennial, with a drainage area of 56 km^2, an average discharge of 0.57 m^3/s. Channel bottom width is 8 m, bank height is 2.1 m, and channel slope is 3.0 m/km. Equiwidth point-bar stream, incised, semi-alluvial, sinuosity of 1.1, valley relief of 12 m, wide flood plain, less than 50 percent tree cover along bankline. Bed material is fine gravel. On a 1956 airphoto, the channel appears stable except for local erosion at the sharper bends and disturbance by housing construction is apparent.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

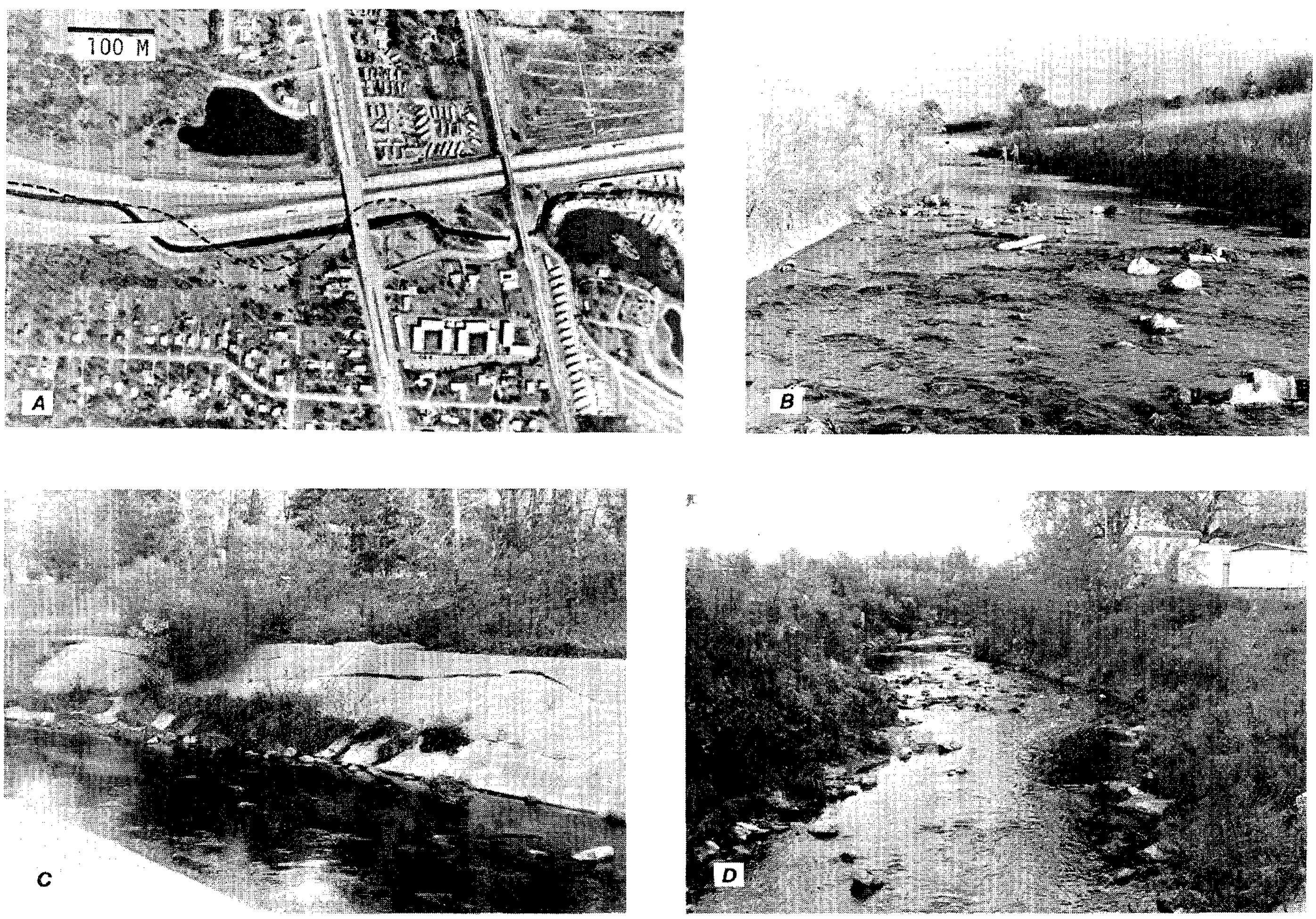


Figure 76. Lick Creek at site 29. A, Airphoto of relocated channel in 1972. Approximate course of prior channel is shown in dotted line. (From Indiana Dept. of Transportation). B, Upstream view, toward bridge, of relocated channel in 1978. C, Partial failure of concrete slope pavement at side drain upstream from bridge, as photographed in 1978. D, "Natural" channel upstream from relocation, in 1978.

DISCUSSION--The failure of bank revetment by undermining at side drains and culverts is noteworthy. The articulated concrete blocks seem superior to the concrete slope pavement, because their failure is more localized and because vegetation, including trees, has become established on them. The relocated channel is assigned to stability class A because of the generally good performance of the revetment, whose local failure is tentatively attributed to lack of a suitable filter blanket.

SITE 30. BROUILLETTS CREEK AT SR-63 NEAR UNIVERSAL, IND.

SYNOPSIS--Channel relocation, reach 610 m in length straightened to a length of 510 m, to prevent encroachment of meander loop against new roadway (figs. 77 and 78A). Performance period 15 yr, 1963-78. Except for erosion of the toes of side slopes, the relocated channel did not change significantly in general dimensions during the performance period. Local erosion has occurred at sections of the right bank just upstream and downstream from the bridge (fig. 78 B), and a point bar has formed at the left bank upstream from the bridge. A meander may eventually form just upstream from the bridge. As indicated by comparison of airphotos taken in 1949 and in 1962, adjacent segments of the natural channel were eroding at the outside of bends prior to the relocation, and the rate of erosion increased somewhat during the period 1962-72. The relocation may have contributed to this increase in erosion, particularly at bends downstream from the bridge (fig. 78C). Stability class B2 for relocated channel, C3 for adjacent segments of natural channel. In general, the relocated channel has performed well in view of its curvature, the limited use of bank revetment, and the prior instability of the natural channel. The critical factor in this performance is probably the absence of major floods during the time that vegetation was becoming established along the bankline.

SITE FACTORS--Lat 39°37', long 87°26', on SR-63, 1.5 km east of Universal, Ind., on New Goshen 7.5' map. Brouilletts Creek is perennial, drainage area of 860 km^2, average discharge of 8.4 m^3/s during the period 1966-70. Channel width is 25 m, bank height is 2.7 m, and channel slope is 0.88 m/km. Wide-bend point-bar stream, somewhat incised, alluvial, sinuosity 1.15. Valley relief is about 35 m, width of flood plain is 600 m, tree cover along channel is 50-90 percent. Bed material is gravel and sand, bank material is moderately coherent clay, sand, and silt. During the period 1949-1962, a moderate amount of lateral migration occurred at bends in the natural channel. The flood plain of the stream has been mostly cleared for agriculture, leaving a narrow and discontinuous strip of trees along the channel. Coal strip mining and gravel mining, although active in the general area, have had no apparent effect on the stream channel.

ALTERATION FACTORS--Relocation involved the cutting off of a meander, which shortened the reach by a factor of 0.84, and widening of the natural channel near the bridge from about 25 m to 55 m, or by a factor of 2. Limestone riprap, having a maximum weight of 200 kg and a median weight of 10 kg and containing much fine material, was placed on the abutment fill-slopes of the bridge and extended about 15 m along the right bank upstream and downstream from the bridge.

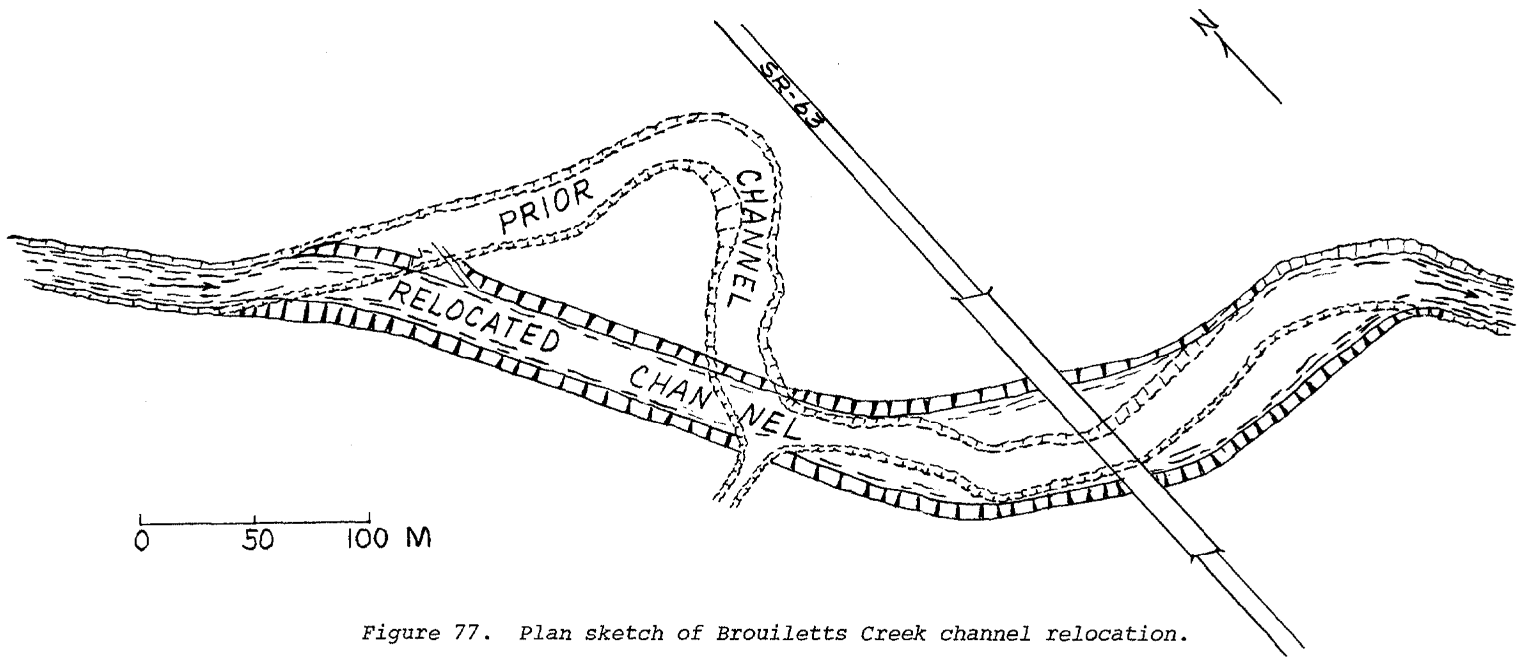


Figure 77. Plan sketch of Brouiletts Creek channel relocation.

The banks of the relocated channel were also riprapped where they intersected the prior channel. The relocated channel forms a broad curve that is conformable with the natural channel at its upstream end (fig. 78D), but meets it at a slight angle downstream. Vegetation was entirely removed from the area of relocation, and there is no record of any replanting.

POST-ALTERATION FACTORS--No maintenance or installation of countermeasures since relocation, is evident. Vegetation along the relocated channel was slow in becoming established, as little is evident on 1972 airphotos; but a good vegetal cover was present, except for a few places, in 1978 (fig. 78B).

DISCUSSION--Although the relocated channel has performed satisfactorily during the 16-yr period since relocation, the development of point (or alternate) bars in the channel (fig. 78A) is an indication that meander development has begun. However, this development is progressing slowly, and is not likely to be a problem during the normal life span of the bridge. Now that vegetation has become established, the relocated channel (fig. 78B) looks much like the natural channel (fig. 78C and D).

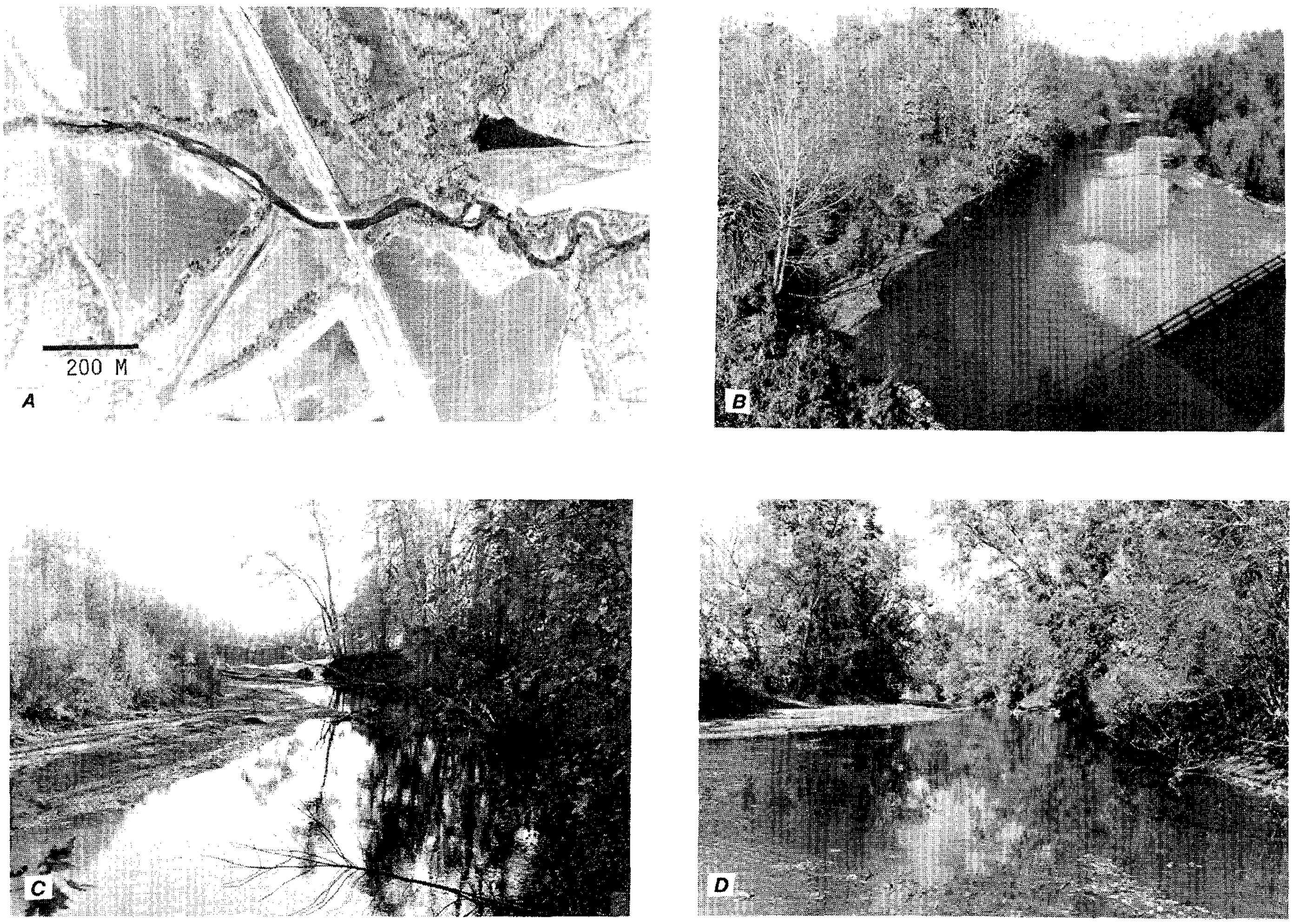


Figure 78. Brouiletts Creek at site 30. A, Airphoto of relocated channel in 1972. B, View of relocated channel looking upstream from bridge, in 1978. C, Natural channel downstream from bridge, in 1978. D, Natural channel upstream from bridge, in 1978.

SITE 31. FEATHER CREEK AT SR-63 AT CLINTON, IND.

SYNOPSIS--The alteration involved channel widening with a slight increase in channel length; bottom width of the natural channel (about 6 m) was increased to 23 m over a channel length of about 90 m (fig. 79). The apparent purpose was to match stream width to a long bridge, and to avoid any constriction that might contribute to flooding of a nearby residential area. Performance period 15 yr, 1963-78. The altered channel seems much too wide in relation to natural channel width, and the low-water channel has shifted to the toe of the left-bank abutment, with infilling of the rest of the altered channel. Minor erosion has occurred at the left-bank pier and toe of abutment fill-slope (fig. 80B). Adjacent segments of the natural channel were actively eroding at bends prior to channel alteration, as indicated by a 1962 airphoto. The streambanks appear better vegetated and more stable on a 1973 airphoto, probably as a result of the abandonment of some previously cultivated fields, and no detrimental effects of channel alteration on adjacent channel segments could be discerned.

Stability class B2 for altered channel, B for adjacent segments of natural channel. The critical factor in the infilling of the altered channel, and in the shift of the low-water channel against the left-bank abutment, is over-widening.

SITE FACTORS--Lat 39°40.5', long 87°25', on SR-63 about 2 km northwest of Clinton, Ind., on Clinton 7.5' map. Feather Creek is perennial with a drainage area of about 11 km^2. Channel width is 6 m, bank height is 1.5 m, channel slope is 3.4 m/km. Wide bend point-bar stream, alluvial, sinuosity about 1.2, valley relief of 50 m, flood plain wide at site, tree cover along channel 50-90 percent. Bed material is sand and fine gravel, bank material is coherent silt, clay, and sand; banks cut locally against glacial till.

ALTERATION FACTORS--Over a length of 93 m, the natural channel was widened to a maximum bottom width of 18.5 m and a top width of about 23 m (fig. 79), which represents an increase in channel width by a factor of three or four. Channel curvature was slightly increased by widening, as was channel length.

POST-ALTERATION FACTORS--Although the low-water flow line was placed in the center of the widened channel at the time of construction, it has subsequently migrated against the toe of the left-bank abutment fill-slope. Except for scattered shrubs and annuals, little vegetation had become established along the widened channel by 1978.

DISCUSSION--The reasons for widening the natural channel by such a large factor are not apparent, but the designer may have operated on the premise that overwidening could do no harm. The consequent lateral migration of the low-water channel is probably not serious in view of the small size of the stream and the very large area of the bridge waterway, but it may lead to maintenance expense.

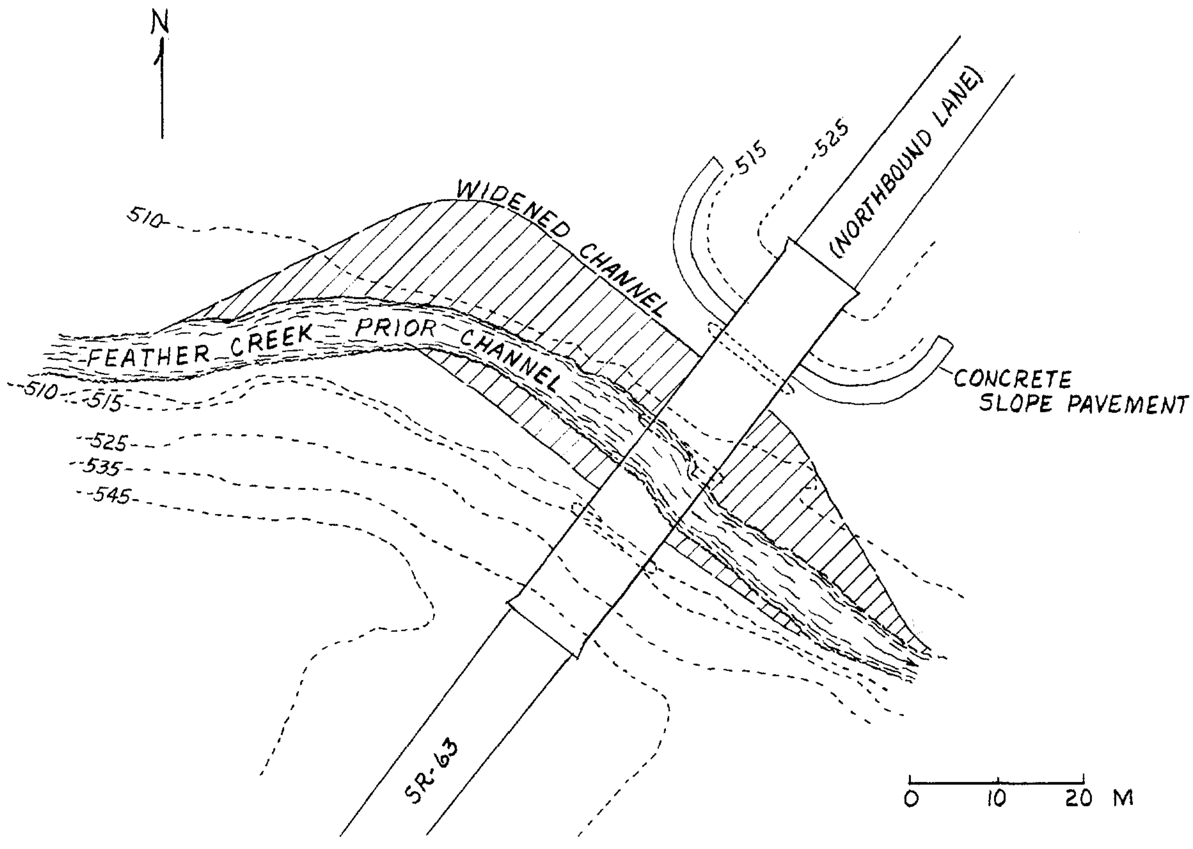


Figure 79. Plan sketch of Feather Creek channel relocation

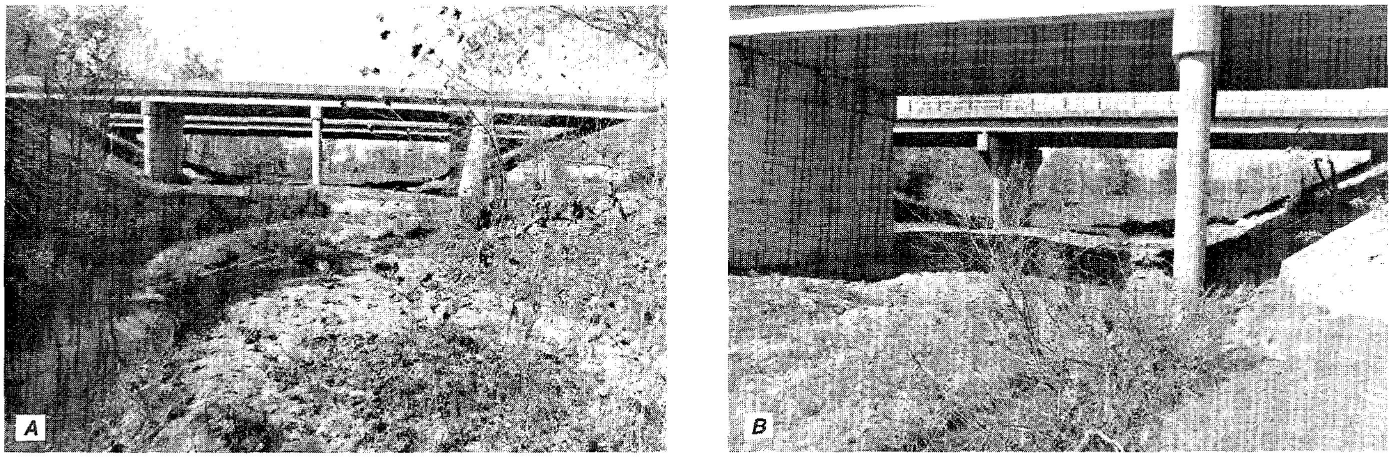


Figure 80. Feather Creek at site 31. A, View upstream in 1978, showing width of bridge waterway in relation to that of natural channel, in left foreground. B, View in 1978, showing location of low-water channel against abutment, at right, and, at left, infilling of wide channel.

SITE 32. SMOKY HILL RIVER AT I-70 AT JUNCTION CITY, KANS.

SYNOPSIS--Channel was relocated by cutting off a meander loop, thereby reducing the length of the segment from 3,475 m to a value of 1,675 m; for the purpose of avoiding an additional crossing along the planned roadway location and to obtain embankment fill from the excavated channel (figs. 81 and 82A). Performance period, 16 yr (1963-79), during which no major floods occurred. According to the plans, the relocated channel was trapezoidal in cross section, with a bottom width of 134 m, 2:1 side slopes, and a longitudinal slope of 0.3 m/km. No bank protection along the relocated channel was specified in the plans or observed in the field. The ends of the prior channel were closed, but the channel was not filled for most of its length. In 1979, bottom width was 84 m, trees grew densely along the bankline (figs. 82A and 82B), and the streamward faces of banks tended to be steep, rather high (3.3-3.5 m), and unvegetated. Thus, by comparison with the width as planned, the width in 1979 had diminished by about 50 m. No information was obtained as to any departure of as-built width from planned width.

The natural channel upstream from the relocation had a rather rapid rate of lateral migration for the period 1964-78, amounting to a maximum linear distance of about 20 m at several meander loops. However, this rate is not inconsistent with the historical lateral migration since 1863, as plotted by Dort and others (1979). No evidence of channel degradation was observed, and degradation may have been prevented by an outcrop of resistant bedrock in the channel near the downstream end of the relocation. Stability class B1 for relocated channel and class D2 for adjacent segments of natural channel.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

SITE FACTORS--Lat 39°01.5', long 96°48.5', at I-70, near east boundary of Junction City, Kans., on Junction City 7.5' map. Smoky Hill River is perennial, with a drainage area of 51,540 km^2 and an average discharge of 46.8 m^3/s at the nearby Geological Survey gage at Enterprise. Channel bottom width is 53-58 m, bank height is 3.3-3.6 m, channel slope is about 0.17 m/km. Wide-bend point-bar stream, mainly alluvial but with outcrops of resistant bedrock in the channel bottom from place to place, sinuosity of 1.8, valley relief of 90 m, wide flood plain, less than 50 percent tree cover along bankline. Bed material is in the size range of sand to medium gravel, bank material is moderately cohesive sand, silt, and clay. About 3 km downsteam from the relocation, a very large meander loop (channel length of 5,800 m) was cut off naturally about 1950.

DISCUSSION--The relocation involved a meander cutoff that was long both in absolute measurement and in relation to stream width, but longer cutoffs have occurred naturally both upstream and downstream since 1863 (Dort and others, 1979). The bottom width of the relocated channel (134 m) relative to that of the natural channel (55 m) was apparently more than adequate to offset the increase in channel slope consequent upon relocation. Alternate bars that have formed in the relocated channel (fig. 82A) are the precursors of sinuosity and have already induced bank erosion by diverting flow to the opposite bank. However, sinuosity of a degree detrimental to flow alinement at the bridge will probably not develop during the useful life of the bridge.

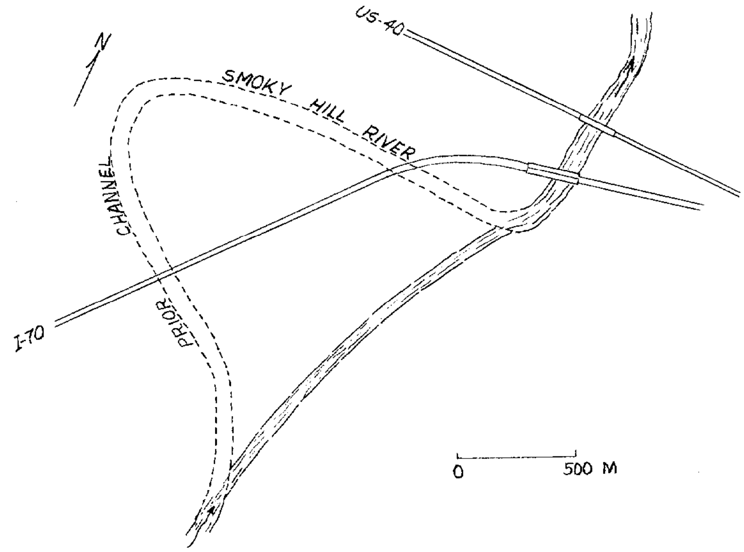


Figure 81. Plan sketch of channel relocation, Smoky Hill River.

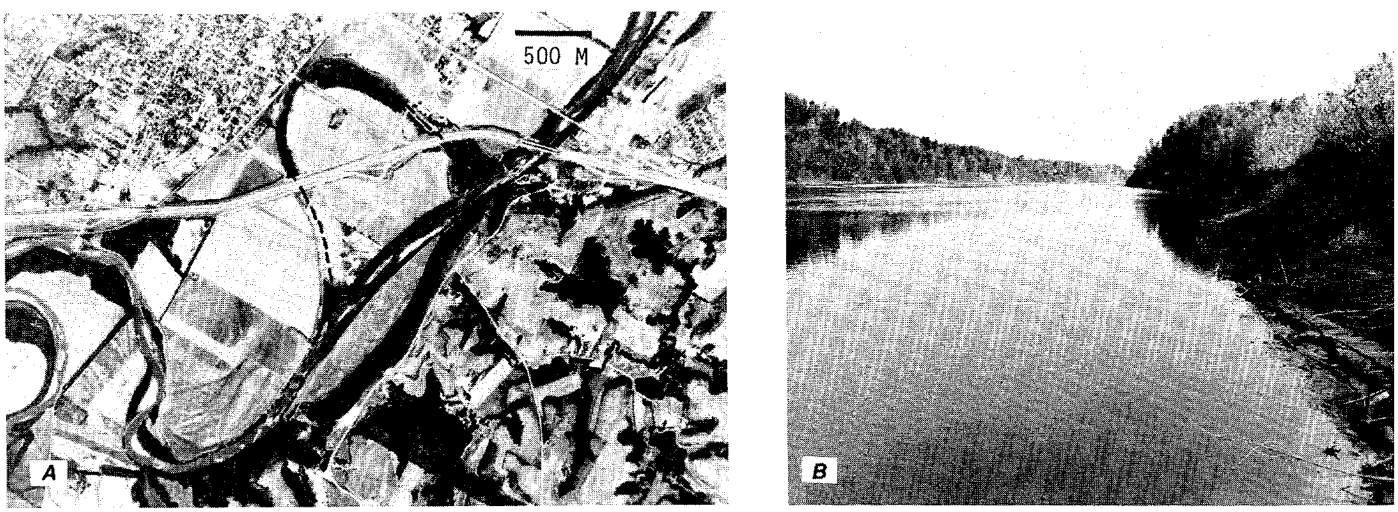


Figure 82. Smoky Hill River at site 32. A, Airphoto of channel relocation in 1978. (From U.S. Dept. of Agriculture). B, Downstream view along relocated channel in 1979.

SITE 33. REPUBLICAN RIVER AT US-81 AT CONCORDIA, KANS.

SYNOPSIS--Channel was relocated by cutting off a meander loop downstream from the US-81 bridge, thereby reducing the channel length from an original value of 1,800 m to 1,000 m; for apparent purpose of preventing growth of a meander at the bridge (fig. 83A). Performance period, 43 yr (1936-79). An extreme flood had occurred in 1935 (peak discharge of 5,858 m^3/s), which had caused rapid lateral migration of meanders. Subsequently, major floods occurred in 1947 and in 1951. Relocation was done by means of a pilot channel (fig. 83A), which was trapezoidal in cross section with a bottom width of 6 m, 1.5:1 side slopes, spoil banks on either side, and a longitudinal slope of 1.6 m/km. No bank protection or flow control measures were applied along the relocated channel. During the period 1937-52, the relocated channel shifted to the right because of the rapid growth of an upstream meander (fig. 83B), and its bottom width increased to 180 m. The width had decreased to 100 m by 1957, and to 80 m by 1975 (fig. 83C). In 1979, the banks were well vegetated and generally stable (fig. 83D). although banks were locally cut because of the sinuous low-flow channel. Adjacent reaches of the natural channel were also much more stable than during the period 1937-52. Stability class B for relocated channel and adjacent reaches of natural channel. The critical factors in channel stability are the lack of major floods since 1951, growth of vegetation along the channel, and a moderate control of flow by upstream reservoirs.

SITE FACTORS--Lat 39°35', long 97°40', at US-81, 1.5 km north of Concordia, Kans., on Concordia 7.5' map. Republican River is perennial, with a drainage area of 23,540 km at the site and an average discharge of 21 m^3/s. Channel bottom width has ranged through time from 180 m in 1957 to 80 m in 1975; bank height is 2-2.5 m, and channel slope is 0.6 m/km. Wide-bend point-bar stream, locally braided, alluvial, sinuosity of 1.6, valley relief of 30 m, wide flood plain, 50-90 percent tree cover along bankline. Bed material is sand, and bank material is weakly coherent sand and silt.

ALTERATION FACTORS--(See "Synopsis")

POST-ALTERATION FACTORS--Owing to growth of the meander loop upstream from the US-81 bridge in the late 1940's, lateral bank erosion was endangering the right-bank bridge abutment. In 1948, a pilot channel was constructed beneath the bridge to divert flow to the left, and a pile retard was constructed at the left bank upstream from the bridge (fig. 83B). Flow was not diverted by the pilot channel. In 1972, a jack field was constructed at the right bank near the bridge. The countermeasures, together with the general increase in stability of the river, have prevented further lateral migration toward the left bridge abutment.

DISCUSSION--Although the relocated channel has become stabilized and has had little or no detrimental effect on the river, the purpose that it has served in protecting the bridge is questionable. Bank protection or flow-control measures at and downstream from the left bridge abutment would probably have been more effective, at less cost.

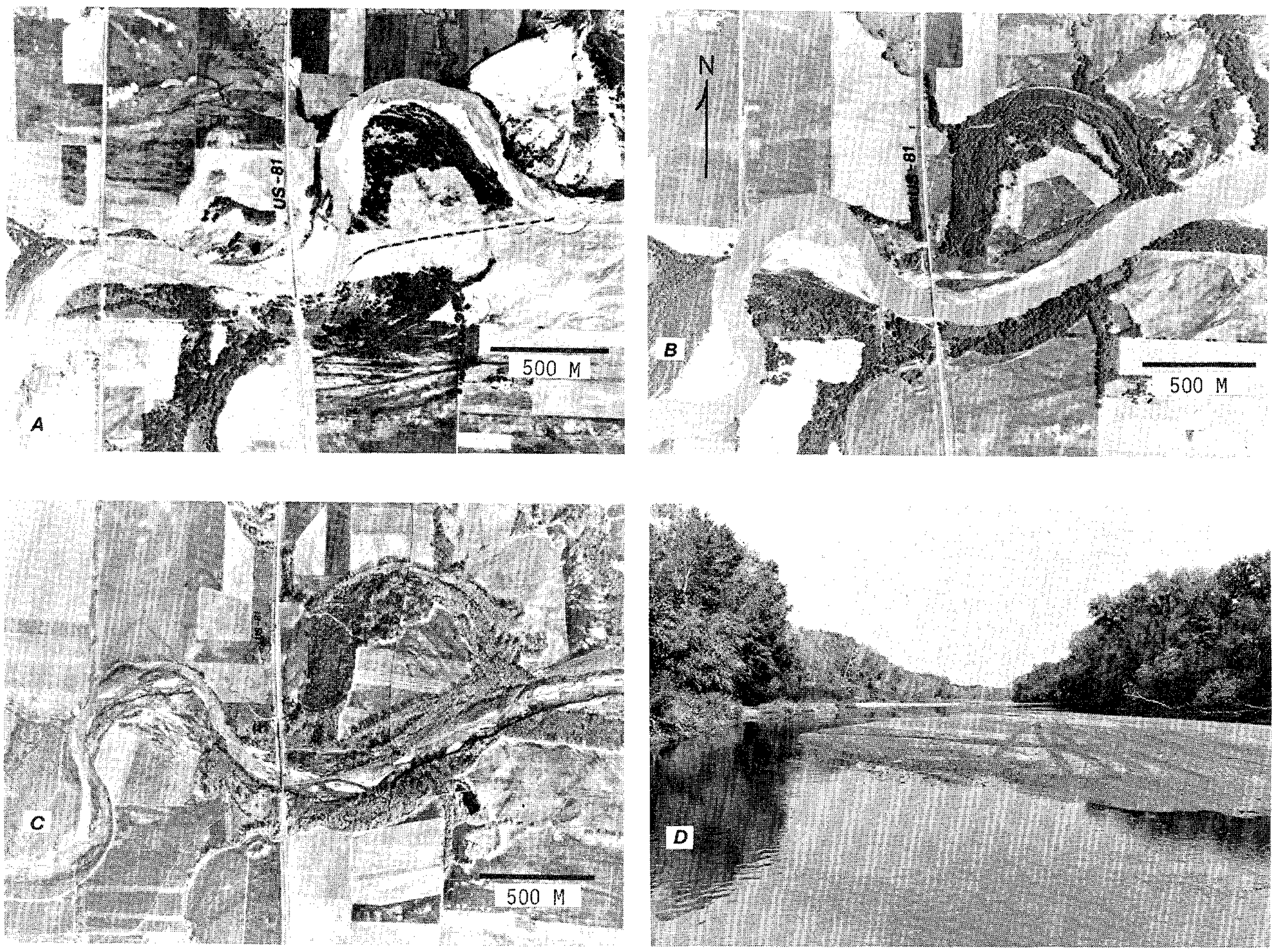


Figure 83. Republican River at site 33. A, Airphoto of channel relocation in 1937. (From U.S. Dept. of Agriculture). B, Airphoto of relocated site in 1952. (From U.S. Dept. of Agriculture). C, Airphoto of relocation site in 1975. (From Kansas Dept. of Transportation). D, View downstream about midway along relocated channel, in 1979.

SITE 34. YELLOW CREEK AT SR-144 NEAR OWENSBORO, KY.

SYNOPSIS--Channel relocation, reach 70 m in length shortened to 50 m, in order to improve flow alinement at culvert on relocated roadway (fig. 84). Performance period, 15 yr (1964-78). Most of the relocated reach is within a concrete culvert, and no channel instability was observed at either end of the culvert (fig. 85A). The stream channel upstream and downstream from the relocation is abnormally straight and has presumably been straightened by some agency; but it is now stable and bordered by mature trees (fig. 85B).

Stability class A1 for relocated channel, and class A1 for "natural" channel. Critical factors in stability are: (1) The short length of channel involved in the relocation. (2) Enclosure of most of the relocated channel within a concrete culvert. (3) Preservation of natural vegetation along the channel at the site of relocation.

SITE FACTORS--Lat 37°48', long 87°02', on SR-144, 7 km northeast of Owensboro, Ky., on Owensboro East 7.5' map. Yellow creek is perennial, drainage area of about 12 km^2 at site. Channel width, 9 m; bank height, 2 m to flood plain; channel slope, 1.7 m/km. Stream channel for a distance of several hundred meters upstream and downstream from site was probably straightened several decades ago, because it is abnormally straight and bordered by mature trees. Stream is alluvial, sinuosity of 1; valley relief, 12 m; width of flood plain, 150 m. Bed material is sand, bank material is coherent, fine-grained alluvium.

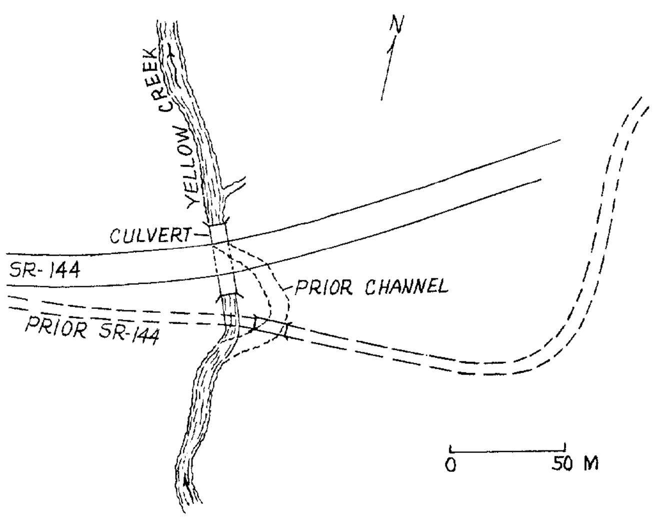


Figure 84. Plan sketch of channel relocation, Yellow Creek at SR-144.

ALTERATION FACTORS--In relocation, the channel was shortened by a factor of 0.7, and the relocated channel was constructed to about the same width as the prior channel. Most of the relocated channel is within a double, 12 by 10 ft (3.66 by 3.05 m) reinforced concrete box culvert (fig. 85A). The wide concrete wingwalls of the culvert have apparently been effective in preventing lateral erosion.

POST-ALTERATION FACTORS, DISCUSSION--(See "Synopsis")

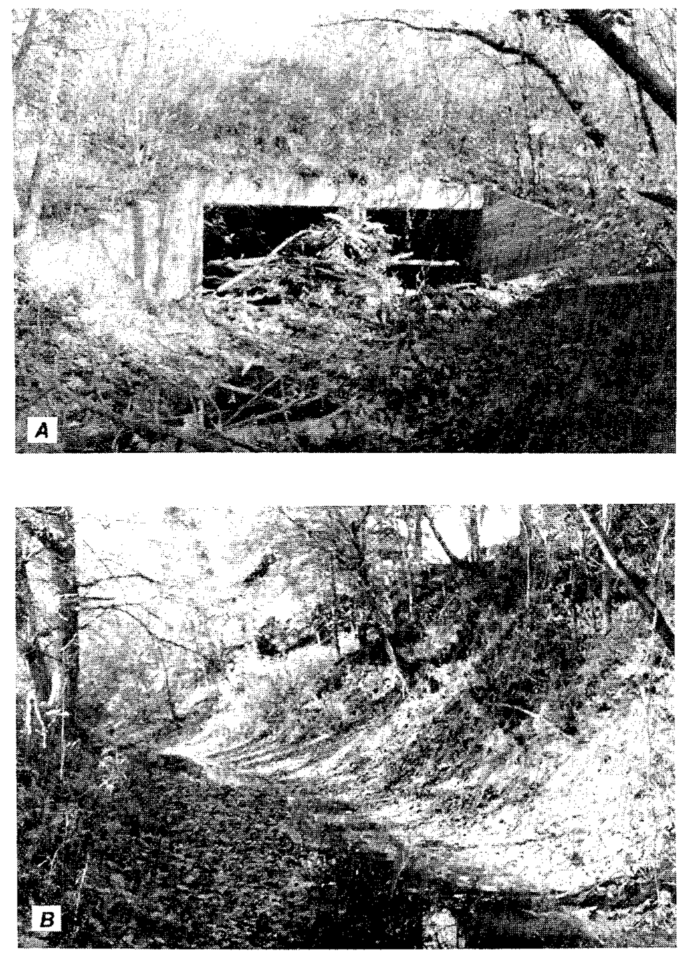


Figure 85. Yellow Creek at site 34. A, Culvert entrance at upstream end of relocated channel, in 1978. B, Natural channel upstream from relocation, in 1978.

SITE 35. ROLLING FORK AT BLUE GRASS PARKWAY NEAR BOSTON, KY.

SYNOPSIS--Channel relocation, reach 785 m in length shortened to 400 m, for purpose of improving flow alinement at bridge (figs. 86 and 87A). Performance period, 13 yr (1966-78). At the U.S.G.S. stream gage, three km downstream from the site, the largest flood in a 32-yr period of record (1938-70) occurred in 1970. No plans showing the as-built dimensions of the relocated channel could be obtained, but measurements of channel width on a 1969 airphoto, as compared with field measurements made in 1978, indicate that the top width has increased slightly (fig. 87B) and the bottom width has decreased. No effect of relocation on adjacent segments of the natural channel could be discerned (figs. 87C and D).

Stability class B2 for relocated channel, A1 for natural channel. Critical factors in the stability of the relocated channel are: (1) The exceptional prior stability of the natural channel, which is attributed to coherent bank materials and to incision. (2) Dimensions of the relocated channel are similar to those of the natural channel. (3) The natural channel is conformable in trend with the relocated channel at both junctions.

SITE FACTORS--Lat 37°45', long 85°41', on Blue Grass Parkway, 5 km south of Boston, Ky., on Nelsonville 7.5' map. Rolling Fork is perennial, drainage area of about 1,475 km, average discharge about 21 m^3/s. Channel width is 15-17 m; bank height is 6 m to flood plain; and channel slope is 0.6 m/km. Equiwidth, point-bar stream, incised, alluvial, sinuosity of 2. Valley relief, 90 m; width of flood plain, 1,800 m. Narrow strip of mature trees grow on sloping banks (figs. 87C and D) but this strip is locally discontinuous. Bed material is sand, bank material is coherent silt and clay. Comparison of 1938 and 1969 airphotos indicates that the channel is laterally stable, as no migration of the channel could be measured. However, two large slumps occurred during the period 1938-69, along the streambanks upstream from the site. The oxbow lake near the site (fig. 87A) was probably formed more than a hundred years ago, perhaps several hundred years ago, as it changed little during the period 1938-1978.

ALTERATION FACTORS--According to measurements made on a 1969 airphoto (fig. 87A) taken three years after relocation, the top width of the relocated channel was 36 m near the bridge, tapering to about 32 m at either end. The bottom width was 21 m near the bridge, tapering to about 19 m at either end. Thus, the side slopes were about 1.5:1. The reduction in channel length by a factor of 0.51 would be expected to increase the natural channel slope by a factor of 2, or from 0.6 m/km to 1.2 m/km. The bridge abutment fill-slopes were revetted on the upper part with small limestone riprap, but there is no evidence of bank protection or the planting of vegetation along the banks of the relocated channel.

POST ALTERATION FACTORS--A major flood occurred at the site in 1970, four years after the alteration and before natural vegetation could have been well established. Field study of the site in 1978 indicated that no severe erosion occurred, and that the channel bottom was in fact less wide than in 1969. Gully erosion and recession of the upper right bank upstream from the bridge (fig. 87B) is attributed to the planting of row crops close to the channel, and the failure of natural vegetation to become established on the bank slope. In 1978, trees were well established along the left bank. No maintenance work on the relocated channel is apparent.

DISCUSSION--In view of the site of the stream, the degree of channel shortening, the occurrence of a major flood, and the lack of bank protection, the stability of the relocated channel is surprising. The factors that account for the prior stability of the natural channel--coherence of bank materials and degree of incision--have apparently contributed to the stability of the relocated channel. Recession and gullying of the upper bank upstream from the bridge is troublesome, but it does not constitute a real threat to channel stability.

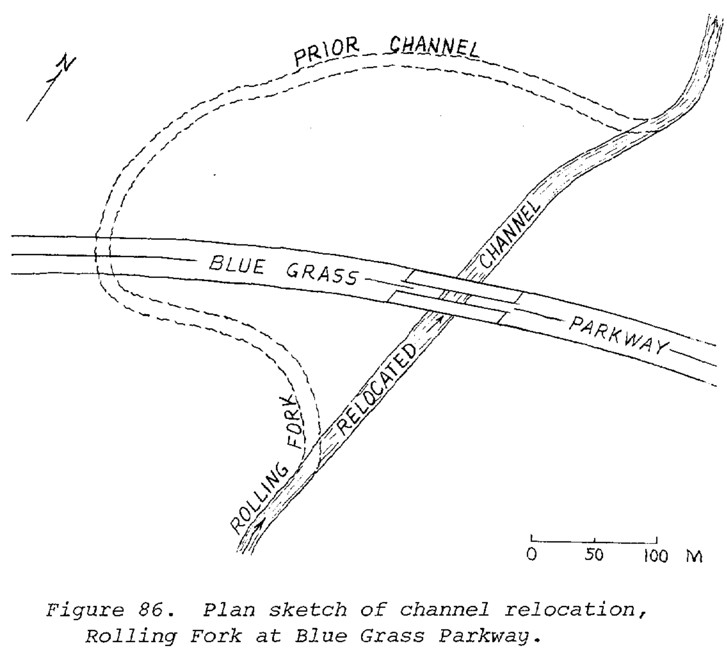


Figure 86. Plan sketch of channel relocation, Rolling Fork at Blue Grass Parkway.

Figure 87. Rolling Fork at site 35. A, Aerial photograph of channel relocation in 1969. (From U.S. Dept. of Agriculture). B, View of relocated channel, looking upstream from bridge, in 1978. C, Natural channel downstream from relocated channel, in 1978. D, Natural channel upstream from relocated channel, in 1978.

SITE 36. BEARGRASS CREEK AT I-64 AT LOUISVILLE, KY

SYNOPSIS--Channel relocation, reach about 3,000 m in length straightened and shortened to 1,800 m, for purpose of avoiding several crossings and to make room for roadway (fig. 88A). Performance period, 12 yr (1967-78). In 1970, the relocated channel was subjected to the maximum flood in a 35-yr period of record; peak flow was about 150 m^3/s, as compared with an average discharge of 0.8 m^3/s. In 1978, the relocated channel was stable except for minor local bank erosion, the banks were vegetated (mainly with grass), and the channel dimensions had not increased significantly (figs. 88B , C, and D). Upstream from the site, in Cherokee Park, the natural channel was stable.

Stability class B1 for relocated channel and class A1 for natural channel. Lateral stability of the relocated channel is attributed to coherence of the bank materials, which have a moderately high clay content; and to the shape of channel in cross section, which consists of a low-water channel bordered by berms that serve to contain flood flows. Absence of degradation is attributed to the concrete check dam and to the fact that the channel is cut in limestone bedrock for a short distance at a point downstream from the Grinstead Drive bridge. Stability of the natural channel is attributed to the coherence of bank materials.

SITE FACTORS--Lat 38°15', long 85°42', on I-64 at Grinstead Drive in Louisville, Ky., on Louisville East 7.5' map. Beargrass Creek is perennial, drainage area of about 60 km^2 at site, average discharge about 0.8 m^3/s (as extrapolated from the U.S.G.S. gage located 6 km upstream). Channel width is 10-12 m, bank height is 1.5-2 m, and channel slope is 2.5 m/km. Equiwidth point-bar stream, alluvial, sinuosity about 2. Valley relief of about 30 m; flood plain narrow, width about 80 m, set in a meandering valley. Tree cover along channel, 50-90 percent.

ALTERATION FACTORS--In straightening the channel, its length was decreased by a factor of 0.6, and the consequent increase in slope was partly offset by a concrete check dam. Top width of the relocated channel was constructed to about the same dimension as that of the natural channel; but a berm, set back from the banks, serves to contain flood flow. Except for the check dam, there is no evidence of bank revetment or other countermeasures along the relocated channel.

POST-ALTERATION FACTORS--As indicated on an airphoto taken in 1971, bank erosion occurred during the 1970 flood along the relocated channel downstream from Grinstead Drive. However, this erosion was not severe, and by 1978 the banks were vegetated and only minor local erosion was evident (figs. 88B and C).

DISCUSSION--In view of the degree of shortening, the stability of the relocated channel is better than would be expected, and it has been adequately tested by flood. The relocated channel is much less attractive in appearance than is the natural channel upstream in Cherokee Park. However, the appearance of the channel would have been much impaired by several crossings of the interstate highway, even if no relocation had been done.

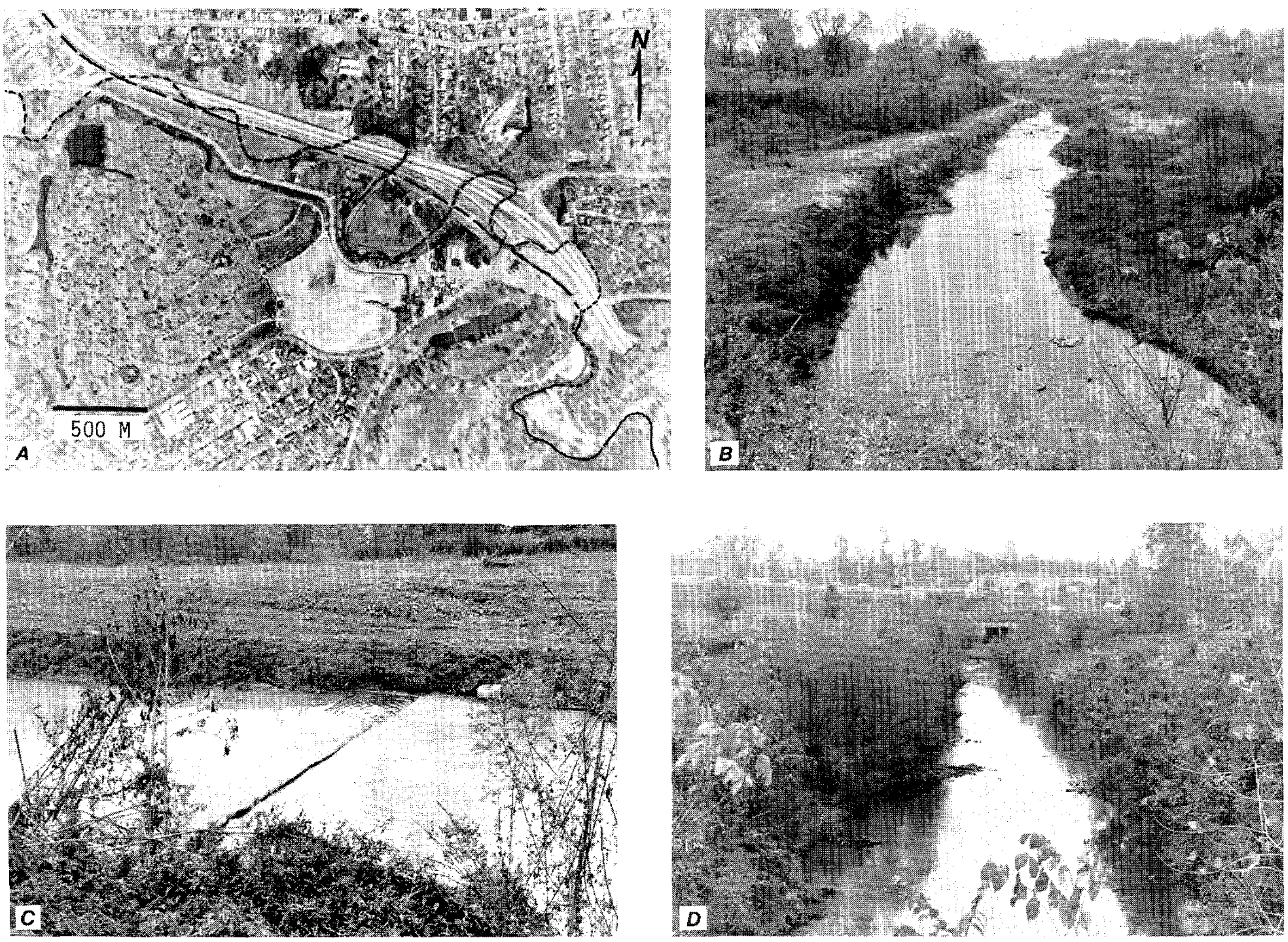


Figure 88. Beargrass Creek at site 36. A, Aerial photograph, taken in 1971, showing channel relocation. Prior channel is shown in dotted line, relocated channel in dashed line. (From U.S. Geological Survey) B, Relocated channel looking downstream from bridge at Grinstead Drive. C, Relocated channel at concrete check dam. D, Relocated channel, looking upstream from bridge at Grinstead Drive.

SITE 37. BENSON CREEK AT I-64 NEAR FRANKFORT, KY.

SYNOPSIS--Channel relocation, reach 245 m in length, moved laterally by 25 m and straightened with no significant change in length for purpose of improving channel alinement at bridge (fig. 89). Performance period, 14 yr (1965-78). No floods significantly larger than mean annual have been recorded since 1965 at nearby gages. Banks of both relocated and natural channel were stable in 1978 (figs. 90A and B), and no change in channel width since relocation could be discerned.

Stability class A1 for both relocated channel and adjacent segments of natural channel. Critical factors in channel stability are: (1) the minor nature of the relocation, (2) the prior stability of the natural channel, (3) similarity in size of natural and relocated channels.

SITE FACTORS--Lat 38°09', long 18°00', 14 km east of Frankfort, Ky., at border of Waddy 7.5' and Frankfort West 7.5' maps. Benson Creek is perennial, with a drainage area roughly 65 km^2. Channel width is 10-11 m, bank height is 1.5-2.5 m, and channel slope at site is 0.75 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.9. Valley relief of 40 m, flood plain narrow, width about 60 m, in meandering valley. Narrow strip of trees along channel, tree cover 50-90 percent. Bed material is sand and small gravel; bank material is moderately coherent silt-clay. Comparison of airphotos taken in 1949, 1957, and 1969 indicates that the natural channel has a high degree of lateral stability.

ALTERATION AND POST-ALTERATION FACTORS--Straightening of the channel led to only a slight decrease in length, from 245 m to 240 m, and consequently only a slight change in slope. No information was obtained on the as-built width of the relocated channel, but both the bottom and top width as measured on a 1969 airphoto are very nearly the same as for the natural channel. The banks of the relocated channel were evidently revetted to some degree with limestone riprap, of which only discontinuous remnants were visible in 1978. Sycamore, willow, and box elder have become well established along both banks of the relocated channel (fig. 90A).

DISCUSSION--The factors that account for the stability of the natural channel--low slope, coherent bank materials, and a slight degree of incision--have also contributed to the stability of the relocated channel. In addition, the riprap placed along the relocated channel contributed to stability and probably to the early establishment of vegetation.

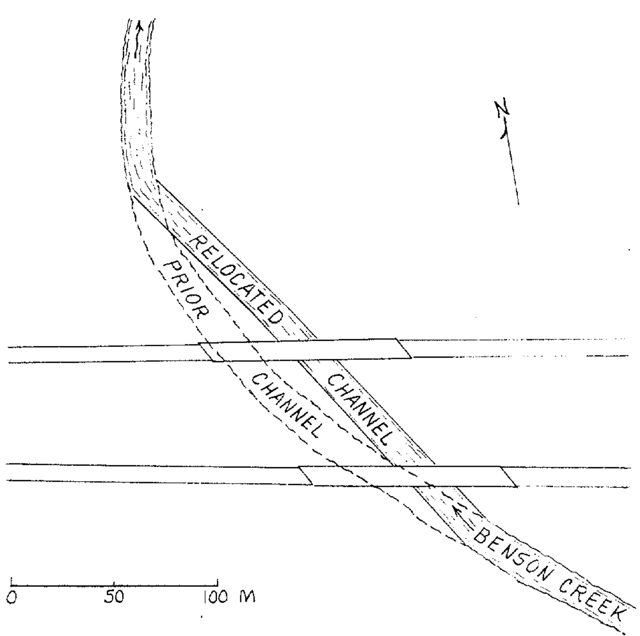


Figure 89. Plan sketch of Benson Creek channel relocation.

Figure 90. Benson Creek at site 37. A, View upstream toward bridges in 1978, from end of relocation. B, Natural channel upstream from relocation, in 1978.

SITE 38. NORTH FORK TRIPLETT CREEK AT I-64 NEAR MOREHEAD, KY.

SYNOPSIS--Channel was relocated by shortening a bend, thereby reducing the length of a channel segment from 525 m to 225 m, for purpose of accommodating the planned roadway location without a stream crossing (fig. 91A). Performance period, 10 yr (1969-79), during which a moderate flood occurred in December 1978. No information on the as-built dimensions of the relocated channel was obtained, but a bottom width of 18 m was measured on a 1972 airphoto. Channel slope was about 4 m/km. No bank protection measures were specified on the plans. In 1980, field observations indicated no significant bank erosion along the relocated channel or at its angular junctions with the natural channel (fig. 91B); and adjacent segments of the natural channel were tree-lined and stable. Stability class A1 for relocated channel and adjacent segments of the natural channel. Channel stability is attributed to the prior stability of the natural channel, to the preservation of existing natural vegetation at the junctions of natural and artificial channel, and to the lack of floods prior to re-establishment of vegetation.

SITE FACTORS--Lat 38°12', long 83°28', at I-64, 4 km east of Morehead, Ky., on Morehead 7.5' map. North Fork Triplett Creek is perennial, with a drainage area of 220 km^2 and an average discharge of about 3.5 m^3/s. Channel bottom width is 16 m, and channel slope is 4 m/km at the site, although less than half this value upstream from the site. Equiwidth point bar stream, alluvial, sinuosity of 1.2, valley relief of 100 m, flood plain about 15 times stream width, bordered by well developed terraces. A narrow strip of trees along the bankline is almost continuous. Bed material is sand and gravel. As observed on a 1969 airphoto, the channel was stable without cut banks at bends.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--The junctions of relocated and natural channel are nearly at 90°, a factor that commonly leads to bank erosion. The lack of bank erosion is tentatively attributed to natural bank coherence, enhanced by vegetation.

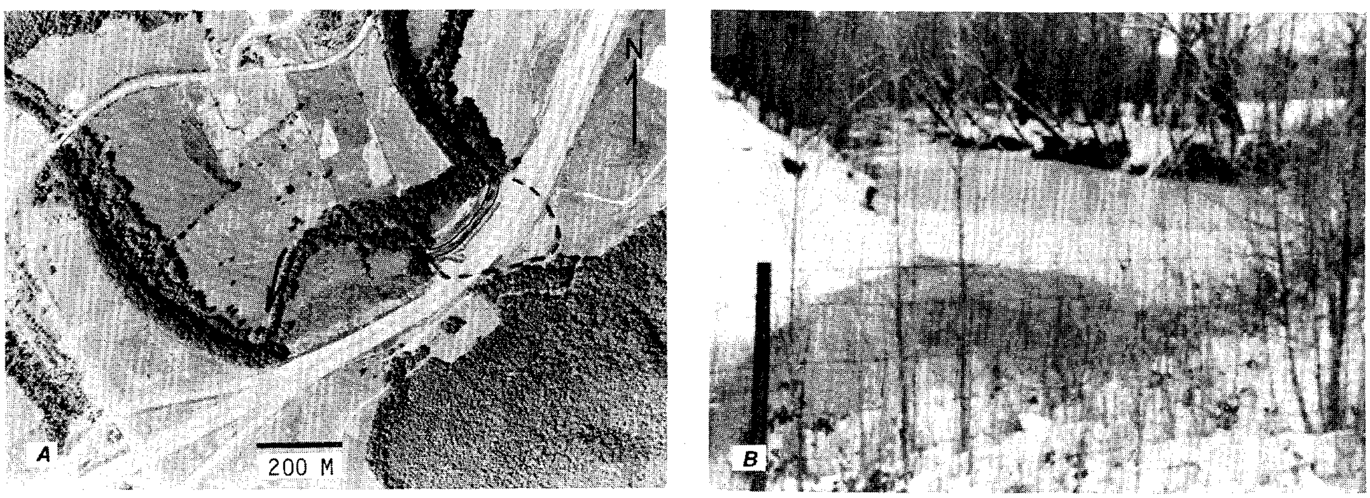


Figure 91. North Fork Triplett Creek at site 38. A, Airphoto of channel relocation in 1972. Prior channel shown in dashed line. (From U.S. Dept. of Agriculture). B, Upstream junction, at bend, of relocated and natural channel in 1980.

SITE 39. AMITE RIVER AT SR-10 NEAR DARLINGTON, LA.

SYNOPSIS--Channel relocation, reach 1,060 m in length shortened to 545 m by cutting off a single meander loop; to improve alinement at new bridge and to avoid future encroachment of meander on bridge and roadway embankment (figs. 92 and 93A). Performance period 17 yr (1963-79). An unusual number of floods have occurred on the Amite River since 1963, including a 25-yr flood in 1977. By 1979, the dimensions of the relocated channel had not changed significantly, but the channel had migrated about 15 m laterally and further migration is probable, which presents a hazard to the left bridge abutment.

Stability class D4 for relocated channel, and also class D4 for adjoining reaches of the natural channel. As observed on a 1957 airphoto, taken prior to the channel relocation, the natural channel has an unstable aspect because of its wide point bars and cut banks at bends (fig. 93B). At some time during the period 1957-73, at a point about 2.5 km upstream from the bridge site, a large complex meander loop was cut off naturally. The relocation has probably had little effect on the natural channel upstream from the bridge but has induced, or contributed to, severe bank erosion at the first bend downstream (fig. 93A) and imminent cutoff of the bend. The critical factor in instability of the relocated channel is prior instability of the natural channel, which is in turn attributed to erodible banks and, in part, to local clearing of the flood plain forest. Bank erosion of the natural channel downstream from the relocation is attributed to the unfavorable alinement of the transition.

SITE FACTORS--Lat 30°53', long 90°51', on SR-10, 7 km west of Darlington, La., on Felixville 15' map. Amite River is perennial, drainage area 1,502 km^2, average discharge 22 m^3/s. Channel width is 35-40 m, bank height is 2.5-3 m, and channel slope is 0.54 m/km. Wide-bend, point-bar stream, locally anabranched, alluvial, sinuosity 1.6. Valley relief of 30 m, width of flood plain 3 km. Flood plain has a continuous forest cover, except for patchy clearing that encroaches locally on the river banks; tree cover on banks, greater than 90 percent. Bed material dominantly sand, with gravel having a maximum diameter of 4 cm and a median diameter of 1 cm. Bank material is silt with minor clay content, coherence weak to moderate.

ALTERATION FACTORS--The cutting off of a meander loop shortened the affected reach by a factor of 0.5 and therefore increased the slope by a factor of 2. The relocated channel was designed with a bottom width of 61 m, a top width of 79 m, a trapezoidal cross section, side slopes of 2:1, and a bank height of 4 m at the bridge. The relocated channel terminated at a broad meander loop upstream and a more narrow loop downstream (fig. 93A), such that bank erosion was probable at the downstream loop.

POST ALTERATION FACTORS--The unstable aspect of the Amite River is attributed in part to a sequence of floods that have occurred since 1963. Floods having recurrence intervals in the range of 5-10 yr occurred in 1964, 1965, 1967, 1972, 1975, and 1979; a flood having a recurrent interval in the range of 10-25 yr occurred in 1973, and a 25-yr flood, in 1977. By 1973, the relocated channel had migrated about 12 m toward the left bridge abutment, and a point bar had formed at the right bank. About 1975, broken-concrete riprap was dumped along the left bank at and near the bridge, and this has apparently been effective in halting bank recession, although much of it has been removed by erosion.

DISCUSSION--Inasmuch as the river has rather high sinuosity and an apparently rapid rate of lateral migration at bends, good crossing sites are uncommon. The former crossing site was decidedly unsatisfactory (fig. 93B), and cutting off the meander loop seems the most logical way of improving it. Protection of the bridge at the present site will require countermeasures both at the left abutment and at the outside of the first meander loop upstream.

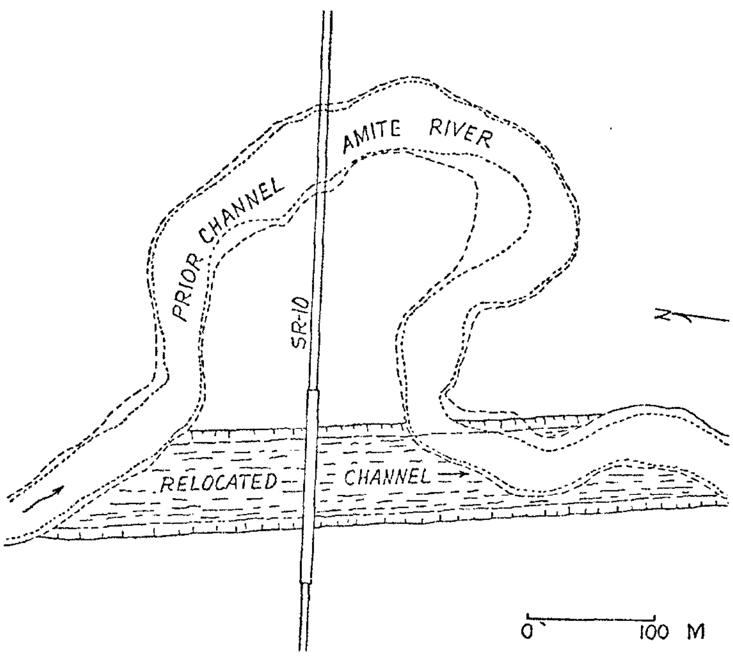


Figure 92. Plan sketch of Amite River channel relocation.

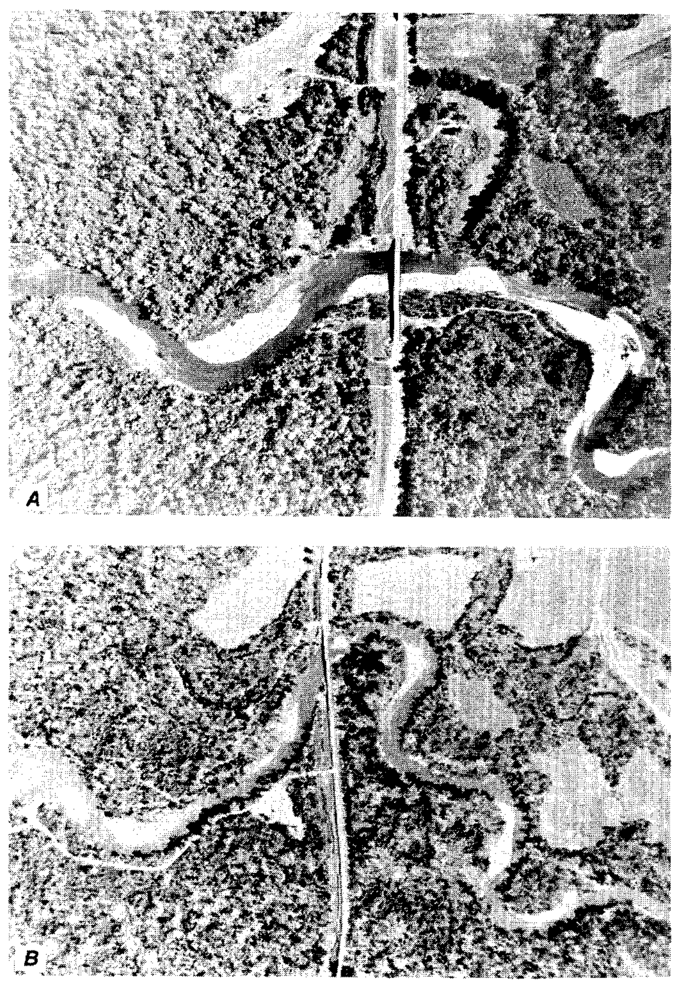


Figure 93. Amite River at site 39. A, Airphoto of site in 1975. (From Louisiana Dept. of Transportation) B, Airphoto of site in 1937. (From U.S. Dept. of Agriculture).

SITE 40. COOL CREEK AT I-55 NEAR KENTWOOD, LA.

SYNOPSIS--Channel relocation, reach 457 m in length straightened and shortened to 229 m for purpose of channel alinement at bridge and to improve conveyance of flood flows (figs. 94 and 95A). Performance period, 15 yr (1965-79). The relocated channel was subjected in 1974 to a major flood that almost overtopped the roadway embankment. In the vicinity of the I-55 bridges, the relocated channel was enlarged and deepened by general scour, which extended about 30 m downstream beyond the bridges. For a distance of about 150 m upstream from the relocation, the natural channel was widened by lateral erosion; and degradation may also have occurred, but this could not be established. Elsewhere, the natural channel, as observed on a large-scale airphoto taken in 1975, showed little effects from the relocation.

Stability class B3 for both relocated and natural channel. Critical factors in the instability of the relocated channel are the *magnitude of the flood and the contraction of* flood flow by the bridges and approach embankments.

SITE FACTORS--Lat 30°57', long 90°32', on I-55, 0.5 km northwest of Kentwood, La., on Kentwood 15' map. Cool Creek is perennial, drainage area of 15 km^2. Channel width 8 m; bank height, 1.2 m, channel slope 1.3 m/km. Equiwidth point-bar stream, alluvial, sinuosity about 1.4. Valley relief, 30 m; width of flood plain, 300 m. Natural channel is bordered by dense forest, which was cleared along the relocated channel. Bed material is sand and small gravel (maximum diameter, 25 mm); bank material is silt, clay, and sand of moderate coherence. Stability of the natural channel prior to relocation was good.

ALTERATION FACTORS--In relocation, the affected reach of the natural channel was shortened by a factor of 0.5 and slope was increased from 1.4 m/km to 2.8 m/km. The design bottom width of the relocated channel was 7.5 m, top width was 14 m, and the cross section was trapezoidal with 2:1 side slopes and an average depth of 1.3 m. The outer bank of the curved downstream section of the relocated channel is cut in stratified bedrock, which probably prevented erosion there during the flood. Abutment fill-slopes of the bridges were revetted, with concrete slope pavement on the left bank and sacked concrete on the right.

POST-ALTERATION FACTORS--In connection with general scour at the bridges, the bank revetment on the abutment fill-slopes was undermined. The concrete slope pavement subsided and the slabs were displaced downslope. The sacked concrete also failed on the lower slope but remained more intact than did the pavement. In the area of general scour, bottom width of the relocated channel was increased from its original value of 7.5 m to 11 m. The revetment had not been repaired by 1979, and no further erosion was apparent. Vegetation had become re-established along the relocated channel (fig. 95B).

DISCUSSION--In view of the small size and prior stability of the natural channel, and its border of dense forest, it would probably have remained stable if general scour had not been induced at the bridges by contraction of flood flow.

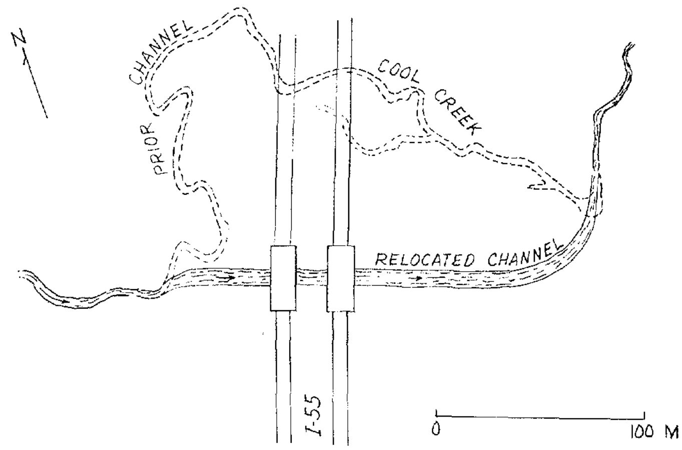


Figure 94. Plan sketch of channel relocation, Cool Creek.

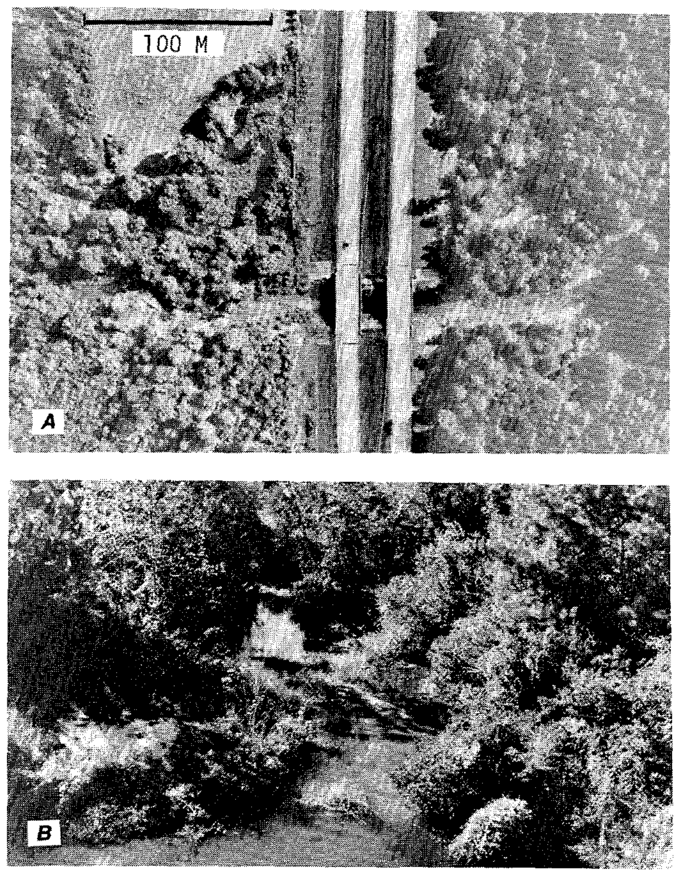


Figure 95. Cool Creek at site 40. A, Airphoto of site in 1975. B, Relocated channel in 1979, as viewed upstream from I-55 bridge.

SITE 41. TICKFAW RIVER AT
I-12 NEAR HOLDEN, LA.

SYNOPSIS--Channel relocation, reach 825 m in length straightened and shortened to 488 m, for alinement at bridge and to improve conveyance of flood flows (fig. 96). Performance period, 13 yr (1967-79). Major floods, having recurrence intervals of about 25 yr, were recorded at the U.S. Geological Survey gage on the Tickfaw River at Holden for the years 1974, 1977, and 1979. By 1979, bottom width of the relocated channel at the bridges, and extending upstream for about 25 m, had increased by 8 m owing to erosion of the left bank. Elsewhere, the bottom width had remained as built or had increased by no more than 5 m. The left bank is slumped at the downstream bend in the relocated channel (fig. 96C), but recession does not appear to be rapid. Comparison of large scale airphotos taken in 1967 and 1978 shows no perceptible effect of relocation on adjacent reaches of the natural channel.

Stability class B3 for relocated channel, class B2 for adjacent reaches of natural channel. Critical factors in widening of the relocated channel are the removal of bank vegetation, which was not replaced, and contraction of flood flows at the bridge.

SITE FACTORS--Lat 30°29', long 90°41', on I-12, 3 km south of Holden, La., on Frost 7.5' map. Tickfaw River is perennial, drainage area of 648 km^2, average discharge 10 m^3/s, 50-yr flood estimated at 546 m^3/s. Channel width is 18 m; bank height is 3-3.5 m, and channel slope is 0.54 m/km at site. Equiwidth point-bar stream, alluvial, sinuosity 1.4. As seen on an airphoto taken in 1959, the channel banks were continuously raw, apparently from a dredging operation. By 1967, the channel width had narrowed and vegetation was mostly re-established. Tickfaw River is on the deltaic plain of the Mississippi River, and has no flood plain in the usual sense. It flows through a dense forest, and tree cover along the channel is greater than 90 percent. Bed material is sand, and bank material is homogeneous clayey silt of low to moderate coherence.

ALTERATION FACTORS--Relocation resulted in a reduction in channel length by a factor of 0.6, and an increase in channel slope from 0.54 m/km to 0.91 m/km. The relocated channel had a trapezoidal cross section, with a bottom width of 24.4 m, a top width of 41 m, average depth of 3.5 m, and side slopes of 2:1. No countermeasures were placed along the channel, although the bridge abutment fill-slopes were revetted with sacked concrete.

POST-ALTERATION FACTORS--Although a pile bent at the bridge, originally on the flood plain, has been brought within the channel by erosion of the left bank, the bank recession does not appear to be progressive; and no countermeasures have been applied. Vegetation has been re-established partially, but not continuously, along the relocated channel.

DISCUSSION--As compared with the natural channel, which has a bottom width of about 18 m and a top width of about 24 m, the relocated channel was built with a bottom width of 24.5 m and a top width of 41 m. This increase in width was enough to offset the increase in slope, yet not so much as to induce infilling and the formation of a meandering low-water channel. Widening of the relocated channel in the vicinity of the bridge is attributed to contraction of flood flow, and could probably have been prevented with a suitable revetment.

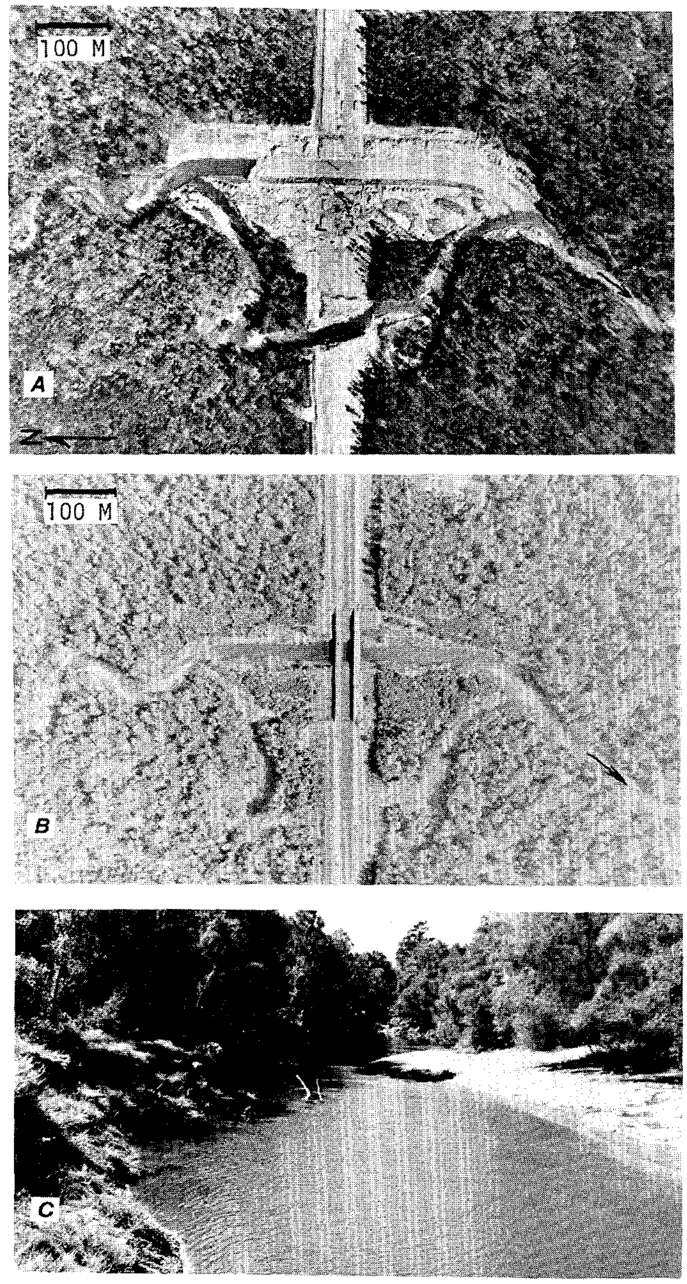


Figure 96. Tickfaw River at site 41. A, Airphoto of site during relocation in 1967. B, Airphoto of site in 1978. (From Louisiana Dept. of Transportation) C, Downstream end of relocated channel. Left bank is at outside of curve in channel.

SITE 42. BIG BRANCH AT I-12 NEAR HOLDEN, LA.

SYNOPSIS--Reach 297 m in length relocated for channel alinement with bridges; relocated reach has a length of 305 m (figs. 97A and B). Performance period, 13 yr (1967-79). Although Big Branch is ungaged, it probably had major floods in 1974, 1977, and 1979, as floods of approximate 25-yr recurrence interval were recorded for these years on the nearby Tickfaw River. No instability of the relocated channel was observed in 1979. Because of the excessive width of the relocated channel, a meandering low-flow channel has developed within it (fig. 97C).

Stability class A1 for relocated channel, and class B1 for natural channel, which appears to have been locally straightened, perhaps several decades ago. Inasmuch as channel length was slightly increased in relocation, change in slope is not a critical factor. Bank stability has been in part due to the excessive channel width, which may subsequently prove to be a liability.

SITE FACTORS--Lat 30°29', long 90°39', at I-12, about 3 km southeast of Holden, La., on Frost 7.5' map. Big Branch is perennial, drainage area of 28 km^2, 50-yr flood estimated at 71 m^3/s. Bottom width of channel, 4.5 m; top width, about 7 m, bank height, 2 m; channel slope, 0.3 m/km. Equiwidth stream, consisting mainly of straight segments, which may have been artificially straightened at some past date; alluvial, sinuosity 1.4. Valley relief, 5 m; continuous forest along channel. Bed material is sand, bank material is clayey silt of moderate coherence.

ALTERATION FACTORS--The relocated channel was built to a trapezoidal cross section, with a bottom width of 17 m, a top width of 24 m, side slopes of 2:1, and an average depth of 2 m. The natural channel is intersected at nearly a right angle at the downstream transition.

POST-ALTERATION FACTORS--No significant amount of erosion is apparent from major floods during the performance period, and no maintenance has been required. Re-establishment of vegetation along the relocated channel is generally good.

DISCUSSION--Bottom width of the relocated channel is 17 m, as compared with a bottom width of about 4.5 m for the prior channel. Probably, this increase in width was intended to convey flood flows without the use of spur dikes. Downstream from the bridges, a meandering low-flow channel has formed and most of the channel bottom is grassed (fig. 97C). Conveyance of the channel may eventually be reduced by the growth of trees on the channel bottom.

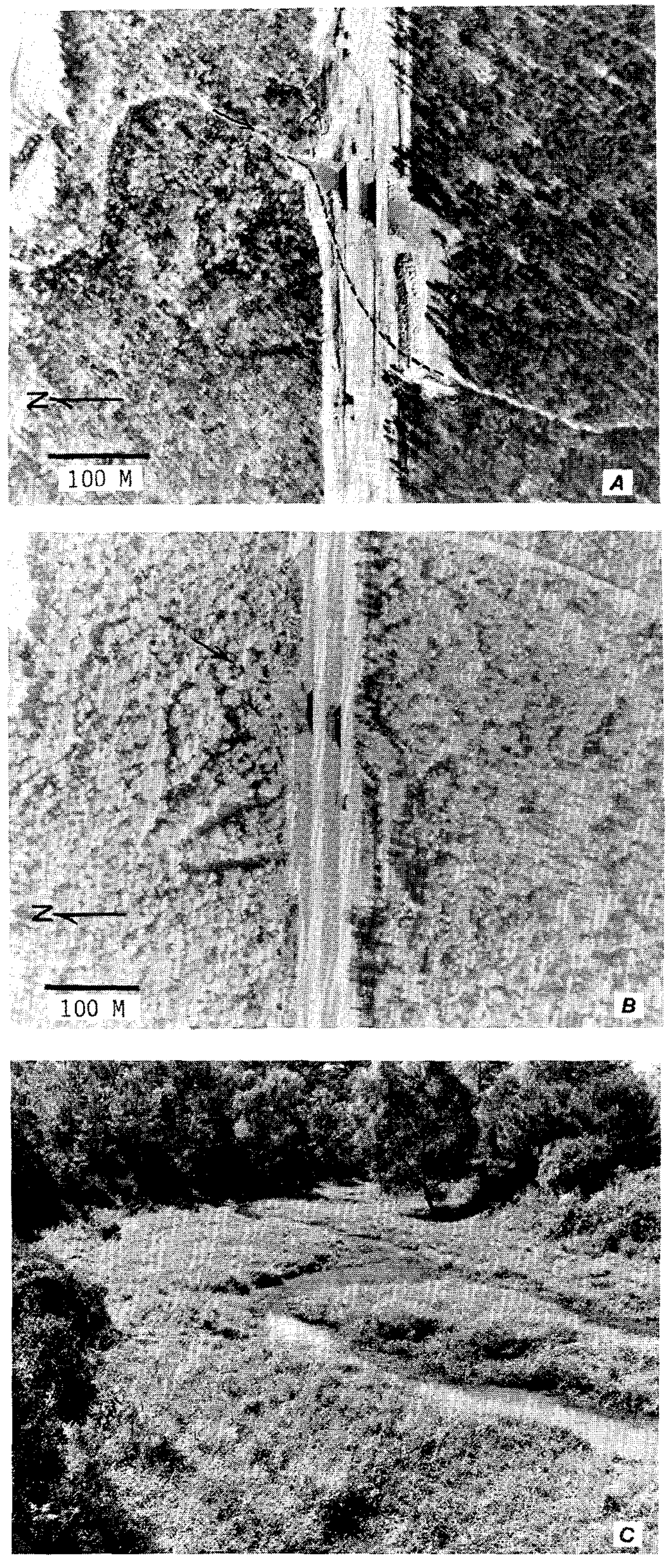


Figure 97. Big Branch at site 42. A, Airphoto of channel relocation, in 1967. Prior channel is indicated by dashed line. B, Airphoto of relocated channel, in 1978. (From Louisiana Dept. of Transportation) C, Relocated channel as viewed downstream from I-12 bridge, in 1979.

SITE 43. REDWOOD CREEK AT SR-19 NEAR ETHYL, LA.

SYNOPSIS--Channel relocation, reach 198 m in length straightened and shortened to 134 m for improvement of channel alinement at bridge (figs. 98 and 99A. Performance period, 31 yr (1949-79). The highest peak water discharge for the period of record (1966-79) occurred in 1977. Field observation in 1979 indicated that the relocated channel was stable except for minor bank slumping, and its width was less than the value shown on the design plans. Adjoining segments of the natural channel tend to be unstable, as indicated by cut banks at bends and a generally sparse growth of vegetation on the bank slopes; also, a history of instability is indicated by oxbow lakes and abandoned former courses on the flood plain.

Stability class B1 for relocated channel, class C2 for adjoining reaches. Critical factors in stability of the relocated channel are the short length of the relocation, the bottom width of the relocated channel (which is slightly greater than that of the natural channel), and the establishment of vegetation along the relocated channel.

SITE FACTORS--Lat 30°47.5', long 91°07.5', at SR-19, about 1 km east of Ethyl, La., on Clinton 7.5' map. Redwood Creek is perennial, drainage area of 70 km^2, no information on discharge. Bottom width of channel is 8 m, top width is 15 m, bank height 2.5 m, channel slope 6.2 m/km. Equiwidth point-bar stream, somewhat incised, alluvial, sinuosity about 1.5. Valley relief, 15 m; width of flood plain, 900 m; tree cover along channel, greater than 90 percent. Bed material is sand, bank material is dominantly silt of low to moderate coherence.

ALTERATION FACTORS--By cutting off a meander loop, the reach was shortened by a factor of 0.68. The relocated channel was built to a trapezoidal cross section, with a bottom width of 12 m, a longitudinal slope of 8.8 m/km, and a depth of 2.5 m. Sacked concrete was placed on the bridge abutment fill-slopes, but no countermeasures were placed along the relocated channel.

POST-ALTERATION FACTORS--Although Redwood Creek is not gaged at this site, a flood was recorded at the U.S. Geological Survey gage at Slaughter (16 km downstream) in 1977. In 1979, the banks of the relocated channel were grassed within the highway right-of-way, and elsewhere bordered by trees (fig. 99B).

DISCUSSION--In 1979, the relocated channel was somewhat more stable in aspect than sinuous reaches of the natural channel. It is doubtful if relocation had any effect on the natural channel, which tends to be somewhat unstable because of erodible banks.

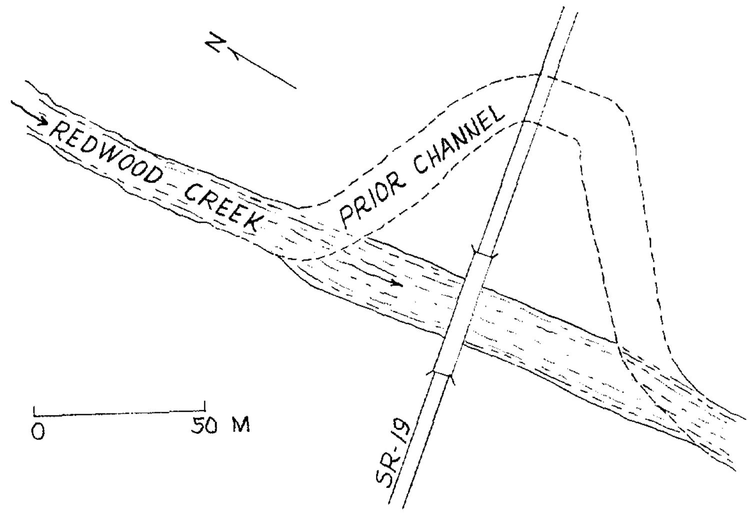


Figure 98. Plan sketch of channel relocation, Redwood Creek at SR-19.

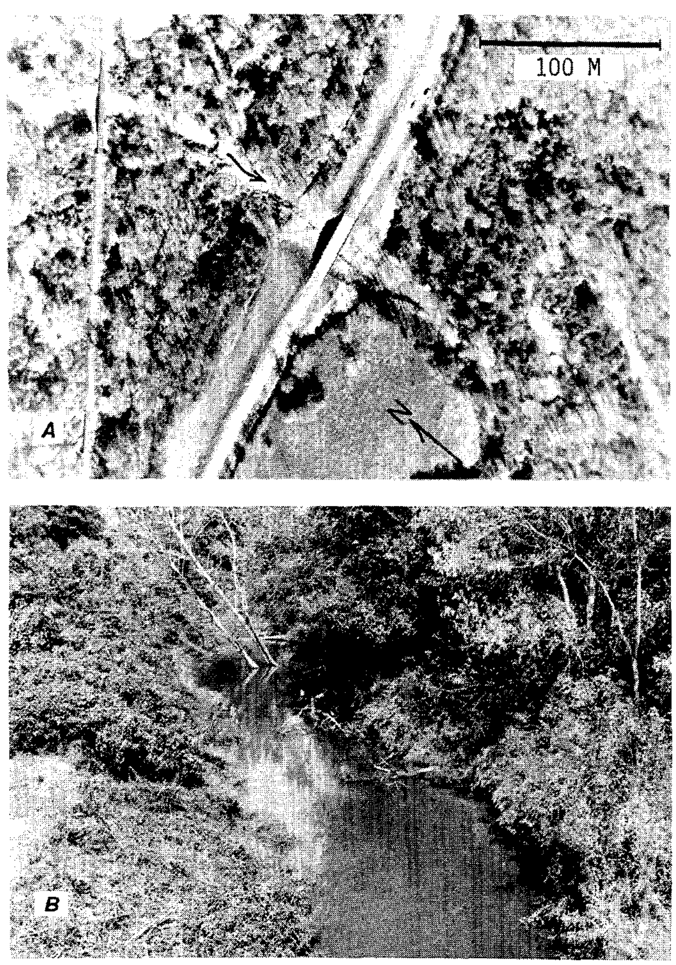


Figure 99. Redwood Creek at site 43. A, Airphoto of site in 1974. (From Louisiana Dept. of Transportation). B, Creek as viewed upstream from SR-19 bridge, in 1979. Natural channel begins at trees.

SITE 44. DOYLE BAYOU AT SR-19 NEAR SLAUGHTER, LA.

SYNOPSIS--Reach 220 m in length relocated, widened, and decreased slightly in length for purpose of alinement at bridge (fig. 100). Performance period, 31 yr (1949-79). By 1979, the relocated channel had increased in width from an as-built value of 11 m to about 13 m. The low banks were vegetated, with grass on the left bank and trees on the right (fig. 101), and were generally stable except for minor erosion at the bend just downstream from the SR-19 bridge.

Stability class B2 for relocated channel and B2 for adjacent segments of the natural channel. Critical factors in bank stability of the relocated channel are evidently its near correspondence in length and slope with the cut-off section of natural channel, and its width, which is large for the size of its drainage basin (6 km^2). At normal stage, water velocity in the relocated channel is barely preceptible.

SITE FACTORS--Lat 30°44.5', long 91°08', at SR-19, 1.2 km north of Slaughter, La., on Jackson 7.5' map. Doyle Bayou is perennial, alluvial, drainage area of 6 km^2, bankfull channel width of 6-8 m, channel slope 1.6 m/km. Sinuosity is 1.1, valley relief is 5 m, and tree cover along channel is in the range of 50-90 percent. Bed material is sand, and bank material is silt with minor clay content.

ALTERATION FACTORS--The relocated channel has nearly the same length and slope as the natural channel, but its top width is nearly twice as great (11 m, as compared with 6 m for the natural channel).

POST-ALTERATION FACTORS--No flood history of the site is available, but at the nearby gage on Redwood Creek the highest peak flow in a 13-yr period of record occurred in 1977.

DISCUSSION--A bend such as that in the relocated channel downstream from SR-19 bridge (fig. 100) would have induced more severe bank erosion on many streams, as would the bend at the railroad bridge. Here, water velocity at normal discharge is too low to have any erosive effect, and, because of the wide shallow cross section, velocity would not be high at bankfull stage.

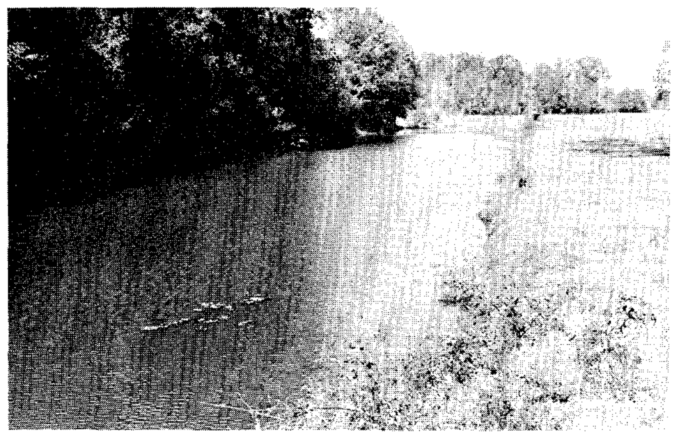


Figure 101. Relocated channel of Doyle Bayou in 1979, as viewed upstream toward bridge.

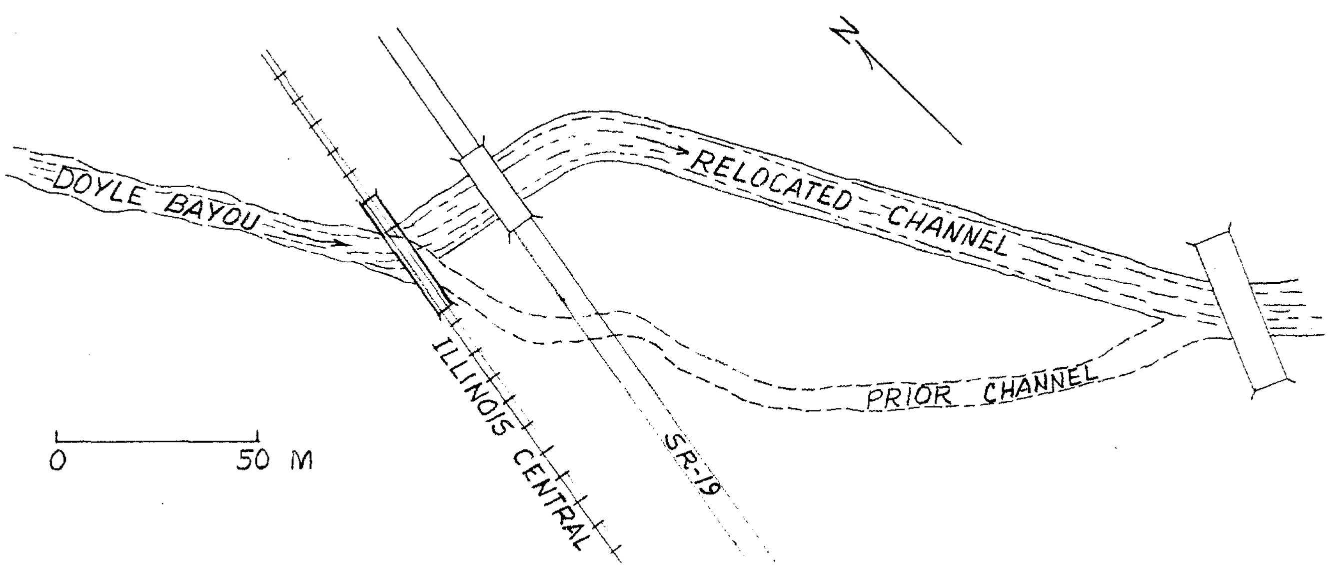


Figure 100. Plan sketch of channel relocation, Doyle Bayou.

SITE 45. TRIBUTARY TO MAIDEN CHOICE BRANCH AT I-95 AT BALTIMORE, MD.

SYNOPSIS--A 650-m length of a small ephemeral drainage channel was relocated to accommodate the interchange at I-95 and Caton Avenue (fig. 102). Performance period, 7 yr (1971-78). In 1972, an extreme peak discharge was recorded in the nearby Gwynns Falls basin, and a smaller flood occurred in 1975. The relocated channel was trapezoidal in cross section, with a bottom width of 2.2 m and side slopes of 2:1. A series of controlled vertical drops with concrete bottoms and side slopes (fig. 103A) was constructed in the relocated channel to diminish slope and the possibility of supercritical flow. During subsequent severe rainstorms, the vertical drops were damaged and several sections of the concrete lining were transported downstream for a distance of about 30 m. The damaged sections of concrete lining were replaced by gabions. Sediment that has accumulated in the channel downstream from the relocation appears to have been derived from a steep, wide side slope that was graded and left bare.

Failure of the concrete lining is tentatively attributed to hydrostatic pressures, for the relief of which no weep holes were provided. Bulging and cracking of some remaining sections of the lining (fig. 103A) were observed in 1978. Peak flow in the stream channel was very probably increased by extensive removal of vegetation during interstate construction (compare figs. 103B and C), and sediment supply was much increased by erosion of the bare side-slope, on which gullies were observed in 1978. The timing of the severe 1972 storm, soon after construction, was unfortunate, because it did not allow time for vegetation to become established.

SITE FACTORS--Lat 39°16', long 76°40', near south boundary of Baltimore, Md., at I-95 at Caton Avenue interchange, on Baltimore West 7.5' map. The unnamed tributary is ephemeral, with a drainage area of about 1 km^2. The channel is alluvial, with a slope in the range of 13-28 m/km. Prior to interstate construction, most of the drainage basin was forested (fig. 103B).

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(See "Synopsis")

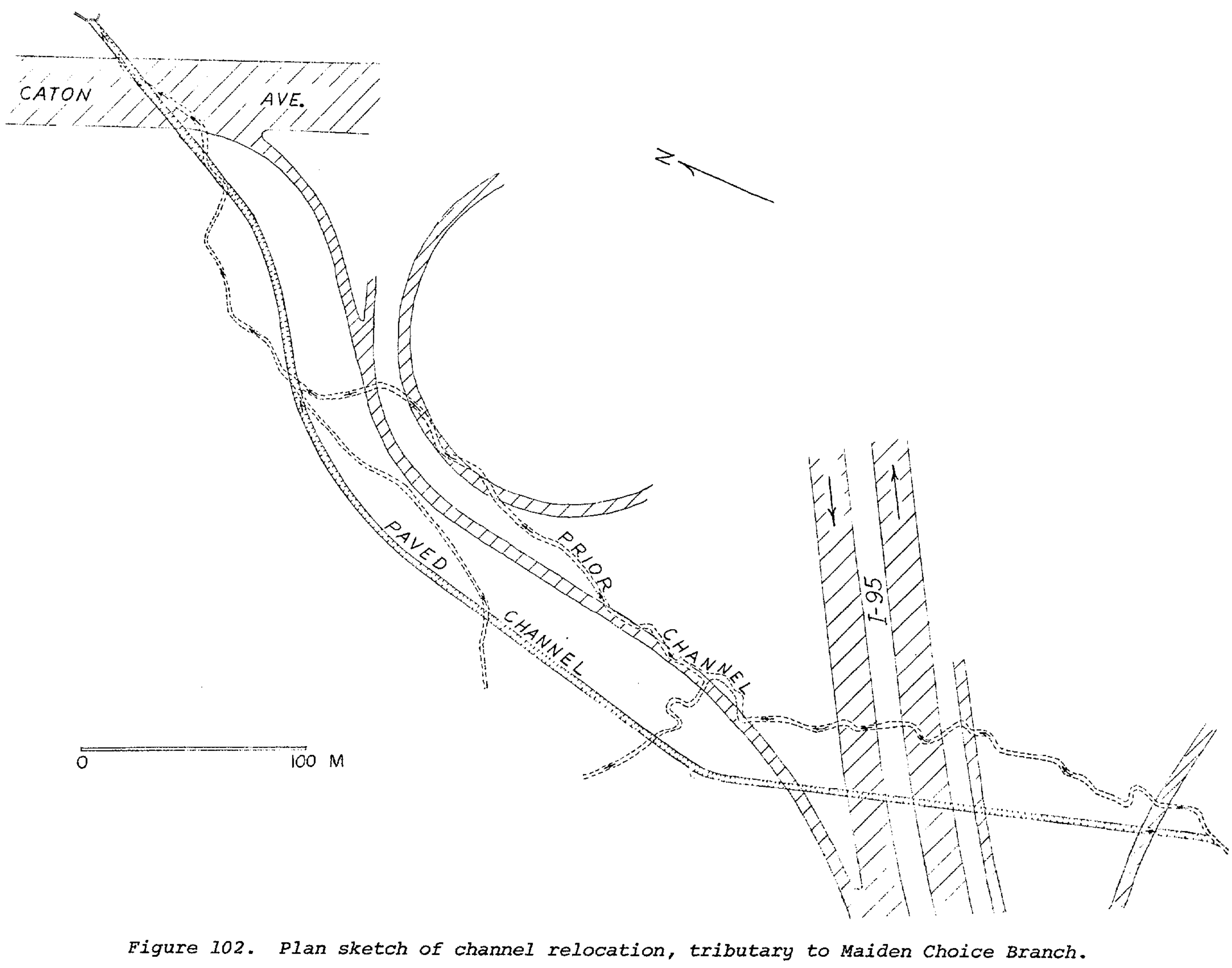


Figure 102. Plan sketch of channel relocation, tributary to Maiden Choice Branch.

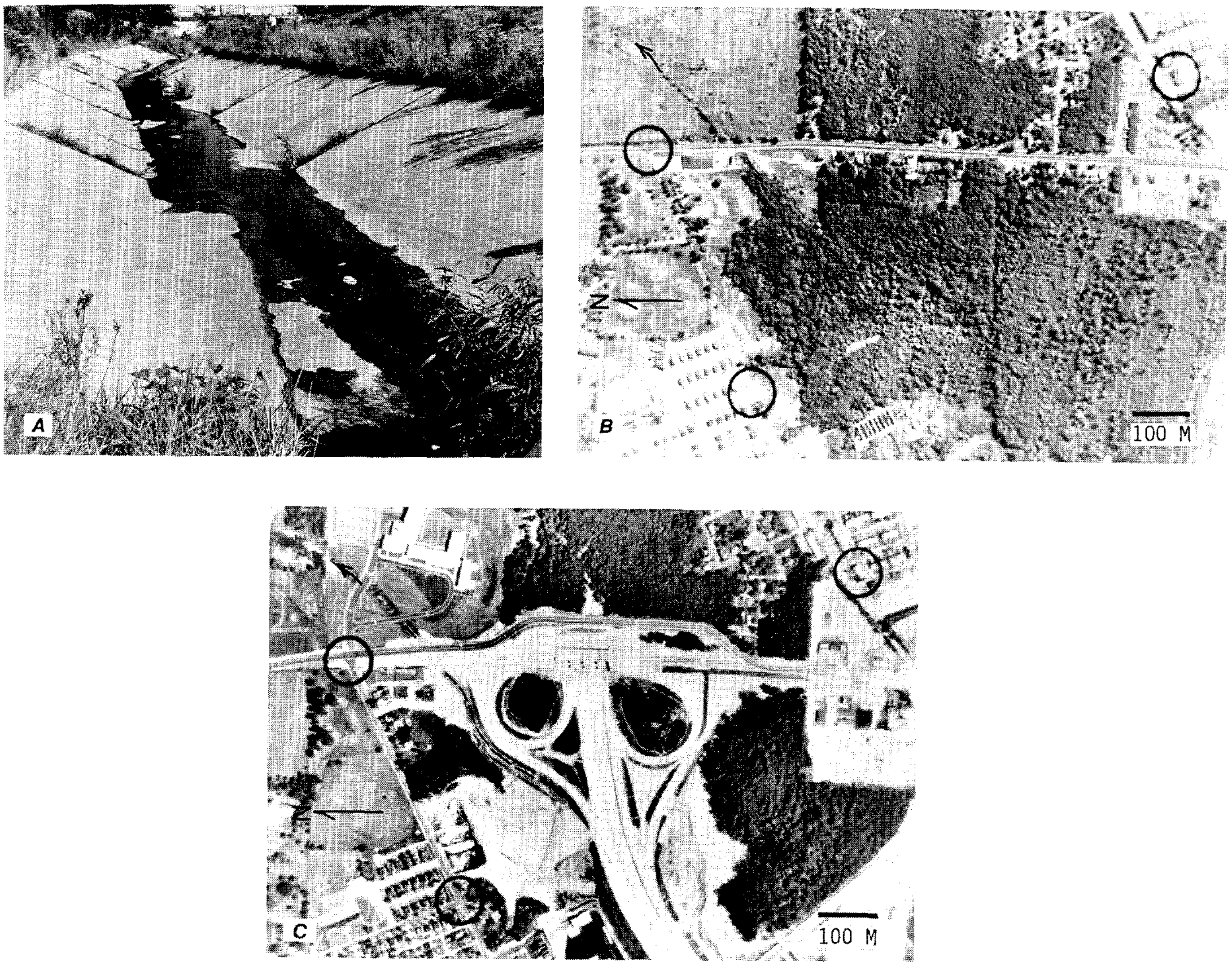


Figure 103. Tributary to Maiden Choice Branch at site 45. A, Original concrete lining of relocated channel, as photographed in 1978. Note bulging and cracking of bottom. B, Airphoto of relocation site in 1957. Reference points are circled for comparison with 1971 airphoto. (From U.S. Dept. of Agriculture). C, Airphoto of relocation site in 1971. Note bare side slope above bottom circled reference point.

SITE 46. MOORES RUN AT I-95 AT BALTIMORE, MD.

SYNOPSIS--Channel relocation, reach 1,128 m in length shortened to 945 m, to reduce number of crossings and to make room for roadway (fig. 104). Performance period, 7 yr (1971-78). Although there is no stream gage on Moores Run, a nearby gaged stream (Stemmers Run) of similar drainage area has an average discharge of 0.15 m^3/s and has had two flows at or near bankfull stage since 1971. The relocated channel was designed for a 50-flood of 168 m^3/s; peak flow in 1978 is estimated at 55 m^3/s. The relocated channel was protected from lateral erosion by continuous rock-and-wire mattress along both banks; and from degradation by gabion stilling pools downstream from the culvert (fig. 105A) and the twin bridges. In general, the countermeasures are in good condition, but the rock-and-wire mattress has sagged locally because of piping in the underlying soil. Also, the gabion toe wall appears to have been undercut at the stilling pool downstream from the bridges (fig. 105B), exposing the plastic filter cloth. As shown on an airphoto taken in 1966, cut banks and wide point-bars were present on adjacent segments of the natural channel prior to relocation, indicating a moderate degree of lateral instability.

Stability class of relocated channel, A1; of adjacent segments of natural channel, B. Aside from the fact that no major floods have occurred since relocation, the critical factor in the stability of the relocated channel is probably the use of countermeasures. In addition, the actual shortening of the channel by relocation was not very severe (shortening factor of 0.84).

SITE FACTORS--Lat 39°19', long 76°32', on I-95 in Baltimore, Md., on Baltimore East 7.5' map. Moores Run is perennial, drainage area of 12 km^2 at site, 50-yr flood estimated by Maryland Dept. of Transportation at 168 m^3/s. Channel width is 10 m, bank height is 1.5-2 m, and channel slope is 2.8 m/km. Wide-bend point-bar stream, alluvial, sinuosity of 1.3. Valley relief is 25 m, width of flood plain is 75 m. Tree cover along channel, 50-90 percent. Bed material is small gravel, bank material is coherent silt-clay. Prior to relocation, the natural channel had probably been affected by urbanization, as indicated by local cut banks and apparent incision upstream from the site.

ALTERATION FACTORS--Channel length was decreased by a factor of 0.84. Channel width was increased by a factor of 2.3, from a top width of 10 m for the natural channel to 23 m for the relocated channel. The relocated channel has a bottom width of 16 m, a slope of 3.6 m/km, a side slope of 1.5:1, and a maximum depth of 3 m at design flood. Rock-and-wire mattress 0.3 m (1 ft) in thickness, on plastic filter cloth, was placed continuously along both banks, and check dams consisting of 1x1-m gabions were placed across the channel at 30-m intervals. Stilling pools lined with rock-and-wire mattress were placed downstream from the culvert and the twin bridges. Side ditches were lined with rock-and-wire mattress. The mattresses and the gabions were constructed of PVC-coated wire, and filled with stones ranging in diameter from 50 to 200 mm. The two bends in the channel, on either side of the culvert, are about 120 m in radius.

POST-ALTERATION FACTORS--In addition to the minor undercutting of countermeasures, previously described, sediment has accumulated in the north cell and the center cell of the three-cell box culvert, such that low flow is conveyed by the south cell. However, the flood capacity of the culvert has not been significantly reduced. In 1978, young trees had become well established in and around the mattress on the relocated channel, providing additional bank protection (figs. 105A and B). Trees are likely to encroach on the overly-wide channel and reduce its flood capacity.

DISCUSSION--The relocated channel is well protected by countermeasures and, because of the establishment of vegetation, is likely to remain stable even if the rock-and-wire mattress should fail locally. The channel was made overly wide in order to contain, within banks, the design flood; but this has entailed the risk of reduction in capacity by encroachment of vegetation, unless it is periodically cleared.

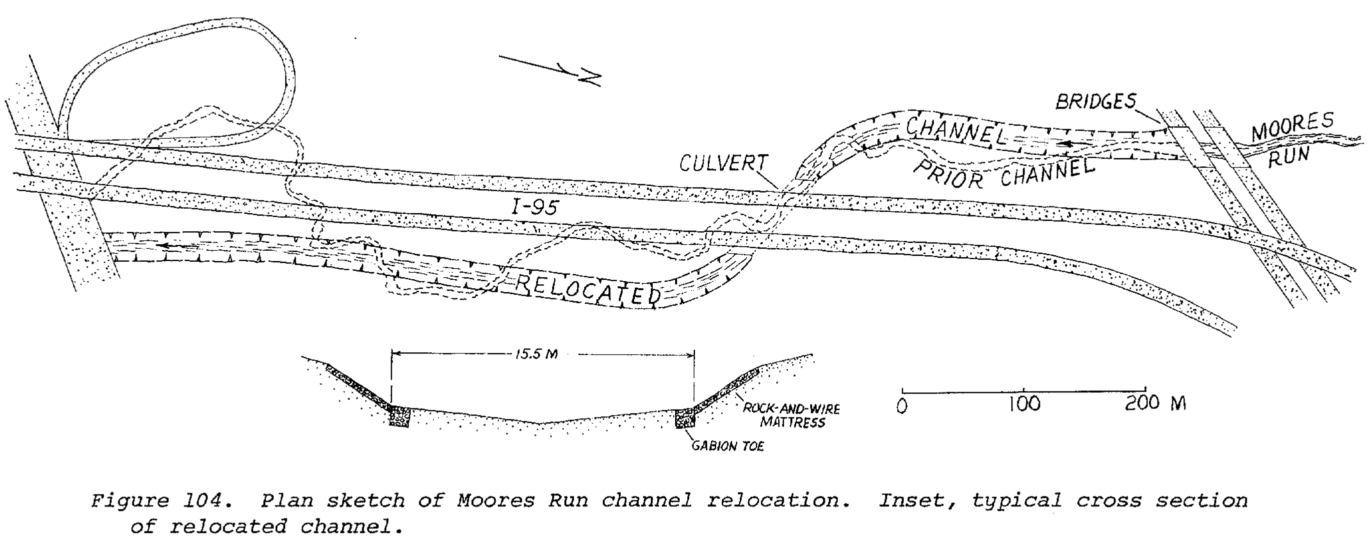
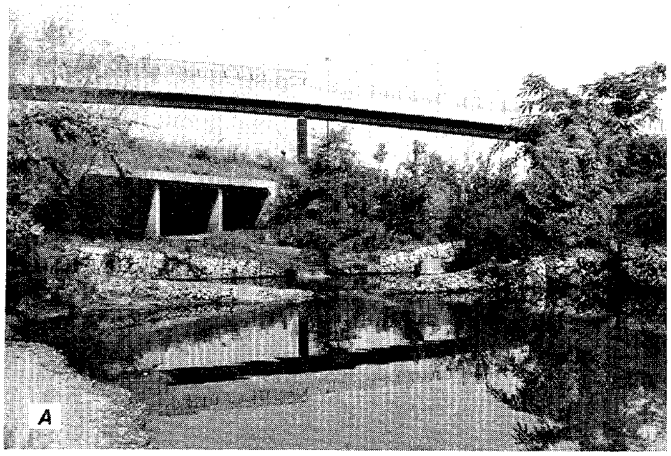


Figure 104. Plan sketch of Moores Run channel relocation. Inset, typical cross section of relocated channel.



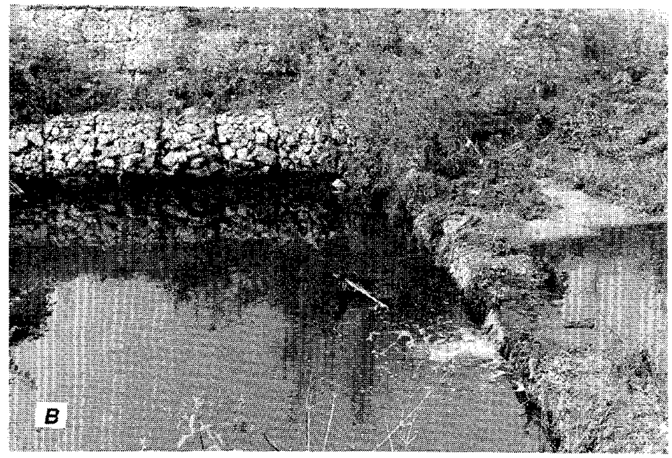


Figure 105. Moores Run at site 46. A, View upstream of stilling basin downstream from culvert. B, Apparent undercutting of gabion at toe of side slope, on stilling pool downstream from twin bridges. Note rock-and-wire mattress in background.

SITE 47. SOUTH BRANCH TOBACCO RIVER AT US-27 AT CLARE, MICH.

SYNOPSIS--Channel relocation, reach 555 m in length shortened to 252 m by cutting off two meanders; for purpose of improving channel alinement at bridges and facilitating passage of floods (fig. 106). Performance period, 17 yr (1962-79). The nearest stream gage is on the Tobacco River at Beaverton, where the maximum flow has neared, but not exceeded, bankfull stage in only two years since 1962. Vegetation has become well established along the relocated channel (fig. 107A). The only indication of instability on adjacent segments of the natural channel is minor bank erosion on the outside of the bend at the downstream junction of relocated and natural channel (fig. 107B).

Stability class A1 for both the relocated channel and adjacent segments of the natural channel. Critical factors in stability of the relocated channel are judged to be the same as those that account for the unusual stability of the natural channel: (1) Because of storage of ground and surface water on the glacial drift plain traversed by the stream, flood hydrographs tend to be flat; also maximum discharges tend to be similar each year, and the maximum discharge of record (at the U.S.G.S. gage on Tobacco River at Beaverton) is only about twice that of the annual maximum discharge. (2) Because of the low evaporation rate, the banks tend to remain moist and vegetation becomes established quickly.

SITE FACTORS--Lat 43°50', long 84°45', on US-27, 1.5 km east of Clare, Mich., on Clare 15' and Loomis 7.5' maps. South Branch Tobacco River is perennial, drainage area of 157 km^2, which is entirely on a glacial drift plain characterized by swamps, lakes, and irregular hummocky topography. At the nearest stream gage, which is about 32 km downstream on the main stem of the Tobacco River, the two largest flows during the period of record (1948-78) exceeded bankfull stage by less than 0.3 m. Channel width, 12 m; bank height, 1 m; channel slope, 1.8 m/km. Equiwidth point-bar stream, alluvial, sinuosity 2.2 at site. Valley relief, about 15 m; width of flood plain, 250 m. Trees along the channel have been partially cleared for agriculture and housing, and tree cover was in the range of 50-90 percent in 1958. Bed material is sand and gravel, and bank material is non-coherent sand and gravel. A small reservoir (lake) was constructed in the town of Clare, just upstream from the site at some time during the period 1958-65. The natural channel has few cut banks, and no lateral migration could be discerned by comparison of airphotos taken in 1958 and in 1965. At one locality, however, a bypass channel across a meander loop had become substantially widened.

ALTERATION FACTORS--Relocation resulted in shortening of the natural channel by a factor of 0.45 and a consequent increase in slope from 1.8 m/km to 4 m/km. No as-built cross sections of the relocated channel were available, but a width of 12 m was measured on the plans, and this is nearly the same as the width of the natural channel. In 1978, remnants of "fieldstone" (glacial boulder) riprap were observed along the banks, but the extent of the original revetment could not be ascertained.

POST-ALTERATION FACTORS--In 1978, the relocated channel was bordered by well-established vegetation and there was no indication of present or past instability. Bank stability of adjacent segments of the natural channel was generally good, and similar to that observed on a 1958 airphoto.

DISCUSSION--On stream in many regions, a channel relocation of this kind would likely result in bank erosion and channel degradation, unless effective countermeasures were used. Since the bank materials are non-coherent, the stability of this site must be attributed to the "non-flashy" flow characteristics of the stream and to the effects of vegetation.

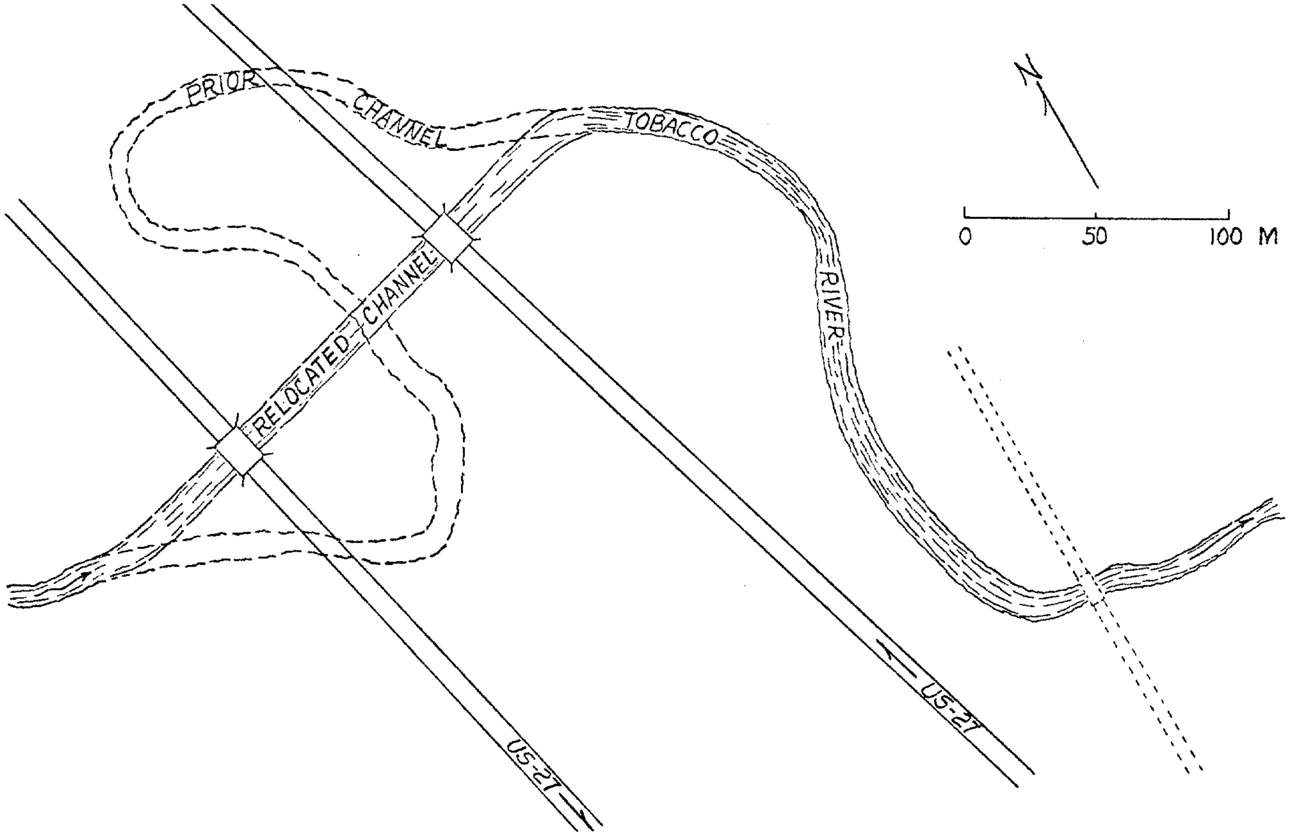


Figure 106. Plan sketch of channel relocation, South Branch Tobacco River.

Figure 107. South Branch Tobacco River at site 47. A, Relocated channel in 1978, as viewed downstream from bridge on southbound lane. B, Downstream junction of relocated and natural channel, in 1978.

SITE 48. TOWN LINE CREEK AT
US-27 NEAR HARRISON, MICH.

SYNOPSIS--Channel relocation, reach 130 m in length shortened to 100 m, to improve flow alinement at bridges and to avoid crossing a wide divided section of channel (figs. 108 and 109A). Performance period, 15 yr (1964-79). Although Town Line Creek is ungaged, records at a nearby gage (Muskegon River near Merritt) suggest that no flows much greater than bankfull stage have occurred since 1964. In 1978, both the relocated channel and adjacent segments of the natural channel had well vegetated banks (figs. 109B and C) and there was no indication of past or present instability.

Stability class A1, for both relocated and natural channel. Critical factors in channel stability are: (1) Regulation of flow by storage of water in swamps and lakes. (2) Growth of swamp vegetation along the banks. (3) The low slope and shallow depth of the channel, which are usually associated with low flow velocities.

SITE FACTORS--Lat 44°09', long 84°48', on US-27, 13 km north of Harrison, Mich., on Harrison 15' map. Town Line Creek is perennial, drainage area of roughly 140 km, which occupies a glacial drift plain characterized by many swamps and lakes; no records of discharge. Channel width is 10 m, bank height is 0.5 m, and channel slope is about 0.1 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 2. Valley relief, 10 m; no flood plain formed by stream, which is flowing through a swamp on glacial deposits. Channel is bordered by a dense and continuous growth of swamp vegetation. Bank material is peat.

ALTERATION FACTORS--In relocation, the channel length was shortened by a factor of 0.77. The channel slope was not significantly changed, nor was the channel width. No countermeasures were installed.

DISCUSSION--This site provides an example of an exceptionally stable natural channel that was not likely to be disturbed by relocation. All of the factors that promote channel stability are operative: coherent banks, dense vegetal cover, low channel slope, and natural regulation of flow.

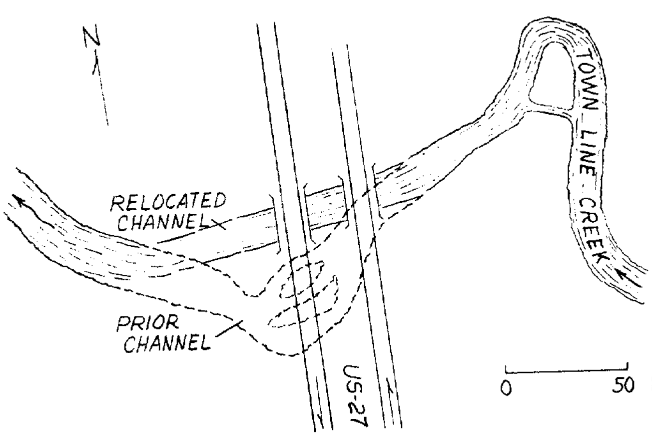


Figure 108. Plan sketch of channel relocation, Town Line Creek.

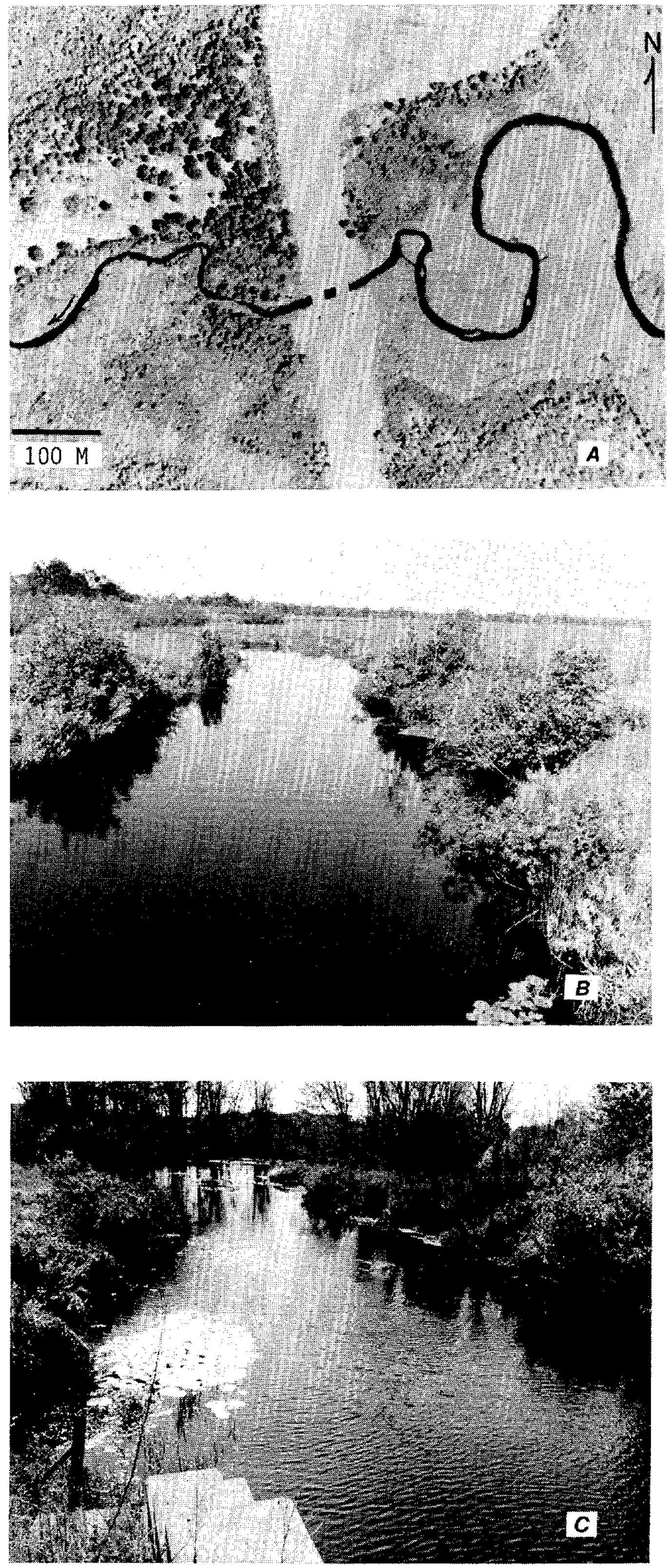


Figure 109. Town Line Creek at site 48. A, Airphoto of channel relocation in 1965. (From U.S. Dept. of Agriculture) B, View downstream from bridge, in 1979, relocated channel in foreground. C, View of natural channel upstream from bridge, in 1979.

SITE 49. MUSKEGON RIVER AT SR-155 NEAR MARION, MICH.

SYNOPSIS--Channel relocation, reach 1,840 m in length shortened to 520 m by cutting off three meander loops, to improve alinement at crossing and to prevent encroachment of meander loops on the roadway (fig. 110A). Performance period, 41 yr (1939-79). At the nearest stream gage (at Evart, 25 stream-kilometers downstream), floods about 0.6 m above bankfull stage occurred in 1957, 1959, and 1976. Bottom width of the relocated channel as shown on the plans is 140 ft (42.5 m), but the as-built width may have been somewhat greater. In 1979, bottom width of the relocated channel (fig. 110B) ranged from 45 to 50 m. This is a common width range in straight reaches of the natural channel. In 1979, adjacent segments of the natural channel were generally stable (fig. 110C), and the cut banks at the outside of some bends were considered a normal characteristic of the stream.

Stability class A2 for relocated channel, B for adjacent segments of the natural channel. Critical factors in channel stability are: (1) natural regulation of flow by storage in lakes and swamps, and (2) dense growth of natural vegetation, which is almost continuous along the channel.

SITE FACTORS--Lat 43°59', long 85°05', on SR-155, 16 km south of Marion, Mich., on Lake 15' map. Muskegon River is perennial, with a drainage area of about 3,400 km^2 at site and an average discharge of about 24 m^3/s. Channel width, 50 m; bank height, 1.5 m; channel slope, 0.26 m/km. Equiwidth point-bar stream, whose width tends to be greater in straight reaches than at bends; alluvial, sinuosity of 2.3 at site. Valley relief is 15 m; width of flood plain is about 2,000 m. Stream traverses dense forest, except for scattered patches of cleared ground. Bed and bank materials are sand, and logs of bore holes indicate that sand, interbedded with "blue clay", extends to a depth of at least 12 m. Comparison of airphotos taken in 1958 and in 1965 showed no measurable lateral migration of the natural channel, but some lateral migration, probably at a slow rate, is indicated by the few cut banks and the oxbow lakes.

ALTERATION FACTORS--The reach was shortened by a factor of 0.28, which increased the channel slope from 0.26 m/km to a probable value of 0.4 m/km, the slope of the valley. No channel cross sections or design data are on file at the Michigan Department of Transportation, and the available plans indicate that the relocated channel had a flat bottom 42.5 m (140 ft) in width, with 2:1 side slopes. The bridge abutment fill-slopes are riprapped with "fieldstone" of boulder size, grouted with concrete where immediately beneath the bridge. There is no record and no field evidence of countermeasures along the relocated channel

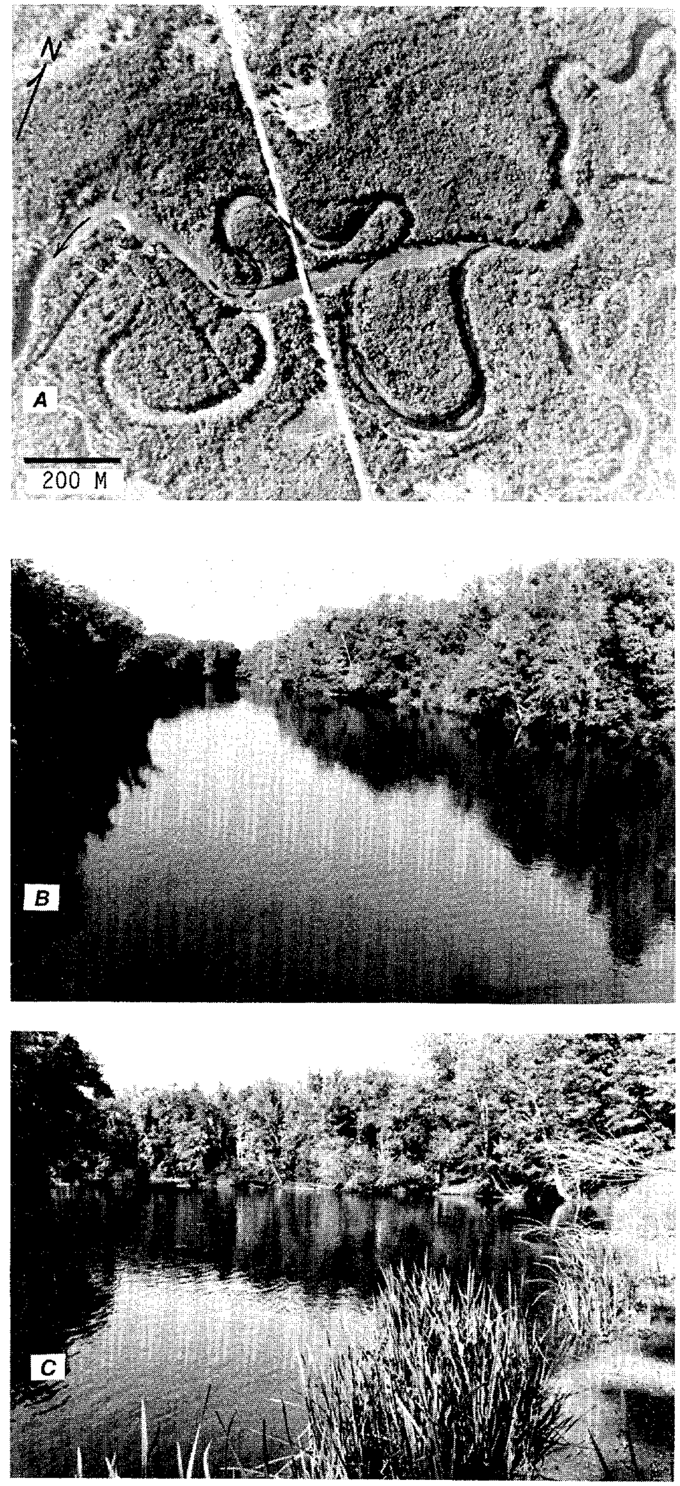


Figure 110. Muskegon River at site 49. A, Airphoto, taken in 1965, showing relocation at SR-155. (From U.S. Dept. of Agriculture) B, relocated channel downstream from bridge, in 1979. C, Natural channel at first bend downstream from relocation.

POST-ALTERATION FACTORS--At the U.S.G.S. stream gage at Evart, where bankfull stage is 12 ft (3.7 m), floods about 2 ft (0.6 m) above bankfull stage occurred in 1957, 1959, and 1976. Floods above bankfull stage probably occurred in these years at the site. In 1979, the banks of the relocated channel and surrounding areas were densely forested. There is no evidence of maintenance or installation of countermeasures at the site.

DISCUSSION--In view of the size of the stream and the rather drastic shortening in relocation, the stability at this site is remarkable, and it must be attributed to the factors that account for the prior stability of the natural channel. The principal type of instability evident for the natural channel is the diversion of flow into bypass channels, which are probably formed during ice jams.

SITE 50. PERE MARQUETTE RIVER AT BALTIMORE AND OHIO RAILROAD CROSSING NEAR BALDWIN, MICH.

SYNOPSIS--No channel alteration was done at this site, but it provides an extraordinary example of the feasibility of dispensing with alterations on very stable streams (fig. 111A). In spite of the apparent danger that two meander loops might encroach on the railroad embankment, the railroad was built on a narrow neck of land between two loops. The railroad was probably constructed about 1900, but not later than 1911, because it is shown on its present location on a map dated 1911. No lateral migration of the loops could be discerned by comparing a 1958 airphoto with field conditions in 1979, and the loops have probably not migrated by a significant amount since construction of the railroad.

SITE FACTORS--Lat 43°52', long 85°51', on Baltimore and Ohio Railroad 5 km south of Baldwin, Mich., on Baldwin 15' map. Pere Marquette River is perennial, drainage area of about 400 km^2 at site, no record of discharge at site. At the nearest stream gage (Pere Marquette River at Scottville, about 50 kilometers downstream), the four maximum flows during the period of record (1940-78) were about 0.6 m above bankfull stage. Channel width, 20 m; bank height, 1.5 m to very narrow flood plain, about 10 m to bordering upland. Channel slope variable, but maximum value is about 1.6 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 2.9 downstream from site. Valley relief, 25 m; flood plain very narrow, about 80 m in width, bordered by glacial outwash plain. Dense forest cover is continuous along channel. Bed material is sand and small gravel, bank material is non-coherent sand and gravel.

DISCUSSION--The stability of this stream is attributed to natural regulation of flow by ground- and surface-water storage, to incision, and to the dense growth of vegetation along the banks and surrounding areas. Steep unvegetated banks of non-coherent sand and gravel occur at the outside of some bends (fig. 111B), but these evidently erode very slowly.

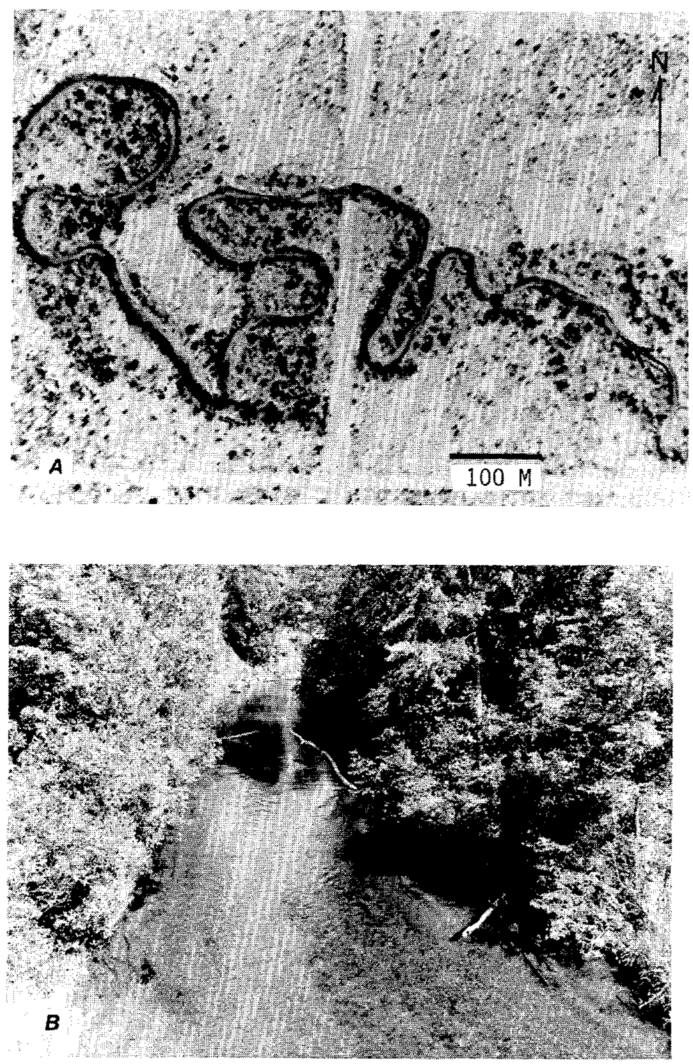


Figure 111. Pere Marquette River at site 50. A, Airphoto of site in 1958. (From U.S. Dept. of Agriculture) B, Channel upstream from railroad bridge, in 1979.

SITE 51. BETSIE RIVER AT SR-115
NEAR THOMPSONVILLE, MICH.

SYNOPSIS--Channel relocation, reach 360 m in length straightened and shortened to a length of 260 m, for purpose of improving channel alinement at bridge (figs. 112 and 113A). Performance period, 40 yr (1940-79). Although the streamflow is unrecorded, the performance period is sufficiently long that moderately high flows probably occurred during the period. Bottom width of the relocated channel is given as 13 m (42 ft) on the relocation plans; in 1965, the bottom width ranged from 13 to 19 m, and this same width range was observed in the field in 1979. Bank stability of the relocated channel was generally good in 1979 (figs. 113B and C), and bank erosion was restricted to minor undercutting of the root mat at water level. Banks along adjacent segments of the natural channel were well vegetated except where bends impinged against terraces, and raw banks at such localities are probably natural features of the stream.

Stability class A2 for relocated channel, class B for adjacent segments of the natural channel. Critical factors in channel stability are: (1) natural regulation of flow by storage of ground and surface water on the glacial drift plain traversed by the stream, and (2) stabilization of the banks by vegetation.

SITE FACTORS--Lat 44°30.5', long 85°53', on SR-115, 2.5 km southwest of Thompsonville, Mich., on Thompsonville 15' map. Betsie River is perennial, drainage area of approximately 260 km^2 at site, no record of discharge. Channel width varies irregularly, but is in the range of 10-15 m; bank height to the active flood plain is about 1.5 m, but banks are commonly higher where the stream impinges against terraces; channel slope is 0.5 m/km as measured on the topographic map. Equiwidth point-bar stream, alluvial, sinuosity in range of 1.5 to 2. Valley relief of about 60 m; flood plain about 300 m in width, bordered by several distinct terrace levels. Less than 50 percent of the bankline is bordered by mature trees, but the banks are well vegetated with small trees, shrubs, and annuals. Bed material is sand and gravel, bank material is mostly sand containing abundant organic matter.

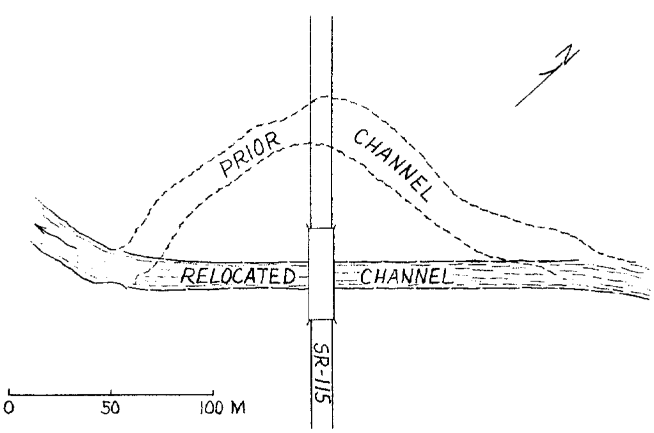


Figure 112. Plan sketch of channel relocation, Betsie River.

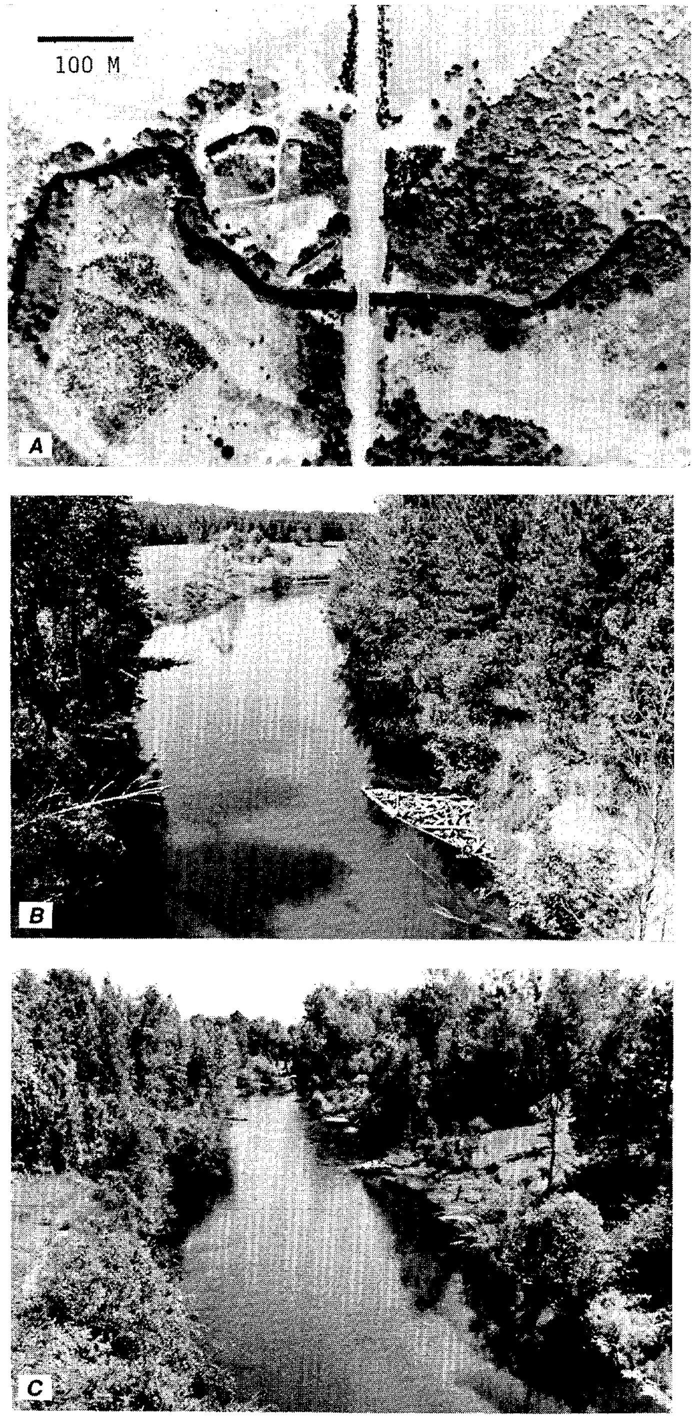


Figure 113. Betsie River at site 51. A, Airphoto of site in 1965. (From U.S. Dept. of Agriculture) B, Relocated channel downstream from bridge, in 1979. Grouted-riprap bank revetment and fish habitat structure at right. C, View upstream from bridge in 1979; relocated channel in foreground.

ALTERATION FACTORS--Channel length at the site was reduced by a factor of 0.72 by relocation, but channel width was not significantly changed. Slope of the relocated channel is specified at 0.3 percent (3 m/km) on the plans, a value substantially higher than would be indicated by the general channel slope (0.5 m/km) as measured on the topographic map. A channel of trapezoidal shape, with 2:1 side slopes, is specified, but in 1979 the slope of unrevetted banks was more nearly 1:1. Grouted "fieldstone" riprap revetment (fig. 113B now extends along both banks for a distance of 28 m upstream and downstream from the bridge; this was not specified in the plans, but it may have been installed at the time of construction.

POST-ALTERATION FACTORS--Log spurs, probably installed by the Michigan Department of Natural Resources as fish habitat structures (fig. 113B) were in place along the channel in 1979, but are not on a 1965 airphoto. These consist of small logs randomly placed, held together with spikes and secured to the stream bottom with log stakes. That such a structure would remain intact for several years is evidence of the low erosive power of the stream. The grouted riprap revetment, although not keyed into the sandy bank at the upstream end, has not been undercut.

DISCUSSION--Although the stream is small, and its flow regulated by natural storage, the amount of erosion that has occurred during a 40-yr period is surprisingly low, in view of the sandy, noncoherent bank material. Under these circumstances, annual vegetation and shrubs are evidently effective in preventing bank erosion. Flow depth at "normal" stage is shallow, averaging about 0.3 m.

SITE 52. PETERSON CREEK AT SR-37 NEAR YUMA, MICH.

SYNOPSIS--Segment of small stream (2.5 m in width and 430 m in length) relocated and thereby shortened to 320 m, to avoid multiple crossings and to improve alinement at culvert (fig. 114). Performance period, 28 yr (1952-79). There is no record of flow, but some moderately high flows during a period of this length are probable. Banks of both relocated and natural channel were densely vegetated in 1979 (fig. 115), and there was no indication of present or past instability.

Stability class A1 for relocated channel, class A for adjacent segments of natural channel. Critical factors in channel stability are: (1) Natural regulation of flow by swamps and lakes on the glacial drift plain traversed by the stream. (2) The effectiveness of vegetation, including shrubs and grasses, in controlling bank erosion on a small stream.

SITE FACTORS--Lat 44°14', long 85°48', on SR-37, 13.5 km south of Yuma, Mich., on Wellston 15' map. Peterson Creek is perennial, drainage area of approximately 13 km^2, no records of discharge. Channel width, 1.5-2 m; channel slope, 1.4 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.5. Valley relief, 60 m; narrow flood plain. Both banks densely wooded, tree cover greater than 90 percent. Bed material is sand and fine gravel.

ALTERATION FACTORS--Channel length was shortened by a factor of 0.75, and the channel slope was thus increased from a value of 1.4 m/km for the natural channel to 1.85 m/km for the relocated channel. Channel width was increased from 2.5 m to about 4 m. At the outside of each of the three bends in the relocated channel (fig. 114), bank revetment consisting of 6 m^3 (8 yd^3) of riprap was installed.

DISCUSSION--Although the planting of vegetation along the relocated channel is not specified in the plans, and no vegetation along the channel is discernible on a 1952 airphoto, soil moisture conditions in the region are favorable for the rapid establishment of natural vegetation.

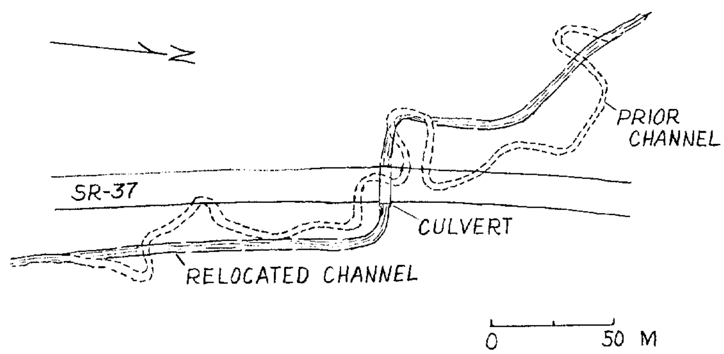


Figure 114. Plan sketch of channel relocation, Peterson Creek.

Figure 115. Relocated channel of Peterson Creek upstream from culvert, in 1979.

SITE 53. TAMARACK CREEK AT
US-31 AT HOWARD CITY, MICH.

SYNOPSIS--Two minor channel relocations, one at each bridge of a dual highway, to improve channel alinement at bridges (fig. 116). At the east bridge, a reach 165 m in length was curved and lengthened to 186 m; at the west bridge, a reach 113 m in length was shortened to 82 m. Performance period, 7 yrs (1972-79). Tamarack Creek is ungaged, but an adjacent stream (Little Muskegon River) had the highest flow for its period of record (1967-78) in 1975. This flow was approximately at bankfull stage. Banks of the relocated reaches (figs. 117A and B) are revetted with concrete slope pavement; and the only instability noted, on field inspection in 1979, was minor local subsidence of the pavement. No effect of relocation on adjacent segments of the natural stream was discerned.

Stability class A1 for relocated reaches, class A for adjacent segments. Critical factors in channel stability are: (1) Natural regulation of flow on the glacial drift plain traversed by the stream. (2) The stabilizing effects of natural vegetation and, along the relocated segments, of concrete slope pavement.

SITE FACTORS--Lat 43°24', long 85°29', on US-31, 1 km west of Howard City, Mich., on Howard City 15' map. Tamarack Creek is perennial, drainage area of approximately 200 km^2, no records of discharge. Channel width, 11 m; bank height, 1 m; channel slope, 0.9 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.3. Valley relief, 10 m; tree cover along channel, greater than 90 percent. Bed material is sand, bank material is non-coherent sand containing organic matter, interbedded with weakly coherent sandy clay.

ALTERATION FACTORS--No channel cross sections or hydraulic data for design were obtained for the site. As compared with the slope of the natural channel (0.9 m/km) the relocated channel slope is slightly less at the east bridge and slightly greater at the west bridge. Top width of the relocated channel ranges from 12 to 15 m, and bottom width ranges from 8-12 m, values that are about 20 percent greater than corresponding values for the natural channel. Both banks of the relocated channels are revetted with concrete pavement, throughout their length.

DISCUSSION--Minor subsidence of the concrete slope pavement is attributed to instability of the foundation rather than to stream erosion. The natural channel was undisturbed in the median area, and the relocated reaches were kept to a minimum length.

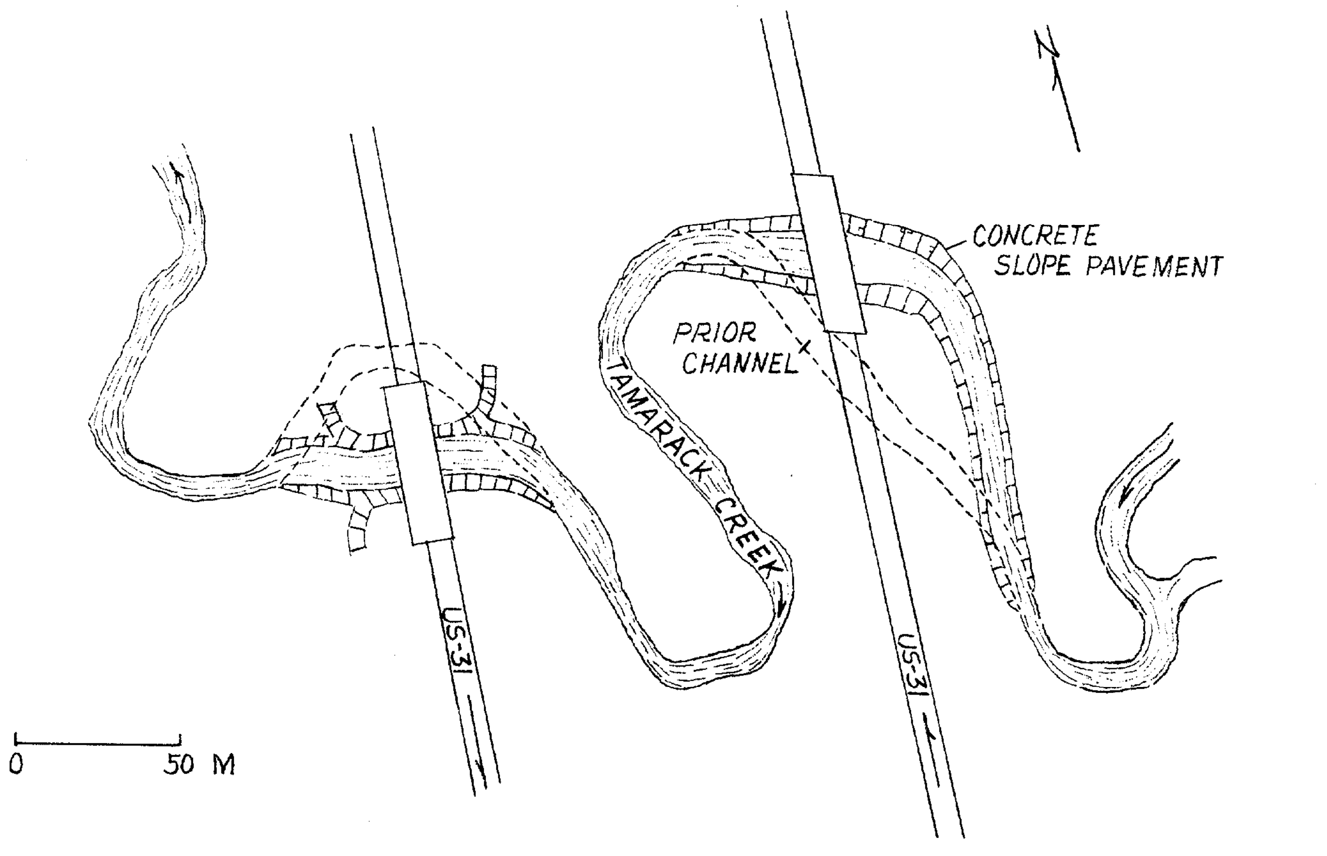


Figure 116. Plan sketch of channel relocation, Tamarack Creek.

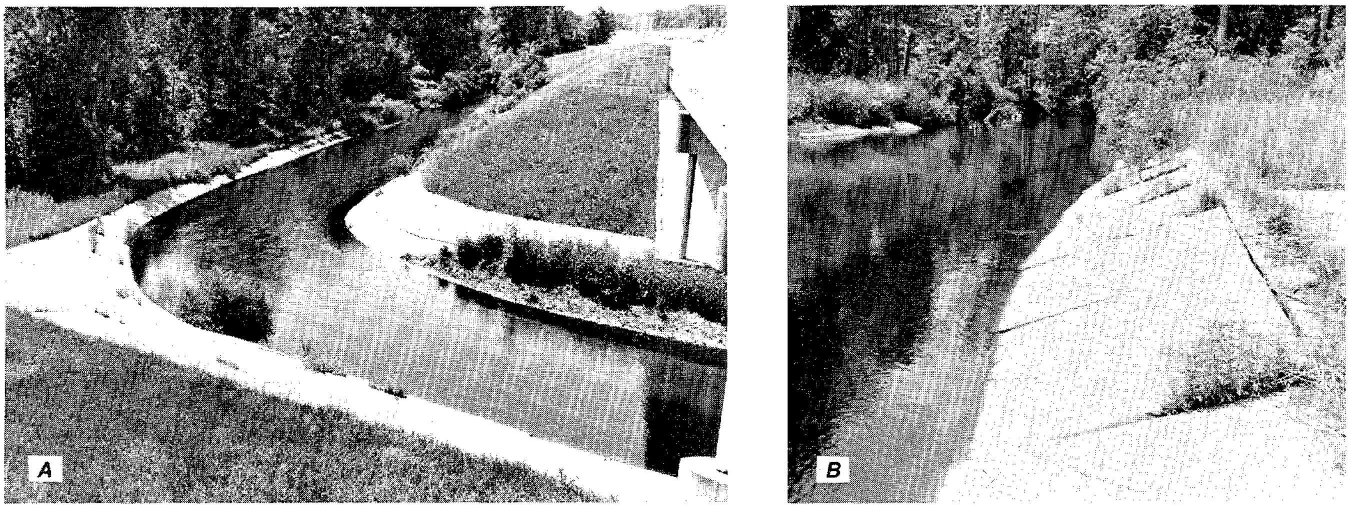


Figure 117. Tamarack Creek at site 53. A, View upstream from east bridge in 1979. B, View downstream from west bridge in 1979.

SITE 54. KANARANZI CREEK
AT I-90 AT ADRIAN, MINN.

SYNOPSIS--Channel relocation, reach 2,480 m in length shortened to 1,160 m, for purpose of improving alinement at a bridge on SR-91 and of avoiding two stream crossings by I-90 (figs. 118 and 119A. Performance period, 15 yrs (1965-79). As a result of normal spring runoff in 1966, bank erosion occurred along both banks downstream from the check dam; this was attributed to the occurrence of a layer of unconsolidated gravel in the bank alluvium. Subsequently, riprap was placed along the left bank upstream and downstream from the check dam, and at two other localities (fig. 118. A moderate flood, the largest in a 12-yr period of record where measured on a Kanaranzi Creek tributary, occurred in 1969. In 1979, the banks of the relocated channel were generally grassed and appeared stable; local cut banks did not appear to be actively eroding, and no further enlargement of the channel could be detected (figs. 119B, C, and D). Cut banks were common along the natural channel, to about the same extent as observed on an airphoto taken in 1954, prior to relocation.

Stability class B1 for relocated channel, class D for natural channel. Critical factors in stability of the relocated channel are: (1) Use of a check dam, with an overfall of 1.35 m, to offset the increase in slope resulting from severe channel shortening. (2) The greater width of the relocated channel, relative to the natural channel has probably served to reduce bank erosion by reducing depth and velocity. However, the stream will eventually meander within this wide channel (fig. 119D), eroding banks at bends. (3) Where installed, riprap has effectively prevented bank erosion.

SITE FACTORS--Lat 43°38.5', long 95°56', on I-90, 0.3 km north of Adrian, Minn., on Adrian 7.5' map. Kanaranzi Creek is perennial, drainage area of 300 km^2, 50-yr flood estimated by Minnesota Dept. of Transportation at 168 m^3/s. Channel width, 8 m at straight reaches; bank height, 1 m to active flood plain; channel slope, 1.3 m/km. Wide bend point-bar stream, alluvial, sinuosity 1.3. Valley relief, 30 m, width of flood plain, 700 m. Banks mostly grassed, tree cover less than 10 percent. Bed material is sand and medium gravel; bank material is moderately coherent silt-clay, with lenses of gravel. Prior to relocation, the natural channel was laterally unstable, as indicated by cut banks at the outside of bends and along straight reaches. The drainage basin of the stream, including the land immediately bordering it, is almost entirely cultivated, and the stability of the stream has no doubt been adversely affected by the removal of natural vegetation.

ALTERATION FACTORS--By relocation, channel length was reduced by a factor of 0.47 and channel slope would have been increased to 2.7 m/km if the check dam had not been installed. Water velocity of the 50-yr design flood was calculated to be 3 m/s without the check dam. With a 1.35 m drop in elevation at the dam, channel slope was reduced to 1 m/km above the dam and 0.8 m/km below the dam. The check dam is built of reinforced concrete and has steel sheet-pile cutoff walls. A .45-m weir at the dam was designed to divert the base flow of the stream through a culvert (fig. 118) into the prior channel, inasmuch as the City of Adrian had requested that flow be maintained in the prior channel. In 1979, this diversion was not functioning, because the culvert that was to convey flow beneath I-90 was mostly filled with sediment.

No "as-built" cross sections of the relocated channel are available. It was designed to have a bottom width of 15 m downstream from the check dam, and a width of 18 m above it, and 2:1 side slopes. According to a typical cross section (fig. 118), the bottom was not flat but had a radius of about 10 m. In 1979, the bottom was nearly flat (fig. 119C), evidently because of aggradation. A large gravel bar had formed in the channel downstream from the check dam. Rock riprap having a median diameter of 0.45 m was used in the vicinity of the check dam, and 0.3-m riprap was used elsewhere.

POST-ALTERATION FACTORS--No significant amount of bank erosion has occurred along the relocated channel after installation of the riprap in 1967, and no scour was observed in 1979 downstream from the check dam. As a result of the flood in 1969, the culvert intended to carry base flow to the prior channel was filled with sediment, and has not functioned since. There is no record of maintenance or installation of countermeasures since 1967. The low-flow channel has shifted from the center of the relocated channel to a position along the left bank (fig. 119C).

DISCUSSION--Bank-to-bank width of the relocated channel is about 26 m, as compared with a width of 16 m for a stable straight reach of the natural channel. By use of the check dam, slope of the relocated channel has been reduced to about 0.8 m/km, as compared with a slope of 1.3 m/km for the natural channel. The combined effect of increase in width and decrease in slope has been to induce minor aggradation, and lateral migration of the low-flow channel. These effects have not proved harmful so far, and the wide channel serves to reduce overbank flow during floods.

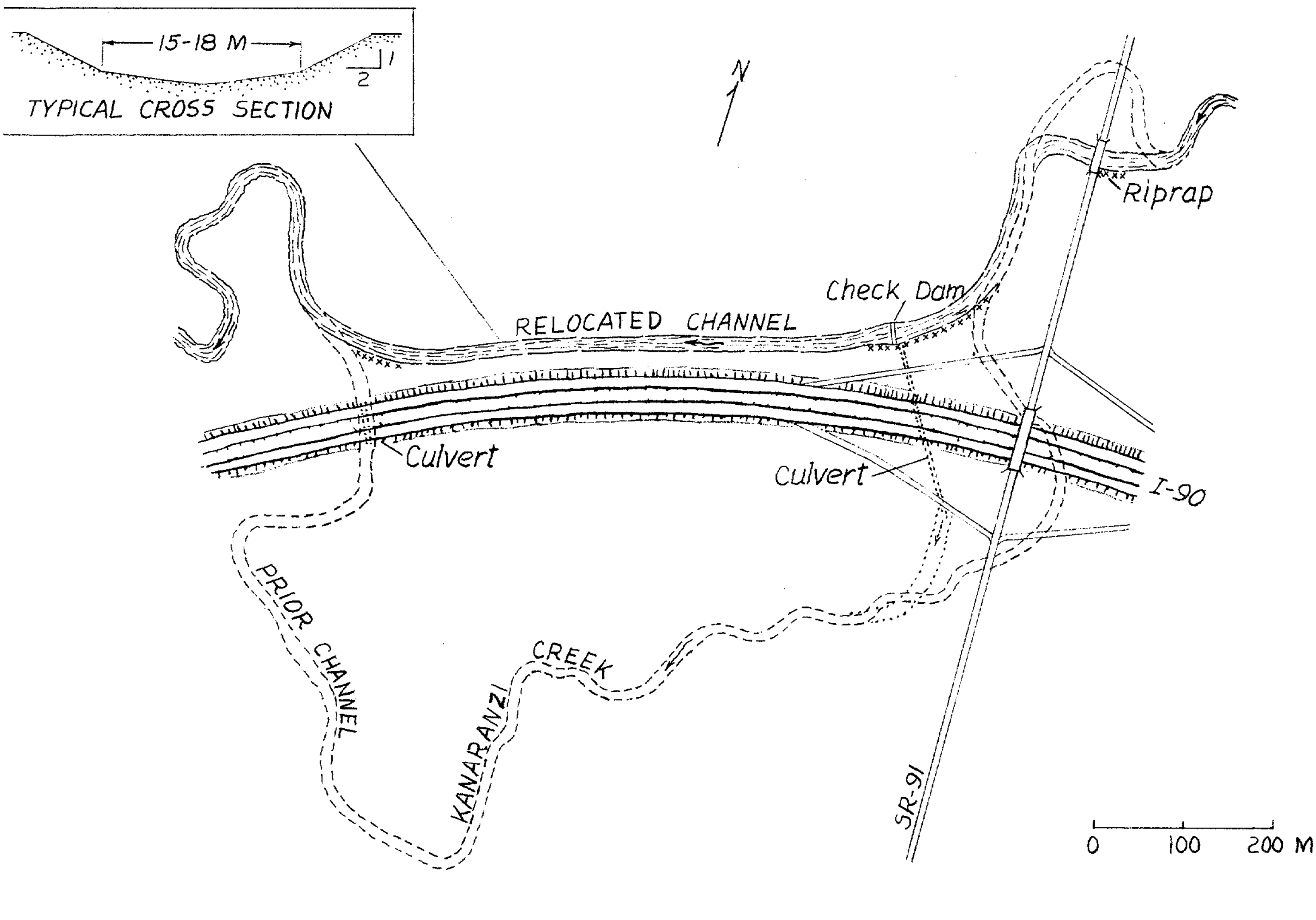


Figure 118. Plan sketch of Kanaranzi Creek channel relocation and (inset) typical cross section of the relocated channel.

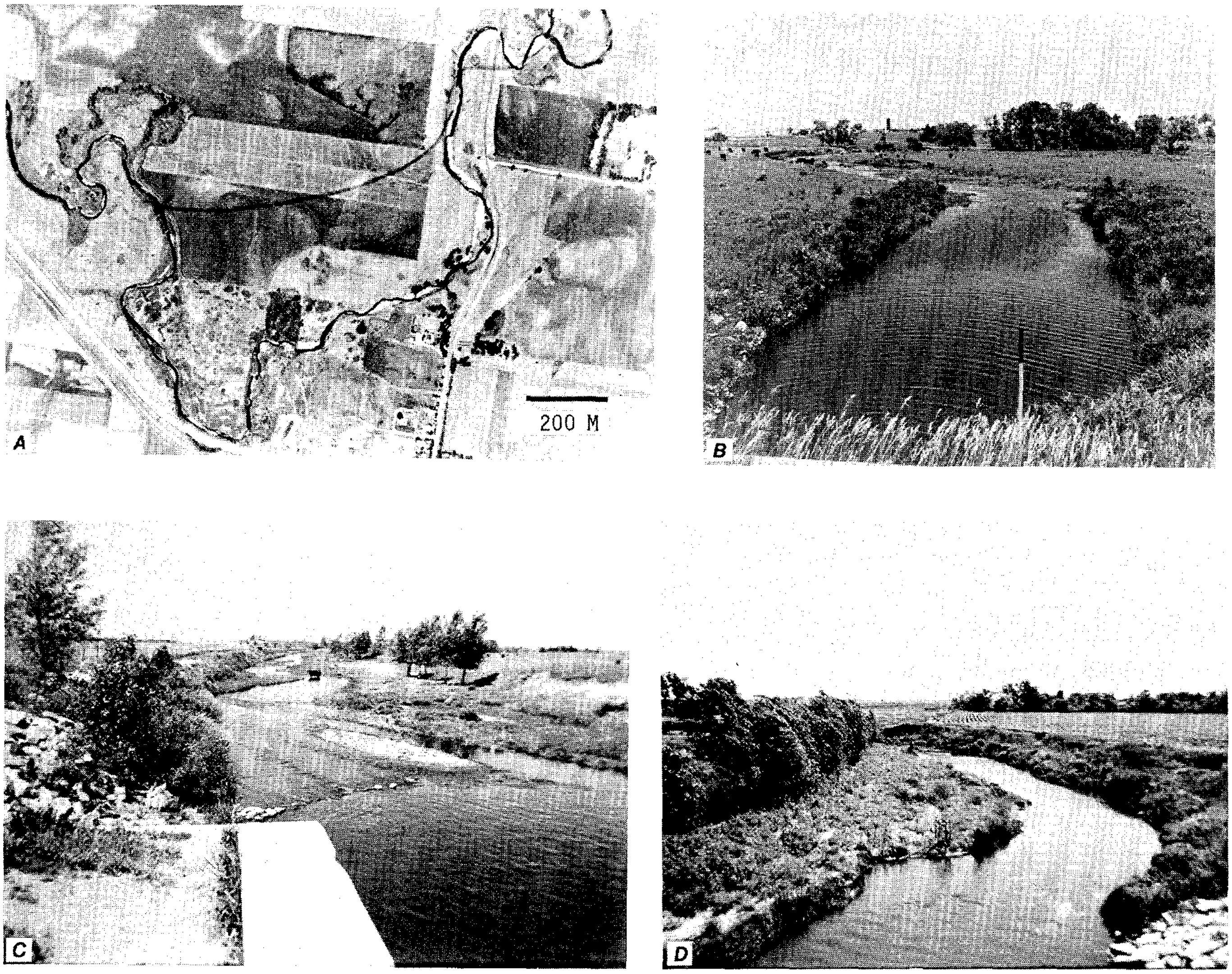


Figure 119. Kanaranzi Creek at site 54. A, Airphoto of site in 1954, before relocation. Solid line indicates position of relocated channel. (From U.S. Dept. of Agriculture) B, Relocated channel upstream from SR-91 bridge, in 1979. C, Relocated channel downstream from check dam, in 1979. D, Downstream intersection of prior channel, foreground, with relocated channel, right background.

SITE 55. COLLIE HOLLOW AT I-44 NEAR WAYNESVILLE, Mo.

SYNOPSIS--Channel was relocated and a segment was thereby shortened from a length 550 m to 490 m, for purpose of improving channel alinement at culvert (fig. 120). Performance period, 18 yr (1960-78), during which two or three rainstorms of fairly high intensity occurred, and a flood of about 5 yr recurrence interval is estimated. The relocated channel was trapezoidal in cross section, with a bottom width of 9 m, side slopes of 2:1, and a channel slope of about 8 m/km. No countermeasures were used. In 1978, the channel bottom width upstream from the culvert was in the range of 9-10.5 m; the right bank was raw and nearly vertical, and the left bank was more gently sloping and stabilized by vegetation (fig. 121A). Downstream from the culvert, the bottom width was about 12 m and the right bank was more stable than the left (fig. 121B). Channel degradation is indicated by the incised nature of the channel, but degradation has been halted by an outcrop of cherty limestone in the channel upstream from the site. Moreover, the degradation, and associated bank erosion, which is common to streams in the area, is attributed to land use practices rather than to relocation.

Stability class D2 for relocated channel and for adjacent segments of the natural channel. Bank erosion along the relocated channel is attributed to prior channel instability, to lack of bank protection measures, and to the erodibility of the bank materials. However, the relocated channel is not very different in stability and appearance from natural channels of similar size in the general area.

SITE FACTORS--Lat 37°47', long 92°17.5', at I-44, 10.5 km west of Waynesville, Mo., on Ozark Springs 7.5' map. Collie Hollow is intermittent, with a drainage area of 6.5 km^2. Channel bottom width is 6-7.5 m, top width is 16-18 m, bank height is about 2 m, and channel slope is 7.5 m/km. Braided incised stream, mainly alluvial but with scattered outcrops of bedrock in channel, sinuosity of 1.1, valley relief of 35 m, flood plain width about 10 channel widths, less than 50 percent vegetal cover along channel. Bed material is angular chert in the size range of gravel to small boulders, bank material is moderately coherent silt-clay and angular chert. About half of the drainage basin has been cleared, including the flat ground along the stream.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--Although the bank on one side of the relocated channel is cut, channel top width has not increased significantly since relocation. Bottom width of the relocated channel (9 m) was only slightly greater than that of the natural channel (6-7.5 m), but the thalweg has shifted against one bank. Bank erosion could probably have been prevented by a vegetal lining or some other bank protection measure.

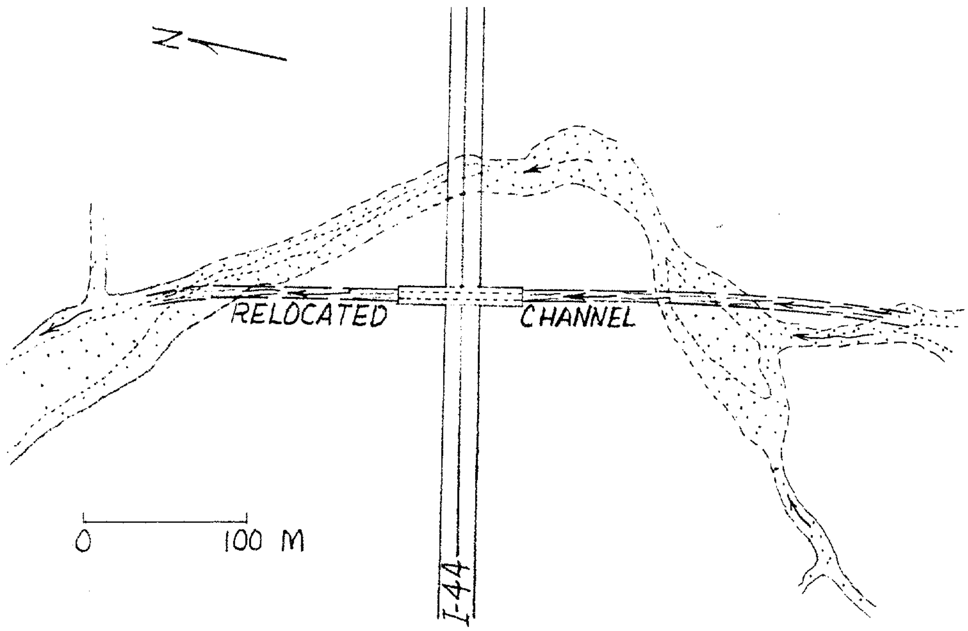


Figure 120. Plan sketch of Collie Hollow channel relocation.

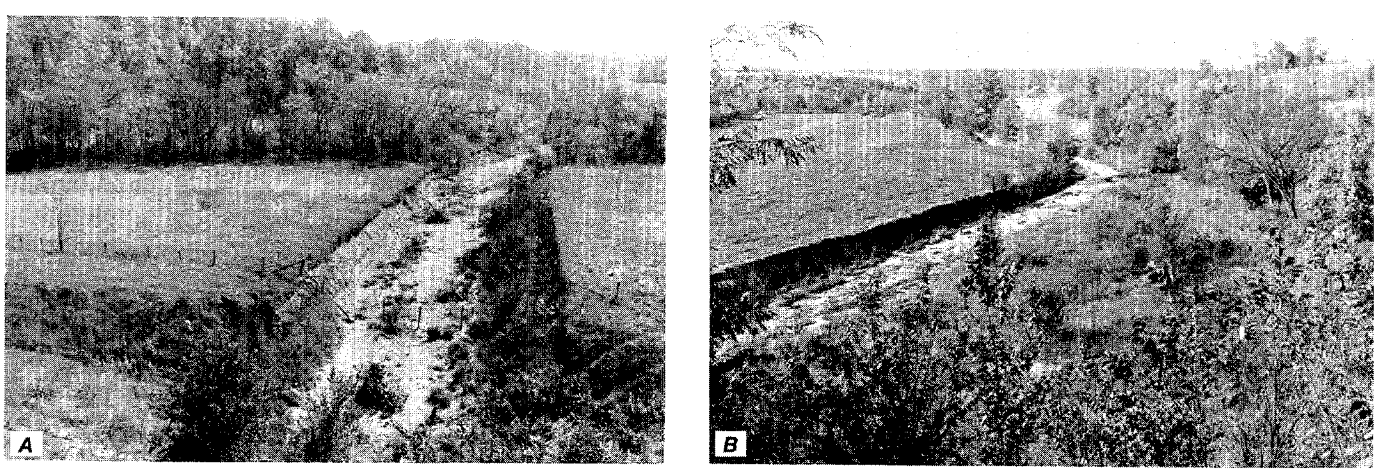


Figure 121. Collie Hollow at site 55. A, View upstream from I-44 embankment along relocated channel in October 1978. Line of trees in left background marks location of prior channel. B, View downstream from I-44 embankment along relocated channel in October 1978.

SITE 56. RAMSEY CREEK AT I-55
AT CAPE GIRARDEAU, MO.

SYNOPSIS--Channel relocation, meandering segment of natural channel shortened from 1,615 m to 792 m, for purpose of avoiding multiple crossings and to improve channel alinement at bridge (fig. 122 and 123A). Performance period, 20 yr (1959-78). The stream is ungaged, but rainstorms in the late 1960's caused floods of 5- to 10-yr recurrence interval on other streams in the area. The relocated channel was trapezoidal in cross section, with a bottom width of 7.5 m, a top width of about 24 m, depth of about 5 m, and a channel slope of about 5 m/km. In 1978, the bottom width was in the range of 6-9 m and local slumping of the upper bank was observed (fig. 123B).

Stability class of relocated channel, B2; local slumping and erosion of banks, local channel widening. Minor degradation, estimated at less than 0.5 m. Critical factors in performance are (1) incision of the channel, which tends to inhibit lateral bank erosion, (2) rapid reestablishment of vegetation along the right bank, at the outside of the sharp bend, and (3) lack of major floods during the time the vegetation was becoming re-established. Absence of significant degradation after relocation is attributed to previous degradation, which resulted from upstream channel straightening for agricultural purposes. This previous degradation apparently reached the base level of a bedrock outcrop in the channel 1 km downstream from the I-55 bridge.

SITE FACTORS--Lat 37°16.5', long 89°34', 1.5 km south of Cape Girardeau, Mo., on Cape Girardeau 7.5' map. Ramsey Creek is perennial, drainage area of about 25 km^2 at site, no measurements of flow. Channel width about 6-9 m, bank height 4.5 m, channel slope 2.6 m/km. Wide bend, point-bar stream, incised, alluvial, sinuosity of 2 at place of relocation. Valley relief about 30 m, wide flood plain, continuous trees along most of channel. Bed material is silt-sand, bank material is weakly coherent silt-clay. Stability rating of channel prior to relocation, B; locally active bank erosion, where trees had been cleared, is discernible on 1958 airphoto. Works of man that have contributed to channel stability are partial deforestation of streambanks and drainage basin; and straightening of channel, for agricultural purposes, upstream from site.

ALTERATION FACTORS--Junction of artificial with natural channel is a smooth transition at the downstream end, but forms a small sharp bend at the upstream end, where meander was intersected. The artificial channel is straight or broadly curved, except for one sharp curve of 30-m radius; the arc on the inside of the curve is 80°. There is a continuous berm on the right bank of the artificial channel, but none on the left. Inasmuch as the as-built plans are not on file, it is not possible to tell whether this berm is an as-built feature, or one formed by subsequent erosion. The condition of vegetation as seen on a 1965 airphoto indicates that nearly all vegetation was removed along the artificial channel at the time of relocation, and there is no indication of replanting.

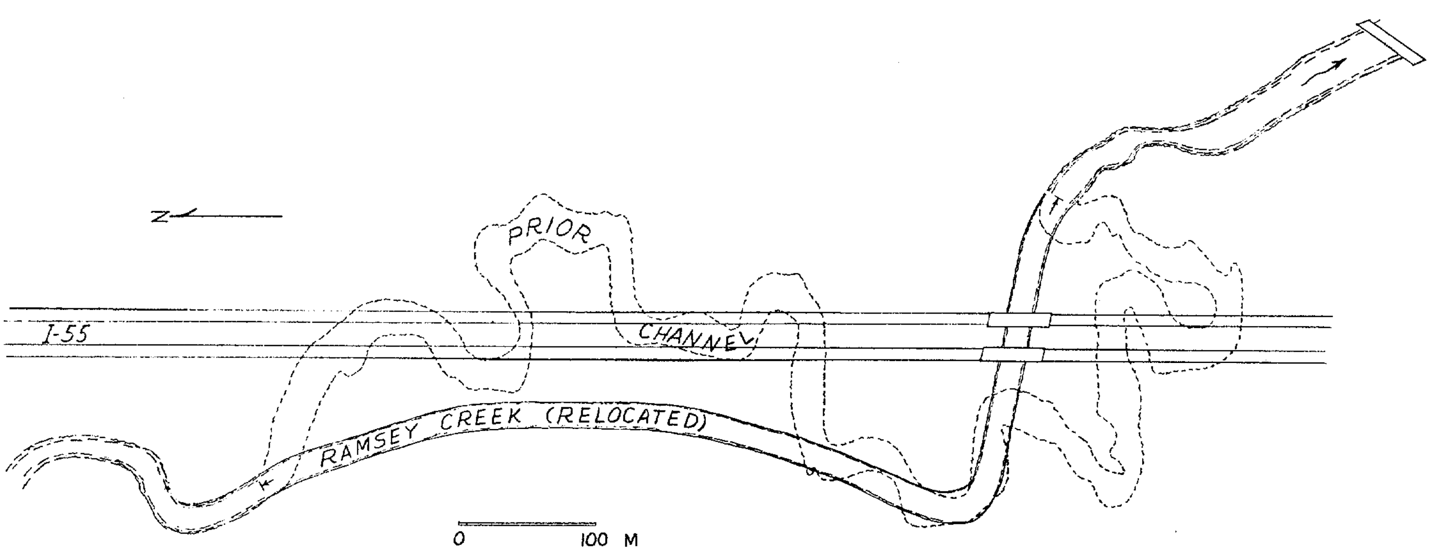


Figure 122. Plan sketch of Ramsey Creek channel relocation.

POST-ALTERATION FACTORS--Re-establishment of natural vegetation is good along the right bank, where the growth of willows, sycamore, and other riparian vegetation is high and dense. The left bank is generally grassed, but thickets of saplings have grown locally.

DISCUSSION--Field inspection in October of 1978 showed that the left bank of the artificial channel is stable and the right bank is stable except for local areas of slumping and erosion (fig. 123B). Erosion at the outside of the sharp bend has evidently been controlled by trees. Because of the lack of as-built plans, channel widening and degradation could not be measured in the field. However, comparison of existing channel width and depth with design plans, indicates that there has been no significant amount of general widening or degradation. In view of the degree of channel shortening, the sharp bend in the relocated channel, and the erodibility of the bank materials, the stability of the relocated channel is surprisingly good. Upstream from the relocated channel, much of the original natural channel has been straightened for agricultural purposes. Instability of this straightened channel appears to be no worse than is evident on a 1958 airphoto.

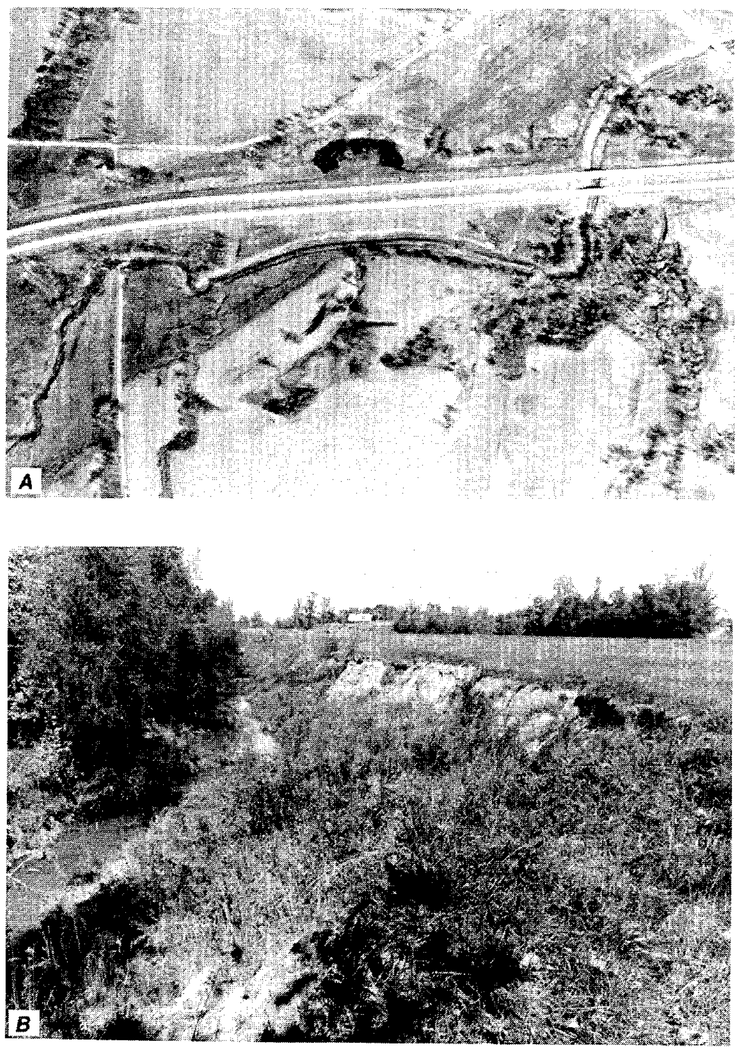


Figure 123. Ramsey Creek at site 56. A, Airphoto of channel relocation in 1965. B, Slumping of left bank, foreground, about midway along relocated channel, in 1978.

SITE 57. WOLF RIVER AT
SR-26 NEAR POPLARVILLE, MISS.

SYNOPSIS--Channel reach 395 m in length was relocated and thereby shortened to 220 m, for purpose of avoiding crossing at apex of meander, where flow alinement was poor (fig. 124). Performance period, 24 yr (1955-79), during which a severe flood of about 50-yr recurrence interval occurred in 1961 and an even larger flood (peak discharge of 362 m^3/s) in 1962. The relocated channel was trapezoidal in cross section, with a bottom width of 9 m, 1:1 side slopes, and a channel slope of 1.5 m/km. No bank protection measures were applied. During the 1961 flood, concrete slope pavement at the bridge abutment fill-slopes was damaged by scour; spur dikes were then built, and no erosion damage was reported for the 1962 flood. In 1979, the banks of both relocated channel (fig. 125) and natural channel were vegetated and generally stable, and no significant increase in bottom width, relative to as-built width, was observed.

Stability class B1 for relocated channel and adjacent segments of natural channel. Stability of the relocated is attributed to the establishment of vegetation prior to occurrence of a flood; and stability of the natural channel, to dense forest on the flood plain. No peak flows larger than 68 m^3/s occurred during the first 5 yr after relocation.

SITE FACTORS--Lat 30°51', long 89°28', at SR-26, 6 km east of Poplarville, Miss., on Carnes 15' map. Wolf River is perennial and has a drainage area of 184 km^2. Channel bottom width is 10-12 m, bank height is about 3 m, channel slope is 0.75 m/km. Equiwidth point bar stream, alluvial, sinuosity of 2, valley relief of 30 m, width of flood plain, about 0.8 km., dense forest cover on flood plain and along channel. Bed material is sand and small gravel, bank material is moderately coherent sand and silty clay.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--Two tributary streams enter the prior channel (fig. 124). The ends of the prior channel were left open to carry the flow from these tributaries, and the center part was filled. No bank instability has resulted from this scheme. The stability of the relocated channel is greater than expected in view of the moderate coherence of the bank materials and the magnitude of floods in 1961 and 1962, and vegetation is the only apparent factor that would account for this.

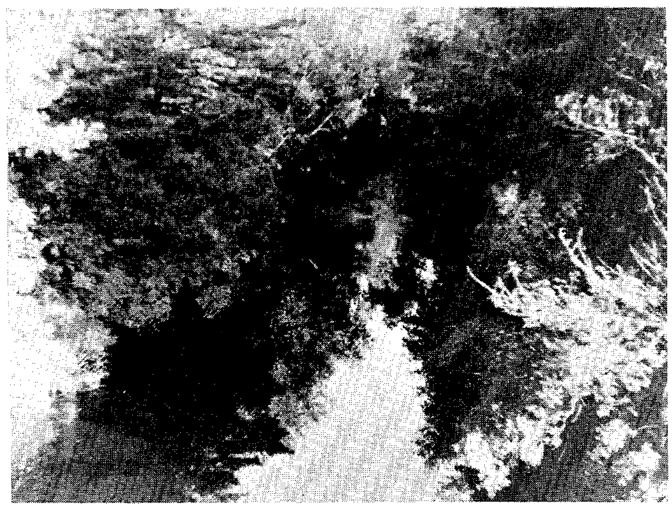


Figure 125. Relocated channel of Wolf River, upstream from bridge, in 1979.

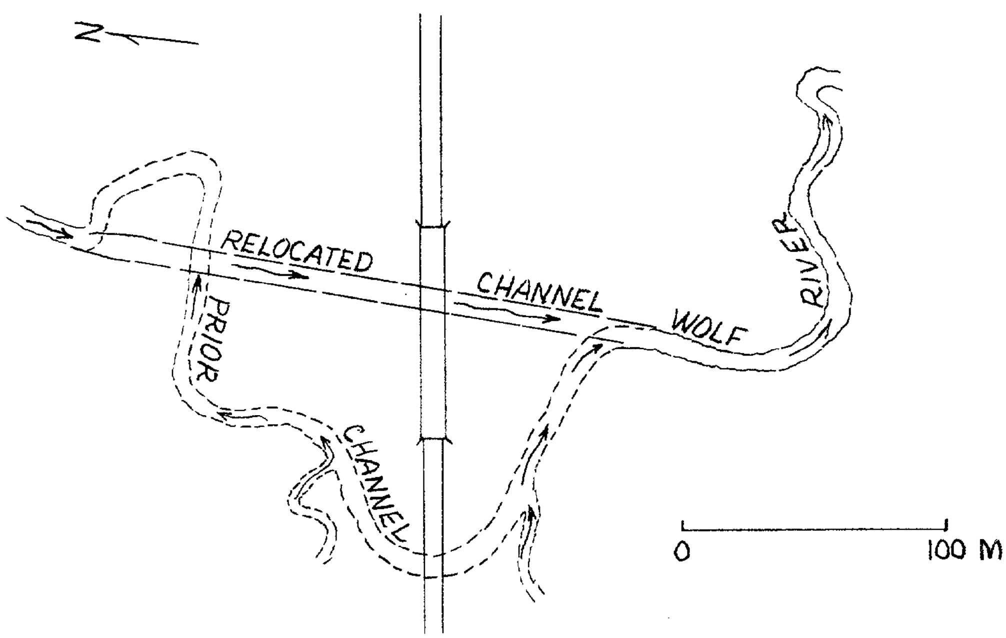


Figure 124. Plan sketch of Wolf River channel relocation.

SITE 58. BEAR CREEK AT I-55
NEAR CANTON, MISS.

SYNOPSIS--A reach 2,200 m in length was relocated and thereby shortened to 1,100 m, for purpose of accommodating planned roadway location and to improve channel alinement at bridge (fig. 126). Performance period, 15 yr (1964-79), during which the highest flood in a 48-yr period of record occurred on nearby Tilda Bogue in April 1979 and a major flood also occurred in 1975. The relocated channel was trapezoidal in cross section, with a bottom width of 18 m, 2:1 side slopes, and a channel slope of about 0.7 m/km. No bank protection measures were applied along the relocated channel. By 1979, the channel width at the bridge had increased to about 35 m, such that pile bents originally set 6 m back from the bankline were at or near the bankline. Elsewhere, the channel width was about 28 m. The banks were mostly covered with annual vegetation (fig. 127) and the channel width appeared to have stabilized. No effects of relocation on the natural channel were observed in the field or on an airphoto taken in 1972.

Stability class B4 for relocated channel and A1 for adjacent segments of the natural channel. In the relocated reach, the increase in slope consequent on relocation has apparently been compensated by channel widening and the banks have been stabilized by vegetation. Stability of the adjacent reaches of natural channel is tentatively attributed to low channel slope and good tree cover along the banklines.

SITE FACTORS--Lat 35°36.5', long 90°04.5', at I-55, 0.6 km north of Canton, Miss., interchange, on Canton 15' map. Bear Creek is perennial, with a drainage area of 230 km^2, and an estimated 50-yr flood discharge of 303 m^3/s. Channel width is 18 m and channel slope is 0.7 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 2.2, valley relief of 15 m, width of flood plain about 2,000 m, greater than 90 percent tree cover along bankline. Bed material is sand and silt, bank material is moderately coherent silt-clay. The natural channel is stable, as no significant change in width or position could be discerned by comparing 1955 with 1972 airphotos.

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(See "Synopsis")

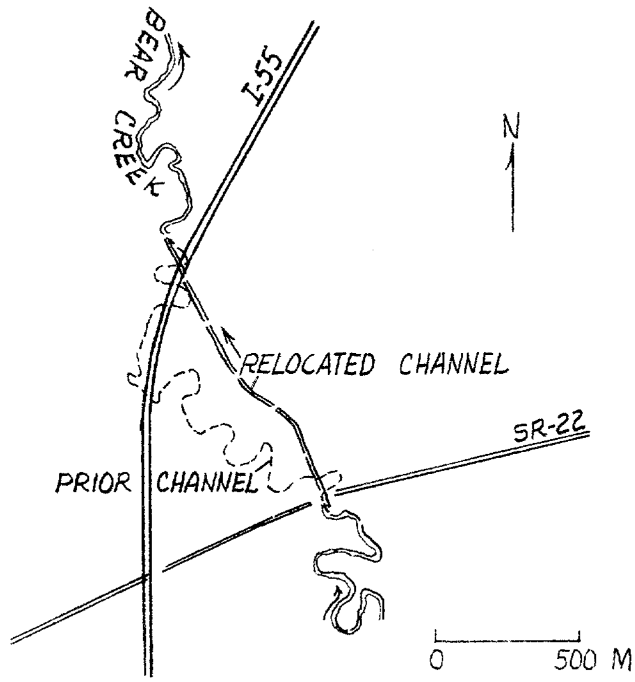


Figure 126. Plan sketch of Bear Creek channel relocation.

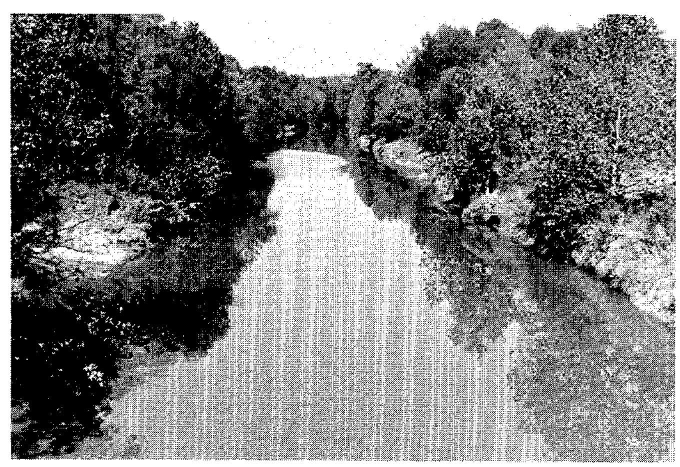


Figure 127. View along relocated channel of Bear Creek downstream from bridge, in 1979.

SITE 59. STRONG RIVER AT
I-20 NEAR MORTON, MISS.

SYNOPSIS--Reach 1,050 m in length was relocated and thereby shortened to 545 m, for purpose of accommodating planned roadway location (fig. 128). Performance period, 14 yr (1965-79), during which three moderate floods were recorded on the U.S. Geological Survey gage 40 km downstream. As built, the relocated channel was trapezoidal in cross section, with a bottom width of 9 m, 2:1 side slopes, and a channel slope of about 0.6 m/km. Rock riprap was placed at the bend in the relocated channel. In 1979, bottom width of the relocated channel was about 6 m, the banks were stabilized with vegetation (fig. 129A), and a beaver dam was observed upstream from the bridge. No instability was observed on the natural channel (fig. 129B).

Stability class A1 for relocated channel and adjacent segments of natural channel. Channel stability is attributed to the prior stability of the natural channel, its small size and low slope, and the rapid establishment of vegetation.

SITE FACTORS--Lat 32°19', long 89°37', at I-20, 5 km southeast of Morton, Miss., on Morton 15' map. Strong River is perennial, with a drainage area of 43 km^2 and an estimated 50-yr flood discharge of 121 m^3/s. Channel bottom width is 5 m, bank height is 1.3 m, and channel slope is about 0.3 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.9, valley relief of 30 m, wide flood plain (400 m in width), tree cover along bankline greater than 90 percent. Bank material is moderately coherent silt-clay, bed material is sand. As observed on a 1956 airphoto, the channel was highly sinuous but very stable in aspect, and no significant changes were observed by comparison with a 1978 airphoto.

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(See "Synopsis")

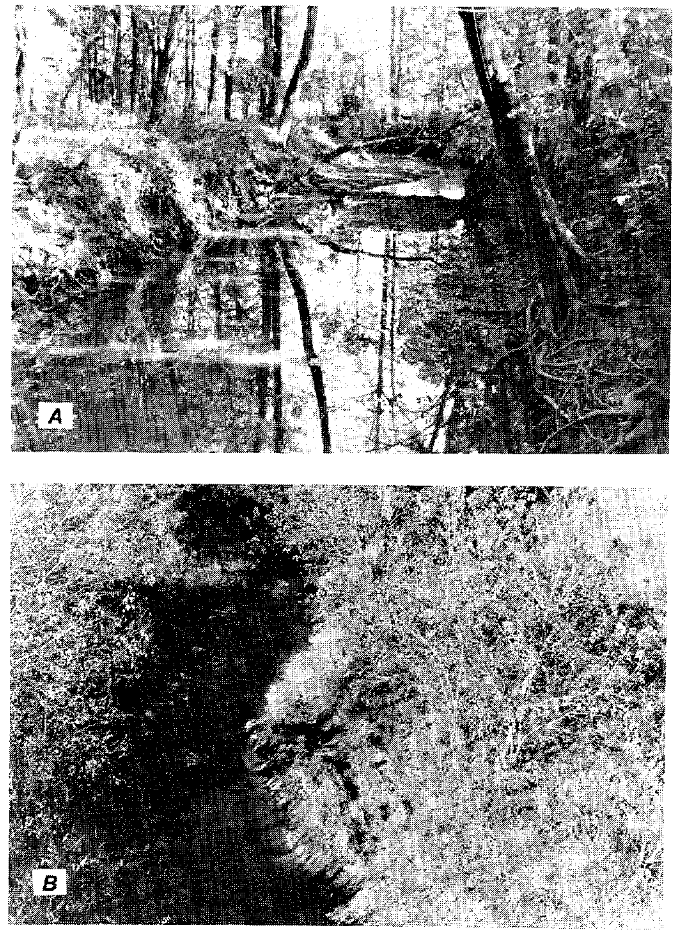


Figure 129. Strong River at site 59. A, Natural channel upstream from relocation, in 1979. B, Relocated channel upstream from I-20 bridge, in 1979.

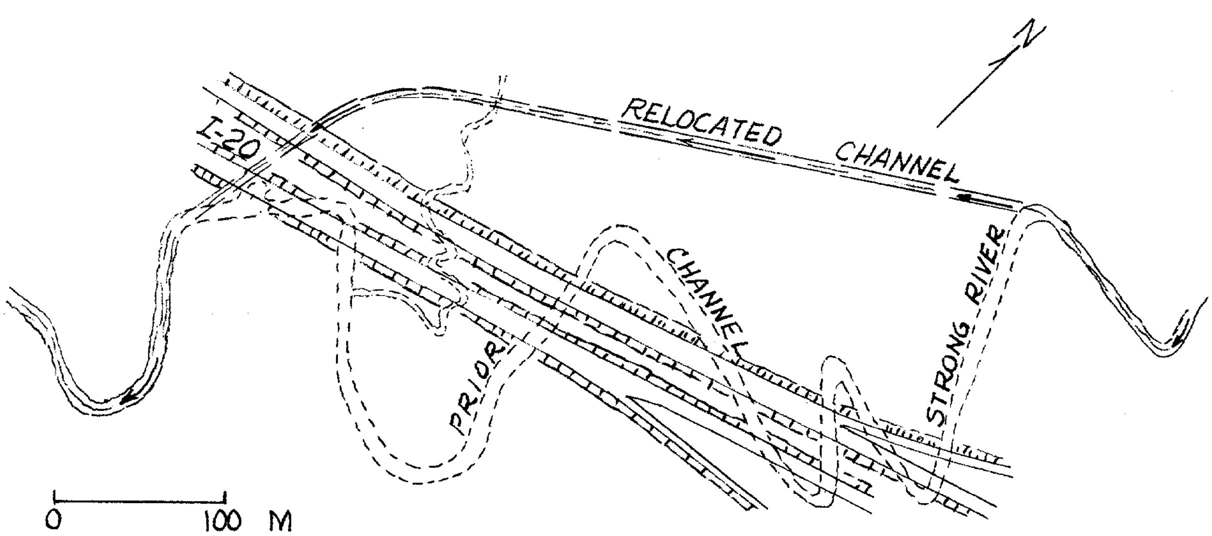


Figure 128. Plan sketch of Strong River channel relocation.

SITE 60. TURKEY CREEK AT
I-20 NEAR NEWTON, MISS.

SYNOPSIS--A reach 625 m in length was relocated and thereby shortened to 270 m, for purpose of improving channel alinement at bridges and to accommodate the planned roadway location (fig. 130). Performance period, 15 yr (1964-79). At the U.S. Geological Survey gage on nearby Chunky River, major floods occurred in April 1974 and January 1975. As specified in the plans, the relocated channel was trapezoidal in cross section, with a bottom width of 9 m and a side slope of 2:1. Channel slope as measured on the Hickory 7.5' map is about 1.6 m/km. No bank protection measures were applied. In 1979, bottom width of the relocated channel between the interstate bridges was in the range of 3-4 m, resistant coherent clay was exposed in the channel bottom, and the banks were stable (fig. 131A). The natural channel was generally stable (although choked with debris) upstream from the relocation; but downstream the bank was eroded and unstable (fig. 131B) at the outside of banks where bordered by a pasture, and bottom width was in the range of 9-11 m. Bank instability at this point was more severe than in 1955, but causes other than the relocation may have contributed to this.

Stability class A1 for relocated channel and class C2 for downstream segment of natural channel. Stability of the relocated channel, which is substantially more narrow than specified in the plans and also more narrow than the natural channel, is attributed to its straightness and to the resistant clay in the bed and lower banks. Evidently because of mowing of the median area, no trees have become established along the bankline.

SITE FACTORS--Lat 32°20.5', long 89°06', at I-20, 3 km east of the SR-15 interchange to Newton, Miss., on Hickory 7.5' map. Turkey Creek is perennial, with a drainage area of 67 km^2. Channel bottom width is 6 m, bank height is 2-2.5 m, and channel slope is about 1.0 m/km. Equiwidth point bar stream, alluvial, sinuosity of 1.7, valley relief of 25 m, wide flood plain, tree cover along bankline 50-90 percent. Bed material is sand, material in lower bank is locally cohesive clay, elsewhere is moderately coherent silt and clay. As observed on a 1955 airphoto, the natural channel was generally stable but cut banks were present at bends bordering cleared areas and also at a straightened reach downstream from the relocation.

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(See "Synopsis")

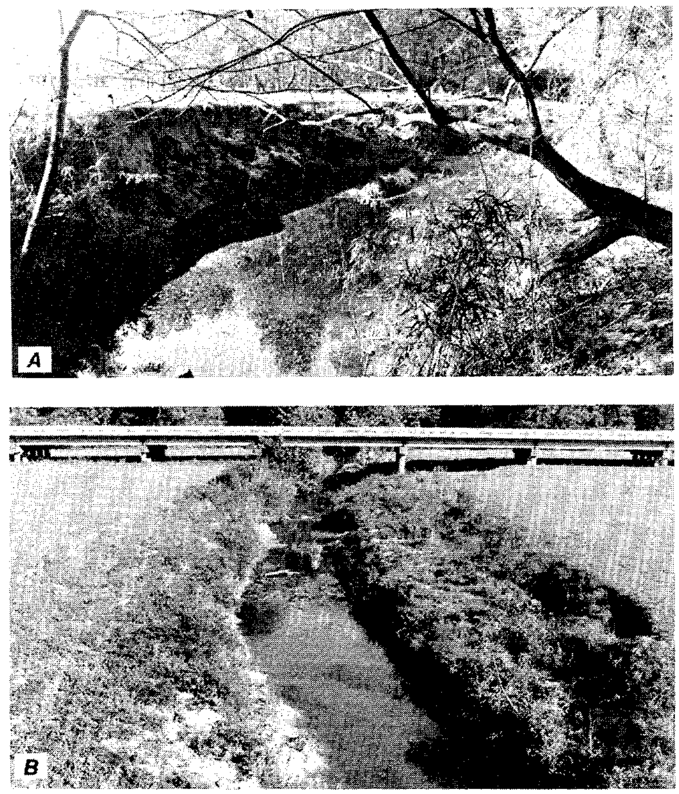


Figure 131. Turkey Creek at site 60. A, Relocated channel between interstate bridges, in 1979. B, Bank erosion at bend downstream from relocation, in 1979.

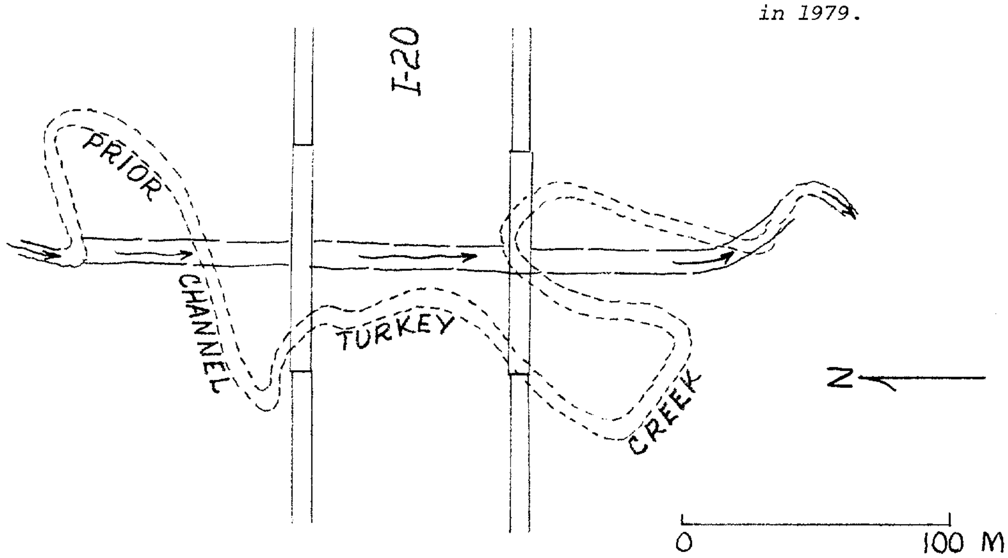


Figure 130. Plan sketch of Turkey Creek channel relocation.

SITE 61. OAKAHATTA CREEK AT
I-20 NEAR HICKORY, MISS.

SYNOPSIS--A reach 690 m in length was relocated and thereby shortened to 420 m, to improve alinement at bridges (fig. 132) and to accommodate planned location of interstate roadway. Performance period, 15 yr (1964-79), during which two major floods were recorded on the nearby Chunky River. As specified on the plans, the relocated channel was trapezoidal in cross section, with a bottom width of 12 m and 2:1 side slopes. Channel slope as measured on the Hickory 7.5' map is 1.25 m/km. No bank protection measures were specified on the plans or observed in the field. In 1979, channel width had increased locally at the bridge to 30 m, such that a pile bent originally 15 m from the bankline was within the channel (fig. 135A). Also, channel depth at the bridge had been increased by local scour. Elsewhere, bottom width of the relocated channel was in the range of 10-15 m, and the banks were vegetated with trees or with a small creeping vine (fig. 133B). At the county road bridge near the downstream end of the relocation (fig. 132) a bank erosion problem evident on a 1955 airphoto had been remedied by the improved channel alinement. Local bank erosion was observed on the natural channel downstream from the relocation, but the prior condition of the channel could not be discerned.

Stability class C2 for relocated channel and B for downstream segment of natural channel. Channel widening at the bridge is attributed to the sandy, weakly coherent bank materials, but in general channel widening has evidently been controlled by vegetation.

SITE FACTORS--Lat 32°20.5', long 89°01', at I-20, 2.7 km north of Hickory, Miss., on Hickory 7.5' map. Oakahatta Creek is perennial, with a drainage area of 109 km^2 and an estimated 50-yr discharge of 240 m^3/s. Channel width is in the range of 9-12 m and channel slope in the range of 0.6 to 1 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.5, valley relief of 25 m, wide flood plain, greater than 90 percent tree cover along bankline. Bed material is sand, and bank material is mainly sand.

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(see "Synopsis")

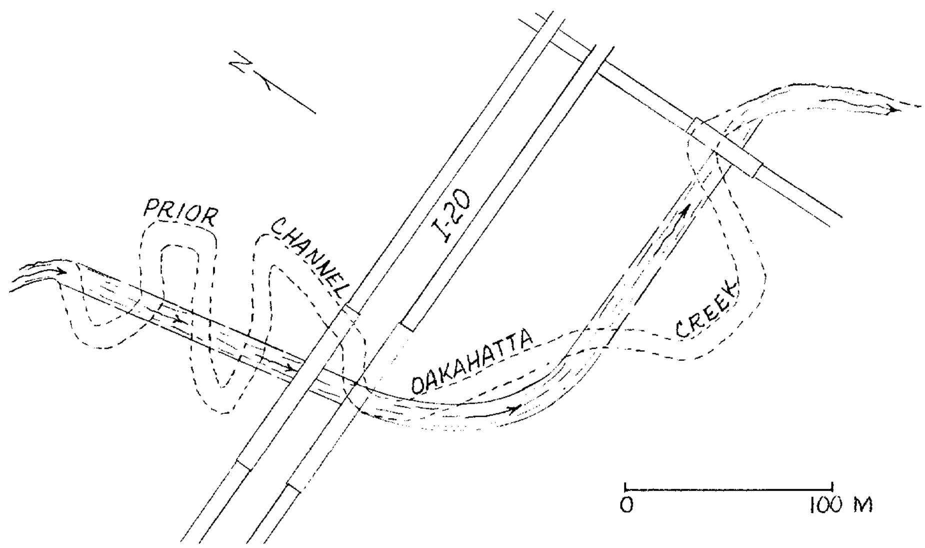


Figure 132. Plan sketch of Oakahatta Creek channel relocation.

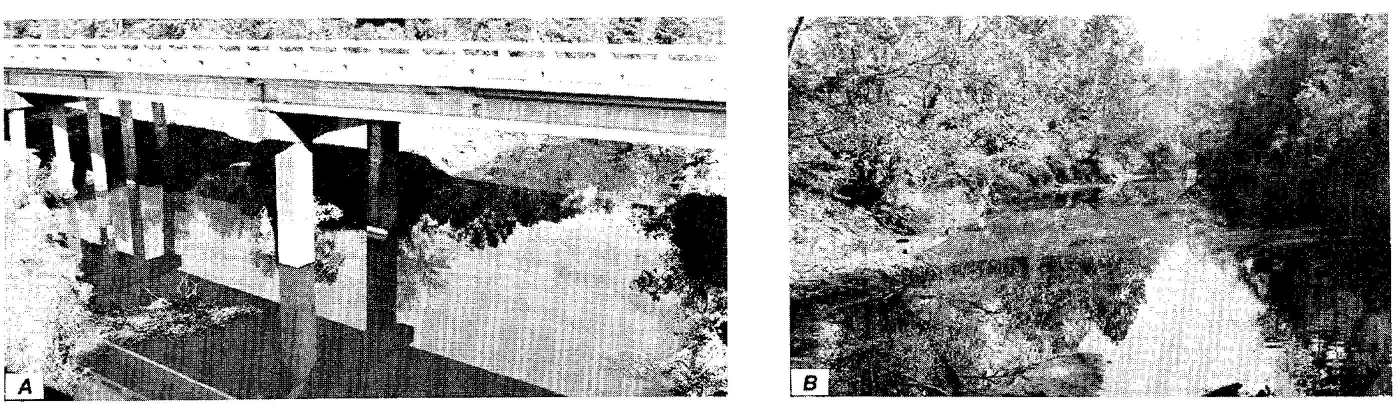


Figure 133. Oakahatta Creek at site 61. A, Channel widening at west-bound interstate bridge, as photographed in 1979. B, Relocated channel downstream from interstate bridges, in 1979.

SITE 62. TALLAHATTA CREEK AT I-20 NEAR CHUNKY, MISS.

SYNOPSIS--A reach 350 m in length was straightened and thereby shortened to 305 m, for purpose of improving channel alinement at bridges (fig. 134). Performance period, 15 yr (1964-79), during which two major floods were recorded on the nearby Chunky River. As specified on the plans, the relocated channel was trapezoidal in cross section, with a bottom width of 15 m and 2:1 side slopes. Channel slope as measured on the Chunky 15' map was 1.2 m/km. No bank protection measures were specified on the plans or observed in the field. In 1979, the relocated channel upstream from the bridge was well vegetated, stable, and tended to be narrower than the specified width (fig. 135A). Downstream from the relocation, the thalweg has been deflected toward the left bank, which is unstable and which has receded about 7-10 m (fig. 135B); a point bar has formed at the right bank. Banks of the natural channel downstream from the relocation are also eroded, and the erosion has been increased by undercutting of trees on the high banks. No degration has occurred at the bridge.

Stability class C3 for relocated channel and C2 for downstream segment of natural channel. The general aspect of the channel, especially the numerous tree falls along the bankline, indicate that a severe flood had occurred not long before the field visit in 1979. The immediate cause of bank erosion downstream from the bridge is deflection of flow against high sandy banks that were poorly protected by vegetation; however, the reason for deflection of flow is not apparent.

SITE FACTORS--Lat 32°20', long 88°53', at I-20, 4.5 km east of Chunky, Miss., on Chunky 15' map. Tallahatta Creek is perennial, with a drainage area of 160 km^2 and an estimate 50-yr flood discharge of 367 m^3/s. Channel width is in the range of 12-15 m, bank height is 4-4.5 m, and channel slope is about 1.1 m/km. Equiwidth point bar stream, alluvial, sinuosity of 1.2, valley relief of 45 m, flood plain 0.6 km in width, tree cover along bankline greater than 90 percent. Bed material is sand and gravel, bank material is weakly coherent sand, silt, and clay. As observed on airphotos taken in 1951 and 1958, the channel had a stable aspect and few cut banks, but the bankline is mostly obscured by dense forest.

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(See "Synopsis")

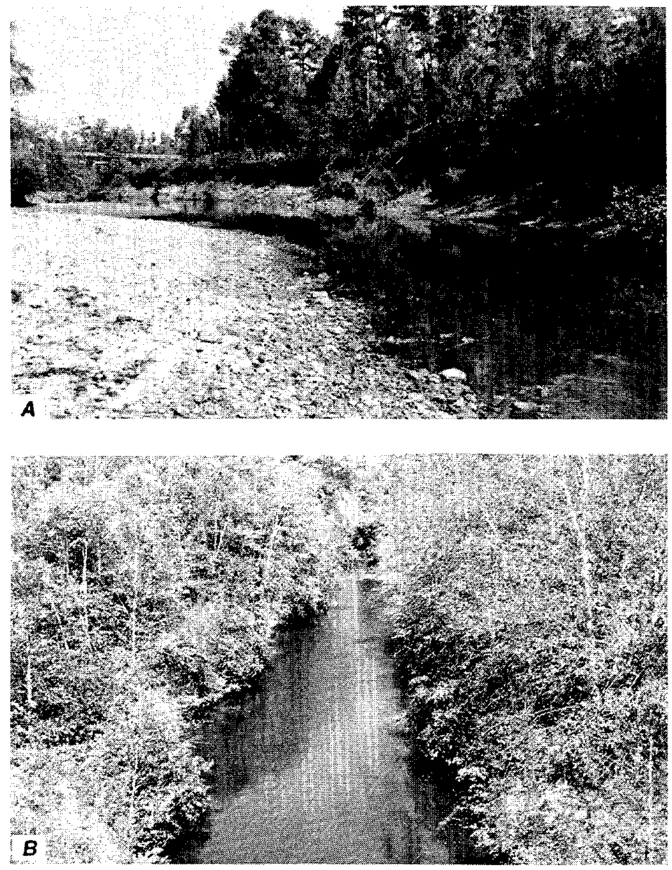


Figure 135. Tallahatta Creek at site 62. A, Relocated channel as viewed upstream from interstate bridge in 1979. B, Eroded left bank downstream from bridge, in 1979. Point bar is in foreground.

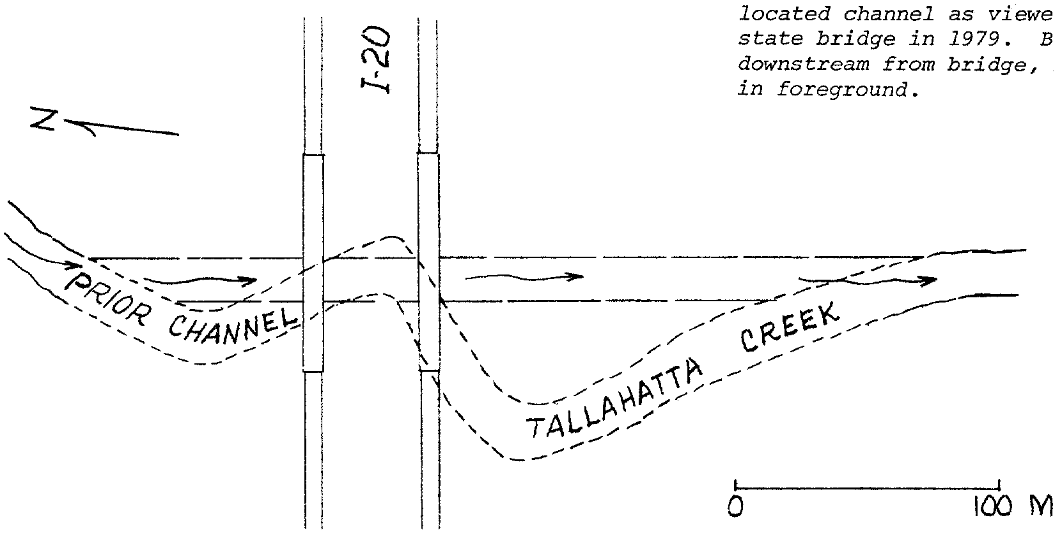


Figure 134. Plan sketch of Tallahatta Creek channel relocation.

SITE 63. BOGUE HOMO AT I-59 NEAR HEIDELBERG, MISS.

SYNOPSIS--A small stream was diverted through a culvert and a reach 400 m in length was relocated and thereby shortened to 190 m, for purpose of improving flow alinement (fig. 136). Performance period, 15 yr (1964-79). The culvert (or box bridge) consists of two 14- by 12-ft sections; and the wingwalls at the downstream end are flared to the width of a trapezoidal channel having a bottom width of 12.2 m, 2:1 side slopes, and a channel slope of about 1.1 m/km. No bank protection measures were applied. In 1979, the upstream end of the left section was partly blocked by sediment, on which trees were growing, and the downstream channel had decreased in width to about 7.5 m (fig. 137). The relocated channel was stable and well vegetated. Bank erosion was noted at bends in the natural channel downstream from the relocation, but bank stability prior to relocation could not be ascertained.

Stability class A1 for relocated channel and B for downstream segment of natural channel. Stability of the relocated channel is attributed to its width (greater than that of the natural channel by a factor of 2-2.5) and to the establishment of vegetation along the banks. The width may eventually lead to a reduction of channel capacity by encroachment of vegetation, but so far this has not occurred.

SITE FACTORS--Lat 31°56', long 88°59.5', at I-59, 4.5 km north of Heidelberg, Miss., on Heidelberg 7.5' map. Bogue Homo is perennial and has a drainage area of 22 km^2. Channel width is 4.5-6 m, bank height is 1.5 m, and channel slope is 0.9 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.3, valley relief of 40 m, wide flood plain, dense tree cover along channel except in patchy areas of clearing. Bed material is sand, bank material is weakly coherent clayey sand.

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(See "Synopsis")

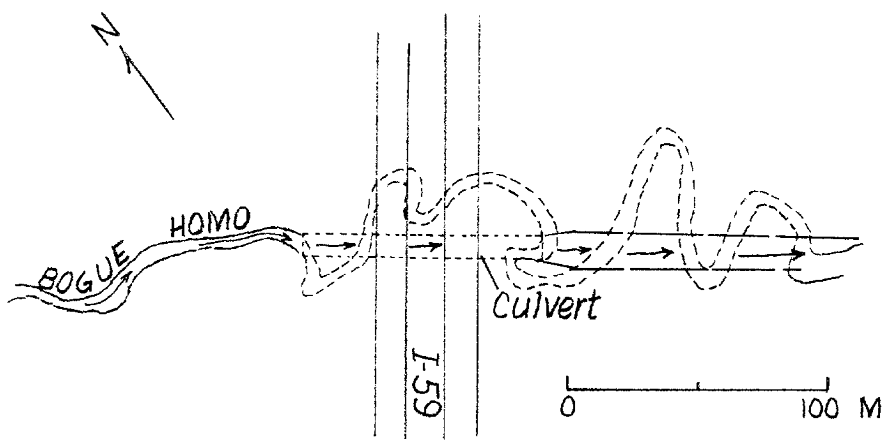


Figure 136. Plan sketch of Bogue Homo channel relocation.

Figure 137. Relocated channel of Bogue Homo downstream from culvert, in 1979.

SITE 64. EAST HOBOLOCHITTO CREEK AT I-59 NEAR PICAYUNE, MISS.

SYNOPSIS--Channel relocation, reach 900 m in length straightened and thereby shortened to 435 m; for purpose of accommodating planned interstate location and to improve channel alinement at bridge (fig. 138). Performance period, 15 yr (1964-79). No major floods were recorded at the nearest U.S. Geological Survey stream gaging station (Wolf River at Poplarville, discontinued in 1971) during the period 1964-71, but two or three floods probably occurred at this station and at the relocated site during the period 1971-79.

The relocated channel was trapezoidal in cross section, with a bottom width of 12 m, 2:1 side slopes, and a channel slope of about 1.3 m/km. No bank protection measures were applied. In 1979, banks of the relocated channel upstream from the bridge were stable and well vegetated (fig. 139A) and the channel downstream was also stable (fig. 139B). At the upstream transition to the natural channel, local bank erosion had increased the channel width to 20 m; but in general the natural channel was stable.

Stability class A1 for relocated channel and B2 for adjacent segments of the natural channel. Stability of the relocated channel is attributed to its straightness and to the establishment of vegetation along the bankline.

SITE FACTORS--Lat 30°43', long 89°33.5', at I-59, 20 km northeast of Picayune, Miss., on Picayune 15' map. East Hobolochitto Creek is perennial, with a drainage area of 111 km^2, and an estimated 50-yr flood discharge of 380 m^3/s. Channel width is 8-10 m, bank height is 2.4 m, and channel slope is 0.6 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 2, valley relief of 20 m, wide flood plain, densely forested. Bed material is sand and small gravel, bank material is weakly coherent clayey sand. The natural channel is stable, as no significant lateral migration could be discerned by comparison of 1942 and 1969 airphotos.

ALTERATION AND POST-ALTERATION FACTORS: DISCUSSION--(See "Synopsis")

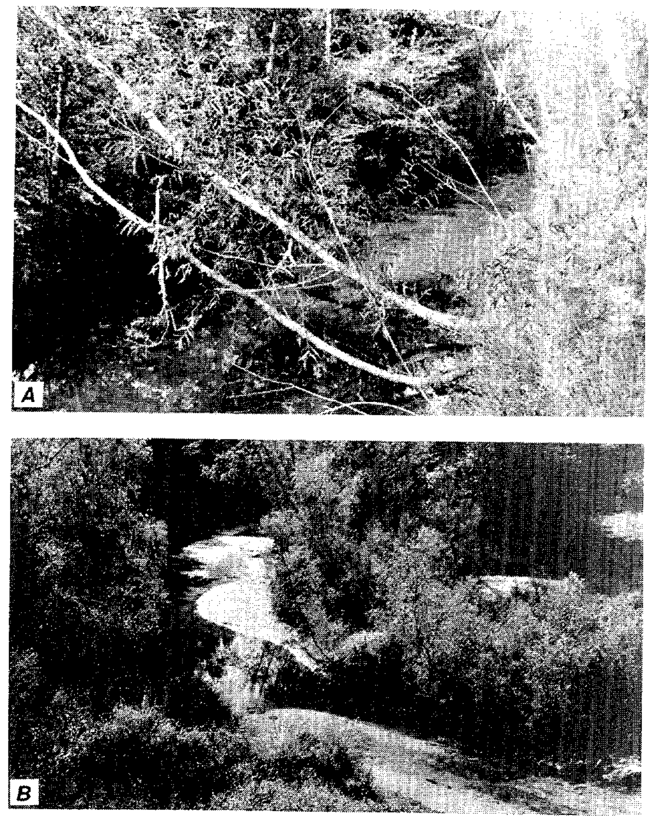


Figure 139. East Hobolochitto Creek at site 64. A, Relocated channel upstream from bridge, in 1979. B, Relocated channel downstream from bridge, in 1979.

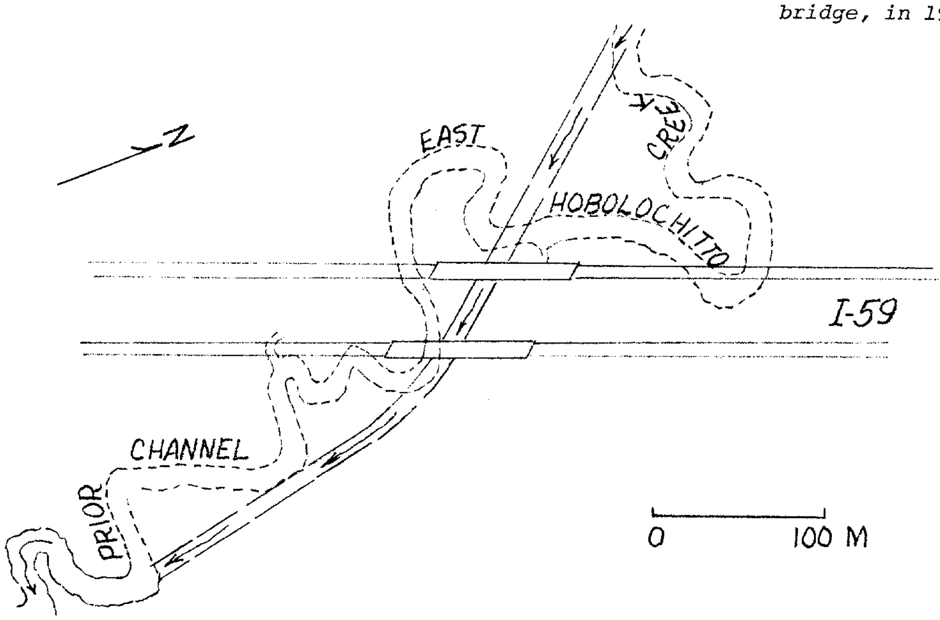


Figure 138. Plan sketch of East Hobolochitto Creek channel relocation.

SITE 65. TONGUE RIVER AT
I-94 AT MILES CITY, MONT.

SYNOPSIS--Channel was relocated by cutting of a meander bend, reducing the length of a channel segment from 2,200 m to 600 m, for purpose of improving alinement at bridge and preventing encroachment of meander on planned roadway location (fig. 140A). Performance period, 17 yr (1962-79). At the U.S. Geological Survey gage about 5 km upstream, the maximum peak flow (377 m^3/s) for a 32-yr period of record occurred in 1962; a second major flood (289 m^3/s), in May 1975; and another, in March of 1979. As built, the relocated channel was trapezoidal in cross section, with a bottom width of 52 m, 2:1 side slopes, and a channel slope of about 1.1 m/km. In the plans, riprap bank protection is specified only at the bridge; but large riprap, at the toe of both banks for the full length of the relocated section, is visible on a 1969 airphoto. This site was not visited in the field, but airphotos taken in 1950, 1958 (fig. 140B), 1966, 1969, and 1979 were obtained mainly from the Montana Department of Transportation. As observed and measured on the airphotos, bottom width of the relocated channel was 56 m in 1966 and 57 m in 1979, and the banks were stable in 1979. Alternate lateral bars, which may be the precursors of meandering, had formed in the straight relocated channel by 1969. Maximum lateral erosion measured at bends on the natural channel was 8 m for the period 1950-58 and 33 m for the period 1969-79. The apparent increase in lateral erosion which occurred at a bend downstream from the relocation is attributed partly to floods and party to the effects of relocation.

Stability class A1 for relocated channel and D2 for adjacent segments of the natural channel. The stability of the relocated channel is similar to that of straight reaches of the natural channel. In general, the lateral erosion rate of the river is moderate in view of the many cut banks and lack of vegetal cover along the bankline; and no factor other than erosional resistance of the bank material can be inferred to explain this, although the banks were not examined in the field.

SITE FACTORS--Lat 46°23', long 105°50', at I-94, 2 km south of Miles City, Mont., on Miles City 7.5' map. Tongue River is perennial, with a drainage area of 13,930 km^2 at the nearby stream gage, and an average discharge of 12.5 m^3/s. Channel width is 30 m, bank height is 3 m, and channel slope is about 0.7 m/km. Wide-bend point-bar stream, locally braided, alluvial, sinuosity of 1.6, valley relief of 125 m, flood plain 180 m in width, vegetal cover along bankline mainly grass.

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(See "Synopsis")

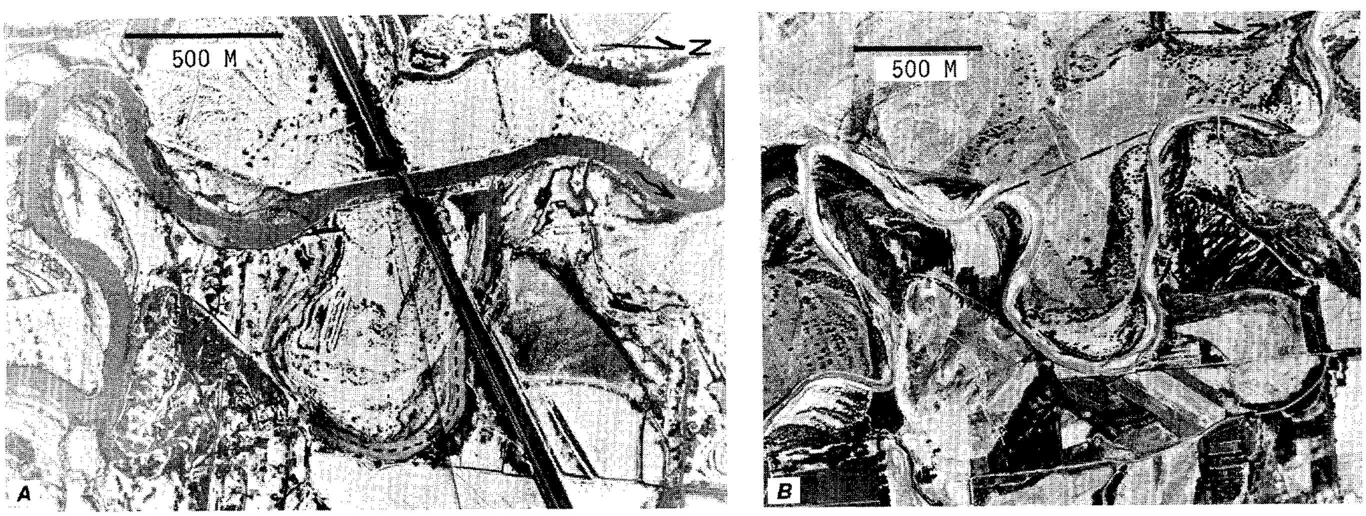


Figure 140. Tongue River at site 65. A, Airphoto of channel relocation in 1979. Prior channel is shown in dotted line. (From Montana Dept. of Transportation) B, Airphoto of site in 1958. Position of relocation is shown in dashed line. (From U.S. Dept. of Agriculture)

SITE 66. GALLATIN RIVER AT
I-90 NEAR MANHATTAN, MONT.

SYNOPSIS--Channel relocation, involving a main channel segment of anabranching river about 365 m in length, which was shifted to the left and shortened to 240 m; for purpose of accommodating planned roadway location, improving channel alinement at bridge and confining the stream width (fig. 141A). Performance period, 13 yr (1966-79), during which three floods occurred. The relocated channel had a bottom width of 36.5 m and a channel slope of 6.6 m/km. Riprap was placed along the roadway embankment (fig. 141B) and along the left bank upstream from the bridge. By 1979, the anabranch at the right bank in figure 141B had been abandoned and impingement of flow directly against the riprapped roadway embankment had caused local erosion and slumping (fig. 141C). Otherwise, the streambanks were stable and the relocation appeared to be functioning as planned. Because of the minor nature of the relocation and the shifting anabranches and braids of the stream, no effect on adjacent segments would be anticipated and none was observed.

Stability class B2 for relocated channel. The performance of the relocation depends on the capacity of the riprapped embankment (and streambanks) to resist erosion and deflect the flow.

SITE FACTORS--Lat. 45°49', long 111°16', at I-90, 5.5 km east of Manhattan, Mont., on Manhattan 15' map. Gallatin River is perennial, with a drainage area of about 4,200 km^2. Channel width is 25-35 m, bank height is 2 m, channel slope is 5.9 m/km. Wide-bend point-bar stream, anabranched and braided, alluvial, valley relief of 150 m, wide flood plain, tree cover along less than 50 percent of bankline. Bed material is gravel and cobble, bank material is sand and gravel. Cut banks are present along the river where anabranches or braids impinge against the bankline.

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(See "Synopsis")

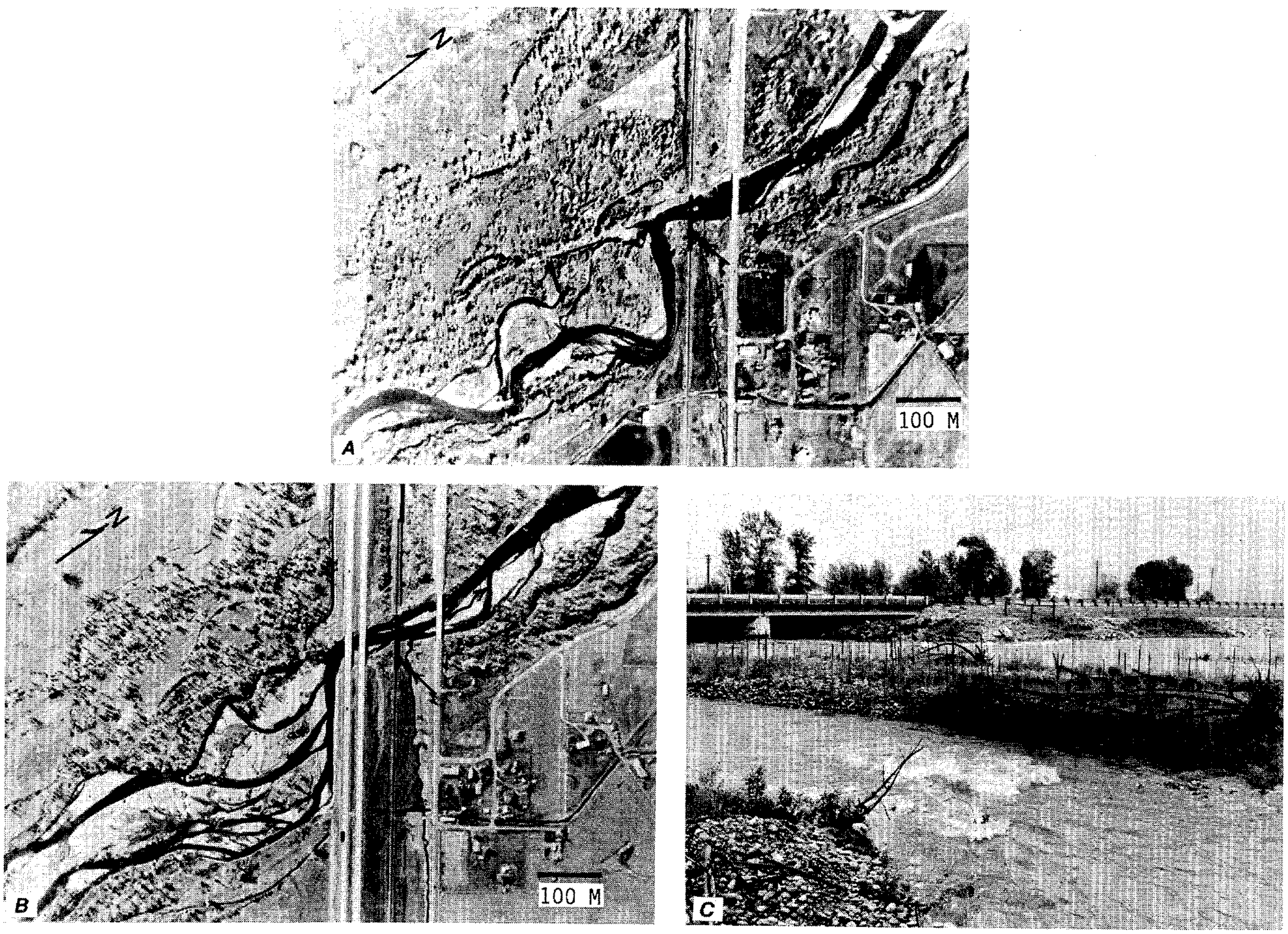


Figure 141. Gallatin River at site 66. A, Airphoto of site in 1963, position of relocated channel indicated by dashed line. Railroad bridge, indicated by arrow, is 90 m in length. (From Montana Dept. of Transportation) B, Airphoto of site in 1972. (From Montana Dept. of Transportation) C, View downstream toward interstate bridge in 1979.

SITE 67. CLARK FORK AT I-90 NEAR MISSOULA, MONT.

SYNOPSIS--A reach about 2,750 m in length was relocated by moving it laterally a distance of about 60 m, to accommodate planned location of interstate highway (fig. 142A and B). Performance period, 15 yr (1964-79), during which major floods occurred in 1968 and 1975. The relocation consisted of a low-water channel having a bottom width of 46 m, bordered on the left bank by a high-water channel having a width of 53 m, total minimum channel width was about 100 m. The roadway embankment, which formed the left bank of the relocated channel, had a 2:1 slope and was protected by a

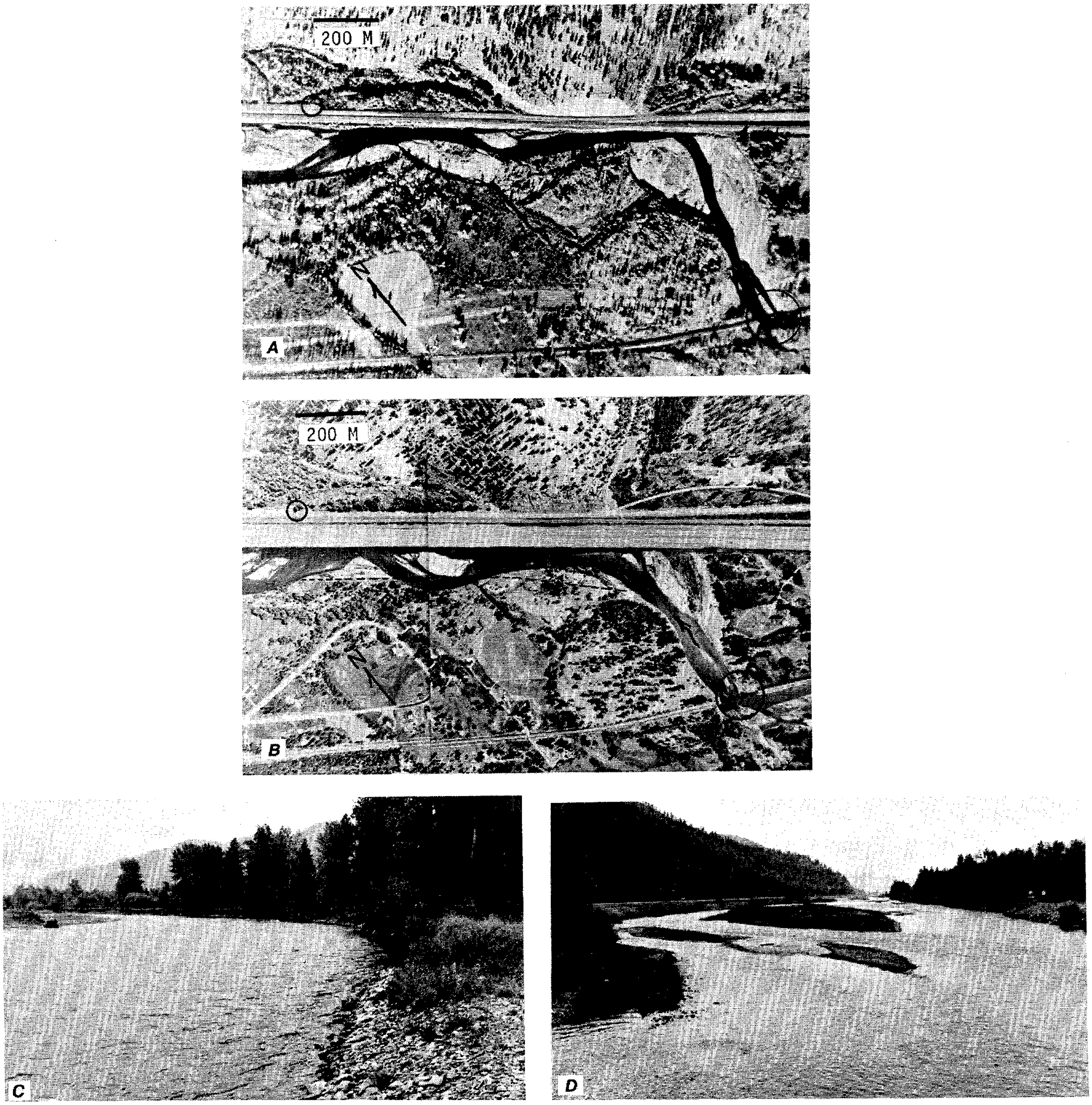


Figure 142. Clark Fork at site 67. A, Airphoto of site in 1956. Milwaukee, St. Paul, and Pacific Railroad bridge, circled at right,is 120 m in length. (From Montana Dept. of Transportation) B, Airphoto showing upstream end of relocated channel in July 1975, after major flood in June 1975. Original left bank of relocated channel is shown in dashed line. Railroad bridge is circled at right. (From Montana Dept. of Transportation) C, Eroded left bank of relocated channel in 1979. D, Upstream end of relocated channel in 1979.

1.2-m thickness of rock riprap. A rock riprap dike was constructed on the right bank at the downstream end of the relocation. During the 1975 flood, two large scallops developed in the left bank near the downstream end of the relocation, increasing the total channel width locally to 140 m (fig. 142B). The channel has shifted away from one of these scallops; but in 1979, active bank erosion was continuing at the other (fig. 142C). The banks were generally stable at the downstream end of the relocated channel (fig. 142D). The natural channel underwent significant changes during the period 1965-78, such that the entire channel length on the Bonner 7.5' map was redrawn on the 1978 photorevision of the 1965 map. However, it is doubtful that the relocation, which involved no change in channel length, had any effect on adjacent segments of the natural channel.

Stability class C3 for relocated channel for which local bank erosion had a maximum value of about 40 m for the period 1964-75. Stability class D4 for natural channel, whose instability is expressed mainly in shifts of anabranches. The immediate cause of bank erosion is the development of bars in the channel, which deflected flood flow toward the erodible and unprotected left bank.

SITE FACTORS--Lat 46°48', long 113°48', at I-90, 18 km west of Missoula, Mont., on Bonner 7.5' map. Clark Fork is perennial, and its drainage area at the site is roughly 9,600 km^2. Channel bottom width is 30-45 m, and channel slope is 4 m/km. Wide-bend point-bar stream, anabranched and braided, alluvial, valley relief of 800 m, flood plain width of about 1 km, less than 50 percent tree cover along channel. Bed material is in the size range of gravel to boulder, bank material is weakly coherent gravel, sand, and silt.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--The channel at this site had previously been relocated (by moving it laterally to the left) during construction of the Burlington Northern Railroad in the early 1900's. By 1956 (fig. 142A), the relocated channel had reached a maximum width of about 170 m, which is within the range of widths for the natural channel. The river has a natural tendency toward lateral instability, and bank erosion can be expected unless the bank is riprapped. The ability of riprap to resist lateral erosion by the river has been established by the many railroad embankments that have been protected by riprap for decades.

SITE 68. MUSSELSHELL RIVER AT SR-200 NEAR MOSBY, MONT.

SYNOPSIS--Channel was relocated by cutting off an irregular bend, thereby reducing the length of the channel segment from 327 m to 122 m; for purpose of improving channel alinement at bridge (fig. 143). Performance period, 7 yr (1972-79), during which a 9-yr flood occurred in 1975, and somewhat larger floods in 1978 and 1979. A spur dike 46 m (150 ft) in height was built at the right bridge abutment (fig. 144A), and both banks of the relocated channel were riprapped (fig. 144-B). In 1979, the alinement of the relocated channel was almost as constructed, despite the fact that no riprap remained along the right bank. During high stages, the area occupied by the prior channel is flooded (light toned area in fig. 144A), and the spur dike is evidently responsible for maintaining channel alinement through the bridge. Comparison of airphotos made in 1954 and 1976 indicates that meander loops upstream and downstream from the bridge had high lateral migration rates for the 22-yr period, amounting to a maximum of 140 m at one bend and 80 m at the other. Because only a short stream segment was involved in the relocation, no effect on adjacent stream reaches is probable.

Stability class B2 for relocated channel and D4 for adjacent segments of natural channel. Stability of the relocated channel is attributed to the spur dike, to riprap along the left bank, and to the effects of a rocky bluff at the left bank upstream from the bridge, which tends to prevent lateral migration to the left. Lateral instability of the natural channel is tentatively attributed to erodible bank materials and lack of vegetal cover along the banklines.

SITE FACTORS--Lat 47°00', long 107°53', at SR-200, at the hamlet of Mosby, on Mosby, Mont., 7.5' map. Musselshell River is perennial, and its drainage area is 20,306 km^2. Channel width is 40 m, bank height is 1.5-2 m, and channel slope is 1.7 m/km. Wide-bend point-bar stream, semi-alluvial, sinuosity of 1.4, flood plain 900 m in width, vegetal cover along bankline mainly grass, tree cover less than 50 percent. Bed material is in the gravel to cobble size range, and bank material is sand, silt, and gravel.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--The prior bridge at this site had been built in 1929, and had survived in spite of a lateral erosion problem at the right abutment. A pilot channel had previously been cut across the meander loop in about the same position as the relocated channel in figure 143 , but it evidently did not serve to divert the flow. In fact, the performance of the relocation has evidently depended mainly on the spur dike, whose function might have been improved by a somewhat greater length. Because of the natural tendency of the river toward rapid lateral migration, the good performance of the relocation is notable.

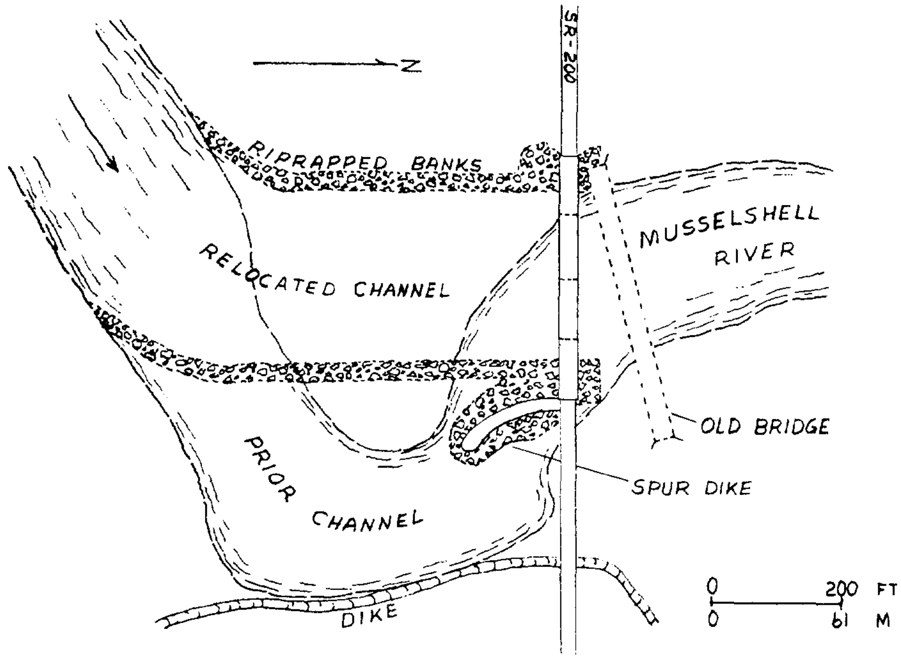
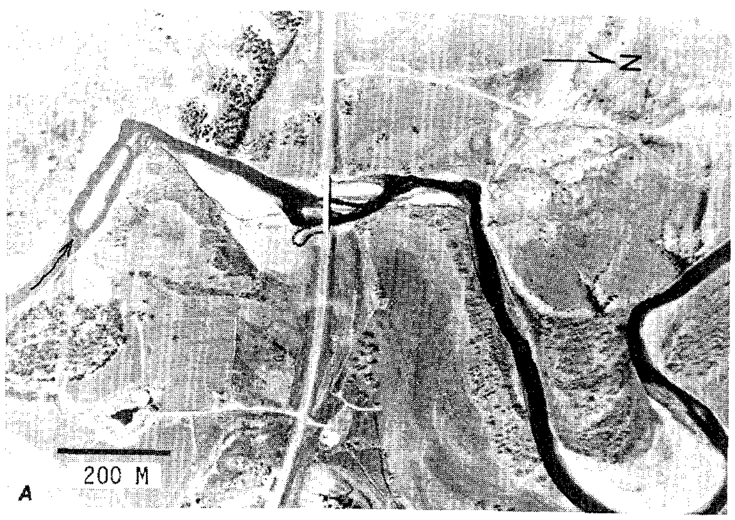


Figure 143. Plan sketch of Musselshell River channel relocation.



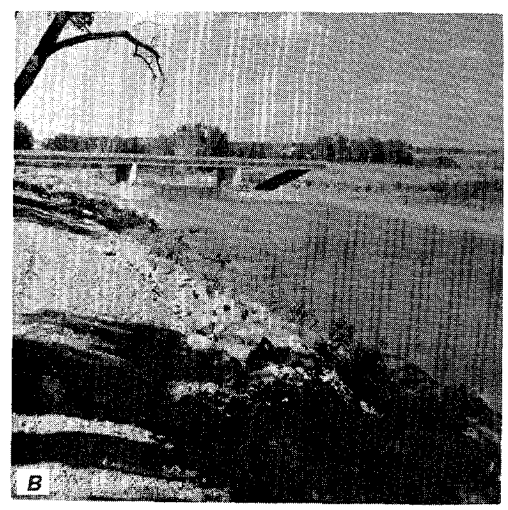


Figure 144. Musselshell River at site 68. A, Airphoto of site in 1976. Spur dike is indicated by heavy line. (From Montana Dept. of Transportation) B, Downstream view along relocated channel in 1979. Riprapped left bank is in foreground.

SITE 69. CAMP CREEK AT
I-80 NEAR LINCOLN, NEBR.

SYNOPSIS--A reach 865 m in length was relocated and thereby shortened to 475 m, for purpose of improving channel alinement at bridge and to accommodate planned interstate location (fig. 145). Performance period, 18 yrs (1961-79), during which a flood of approximately 10-yr recurrence interval was recorded at gaging stations on nearby creeks. The relocated channel was trapezoidal in cross section, with a bottom width of 6 m, 2:1 side slopes, and a channel slope of about 2.7 m/km. Although no countermeasures are specified on the plans, a small riprap check dam was observed upstream from the bridge on a field visit in 1979, and scattered broken concrete riprap was present along the banks of the relocated channel in the vicinity of the bridge. The banks were moderately stable (fig. 146A) by comparison with banks on other streams of this type in Nebraska, but bank slumping was observed downstream from the bridge and bank erosion, at the downstream junction of natural and artificial channel (fig. 146B). On a 1955 airphoto, cut banks are visible at bends along Camp Creek and at reaches where the stream had been channelized for agricultural purposes. Channel stability had not deteriorated significantly by 1979, except at the channelized reaches, where bank erosion was severe.

Stability class B1 for relocated channel, whose bottom width in 1979 was generally less than the width as built, but whose top width had increased because of slumping. Stability class C2 for adjacent segments of the natural channel. As nearly as can be discerned by comparison of 1955 airphotos, 1971 airphotos, and field observations in 1979, relocation has had little effect on adjacent segments of the natural channel except to increase bank erosion at the downstream junction of natural and artificial channels. The critical factor in stability of the relocated channel is the establishment of vegetation on blocks that slumped and formed a berm along the channel; and the establishment of vegetation was favored by the absence of drought and floods during the years following relocation.

SITE FACTORS--Lat 40°55', long 96°28', at I-80, 14.5 km east of interchange to Lincoln, Nebr., on Greenwood 7.5' map. Camp Creek is perennial, with a drainage area of about 60 km^2. Channel width is 4 m, bank height is 4.5-6 m, channel slope is 1.8 m/km. Equiwidth point-bar stream, incised, alluvial, sinuosity of 1.5 at site, valley relief of 30 m, wide flood plain, tree cover less than 50 percent along bankline. Bed material is silt and sand, bank material is moderately coherent clayey silt. Most of the drainage basin has been cleared for agricultural purposes, and the channel has probably degraded to some extent.

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(See "Synopsis")

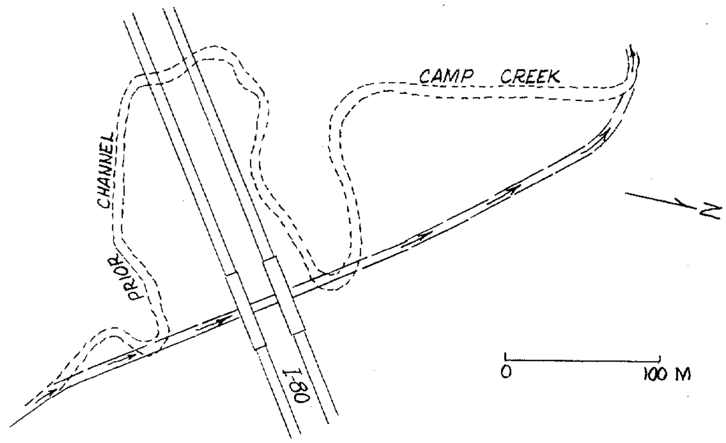


Figure 145. Plan sketch of Camp Creek channel relocation.

Figure 146. Camp Creek at site 69. A, View of relocated channel downstream from I-80 bridge, in 1979. B, Bank erosion at downstream junction of natural and relocated channels, in 1979.

SITE 70. MIDDLE CREEK AT
I-80 NEAR LINCOLN, NEBR.

SYNOPSIS--Channel of deeply incised creek was relocated, thereby reducing the length of a channel segment from 510 m to 255 m; for purpose of improving channel alinement at bridge and accommodating planned interstate location (figs. 147A and B). Performance period, 18 yr (1961-79), during which two floods of recurrence interval in the range of 5-10 yr occurred. No countermeasures were apparent from field inspection in 1979. Channel degradation at the bridge had exposed the top of a pier footing (fig. 147B), the bankline at the pier had receded about 6 m, and bank erosion had occurred along the relocated channel downstream from the bridge. At the first bend upstream from the relocation, severe bank recession was in progress at the outside of a bend (fig. 147C). As observed on a 1955 airphoto, the banks along the natural channel were generally steep and unstable, but the relocation has probably contributed to bank erosion in adjacent segments of the channel. Channel degradation had probably already occurred along the channel prior to relocation, as indicated by countermeasures at the railroad bridge downstream.

Stability class C2 for relocated channel and D4 for adjacent segments of the natural channel. The critical factors contributing to instability of the relocated channel are those that account for prior instability of the natural channel: erodible banks, removal of vegetation along the channel, and cultivation of the drainage basin. Bank protection is difficult and expensive because of the height and erodibility of the banks; but grading of the banks to a low slope and planting with vegetation might be an effective countermeasure.

SITE FACTORS--Lat 40°49.5', long 96°50', at I-80, 11.5 km west of Lincoln, Nebr., on Emerald 7.5' map. Middle Creek is perennial, with a drainage area of roughly 150 km^2. Channel bottom width is 6-8 m, top width is about 20 m, bank height is 6-7.5 m, channel slope is about 1 m/km. Equiwidth point bar stream, deeply incised, alluvial, sinuosity of 2, valley relief of 45 m, wide flood plain, less than 50 percent tree cover along channel. Bed material is sand and fine gravel, bank material is moderately coherent clayey silt.

ALTERATION AND POST-ALTERATION FACTORS; DISCUSSION--(See "Synopsis")

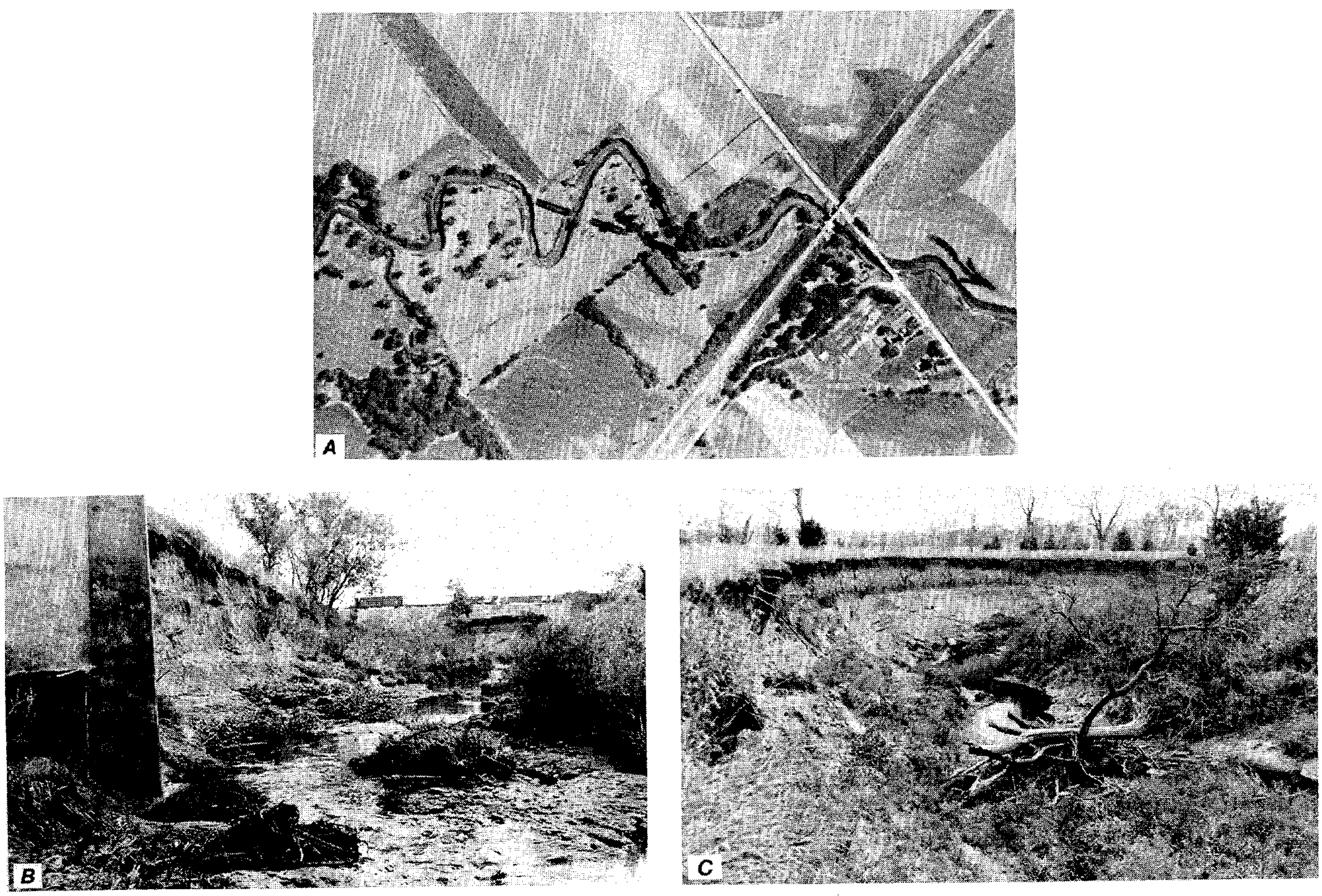


Figure 147. Middle Creek at site 70. A, Airphoto of site in 1955, position of relocated channel shown in dashed line. (From U.S. Dept. of Agriculture) B, View upstream along relocated channel from beneath bridge, in 1979. Top of exposed pier footing is at left. C, Bank erosion at bend upstream from relocated channel, in 1979. Bank height is 7.5 m.

SITE 71. BIG BLUE RIVER AT
I-80 NEAR MILFORD, NEBR.

SYNOPSIS--Channel was relocated by cutting off two bends such that the relocated segments were separated by a short segment of natural channel (fig. 148). At the upstream bend, where the relocation was done to improve channel alinement at the interstate bridge, the channel was shortened from a prior length of 820 m to 400 m. At the downstream bend, where the apparent purpose of the relocation was to reduce flooding of a rest area, the channel was shortened from a prior length of 700 m to 250 m. No bank protection measures were applied. Performance period, 16 yr (1963-79) during which floods approaching a 25-yr recurrence interval occurred in 1963 and 1967. Floods of recurrence interval in the range of 5-10 yr have occurred since 1967. No plans showing the dimensions of the relocated channel were obtained, but the bottom width as measured on a 1965 airphoto was 14.5 m, narrowing to 12 m at the upstream end. In 1979, the banks of the relocated channel were generally stable (fig. 149A, except for bank slumping upstream from the interstate bridge (fig. 149B). Prior stability of the natural channel was good, as observed on a 1955 airphoto, except for cut banks at some bends. However, meander cutoffs that appear to be natural are common along the course of the river. No effect of relocation on the natural channel was discerned (fig. 149C).

Stability class B2 for relocated channel and B1 for adjacent segments of natural channel. Channel stability is tentatively attributed to the establishment of vegetation on the graded banks, which are kept moist by the permanent flow of the stream. In addition, the banks are not high by comparison with those along many smaller streams in the area.

SITE FACTORS--Lat 40°49.5', long 97°04', at I-80, 5 km north of Milford, Nebr., on Milford 7.5' map. Big Blue River is perennial, with a drainage area of 2,852 km^2 at the stream gage at Seward (10 km upstream) and an average discharge of 3.1 m^3/s. Channel width is in the range of 12-15 m, bank height is 2.5-3.5 m, and channel slope is 0.55 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.5-2, valley relief of 30 m, wide flood plain, tree cover along bankline in range of 50-90 percent. Bed material is sand and silt, bank material is moderately coherent clayey silt. As observed on 1955 and 1962 airphotos, the natural channel was generally stable, with graded banks on which many large riparian trees were growing.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--By comparison with Middle Creek (site 70, 25 km to the east on Interstate 80), Big Blue River is stable and has showed no unfavorable response to relocation. Middle Creek is smaller, has higher banks, and was unstable prior to relocation. The instability of Middle Creek is associated with degradation, which is attributed to land use practices and to the channelization of some reaches. Big Blue River has not been channelized, and has not degraded significantly; and its response to the other man-induced factors has been less than that of Middle Creek. Preservation of vegetation along its sloping bankline, which was not suitable for cultivation, has probably been an important factor in its stability.

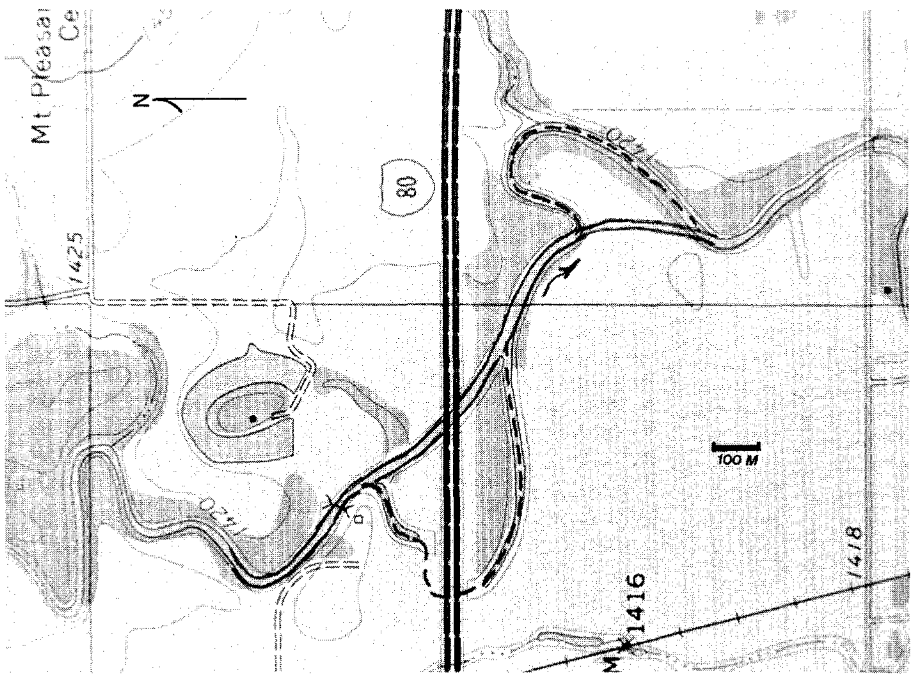


Figure 148. Topographic map showing relocation of Big Blue River. Prior channel is shown in dashed line. (Base from U.S. Geological Survey Milford, Nebr., 7.5' quadrangle).

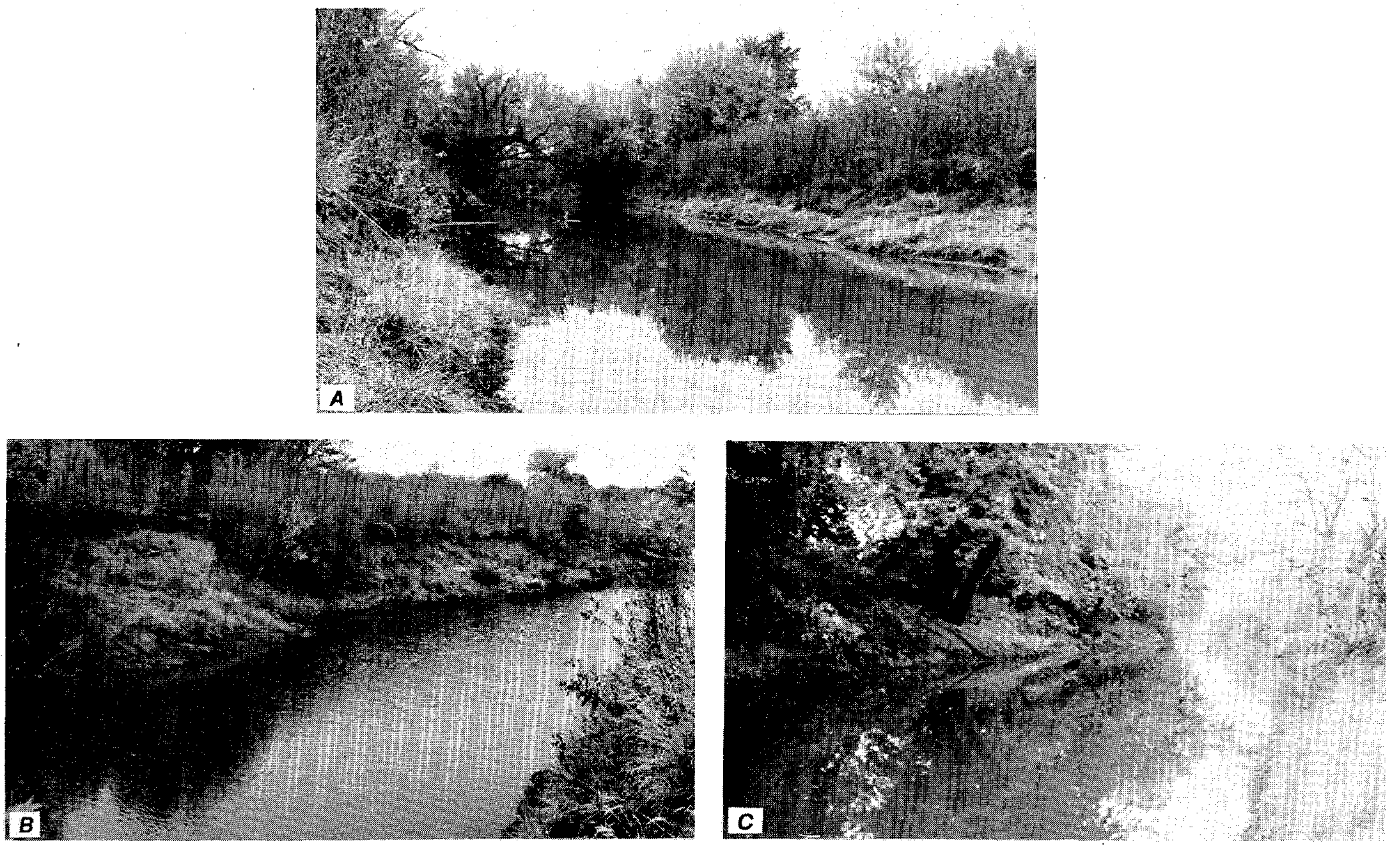


Figure 149. Big Blue River at site 71. A, Downstream junction of relocated channel (foreground) with natural channel, in 1979. B, Bank slumping along relocated channel upstream from bridge, in 1979. C, Natural channel along short segment between relocations, in 1979.

SITE 72. ONE MILE CREEK AT SR-24 NEAR FORT YATES, S.D.

SYNOPSIS--Channel segment of intermittent stream was relocated in 1962 and thereby shortened from a length of 440 m to 370 m, for purpose of improving channel alinement at culvert entrance (fig. 150). During rainstorms between 1967 and 1975, bank erosion and channel degradation occurred downstream from the culvert. Riprap revetment was replaced three times. In 1975, the relocated channel was rebuilt to a lower gradient for a distance of 91 m downstream from the bridge, the box culvert was extended, and a drop structure (having a fall of 2.1 m) and a stilling basin were constructed (fig. 151-A). No significant storms have occurred since 1975. In 1979, field observations indicated that the relocated channel upstream from the culvert was stable and well vegetated. Downstream from the culvert, the channel bottom was grassed but the side slopes were mostly bare and the left bank has slumped at one place (fig. 151B). No effect of relocation on the natural channel was discerned.

Stability class C3 for initial relocation and B1 for modification done in 1975. Instability of the initial relocation is attributed to turbulence at the culvert outlet, to the bend in the relocated channel, and to the erodibility of bank materials.

SITE FACTORS--Lat 46°03.5', long 100°40', at SR-24, 2.5 km south of Fort Yates, S.D., on Fort Yates 7.5' map. One Mile Creek is intermittent, and has a drainage area of 52 km^2 and an estimated 25-yr flood discharge of 46 m^3/s. Channel bottom width is 3-4 m, bank height is 3.5 m, channel slope is about 3 m/km. Equiwidth point-bar stream, alluvial, sinuosity of 1.3, valley relief of 25 m, narrow active flood plain bordered by terraces. Bed and bank material is silt-clay. The terraces and minor levels along the channel indicate a history of degradation. As observed on a 1957 airphoto, cut banks were common along the channel, but no significant lateral erosion was discerned by comparison with a 1972 airphoto.

ALTERATION AND POST-ALTERATION FACTORS--The channel as relocated in 1962 was trapezoidal in cross section with 3:1 side slopes and a bottom width of 6.1 m. For a distance of about 12 m downstream from the culvert outlet, the channel was lined with "fieldstone" riprap to a depth of 0.45 m and extending a vertical distance of 1.5 m onto the side slopes. The ends of the riprap blanket were keyed into the channel sides and bottom by a trench filled with riprap. In the 1975 reconstruction, the channel downstream from the added drop structure and stilling basin was protected with loose rock riprap installed over a filter blanket. The drop structure and stilling basin were designed to achieve a 70 percent reduction in outlet energy.

DISCUSSION--Although the 1975 installation has not been tested by a storm, good performance elsewhere for drop structures and stilling basins of this design has been reported by the North Dakota Department of Transportation. Such structures have been installed at about 25 sites since 1962.

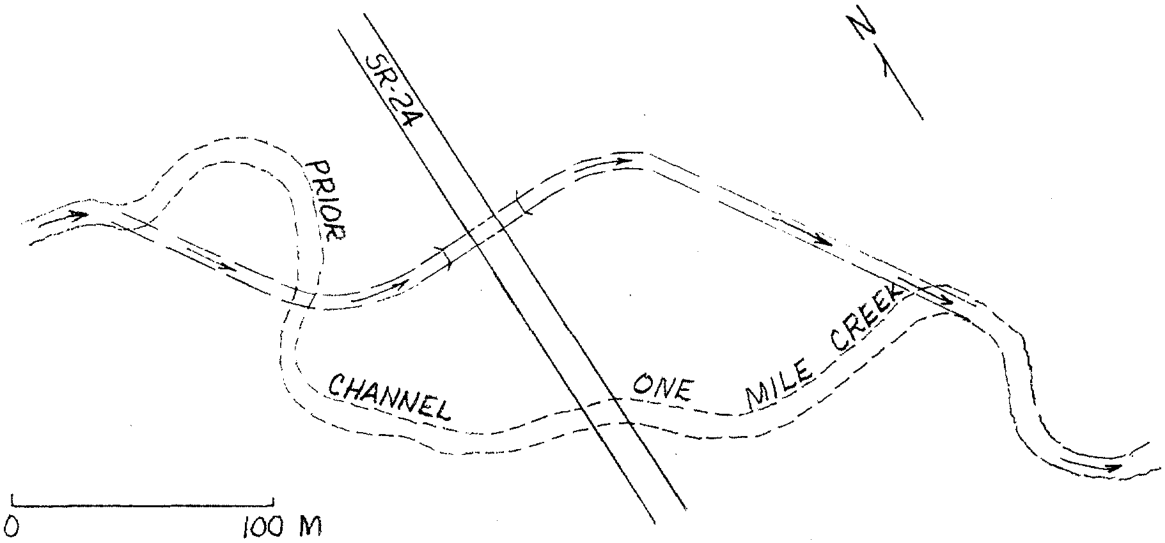


Figure 150. Plan sketch of One Mile Creek channel relocation, in 1962.

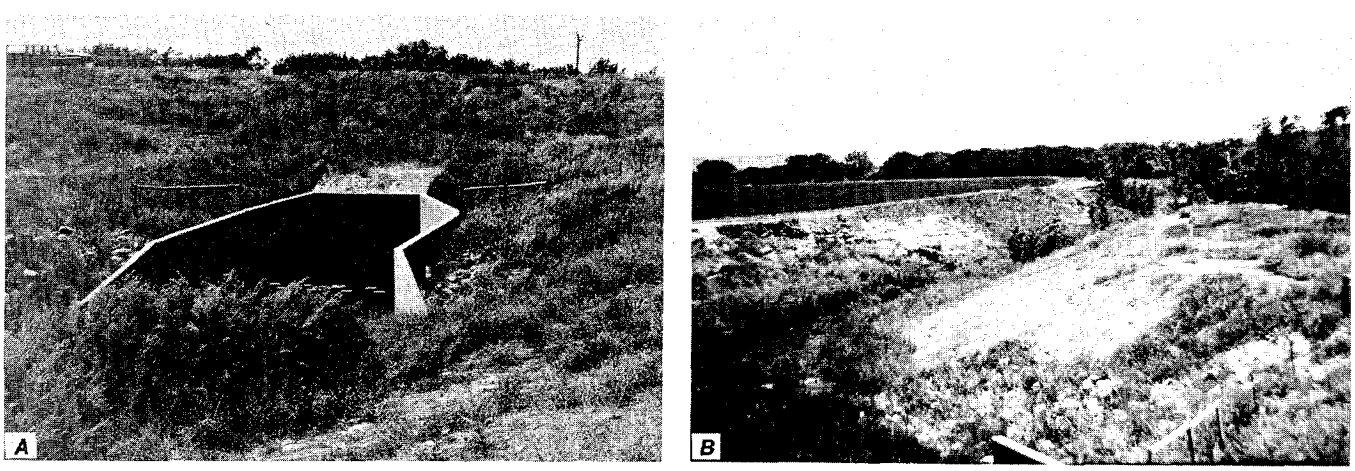


Figure 151. One Mile Creek at site 72. A, Culvert and stilling basin at downstream side of roadway embankment. B, View downstream from bridge along relocated channel of One Mile Creek, in 1979.

SITE 73. HOCKING RIVER AT
US-33 AT LOGAN, OHIO

SYNOPSIS--Along a reach about 3 km in length, the Hocking River channel was moved laterally (fig. 152) by a maximum distance of about 80 m, to accommodate the planned location of US-33. Performance period, 9 yr (1970-79), during which the river has exceeded bankfull stage but no major floods have occurred. Bottom width of the relocated channel was about 30 m, and the bank adjacent to the highway was riprapped. Maximum diameter of the riprap was in the range of 0.5-1.8 m, the larger sizes being used along the downstream section of the relocation. In 1979, the upstream part of the relocated channel was generally stable and well vegetated (fig. 153). Along the right bank of the downstream part, which was not riprapped, minor erosion was observed and vegetation was less well established; however, along the riprapped left bank, a continuous strip of young trees (silver maple, box elder, sycamore) had become established among the large blocks of riprap. Upstream from the relocation, where the river course is nearly straight for a distance of several kilometers, the natural channel was stable and well vegetated before relocation (in 1958) and no effects of relocation were observed on a 1976 airphoto. Downstream from the relocation, where the river course is meandering, cut banks were at the outside bends in 1958, and substantial lateral migration occurred between 1958 and 1976. (Channel relocation, not described here, was done along this meandering reach during the construction of US-33).

SITE FACTORS--Lat 39°32', long 82°24', at US-33, near south boundary of Logan, Ohio, on Logan 7.5' map. Hocking River is perennial; its drainage area is 1,189 km^2 at the U.S.G.S. gage 6.5 km upstream and its average discharge is 12.7 m^3/s. Channel width is 30-40 m, bank height is 2 m, and channel slope is 0.8 m/km. Equiwidth point-bar stream, alluvial, sinuosity low (1.1-1.2) upstream from site and much higher (1.5) downstream, valley relief of 45 m, wide flood plain, tree cover along bankline greater than 90 percent. Bed material is sand and gravel, bank material is moderately coherent silt and clay.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--The explanation for the much greater sinuosity of the natural channel downstream from this site is not apparent, but the greater sinuosity is associated with a decided deterioration in lateral stability. With regard to the relocated channel, the large blocks of riprap along the left bank at the downstream end have apparently aided in the establishment of young trees along the bankline.

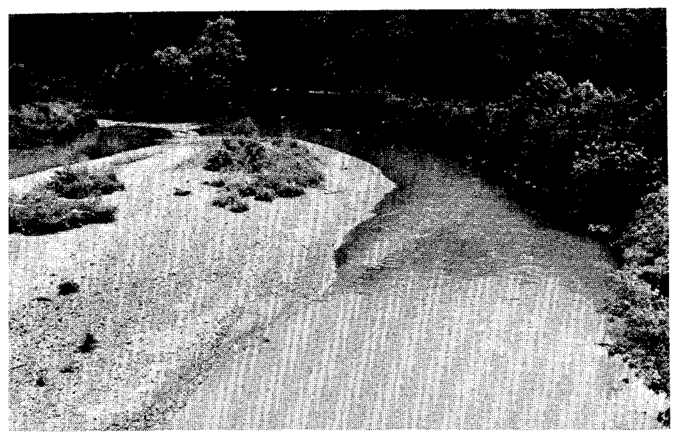


Figure 153. View of relocated channel of Hocking River downstream from US-33 bridge, in 1979.

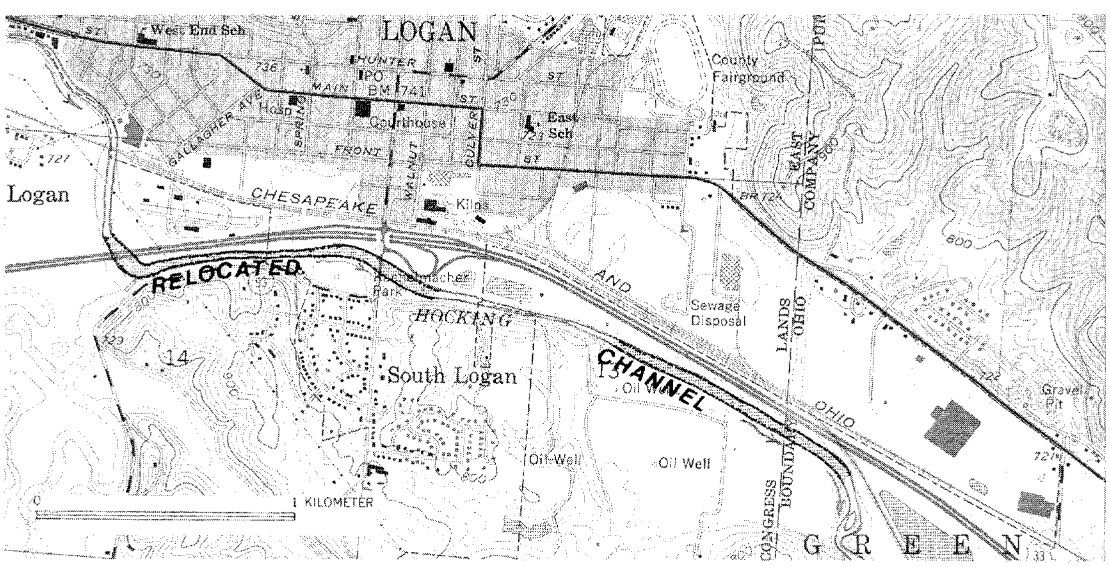


Figure 152. Topographic map showing relocated segments (stippled) of Hocking River. (Base from U.S. Geological Survey Logan 7.5' quadrangle)

SITE 74. OLENTANGY RIVER AT SR-315 AT COLUMBUS, OHIO

SYNOPSIS--Reach 2,200 m in length was relocated and thereby shortened to 1,900 m, for purpose of accommodating planned roadway and interchange location (fig. 154 and 155A). Performance period, 9 yr (1970-79), during which the 2nd and 3rd highest peak flows (about 300 m^3/s) in a 23-yr period of record occurred in 1973 and 1975. The relocated channel had a bottom width of about 25 m and a channel slope of 0.64 m/km. A low berm about 15 m in width was built along the right bank (fig. 155B) evidently to increase channel width for conveyance of flood flow. Limestone riprap having a maximum diameter of about 1 m and a modal diameter of about 0.3 m was installed on the banks at the slight bends in the relocated channel. In addition, five low riprap check dams were placed at 240-m intervals in the channel. No information was obtained on the intended purposes of the check dams, whether to prevent degradation or to provide some environmental diversity. In 1979, the banks of the relocated channel were stable and young trees were becoming established (fig. 155B and C). Whatever their intended purpose, the riffles at check dams added visual interest to the channel (fig. 155C). As indicated by comparison of 1957 and 1964 airphotos, the banks of adjacent segments of the natural channel were stable prior to relocation, and no effects of relocation on the natural channel were discerned during the 1979 field visit.

Stability class A1 for relocated channel and for adjacent segments of natural channel. Stability of the relocated channel is attributed to the use of the berm (which increased the total channel width to 40 m) for conveyance of flood flows, to the riprap bank protection at bends, and to its low sinuosity. Factors contributing to the prior stability of the natural channel (low sinuosity, vegetated banks) were also operative.

SITE FACTORS--Lat 40°07', long 83°02', at SR-315, near northwest boundary of Columbus, Ohio, on Columbus Northwest 7.5' map. Olentangy River is perennial, with a drainage area of 1,287 km^2 and an average discharge of 12.6 m^3/s. Channel width is 25-30 m, bank height is 1.5 m, and channel slope is 0.6 m/km. Equiwidth stream, slightly sinuous, alluvial, valley relief of 45 m, narrow flood plain, 90 percent tree cover along bankline.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--The relocated channel will probably prove to be more stable than was the prior channel, which had a sharp bend. The site is in a residential area, and the visual effects of relocation need to be considered. The less attractive appearance of the relocated channel seems mainly a result of the clearing of trees, which are becoming re-established. The riffles, if maintained, will add an element of interest not previously present.

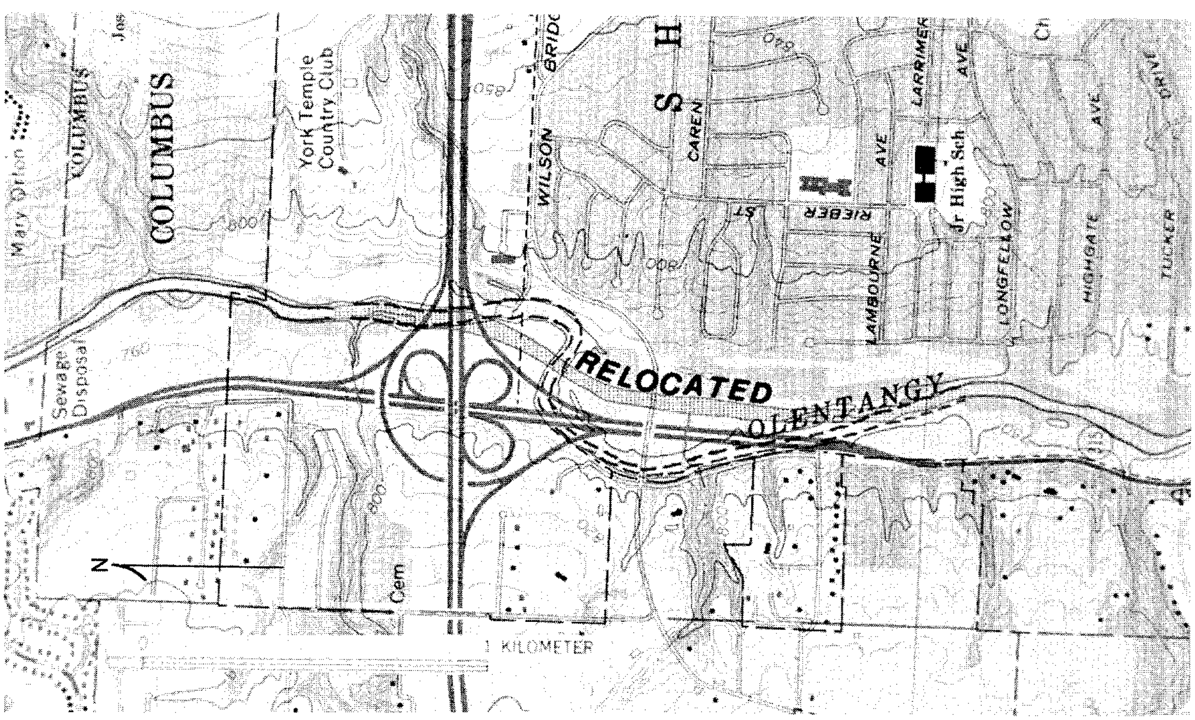


Figure 154. Topographic map showing Olentangy River channel relocation. Relocated channel is in stippled pattern, prior channel in dashed line. (Base from U.S. Geological Survey Columbus Northwest 7.5' quadrangle).

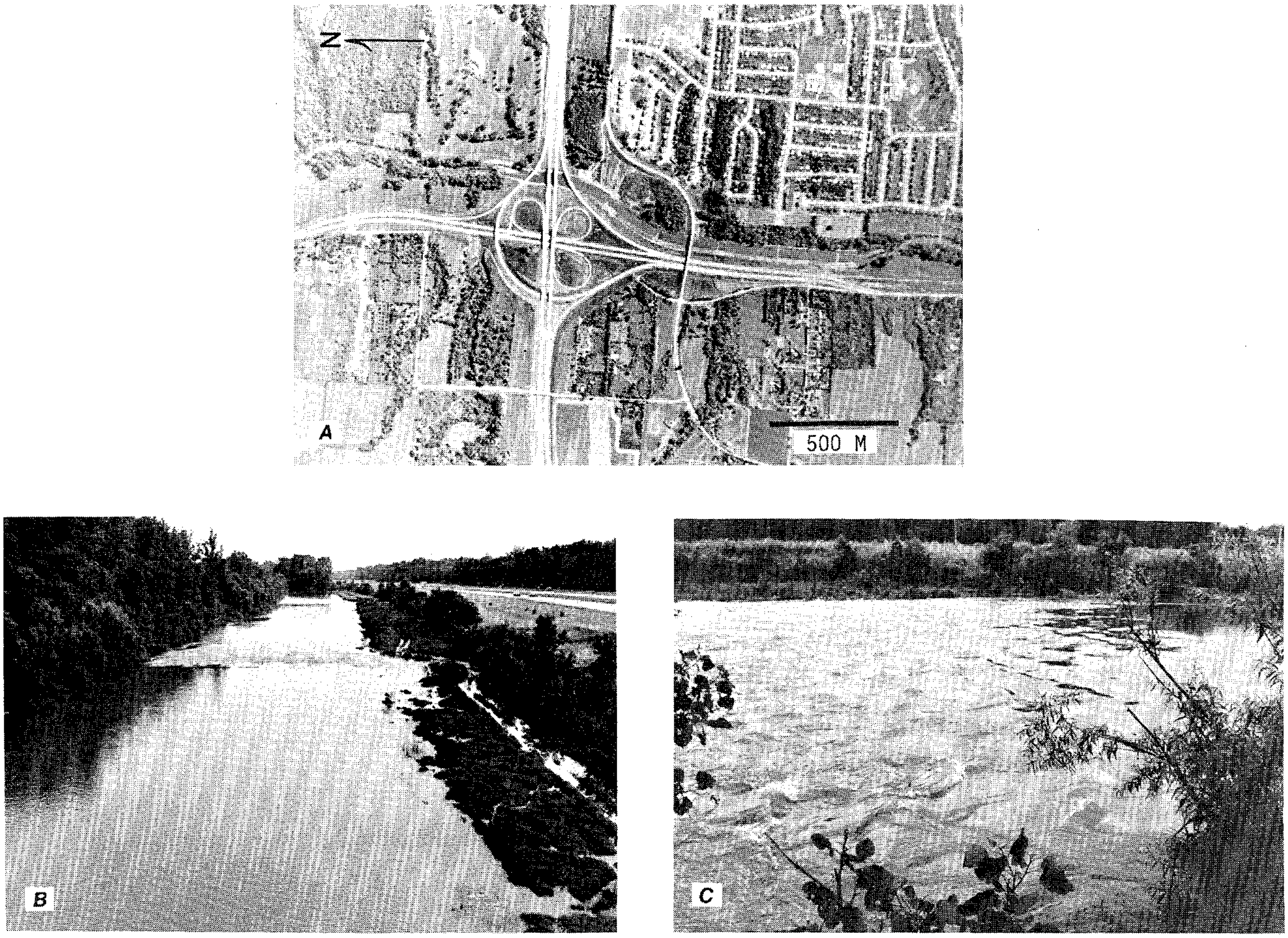


Figure 155. Olentangy River at site 74. A, Airphoto of site in 1971. (From U.S. Dept. of Agriculture) B, View downstream along relocated channel in 1979. Riffle in background is at check dam. C, View of riffle at check dam, in 1979.

SITE 75. RACCOON CREEK AT SR-16 AT NEWARK, OHIO

SYNOPSIS--A reach about 4,200 m in length was relocated and thereby shortened to 3,050 m, for the purpose of avoiding several crossings and to accommodate the planned location of SR-16 (figs. 156 and 157A). A small part of the relocation (at the Octagon State Memorial) was done in 1962 in an effort to remedy severe bank erosion that occurred during a flood in 1959, but most was done in 1971-72. No floods have occurred at the site since 1972. The relocated channel was built with a bottom width of about 23 m, and most of the bankline was revetted with heavy limestone riprap, having a maximum diameter of about 1.2 m (fig. 157B). In 1979, young trees were growing on the riprapped banks, and the only bank erosion noted was minor, and at places not protected by riprap. Channel degradation has evidently been controlled by a sheet-pile check dam and by a bedrock outcrop in the channel near the upstream end of the relocation. As observed on a 1957 airphoto, cut banks were at bends in the natural channel and a substantial lateral migration rate is apparent from comparison with a 1964 airphoto. No apparent effect of relocation on the natural channel (fig. 157 C) was observed.

Stability class B1 for relocated channel and B1 for adjacent segments of natural channel. Where the banks are riprapped, no erosion is likely even during floods; and where not riprapped, erosion is likely to be no worse than along the prior channel. Bends in the natural channel, where the most rapid bank erosion was taking place prior to relocation, have been eliminated.

SITE FACTORS--Lat 40°03', long 82°27', at SR-16, in western part of Newark, Ohio, on Newark 7.5' map. Raccoon Creek is perennial and has a drainage area of roughly 225 km^2. Channel width is 22 m; bank height is 1.5-2 m to the active flood plain and 3-8 m to bordering terraces; channel slope is 2.6 m/km. Wide-bend point-bar stream, semi-alluvial, sinuosity of about 1.3, valley relief of 60 m, narrow active flood plain bordered by terraces, 50-90 percent tree cover along bankline. Bed material is gravel, bank material is silt-clay.

ALTERATION AND POST-ALTERATION FACTORS: DISCUSSION--(See "Synopsis")

ADDENDUM--Upstream from this site, along the adjacent 10 km length of Raccoon Creek ending near the town of Granville, several channel relocations were made in 1962 during the construction of State Routes 16, 37, and 161. The length of natural channel affected was 300 m for one relocation, 550 m for another, and 1,100 m for the one farthest upstream, about 2 km west of Granville. At the site west of Granville, the relocated channel was 885 m in length, straight except for slight curves at either end, and trapezoidal in cross section, with a bottom width of 18 m, 2:1 side slopes, and a channel slope of 2 m/km. No bank protection was installed except at the curved ends, where the banks were riprapped. The prior channel was meandering and, as observed on a 1958 airphoto, laterally unstable at bends.

As observed in the field in 1979, the relocated channel was in many places bordered by a dense growth of trees (fig. 157D) and the banks were generally stable except for local erosion where the flow was deflected by mid-channel bars. However, a tendency for reestablishment of the meandering pattern was noted, particularly where the channel was bordered by cultivated fields (fig. 157E).

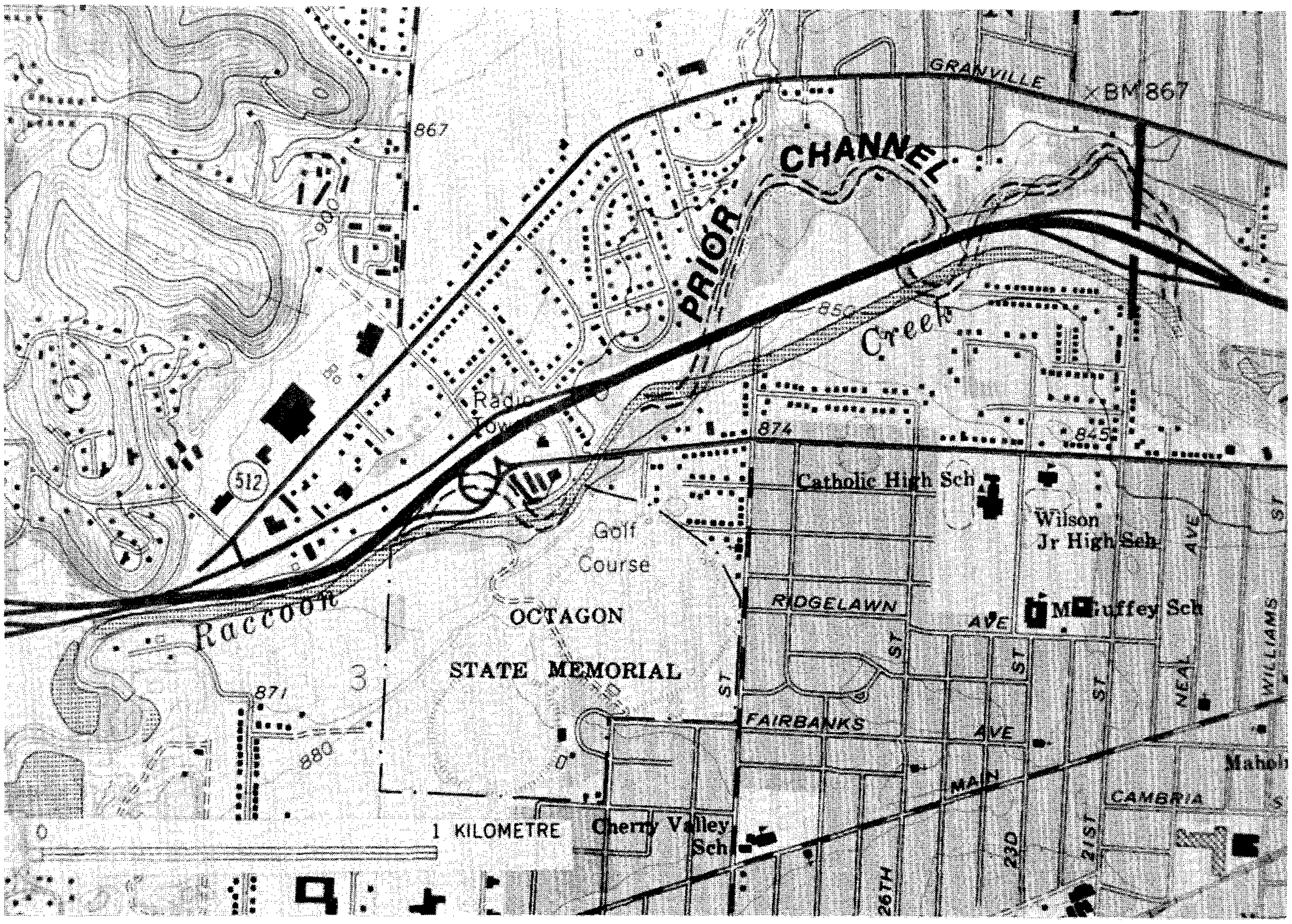


Figure 156. Topographic map showing relocated channel of Raccoon Creek (stippled) and prior channel (dashed lines). (From U.S. Geological Survey Newark, Ohio, 7.5' quadrangle).

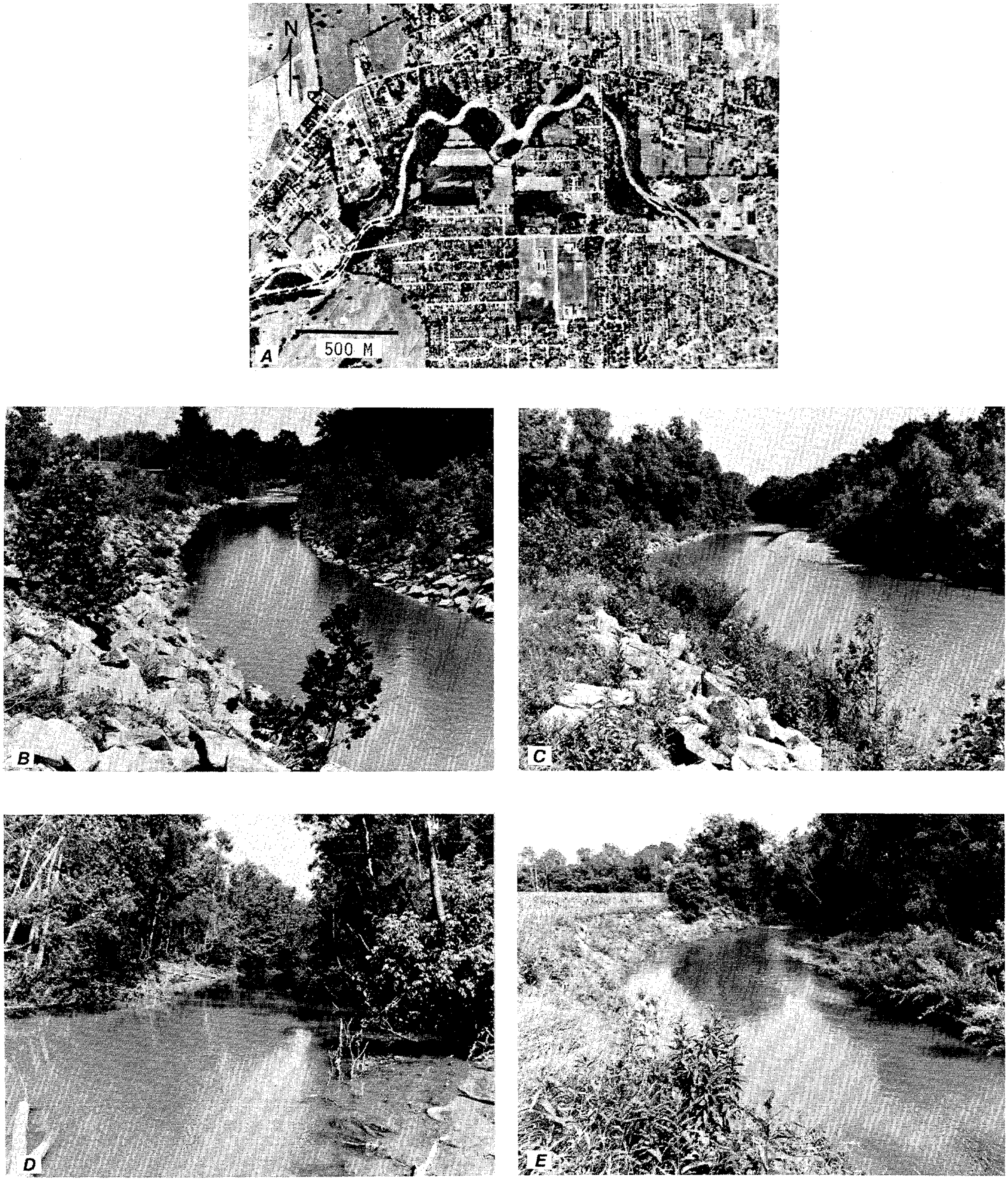


Figure 157. Raccoon Creek at site 75 and near Granville, Ohio. A, Aerial photograph of site in 1964. Approximate position of relocated channel shown in dashed line. B, Riprapped section of relocated channel, in 1979. C, Downstream junction of relocated channel with natural channel, in 1979. D, Relocated channel of Raccoon Creek near Granville, in 1979. E, Bank erosion at bend in relocated channel of Raccoon Creek near Granville, in 1979.

SITE 76. WASHITA RIVER AT
SR-145 NEAR PAOLI, OKLA.

SYNOPSIS--A meander loop was cut off, reducing the length of a channel segment from 1,330 m to 145 m, for purpose of preventing encroachment of the loop on the roadway (fig. 158A). Performance period, 9 yr. (1969-78), during which there were no floods much larger than mean annual. This site has been described by Keeley (1971, p. 3-8), who demonstrated with airphotos (taken in 1940, 1966, and 1969) the downstream migration of a meander loop toward the roadway. In 1940, the loop was about 350 m from the roadway; and in 1969, about 20 m. The loop was cut off by means of an artificial channel in 1969, and there is no record of bank protection measures. By 1978, a slight bend had developed in the relocated channel. Channel alinement at the bridge site was satisfactory; but the bridge itself was missing, for causes unknown to this writer.

Stability class D3 for relocated channel and D4 for adjacent segments of the natural channel. In view of the historical lateral instability of the river, which is attributed to high erodible banks, high sinuosity, and lack of vegetal cover along the bankline, the performance of the relocated channel is relatively good.

SITE FACTORS--Lat 34°48', long 97°20', at SR-145, 7 km west of Paoli, Okla., on Paoli 7.5' map. Washita River is perennial. Its drainage area at the U.S.G.S. gage, 21 km downstream, is 13,800 km^2 and its average discharge is 20 m^3/s. Channel width is 40 m, bank height is 4.5-5 m, and channel slope is 0.4 m/km. Wide-bend point-bar stream, locally braided, alluvial, sinuosity of 1.7, valley relief of 25 m, wide flood plain, tree cover along bankline less than 50 percent. Bed material is sand, and bank material is clayey silt of low coherence. Comparison of airphotos taken in 1940 and 1969 shows that the lateral migration rate was high at bends and relatively low in straight reaches; an elongated meander loop was cut off during this period, just upstream from the site (compare figs. 158A and B).

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--Although the relocated channel is given a low stability rating by comparison with very stable channels, its stability is good by comparison with other reaches of the Washita River. If the channel had been alined with the nearly straight adjacent segments of natural channel (fig. 158A), its stability would probably have been improved.

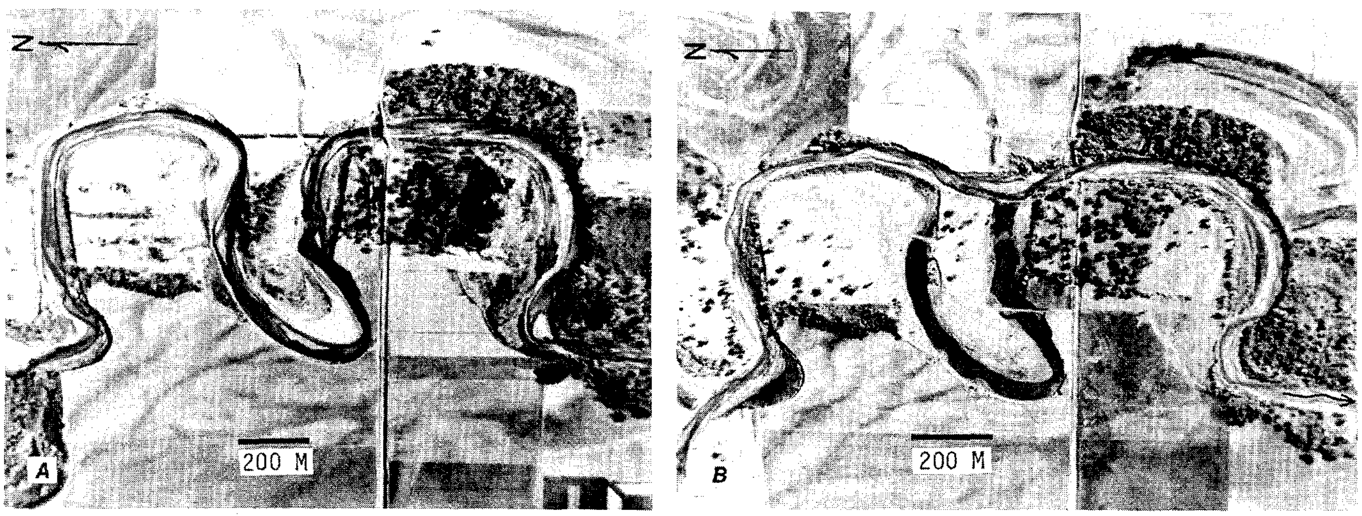


Figure 158. Washita River at site 76. A, Airphoto of site in 1969. Position of relocated channel is shown in dashed line. (From U.S. Dept. of Agriculture) B, Airphoto of site in 1978. (From U.S. Dept. of Agriculture)

SITE 77. UMATILLA RIVER AT I-80N AT PENDLETON, OREG.

SYNOPSIS--Channel relocation, reach 1,300 m in length straightened to avoid two crossings by I-80N and thereby shortened to 975 m (fig. 159A and B). Performance period 11 yr, 1969-79. The relocated channel has been tested by a 9-yr flood in 1970, a 6-yr flood in 1972, and a 15-yr flood in 1975. The banks of the relocated channel were graded to a 4:1 slope and revetted with rock riprap. In addition, 11 spurs of heavy rock riprap were placed alternately on the left and right banks, apparently for bank protection and to induce sinuosity, thereby avoiding a canal-like aspect. By 1973, gravel bars had been deposited downstream from spurs, small-scale sinuosity (as well as a sequence of pools and riffles) had formed, and vegetation had begun to grow in the riprapped banks (fig. 159B). By 1979, vegetation was well established (fig. 159C), as were the pools and riffles. Sinuosity appeared to be somewhat diminished because the tips of spurs had been eroded. No bank erosion was noted. Minor bank erosion along the natural channel downstream was noted (fig. 159D); this may, or may not, be related to the relocation.

Stability class A1 for relocated channel, B for adjacent segments of natural channel. Critical factors in stability of the relocated channel are the placement of countermeasures for bank protection and the existence of bedrock controls in the channel bed, which preclude degradation.

SITE FACTORS--Lat 45°40', long 118°50', at I-80N, at the western city limits of Pendleton, Oreg., on Pendleton 7.5' map. Umatilla River is perennial, with a drainage area of 1,650 km^2 and an average discharge of 14 m^3/s. Width of channel variable, in range of 30-60 m; bank height, 3 m; channel slope, 3.9 m/km. Braided stream without point bars, semi-alluvial, sinuosity of 1.2. Valley

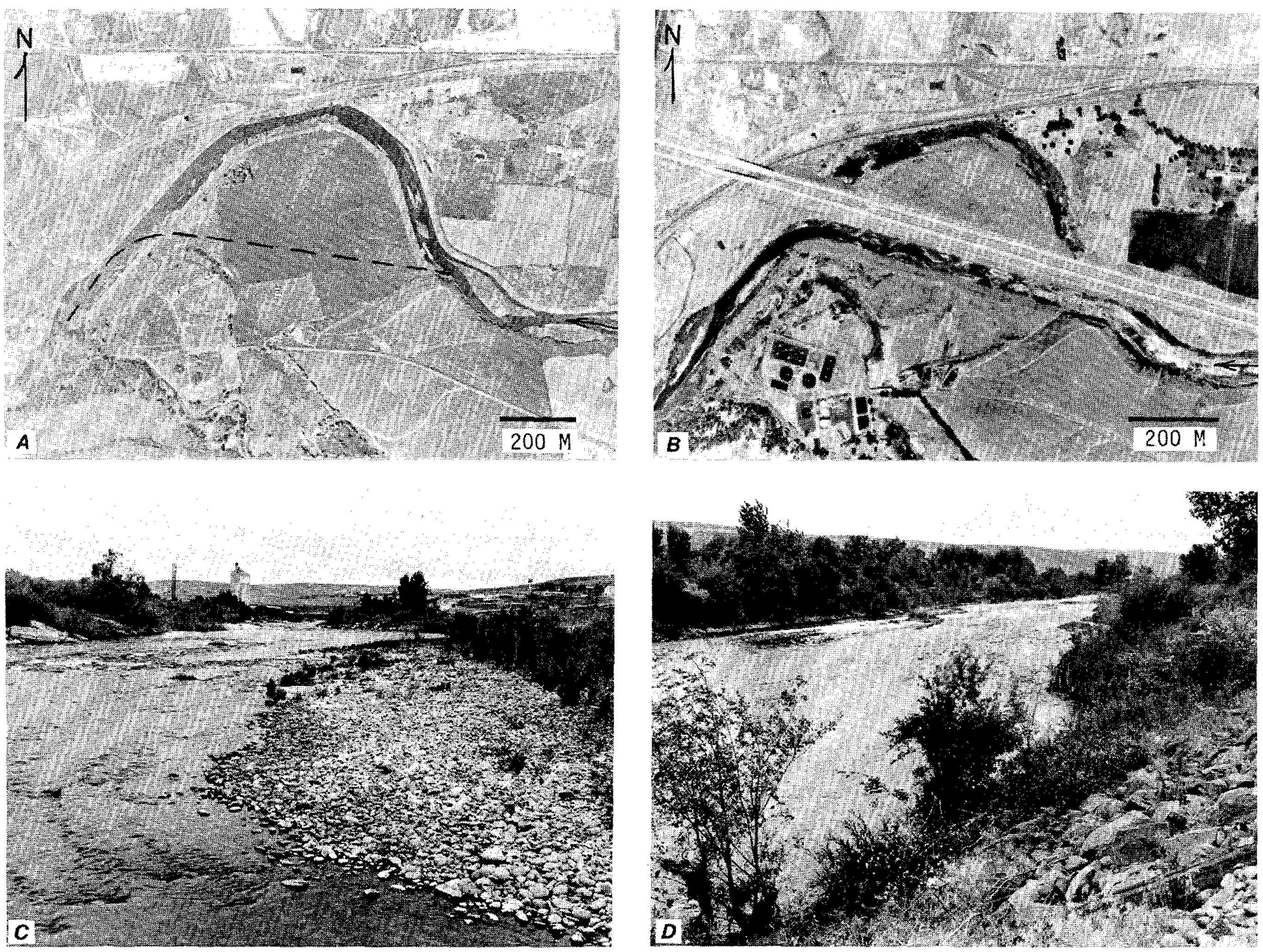


Figure 159. Umatilla River at site 77. A, Airphoto in 1962, prior to relocation. Position of relocated channel shown by dashed lines. B, Airphoto of site in 1973. (From Oregon Dept. of Transportation) C, Downstream view along relocated channel in 1979, showing deposition of gravel bars, and sinuosity induced by spurs. D, Natural channel just downstream from relocated reach.

relief is 125 m, width of flood plain is 500 m; sparse trees along channel, valley is mainly grassland. Bed material is gravel and cobble. Prior channel was leveed along both banks and showed no evidence of instability.

ALTERATION FACTORS--Relocation resulted in a shortening of the affected reach by a factor of 0.75. The slope of the relocated channel is variable, ranging from 0.39 m/km at the upstream end to 0.59 m/km downstream. The cross section is generally trapezoidal, with a bottom width of 49 m, a top width of 75 m, and a depth of 3.5 m. The toe of the riprap bank revetment was carried to a depth of 1.5 m below the channel bottom. The rock riprap spurs placed along the channel were 15 m in length and oriented downstream at an angle of 45° with the bankline.

POST-ALTERATION FACTORS--The main changes since alteration are the deposition of gravel bars downstream from each spur, erosion of the spur tips, and the establishment of vegetation on the riprapped banks. No maintenance work is apparent.

DISCUSSION--Width of the relocated channel is within the upper range of widths measured for the natural channel, and seems to have been well chosen. The sinuosity induced into the channel by the spurs is of a much smaller scale than would be appropriate for a channel of this width, but it will probably be maintained so long as the spurs remain in place. Whether by accident or design, the spurs have served to make the relocated reach more varied and less canal-like than it would otherwise have been.

SITE 78. GRANDE RONDE RIVER AT I-80N AT LA GRANDE, OREG.

SYNOPSIS--A reach 975 m in length was widened and realined, which involved shifting part of the channel a distance of about 75 m to the south (fig. 160A and B). The realined reach is 900 m in length. The purpose of the relocation was to permit a less curved roadway alinement. Performance period, 8 yr (1971-79). A peak discharge of 177 m^3/s (5th highest in a 70-yr period of record) occurred in 1972. The banks of the relocated channel were graded to a 2:1 slope and revetted with a 1-m thickness of dumped rock riprap, the toe of which was carried to a depth of 1.5 m below the channel bed. By 1979, young willows had become well established on the lower part of the riprapped slope (fig. 160C) and there was no evidence of instability. Prior to relocation, cut banks were common along the natural channel, and the relocation has not increased the incidence of these.

Stability class A1 for relocated channel and class B for adjacent reaches of the natural channel. Critical factors in channel stability are the thoroughness of the bank protection, the width of the relocated channel, and the slight degree of shortening involved in relocation.

SITE FACTORS--Lat 45°21', long 118°6.5', at I-80N, near the northwest limits of La Grande, Oreg., on La Grande SE 7.5' map. Grande Ronde River is perennial, with a drainage area of 1,756 km^2 and an average discharge 10.8 m^3/s. Bottom width of natural channel is 25 m, top width is 30 m, bank height is variable because of minor levels along river, bankfull stage regarded as 2.1 m; channel slope is 6.5 m/km. Locally braided, point-bar stream, alluvial, on alluvial fan, sinuosity of 1.1, tree cover along channel in range of 50-90 percent. Bed material is gravel and cobble.

ALTERATION FACTORS--The relocated channel was designed to have a top width of 55 m, a bottom width of 46 m, 2:1 side slopes, and a depth of 2.5 m. The cross section was trapezoidal, except that the bottom sloped gently at 20:1 toward the channel centerline. Boulders were placed in the channel bottom to enhance the fish habitat. Longitudinal slope of the channel bottom was so constructed that sections of 1 m/km slope alternated with flat sections, at 90 m intervals; this feature was evidently intended to provide alternating rapids and pools, which were apparent at normal stage in 1979 (fig. 160C).

POST-ALTERATION FACTORS--The flood of 1972 is considered adequate to test the relocated channel.

DISCUSSION--This site provides an example of measures to provide fish habitat, and also an example of the establishment of a good growth of willows in riprap, despite the occurrence of four floods just over bankfull stage since 1971.

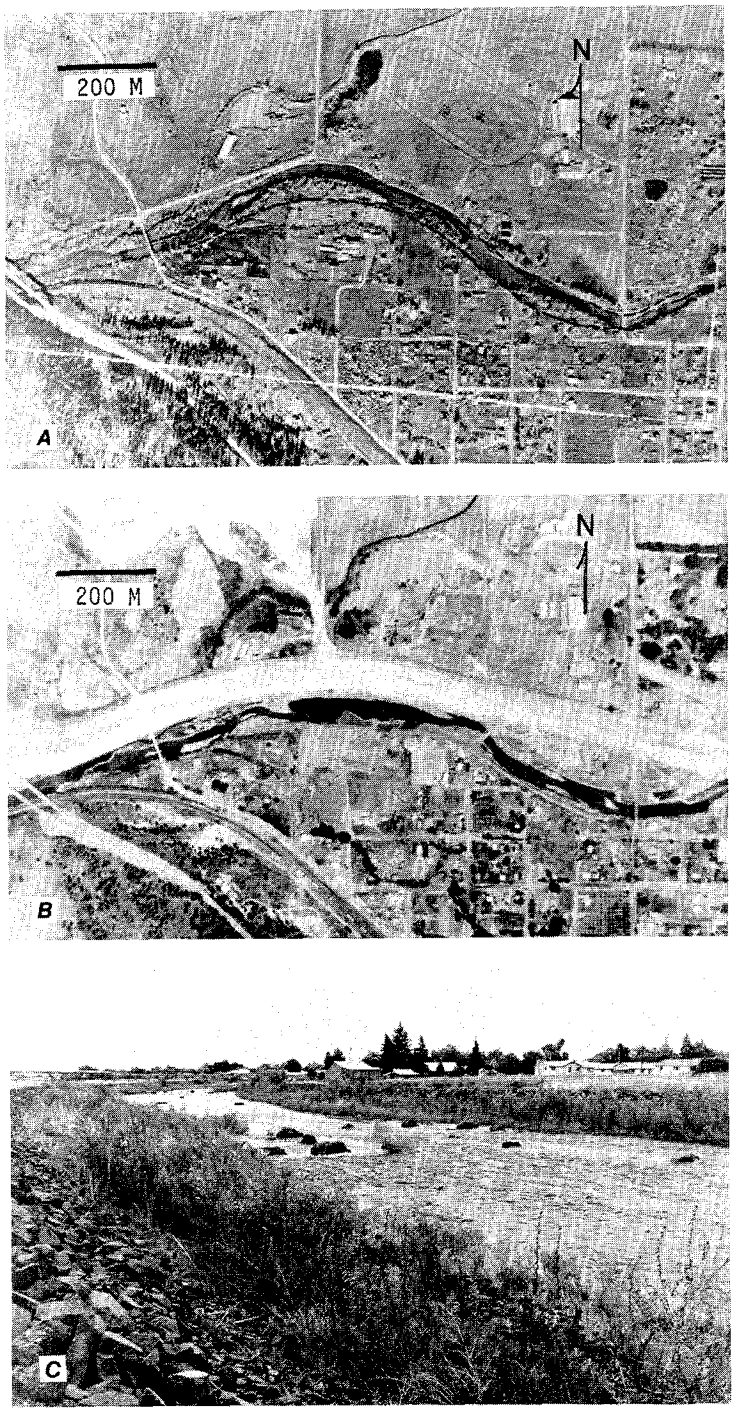


Figure 160. Grande Ronde River at site 78. A, Airphoto in 1963, prior to relocation. Position of relocated channel shown in dotted line. (From Oregon Dept. of Transportation) B, Airphoto of channel relocation under construction, in 1971. (From U.S. Dept. of Agriculture) C, View downstream near center of relocated reach, in 1979. Boulders have been placed in channel for fish habitat.

SITE 79. BURNT RIVER AT
I-80N NEAR WEATHERBY, OREG.

SYNOPSIS--Channel relocation in mountain valley, reach 680 m in length shortened to 370 m, for purpose of avoiding two stream crossings (fig. 161). Performance period, 6 yr (1973-79). At the U.S.G.S. gage on the Burnt River at Huntington, 20 km downstream, the 3rd highest peak flow in a 24-yr period of record (52.6 m^3/s) was recorded in 1978. The relocation involved the making of a deep cut, having a maximum height of 15 m, through unconsolidated material at the right side of the channel. By 1979, several large slumps extending the full height of the cut, had formed (fig. 162A). The largest of these (fig. 162B) was marked by a scarp about 1 m high at the top and by a slip plane along the channel bank at the bottom. According to the plans, the relocated channel was to be revetted with riprap along the left bank for its entire length, and along both banks at the downstream end. Little bank revetment was in place in 1979, although riprap retards were intact at the ends of the relocation. Relocation has had no discernible effect on the natural channel (fig. 162C), which had a slow rate of lateral migration at bends prior to relocation.

Stability class D2 for relocated reach, B2 for adjacent reaches of natural channel. The critical factors in slumping of the cut are its height and steepness, and the unconsolidated nature of the slope material. In addition to its susceptibility to mass movement, this material is also eroded laterally by the stream.

SITE FACTORS--Lat 44°31', long 117°22.5', at I-80N, about 1.5 km north of Weatherby, Oreg., on Durkee 15' map. Burnt River is perennial, drainage area of 2,100 km^2, average discharge in range of 3-3.5 m^3/s. Bottom width of channel is 10 m, bank height is 1.2 m, and channel slope is 3.9 m/km. Wide-bend point-bar stream, confined in many places by valley sides; semi-alluvial; valley relief of 600 m, narrow flood plain; small trees along 50-90 percent of channel. Bed material is gravel. Comparison of airphotos taken in 1946, 1954, and 1969 indicates that straight reaches of the natural channel are generally stable, but that several meters of lateral migration occurred at some bends during the period 1946-69. During past road (or railroad) construction, the channel was relocated at several places downstream from this site.

ALTERATION FACTORS--The altered reach was shortened by a factor of 0.54, and its slope was thereby increased from 3.9 m/km to a value of 7.6 m/km for most of its length and to 8.8 m/km at the downstream end. The relocated channel was trapezoidal in cross section (except that the bottom sloped to 10:1 toward the channel centerline), with a bottom width of 12 m, side slopes of 1.5:1, and a depth of 3.6 m. No information was obtained on the as-built slope of the deep cut along the right side of the channel, but in 1979 the slope was about 1.5:1. A rock-riprap retard was built near either end of the relocated channel.

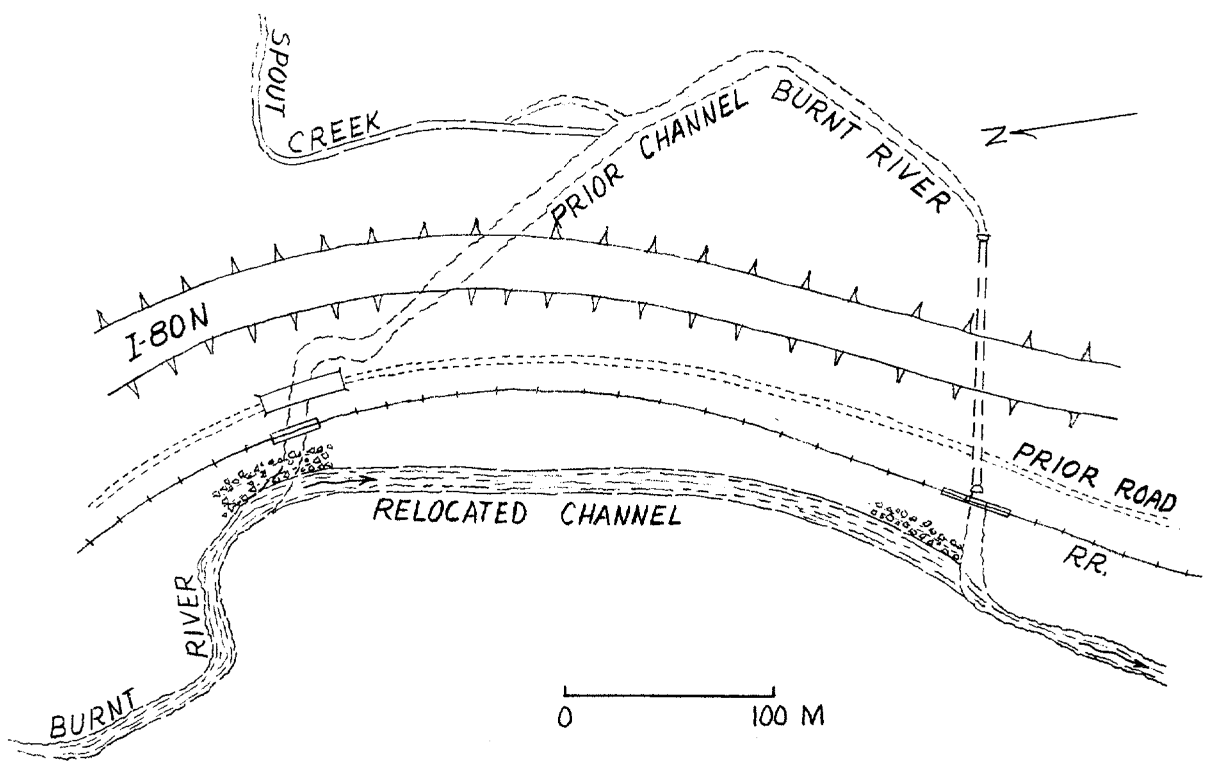


Figure 161. Plan sketch of channel relocation, Burnt River near Weatherby.

POST-ALTERATION FACTORS--In addition to the mass movement along the cut, the banks of the relocated channel have been eroded laterally (fig. 162B); but the channel has not widened significantly. Only annual vegetation (sweet clover) has been established along the bankline.

DISCUSSION--Further movement of the slump blocks along the right side of the relocated channel is highly probable, and the largest block (fig. 162B) presents a particular hazard. This block may move gradually into the channel at a rate no faster than the toe can be removed by stream erosion, or it may move quickly and fill the entire channel.

For the construction of I-80N along the canyon of the Burnt River, other channel relocations were between this site and the hamlet of Lime, which is about 15 km downstream. Two of these were observed in the field in 1979: one at the Weatherby interchange, and the other just downstream from Lime. The relocated channel at Weatherby, which did not involve cuts into the valley side-slopes, was stable and young trees were becoming established along it (fig. 162D). The relocated channel at Lime (fig. 162E), which is bordered by a steep highway embankment and heavily riprapped along both banks, was also stable, with vegetated banks.

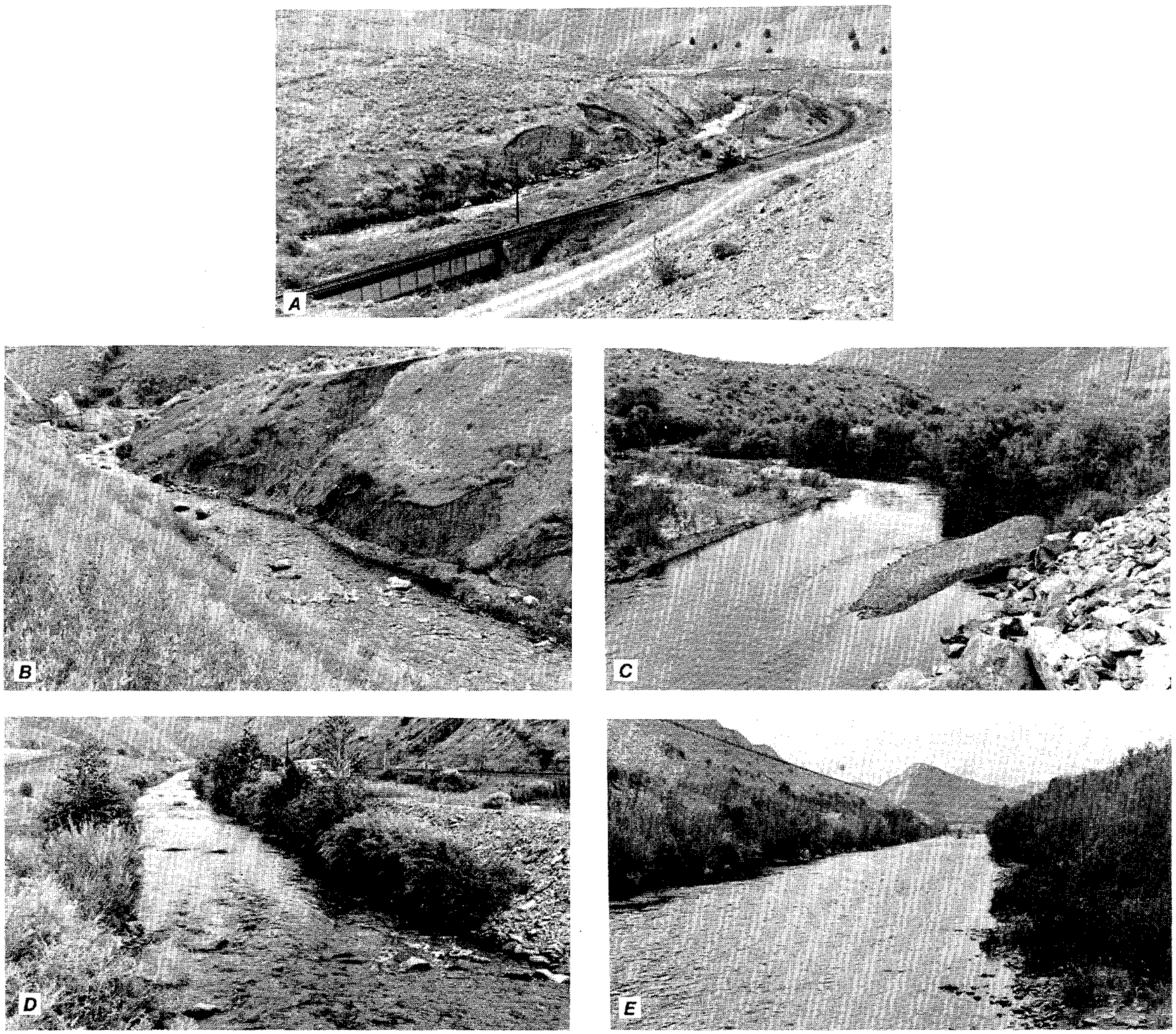


Figure 162. Burnt River at site 79 and vicinity. A, Upstream view showing full length of relocated channel at site. Note large scale slumping along cut. B, View downstream along relocated channel at site, in 1979. At right is a large slump block which extends the full height of the cut. C, View upstream along natural channel at end of relocation. Riprap retard is in right foreground. D, Relocated channel, Burnt River at Weatherby interchange. E, Relocated channel, Burnt River just downstream from Lime.

SITE 80. WOLF CREEK AT
I-5 NEAR GLENDALE, OREG.

SYNOPSIS--Channel relocation, reach 1,160 m in length realined and increased in length of 1,220 m, for purpose of maintaining straight roadway and improving alinement of channel at bridge (fig. 163). Performance period, 14 yrs (1966-79). No records of flow are available, but the resident of a house near the creek reported that a flood in January of 1974 was just overbank, and eroded the shoulder of a secondary road along the creek. The relocated channel was trapezoidal in cross section, with a bottom width of 9 m, which is about twice the bottom width of the natural channel. Riprap was placed at the outside of the two curves. By 1979, there was an almost continuous growth of trees along the channel (fig. 164), and the channel was stable.

Stability class A1 for relocated channel and class B2 for adjacent segments of the natural channel. Cut banks at some bends on the natural channel are discernible on a 1960 airphoto, and the incidence of these had not increased by 1979. Critical factors in channel stability are the increase in channel width with no increase in channel slope, the placement of riprap at bends, and the growth of trees along the banks.

SITE FACTORS--Lat 42°42', long 123°24', at I-5, 5 km south of Glendale, Oreg., on Glendale 15' map. Wolf Creek is perennial, drainage area of about 45 km^2, no records of water discharge. Bottom width of channel is 5 m, top width is 7-8 m; bank height, 1.5 m; channel slope, 16 m/km. Wide-bend point-bar stream, banks are alluvial but bedrock crops out at wide intervals in channel; sinuosity of 1.2; valley relief of 350 m; flood plain width, 250 m; 50-90 percent of bankline bordered by trees. Bed material is of cobble and small boulder size, bank material is gravel and clayey silt of moderate coherence. Some prior straightening of the channel for highway purposes is apparent, and small irrigation diversion dams have been built along the stream.

ALTERATION FACTORS--The relocated channel is longer by a factor of 1.05 than the intersected reach of natural channel, and its bottom width is 9 m as compared with a width of 5 m for the natural channel. In cross-section, the relocated channel was constructed to a trapezoidal shape, with 1.5:1 side slopes.

POST-ALTERATION FACTORS--During the 1974 flood, the left bank of the channel along a straight reach upstream from the relocation was eroded, and large riprap was subsequently placed for a distance of about 30 m along the bank. By 1979, this bank was moderately stable. There is no evidence of bank erosion or maintenance along the relocated channel. Another flood probably occurred in 1971, at the time of the flood recorded on the nearby U.S.G.S. gage on West Fork Cow Creek.

DISCUSSION--The relocated channel is more stable than the sinuous reach of natural channel downstream, in that it has no cut banks. McClellan (1974, p. 38) reports that the stream is used by steelhead salmon and cutthroat trout, and that the bank vegetation serves as a good cover and protection for wildlife. The growth of trees along the channel, a critical element in its performance, apparently occurred naturally without mulching or planting.

Figure 164. Typical aspect of relocated channel, Wolf Creek, in 1979.

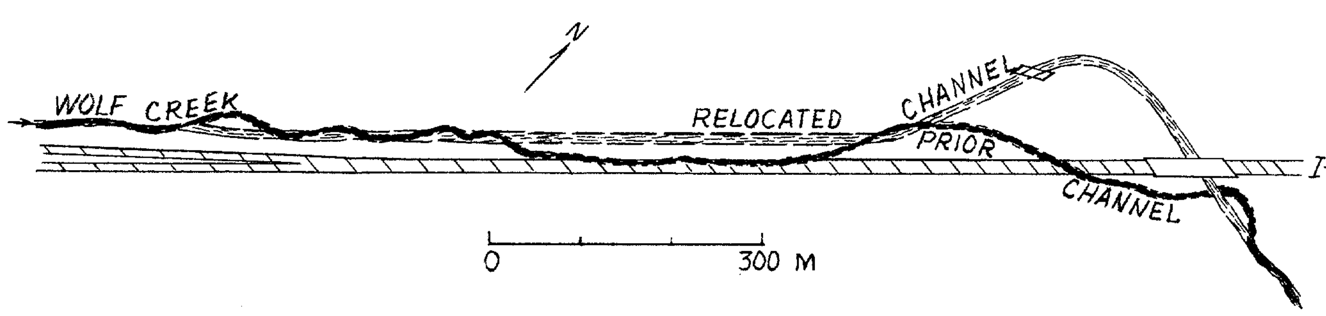


Figure 163. Plan sketch of channel relocation, Wolf Creek.

SITE 81. BEAR CREEK AT
I-5 NEAR MEDFORD, OREG.

SYNOPSIS--This alteration involves the encroachment of the I-5 embankment for a distance of 730 m on the ill-defined channel of Bear Creek, which was here much disturbed and widened by gravel mining (fig. 165). Performance period, 17 yr (1962-79). The two highest peak flows in a 62-yr period of record were recorded in 1962 and 1964 at the U.S.G.S. gage on Bear Creek at Medford. The relocated channel had a design bottom width of about 45 m, with the riprapped highway embankment forming the left bank and the right bank rising gradually to ground level. Evidently, it was assumed that the stream would develop its own channel within the broad cross section, and this has subsequently taken place. By 1979, a well defined low-water channel, having a bottom width of about 11 m, had formed (fig. 166). Trees were well established along the riprapped highway embankment, and the right bank was a gravel flat overgrown with grass and shrubs. At the bridge, the channel is on the right side of the bridge opening and is eroding the right abutment fill-slope. The aspect of the stream is decidedly more stable and attractive than it appeared on an airphoto taken in 1960, when gravel was being mined. Degradation has been precluded by resistant bedrock, which crops out from place to place along the channel bottom.

Stability class B for relocated channel and B for adjacent segments of natural channel. The critical factors in lateral stability are the coarse material in bed and banks, and the braided habit of the stream. Also, the highway embankment has been protected by rock riprap.

SITE FACTORS--Lat 42°16', long 122°47', at I-5, 9 km south of Medford, Oreg., on Medford 15' map. Bear Creek is perennial, drainage area of 725 km^2, average discharge of 3.3 m^3/s at Medford. Active bottom width of channel is 34 m; bank height, 1-1.5 m; channel slope 5.2 m/km. Braided stream, alluvial banks but outcrops of bedrock in channel from place to place; sinuosity, 1.1; valley relief, 600 m; width of flood plain, 500 m; tree cover along channel generally sparse, less than 50 percent of bankline. Bed material is cobble and small boulder. The channel has been widened and disturbed by gravel mining operations at this site and elsewhere.

ALTERATION FACTORS--Channel length was not significantly changed by encroachment and relocation, but in effect the width of the stream was constrained only by the riprapped highway embankment, and its course was directed beneath the bridge by a riprapped dike (fig. 165).

POST-ALTERATION FACTORS--The relocation was tested by major floods in 1962 and 1964. There is no field evidence of maintenance since construction.

DISCUSSION--To allow a stream to form its own channel within a very wide cross section would not be feasible under most circumstances, but it was a good alternative at this site, where the bedload was coarse, the stream was braided, and the general area had been excavated by prior gravel mining operations. However, lateral erosion at the right bridge abutment could prove to be a problem during a flood.

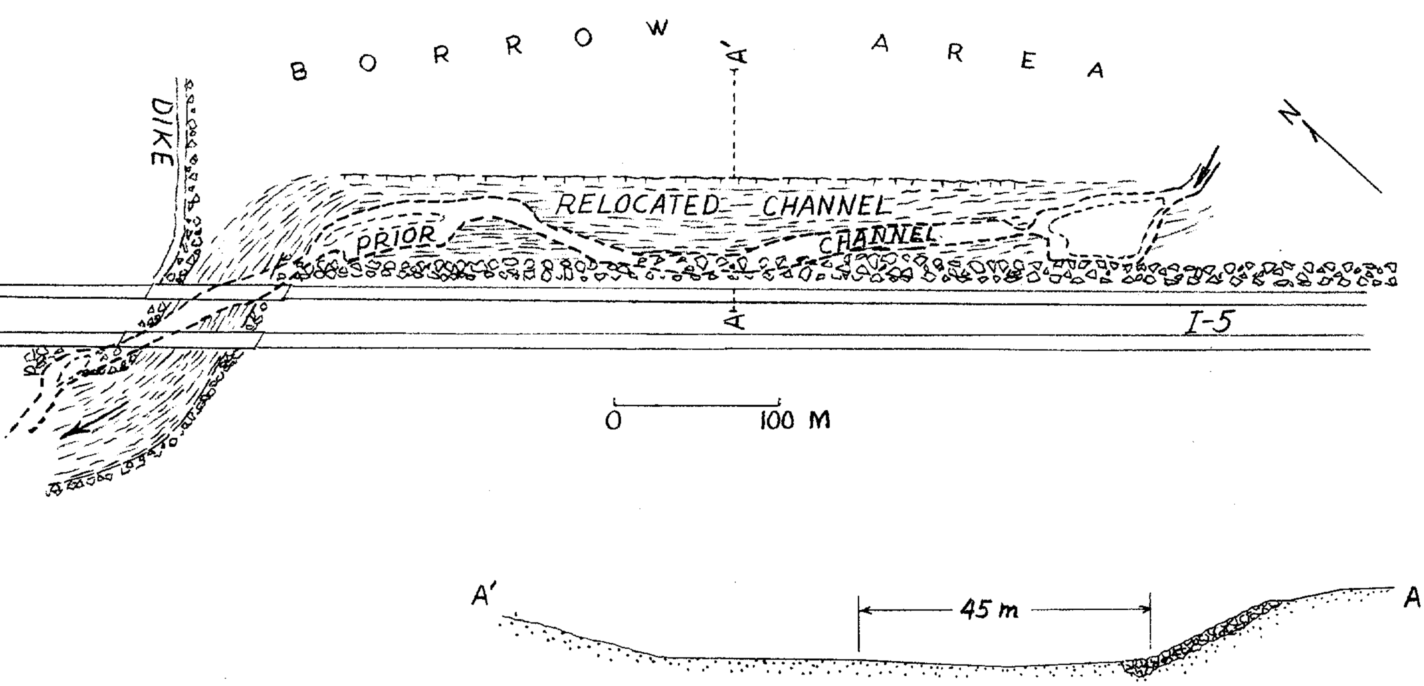


Figure 165. Plan sketch and cross section of Bear Creek channel alteration.

Figure 166. Low-water channel established by Bear Creek, as viewed upstream in 1979.

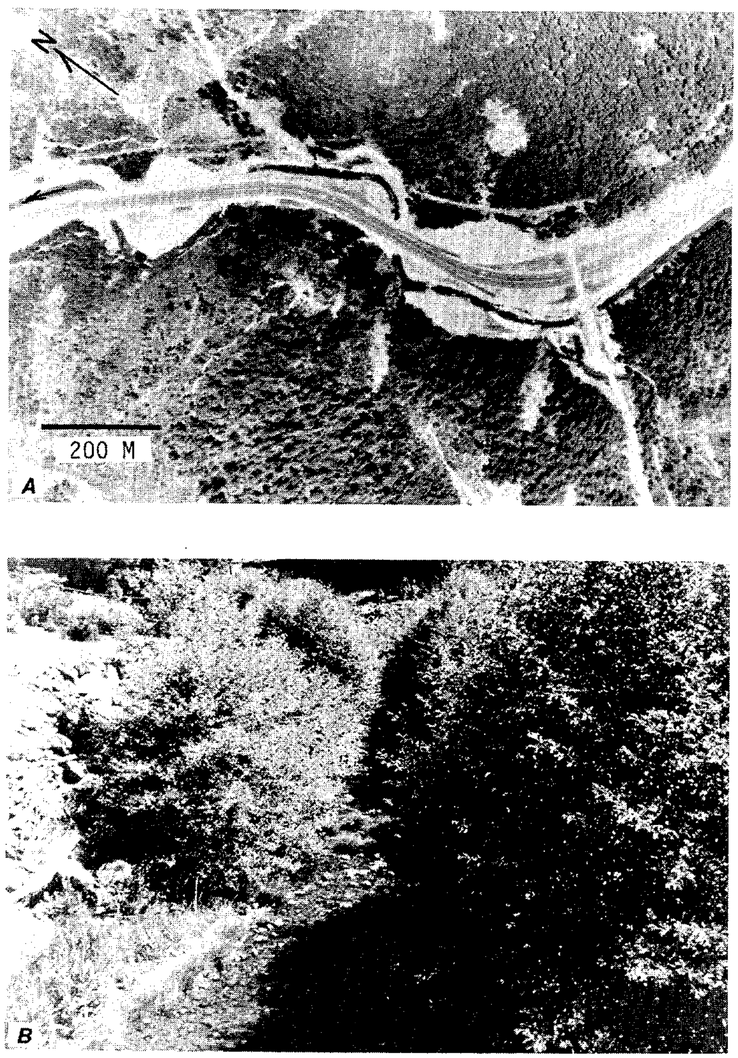


Figure 167. Canyon Creek at site 82. A, Airphoto of site in 1976. The highway overpass is at West Fork Canyon Creek, 4 km south of Canyonville. (From Oregon Dept. of Transportation) B, View downstream from culvert at I-5.

SITE 82. CANYON CREEK AT I-5 NEAR CANYONVILLE, OREG.

SYNOPSIS--This small stream in a narrow mountain valley was relocated, or encroached upon, for a distance of about 16 km (most of its length) for construction of I-5. The site examined in the field, which has a length of about 1 km, is considered to be representative. Because the channel had already been altered during construction of the prior road (US-99), no comparisons can be made with the natural channel. It is evident, from the narrowness of the valley and the preservation of many bends, that relocation has not involved a significant amount of shortening (fig. 167A). Performance period is 13 yr (1967-79). Canyon Creek is ungaged, but the nearby gage on Cow Creek recorded in 1974 the maximum flood in a 45 yr period of record. The relocated channel was lined with riprap, and the interstate crossings were by concrete culvert. By 1979, the bottom of the relocated channel was continuously bordered by alder trees (fig. 167B), and no erosion was evident.

Stability class A1 for relocated channel. The critical factor in lateral stability is the heavy riprap bank protection.

SITE FACTORS--Lat 42°54.5', long 123°16', at I-5, 2 km south of Canyonville, Oreg., on Canyonville 15' map. Canyon Creek is perennial, semi-alluvial, drainage area of about 90 km^2; channel slope at site, about 12 m/km. Valley relief is 600 m, flood plain is very narrow, bed material is gravel and cobble.

ALTERATION FACTORS--According to the plans, the banks of the relocated channel were revetted with a minimum 1 m (3 ft) thickness of dumped rock riprap. Bottom width was gradually increased in a downstream direction, but averaged about 5 m at this site. Side slopes had an average value of about 2:1, and bank height, about 5 m.

POST-ALTERATION FACTORS--The storm that caused the 1974 flood on Cow Creek probably extended to Canyon Creek, but the flood history of Canyon Creek since channel alteration is not known.

DISCUSSION--The ecological recovery of relocated Canyon Creek has been briefly assessed by McClellan (1974, p. 50), who observed the growth of trees along the channel at an earlier stage and reported that few resting areas were available for fish. Subsequently, tree growth has progressed such that the channel is well shaded and reduction of water velocity at above-normal stages is to be expected. Also, the trees will seriously affect the channel capacity at higher flows.

SITE 83. SPANISH HOLLOW CREEK AT US-97 NEAR WASCO, OREG.

SYNOPSIS--A reach 175 m in length, of a small intermittent stream, was relocated and increased in length to 183 m, for purpose of making room for roadway and improving alinement at bridge (figs. 168 and 169A). Performance period, 7 yr (1973-79). During this period, no flood was recorded at the crest-stage gage at Wasco, 5 km upstream; and a debris line at the site indicates that the maximum flow reached a height of 2.2 m above the channel bottom. Much of the bankline of the relocated channel was revetted (figs. 168 and 169B) with dumped rock riprap to a thickness of 1 m. In addition, six gabion check dams, intended to improve fish habitat, were installed. The gabions in each dam had an aggregate height of 1.5 m, a width of 2 m, and projected 0.5 m above the channel bottom. By 1979, reeds had become established in the bottom of the relocated channel, and there was scattered growth of young willow and sagebrush on the banks. Where unprotected by riprap, the left bank was eroded from place to place, particularly at a point just downstream from the relocation (fig. 169C). This bank erosion is localized just downstream from check dams, and was apparently induced by them. However, the natural channel was unstable prior to relocation, and 300 m downstream from the site it has the aspect of an incised arroyo, with raw steep banks 5-6 m in height.

Stability class B2 for relocated channel, D-2 for natural channel downstream. Critical factors in lateral erosion are the erodibility of the bank materials, the prior instability of the natural channel, and turbulence induced by the gabion check dams.

SITE FACTORS--Lat 45°37', long 120°44.5', at US-97, 4.5 km northwest of Wasco, Oreg., on Wasco 7.5' map. Spanish Hollow Creek is intermittent, drainage area of 51 km^2, channel slope 10.5 m/km. Within the recent past, the channel has degraded, and a headscarp probably migrated upstream through the site, gradually decreasing in height as it progressed upstream. Bank height decreases from 5-6 m downstream from the site to 1.5-2 meters upstream from the site, and channel width also decreases. Alluvial channel; sinuosity, 1.1; valley relief, 60 m; width of flood plain, 80 m; sparse growth of trees along channel, because of semi-arid climate. Bed material is sand and silt, bank material is weakly coherent silt and fine sand. Increased runoff from cultivation of the upland is the probable cause of channel degradation.

ALTERATION FACTORS--Channel length was slightly increased, by a factor of 1.05, owing to relocation. The relocated channel was trapezoidal in cross section, with a bottom width of 4.5 m, a top width of about 15 m, side slopes of 2:1, and a depth of 2.7 m. Average slope was 13.5 m/km.

POST-ALTERATION FACTORS--Although flow has not reached bankfull stage since alteration, the flow depth (about 2 m) was sufficient to cause bank erosion. Sediment, held in place by growth of reeds, has accumulated behind some of the check dams, and shallow pools have formed in front.

DISCUSSION--Inasmuch as the slope of the channel was not increased by relocation, and the width was increased, this relocation would probably have not contributed to bank erosion if gabion check dams had not been set against erodible materials in the right bank. The function of the gabions as fish habitat structures is unclear, in view of the shallow and intermittent nature of the stream.

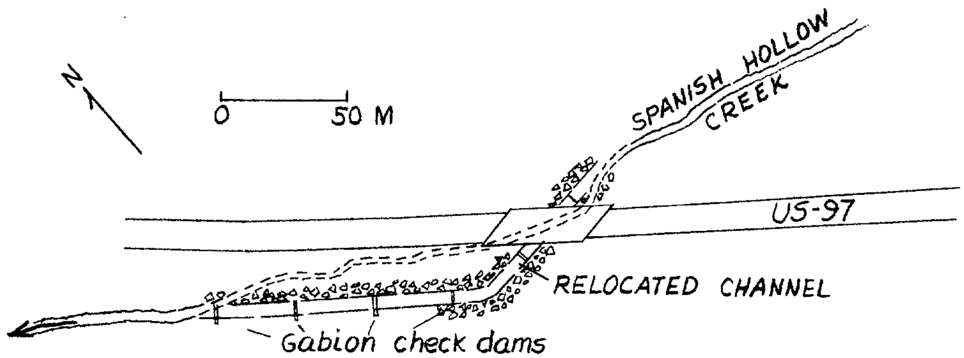


Figure 168. Plan sketch of channel relocation, Spanish Hollow Creek.

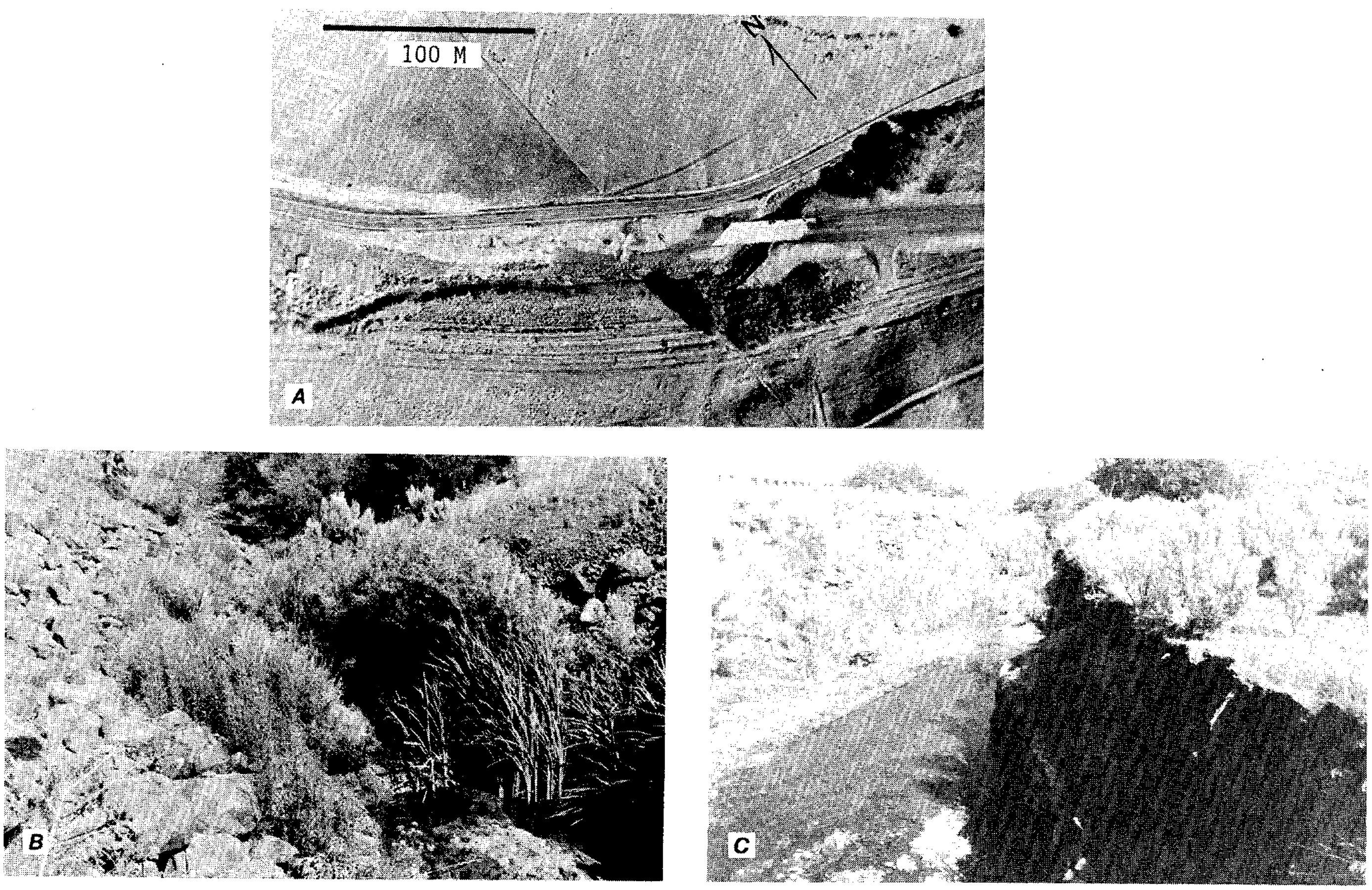


Figure 169. Spanish Hollow Creek at site 83. A, Airphoto of channel relocation under construction, in 1973. (From Oregon Dept. of Transportation) B, Relocated channel upstream from US-97 bridge, in 1979. C, Bank erosion downstream from relocated channel, in 1979.

SITE 84. WILDCAT CREEK AT
SR-126 NEAR WALTON, OREG.

SYNOPSIS--Channel relocation, reach 575 m in length straightened and shortened to 400 m, for purpose of straightening roadway and avoiding two crossings (fig. 170A). Performance period, 17 yr (1963-79). Wildcat Creek is ungaged, but floods occurred in an adjoining drainage basin (Long Tom River) in 1964, 1966, 1972, and 1974. The roadway embankment forms the right bank of the relocated channel and is protected with heavy rock riprap, having a median diameter of about 0.6 m; the left bank is at a lower elevation and is unprotected by revetment. Bottom width of the relocated channel was 14 m, or about 3 m wider than the natural channel. By 1979, alder trees and other vegetation had become established on the rip-rapped right embankment (fig. 170B); and the left bank, where trees were larger, showed only minor and local bank erosion. Local minor increase in width of the relocated channel was observed on airphotos taken in 1968 and 1976, and there was some growth of bars in the channel. Prior to alteration, cut banks occurred from place to place along the natural channel, particularly at bends. No increase in incidence of cut banks was observed on airphotos taken after alteration.

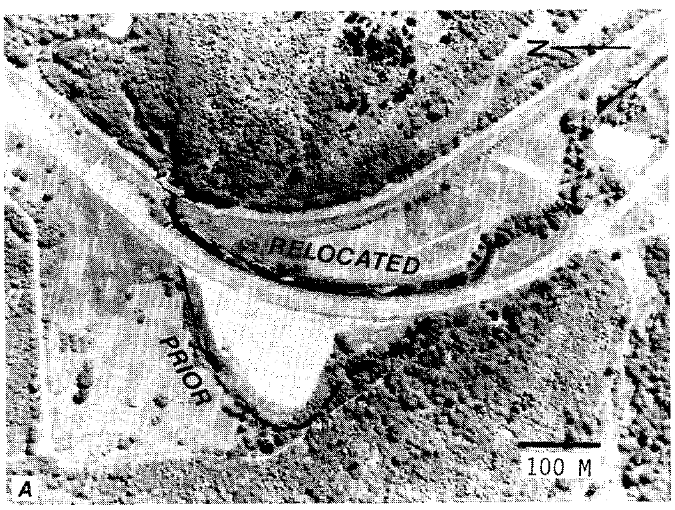
Stability class B2 for relocated channel, class C2 for adjacent segments of the natural channel. Critical factors in lateral stability of the relocated channel are the protection of the right bank with riprap and the growth of vegetation on the left bank.

SITE FACTORS--Lat 44°01', long 123°36', at SR-126, 3 km southwest of Walton, Oreg., on Blachly 15' map. Wildcat Creek is perennial, drainage area of roughly 120 km^2; channel width, 11 m; bank height, 1.5-2 m; channel slope, 1.3 m/km. Wide-bend point-bar stream, alluvial, sinuosity of 1.3, valley relief of 275 m. Flood plain is 200 m in width, mostly cleared, leaving a narrow band of trees along the channel, such that tree cover along the bankline is in the range of 50-90 percent. Bed material is gravel.

ALTERATION FACTORS--The relocated channel is 0.7 as long as the reach of natural channel that it intersects, and its slope is 1.9 m/km as compared with 1.3 m/km for the natural channel. Its cross section was trapezoidal, with a bottom width of 14 m as compared with a width of 11 m for the natural channel. Curves at both ends of the relocation are protected with heavy riprap at the outside bank, and no erosion has occurred there.

POST-ALTERATION FACTORS--As observed on a 1968 airphoto, an almost continuous strip of vegetation had become established along both banks of the re-located channel, about five years after relocation. By 1979, vegetation was becoming established on a bar along the right bank, and this bar will probably eventually induce sinuosity.

DISCUSSION--A case history of ecological recovery for this site on Wildcat Creek has been prepared by McClellan (1974), who visited the site in 1972 with a representative of the Oregon State Game Commission. He concluded that fish habitat was fairly good, although no special measures to improve habitat had been constructed. The subsequent growth of vegeta-tion on the riprapped right bank, and of gravel bars, should have further improved the habitat.



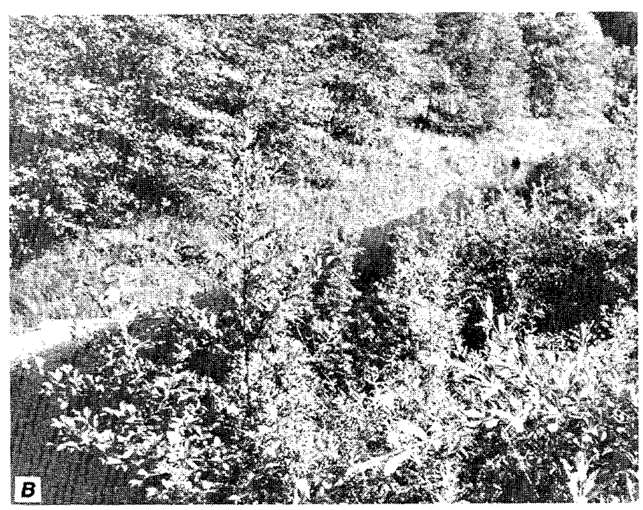


Figure 170. Wildcat Creek at site 84. A, Airphoto of site in 1968. (From U.S. Dept. of Agriculture) B, relocated channel as viewed from right bank in 1979.

SITE 85. GELLATLY CREEK AT US-20 NEAR WREN, OREG.

SYNOPSIS--A small stream in a narrow valley was relocated for a distance of 415 m along the roadway, in order to make room for road widening and realinement. For part of the relocated channel, artificial meanders were constructed (figs. 171 and 172A), such that the relocated channel had a total length of 540 m, a sinuosity of 1.3, and an average slope of 17.5 m/km. The relocated channel was trapezoidal in cross section, with a typical bottom width of 1.5 m, side slopes ranging from 1:1 to 2:1, and a depth of about 1.5 m. Riprap was placed at the apexes of meander loops, and gravel (fig. 172B) was placed on the channel bottom. Pools, extending 1-1.5 m below the channel grade line, were constructed at intervals of about 50 m along the channel. Performance period, 4 yr (1975-79). Although Gellatly Creek is ungaged, a minor flood probably occurred in 1977, at the time of the flood on nearby Marys River (10th highest peak flow in a 38 period of record). By 1979, many small trees were growing along the straight reaches (fig. 85-2C), but very few along the artificial meanders, where the banks were generally eroded. In addition, the introduced bed material had been mostly removed, some of the riprap was displaced and transported downstream (fig. 172-C), and minor degradation was indicated by small rapids (fig. 172B).

Stability class D3 for relocated channel. The critical factor in instability of the relocated channel is probably the lack of vegetation, which, particularly along small streams, reduces velocity by introducing roughness and protects the banks from erosion. The effect of the meanders was to increase the rate of lateral erosion.

SITE FACTORS--Lat 44°36', long 123°27', at US-20, 2.5 km northwest of Wren, Oreg., on Corvallis 15' map. Gellatly Creek is perennial, drainage area of 6.2 km^2. No information was obtained on position and dimensions of the natural channel prior to relocation, but in 1979 the unaltered reach upstream from the relocation was stable and bordered by trees and other vegetation. Valley relief is 50 m. Bed material is silt-clay, with a minor component of angular gravel. Bank material is moderately coherent silt, clay, and gravel, grading downward into coherent clay (fig. 172A).

DISCUSSION--In planning this relocation, an unusual effort was made to impart a natural pattern to the new channel. By the use of meanders, the slope of the relocated channel was reduced to a value no more than (and probably less than) that of the prior natural channel. But a preservation of slope was insufficient to insure stability: two other important factors--vegetation and bedload--were evidently overlooked. Lack of vegetation resulted in a decrease in roughness, an increase in velocity, and increased bank erodibility. The gravel placed on the channel bed was soon carried out of the reach, and the bed was scoured, because the stream lacks an adequate supply of natural gravel or sand. Under these circumstances, the induced sinuosity was too great for bank stability, and point bars did not form on the inside of bends. Instead, a narrow low-flow channel was cut across the inside of bends (fig. 172A). Better results would probably have been obtained with a lesser degree of sinuosity, together with the use of an effective method for establishing vegetation on the banks.

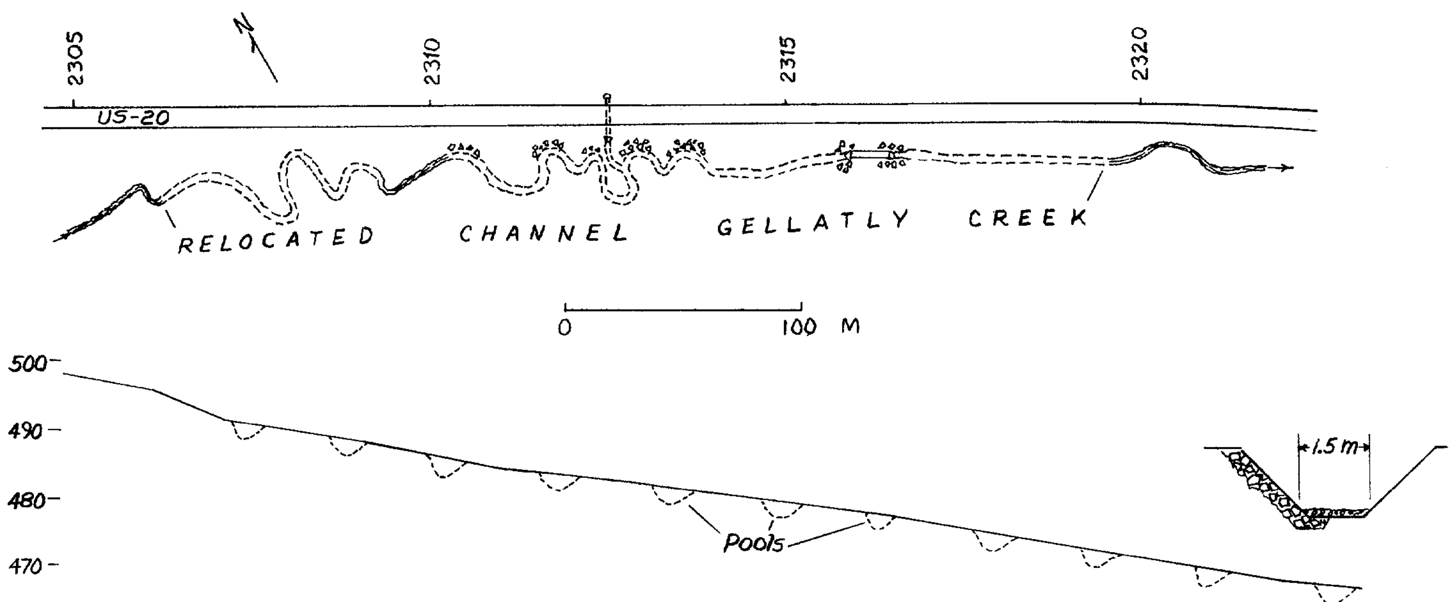


Figure 171. Top, plan sketch of relocated channel, Gellatly Creek. Bottom, longitudinal profile of relocated channel, pools shown by dashed lines. Cross profile as riprapped at bends is shown at right.

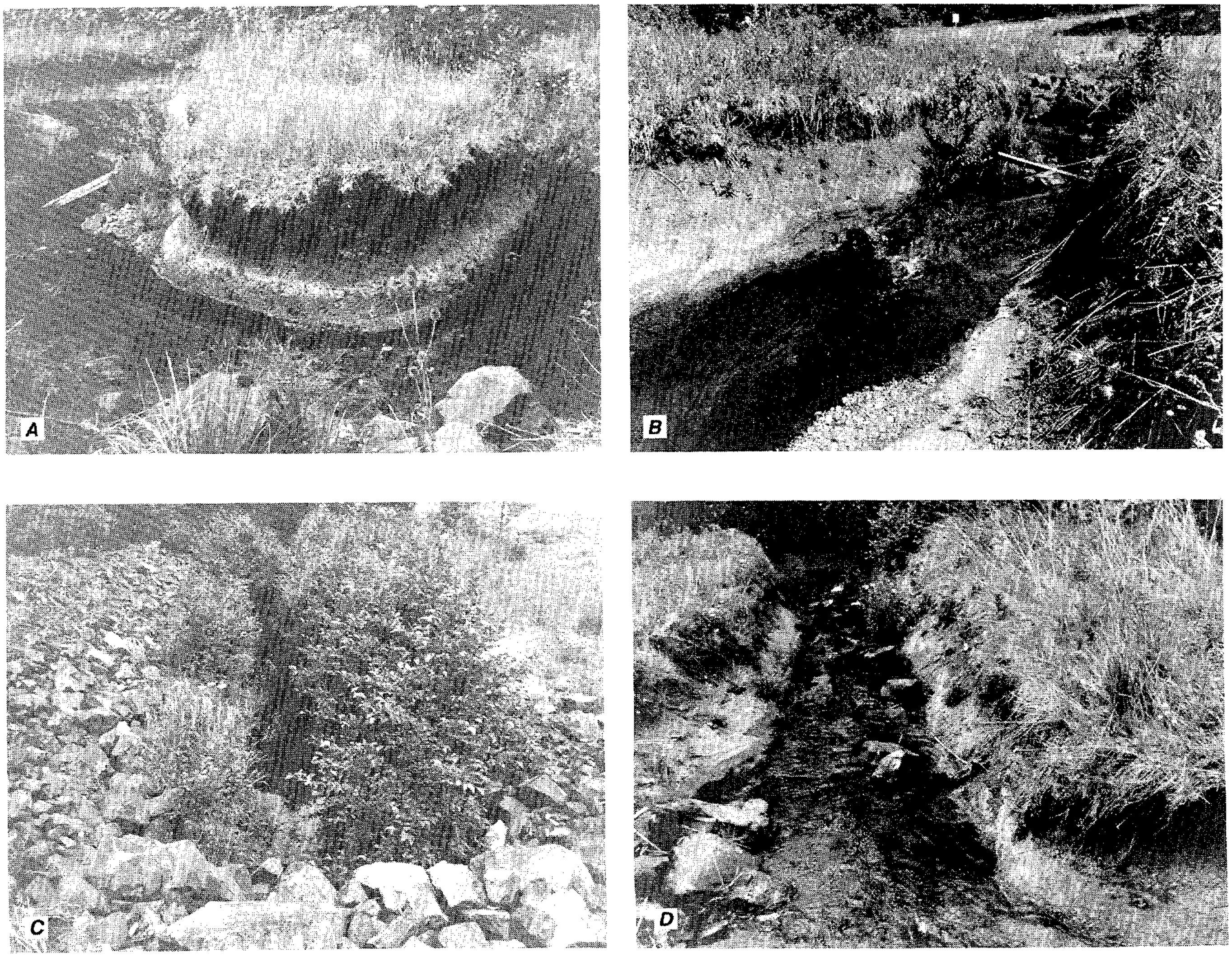


Figure 172. Gellatly Creek at site 85. A, Meander loop of relocated channel, in 1979. B, Reach downstream from apex of meander loop. Note small rapids, which may indicate degradation, and remains of introduced bed material. C, Straight reach of relocated channel. D, Downstream transport of large riprap, originally placed at apex of bend.

SITE 86. BALD EAGLE CREEK AT I-80 NEAR BELLEFONTE, PA.

SYNOPSIS--Reach 640 m in length relocated and lengthened to 790 m, for purpose of channel alinement at bridges (fig. 173). Performance period, 10 yr (1968-78). The relocated channel was subjected to a major flood in 1972 (peak discharge of 596 m^3/s) and a moderate flood in 1975 (308 m^3/s). The 53-m bottom width of the relocated channel was large in relation to average discharge (11 m^3/s) and greater than the modal width of the natural channel by a factor of about 1.5. No bank protection measures were applied to the relocated channel. Minor bank slumping was observed along the concave bank of the relocation in 1979, and tree growth, though locally dense, was not continuous (fig. 174). Adjacent reaches of the natural channel were generally stable prior to relocation, and no effects of relocation on bank stability were observed.

Stability class B2 for relocated channel, class B1 for natural channel. Critical factors in stability of the relocated channel are its wide, shallow cross section, which is suitable for the coarse (gravel, cobble) bed material, and the resistance of the bank materials to erosion.

SITE FACTORS--Lat 40°57', long 77°45', at I-80, 5 km north of Bellefonte, Pa., on Bellefonte 7.5' map. Bald Eagle Creek is perennial, drainage area of 697 km^2, average discharge 11 m^3/s. Bottom width of the natural channel ranges, in straight reaches, from 25 to 44 m with a modal value of about 36 m; bank height ranges from 1.2 to 1.8 m, and channel slope is about 2.8 m/km. Equiwidth stream without point bars, locally braided and locally anabranched, alluvial, sinuosity of 1.1. Valley relief is 250 m, flood plain 1,200 m in width, narrow band of trees along channel, 50-90 percent tree cover. Bed material is gravel and cobble, bank material is clay-silt of moderate coherence but susceptible to slumping.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--Inasmuch as the natural channel was generally stable and the relocated channel was longer and wider than its natural counterpart, the main potential for instability was bank erosion at the outside of the bend or development of a meandering low-flow channel. Bank erosion was inhibited by the wide shallow cross section and moderately resistant bank materials. Development of a meandering low-flow channel was inhibited by the coarse bed material and the natural tendency of the stream toward braiding.

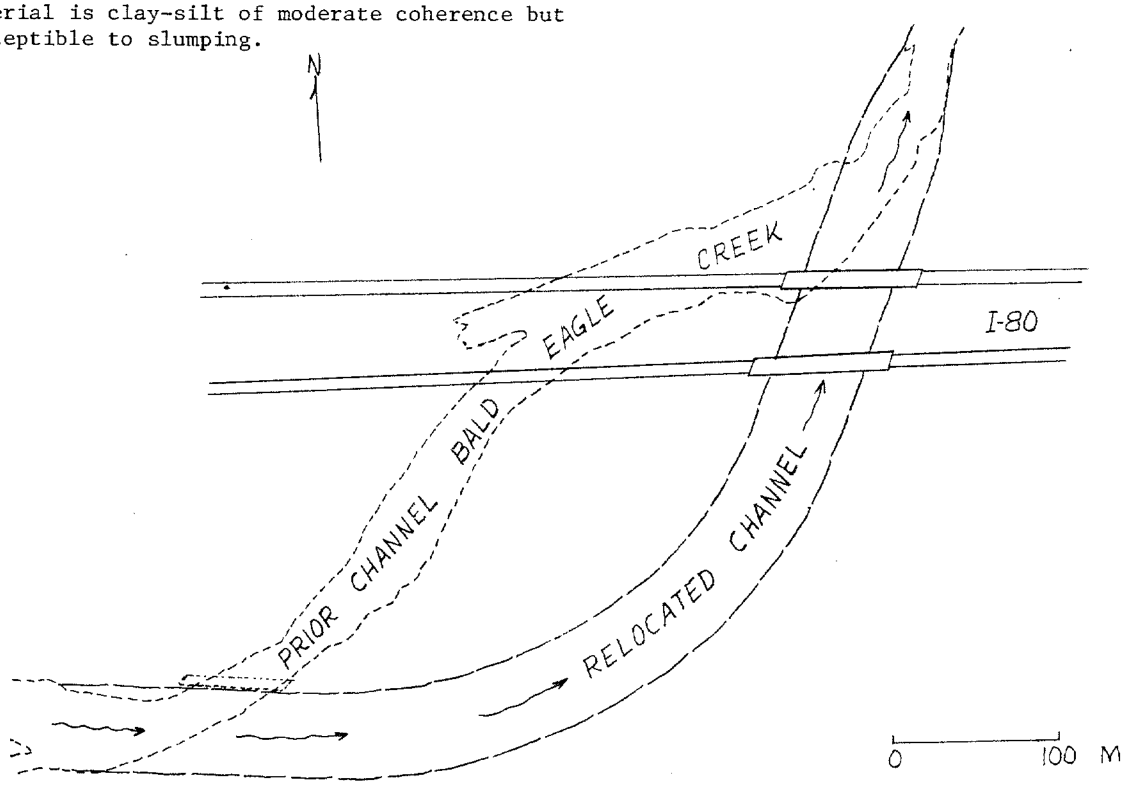


Figure 173. Plan sketch of channel relocation, Bald Eagle Creek.

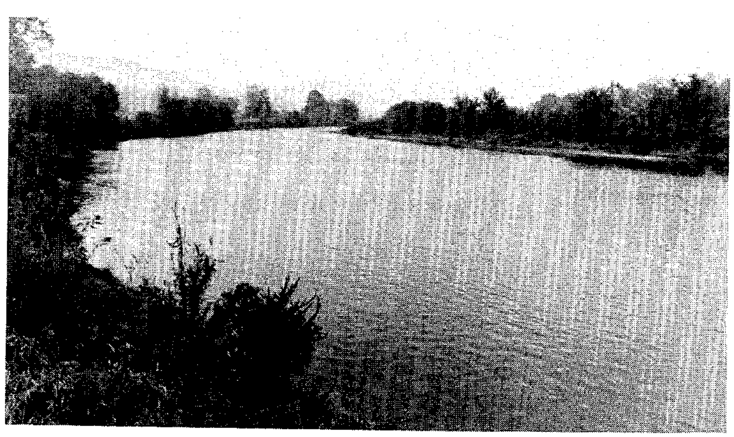


Figure 174. Upstream view at bend in relocated channel, Bald Eagle Creek.

SITE 87. FISHING CREEK AT
I-80 NEAR BLOOMSBURG, PA.

SYNOPSIS--Reach 1,830 m in length, which had been dammed before 1951, was relocated and shortened to 1,520 m, to accommodate proposed roadway alinement and to avoid stream crossings (fig. 175). Performance period, 12 yr (1967-78). Two very large floods have occurred on Fishing Creek since the relocation, one in 1972 with a recurrence interval greater than 100 yr, and another in 1975 with a recurrence interval of about 100 yr. As constructed in cross section, the relocated channel consisted of a flood channel with revetted side slopes, and an inset low-water channel (fig. 175). In 1974, the low water channel was not discernible (fig. 176A) and the stream apparently occupied the full width of the flood channel at normal stage. During the flood of 1975, a 30-m length of riprap revetment was removed by erosion, and subsequently replaced. According to field examination of the site in 1978, the channel has shifted toward the right bank of the flood channel; riprap along the right bank is locally undercut (fig. 176B) and missing at the downstream end of the relocation. Along the left bank (highway embankment), the revetment is uneroded. A sheet-pile check dam is in place just upstream from the relocation (fig. 176C) , but it was apparently not built as part of the relocation project. The natural channel downstream from the relocation (fig. 176D) is bordered by large trees and is generally stable.

Stability class B2 for relocated channel, B1 for adjacent reaches of the natural channel. Critical factors in stability of the relocated channel, which has been severely tested, are its width and the use of bank revetment. The check dam may have prevented channel degradation.

SITE FACTORS--Lat 41°01.5', long 76°27.5', at I-80, 2 km north of Bloomsburg, Pa., on Bloomsburg 7.5' map. Fishing creek is perennial, alluvial, drainage area of 770 km^2, average discharge 14.7 m^3/s. Bottom width is 35 m, bank height is 1.2 m, and channel slope as measured on the topographic map is 1.7 m/km. Stream type is dominantly equiwidth of low sinuosity, but some reaches are braided or anabranched. Valley relief, 125 m; width of flood plain, 400 m; almost continuous narrow strip of trees along channel, such that tree cover along the bankline of greater than 90 percent. Bed material is gravel and cobble, bank material is gravel and silt-clay. Bank stability of the stream prior to relocation was generally good.

ALTERATION FACTORS--Although the shortening due to relocation was minor (factor of 0.8), the slope of the relocated reach as specified on the plans (3.2 m/km) is substantially greater than the general slope of the stream as measured on the topographic map (1.7 m/km). The local channel

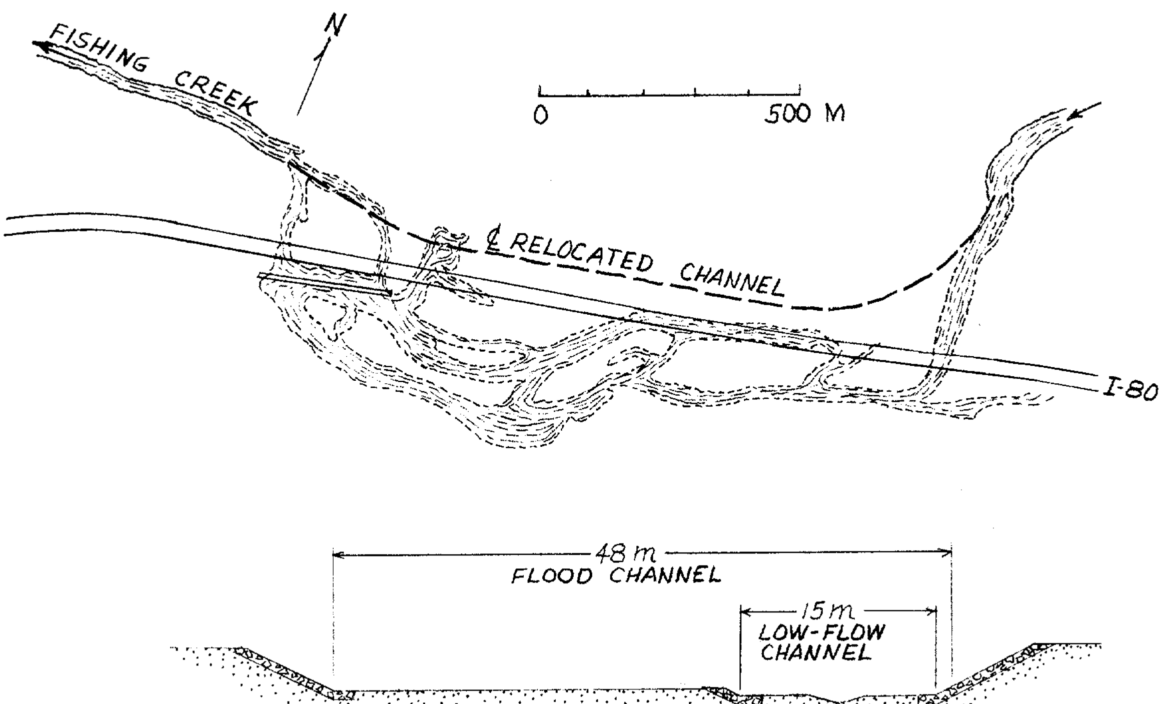


Figure 175. Top, plan sketch of channel relocation, Fishing Creek. Bottom, typical cross section of relocated channel.

slope was perhaps affected by the prior dam and reservoir at the site. In cross section, the flood channel was 48 m in width, having 2:1 side slopes revetted with a 0.65-m thickness of rock riprap, which extended to a depth of 0.75 m below the channel bottom. The low-flow channel, 15 m in width, also had a revetted bankline.

POST-ALTERATION FACTORS--The effect of two very large floods was to obliterate the low-water channel, but the flood channel was not widened significantly. By 1979, young trees were growing along the riprapped bankline (fig. 176B), but the tree cover was not continuous.

DISCUSSION--Although the flood channel is significantly wider than the natural stream channel, by a factor of 1.4, it has so far been mostly occupied by the stream at normal stage. On the 1974 airphoto, there is some indication that the thalweg had shifted toward the right bank downstream from the bend (foreground of fig. 176A). The thalweg is likely to meander broadly within the flood channel, but a bank erosion problem is unlikely because of the revetment.

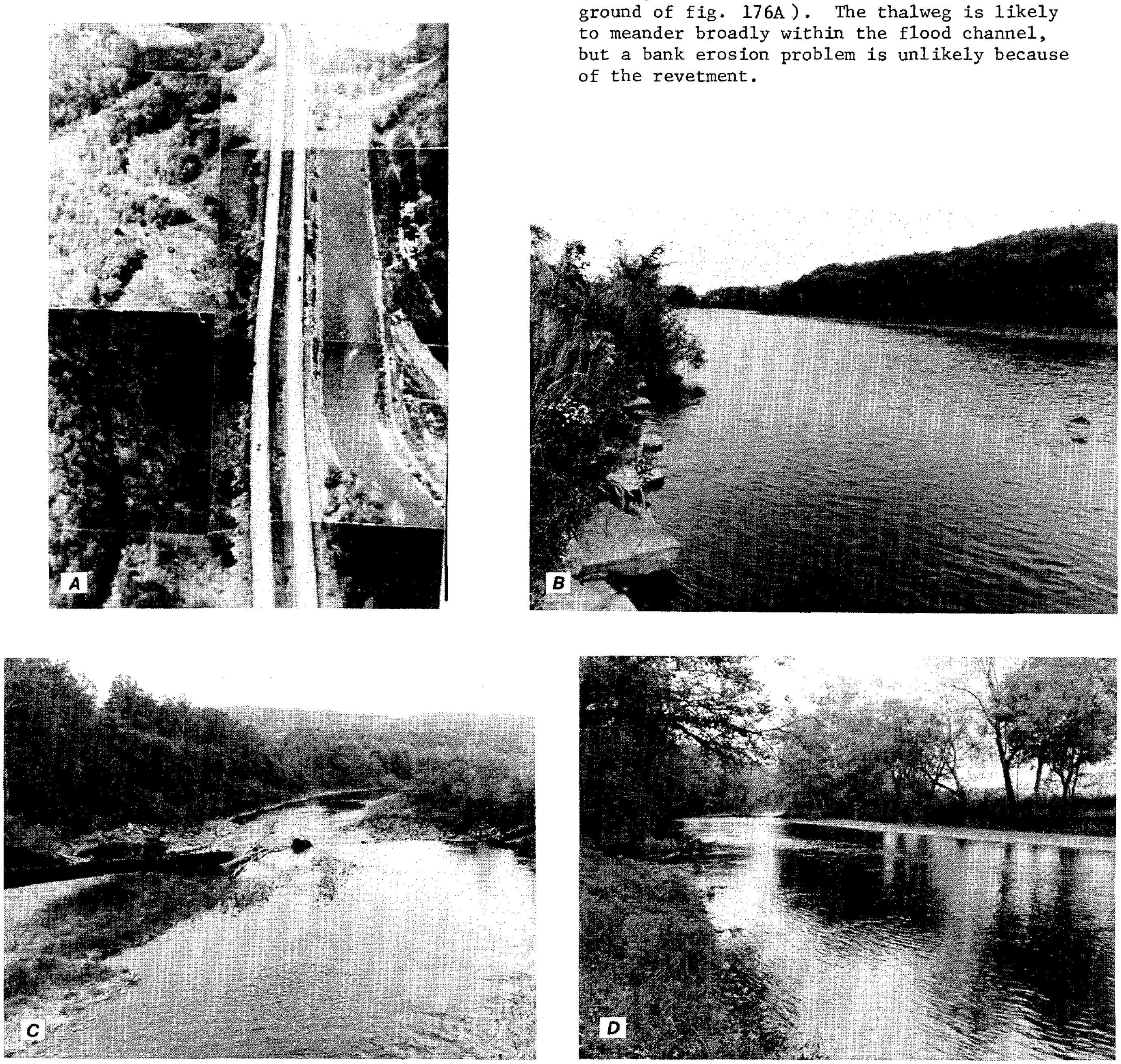


Figure 176. Fishing Creek at site 87. A, Oblique airphoto, looking downstream, of relocated channel in 1974. (From Pennsylvania Dept. of Transportation) B, View upstream along relocated channel, in 1978; riprapped south bank in foreground. C, View toward upstream end of relocated channel, in 1978. Sheet-pile check dam, in foreground, is upstream from relocation. D, Natural channel downstream from relocation, in 1978.

SITE 88. SHAMOKIN CREEK AT SR-161 NEAR SHAMOKIN, PA.

SYNOPSIS--Channel relocation, stream moved laterally by a maximum distance of about 15 m. Total length of relocation was 975 m, but only a 300-m segment, where bank erosion occurred, is described here. Performance period, 11 yr (1968-78). The channel was designed for a maximum flow of 87 m^3/s (maximum of record at time of construction), but a peak flow of 114 m^3/s occurred in 1972. At a broad bend in the channel (fig. 177), the right bank was eroded, about 30 m of concrete slope pavement was destroyed, and the stability of the adjoining railroad embankment was jeopardized. In 1975, rock riprap was dumped along the eroded bank (fig. 178).

Stability class B2 for relocated channel, B1 for adjacent segments of natural channel. The critical factors in bank erosion are the magnitude of the flood (recurrence interval of about 100 yr), and the use of rigid rather than flexible revetment.

SITE FACTORS--Lat 40°48', long 76°35', at SR-161, 1.5 km north of Shamokin, Pa., on Shamokin 7.5' map. Shamokin Creek is perennial, drainage area of 141 km^2, average discharge 2.4 m^3/s. Channel width is 12 m, bank height is 1.5 m, and channel slope is 8.3 m/km. Equiwidth stream without point bars, semi-alluvial, sinuosity of 1.1. Valley relief is 200 m, flood plain is very narrow, tree cover along channel is less than 50 percent. Bed material is gravel, cobble, and small boulders. Bank stability, as judged from a 1966 airphoto, was generally good; but the stream is polluted with sediment from coal mining, acid mine drainage, and raw sewage.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--The bank erosion was not particularly severe in view of the magnitude of the flood, and probably would not have been considered a problem if the railroad embankment had not been jeopardized.

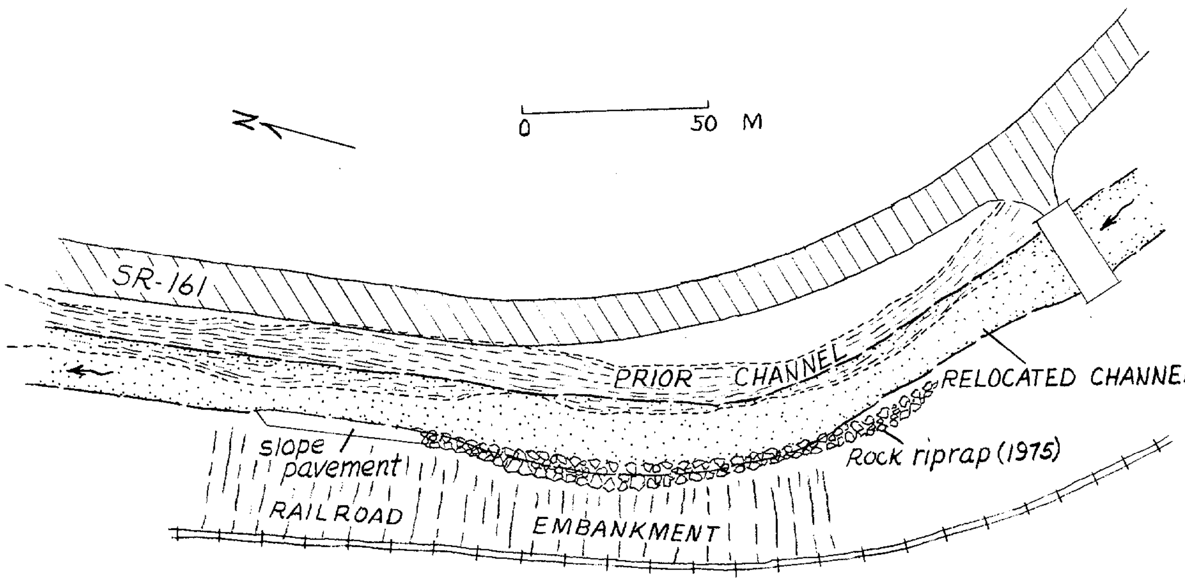


Figure 177. Plan sketch of channel relocation, Shamokin Creek.

Figure 178. View upstream along Shamokin Creek, showing bank slumping above remaining concrete slope pavement, and rock riprap installed in 1972.

SITE 89. WILSON CREEK AT
SR-287 NEAR ANTRIM, PA.

SYNOPSIS--Reach 670 m in length relocated and shortened to 595 m, to avoid two stream crossings (fig. 179). Performance period 6 yr (1973-79). The channel was subjected to a major flood during construction in 1972, to another on September 26, 1975, and to subsequent smaller floods. The channel was designed to have a bottom width of 9 m, and the banks were protected locally by four short spurs of rock riprap and by discontinuous segments of riprap channel lining. "Fish boulders" were placed on the channel bed. The channel began to degrade and to widen soon after construction. The maximum amount of channel widening between July, 1974, and September, 1975, was 2.1 m. Some changes in the channel since construction are shown in figure 180. Dumped rock riprap was placed along the eroding left bank in 1976 or 1977, but the right bank was eroding in 1979.

Stability class D4 for relocated channel. The critical factors in instability are probably the steep slope of the valley (20 m/km), the erodibility of unconsolidated materials in the bed and banks of the relocated channel, and the occurrence of major floods during and soon after construction.

SITE FACTORS--Lat 41°38', long 77°18', at SR-287, 1.2 km northwest of Antrim, Pa., on Antrim 7.5' map. Wilson Creek is perennial, drainage area of 43 km^2, bottom width of 8-10 m, channel slope of 20 m/km. Semi-alluvial stream, sinuosity of 1.1, valley relief of 250 m, narrow flood plain, greater than 90 percent tree cover along channel. Bed material is gravel-boulder, bank material is non-coherent gravel and silt-clay. Channel has stable aspect, without cut banks, on airphotos taken in 1942 and 1971. Coal has been strip-mined on the valley side-slopes, but the area of mining is probably not large enough to have affected stream stability.

ALTERATION FACTORS--(See "Synopsis")

POST-ALTERATION FACTORS--Top width of the relocated channel has been measured (by tape) periodically by the U.S. Geological Survey at three cross sections, about 50 m apart, downstream from the bridge at Road 345:

	Top width of channel, in m		
Date	Sect. A	Sect. B	Sect. C
7/24/74	13.2	11	13.6
9/17/75	14	12	15.7
8/17/76	15.8	12.7	18.9
5/31/79	16.5	---	---

Although no measurements of degradation are available, a waterfall about 1.5 m in height had developed in the channel by 1976 (fig. 180D), and the maximum amount of degradation is probably not less than 2 m. By 1976, four riprap spurs, which had been installed as countermeasures for bank erosion, had been removed by erosion. In 1979, the bridge at Road 345 had been closed because of undermining of the center pier and both abutments, which had been founded on erodible bedrock.

DISCUSSION--The slope of the natural channel was in the range of 17-20 m/km but was not uniform, probably because of bedrock outcrops from place to place. The bedrock consists of almost horizontal beds of sandstone, shale, and conglomerate, susceptible to erosion because of well-defined joints and thin bedding. Instability of the relocated channel is not attributed to the increase in slope relative to that of the natural channel, which was slight. The major floods that occurred during and soon after construction steepened the weakly coherent banks and probably formed scarps in the channel bottom, thus initiating progressive bank erosion and degradation. The bed of the natural channel was well armored with boulders and the low banks were well vegetated, as shown in ground photographs taken prior to relocation (fig. 180E).

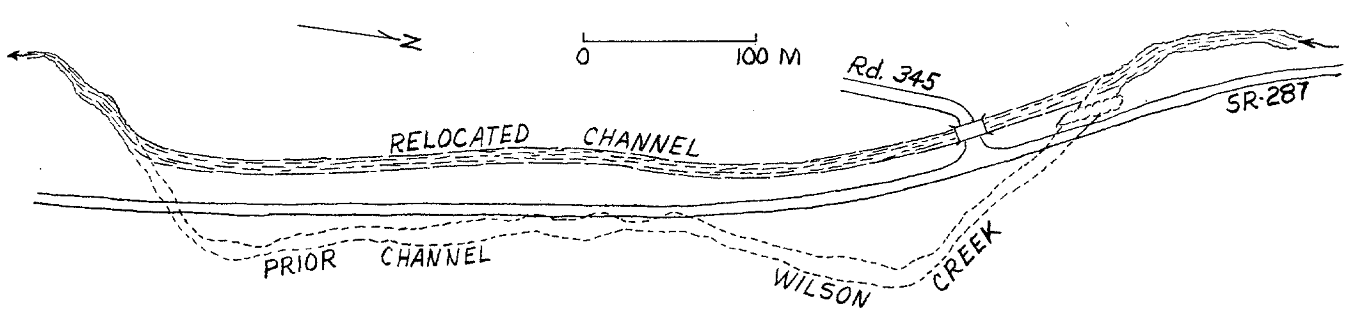


Figure 179. Plan sketch of Wilson Creek channel relocation.

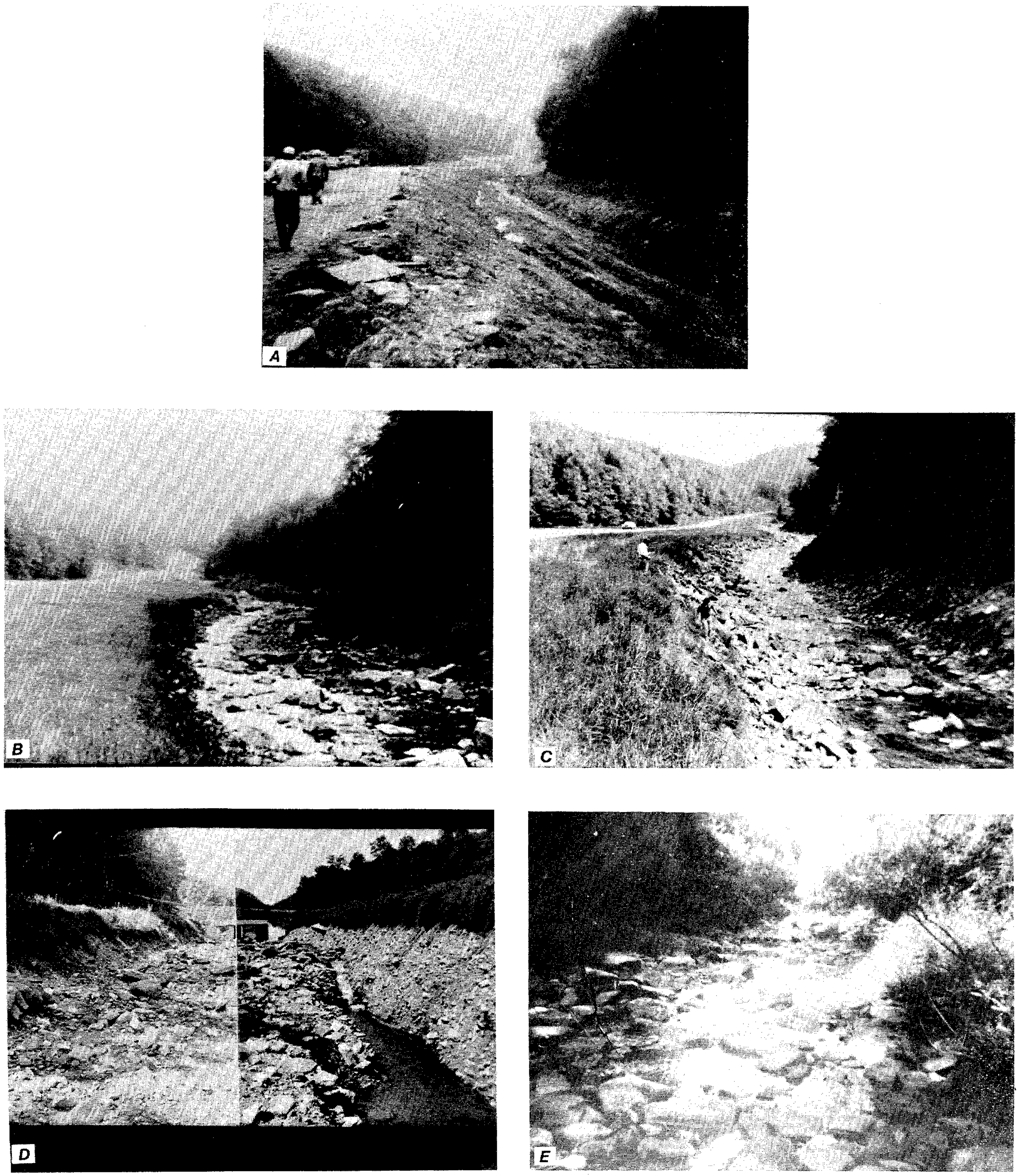


Figure 180. Wilson Creek at site 89. A, View of relocated channel during construction in 1973, looking downstream from a location below the bridge at Road 345. B, View from nearly the same location as for A, in 1974. C, View from nearly the same location as for B, in 1979. Dumped rock riprap has been placed at left bank. D, View upstream toward bridge at Road 345, in 1976. Degradation indicated by scarp in channel, at right. E, Natural channel prior to relocation. (From Pennsylvania Dept. of Transportation).

SITE 90. POCONO CREEK AT
I-80 NEAR STROUDSBURG, PA.

SYNOPSIS--Channel relocation, reach 810 m in length straightened and shortened to 670 m in order to avoid two stream crossings (fig. 181). Performance period, 16 yr (1962-78). Relocated channel was subjected to a major flood in 1969. Although the channel bottom along much of the relocation is on bedrock, erosion occurred in unconsolidated material at the right bank, which is along the roadway embankment. Dumped rock riprap, which had been placed to a thickness of 3 m on the bank, was removed by erosion, apparently because it was not keyed into the streambed. In 1977, rock-filled gabions were installed to replace the riprap (fig. 182A). Downstream from the relocation, the natural channel is stable (fig. 182B).

Stability class A2 for relocated channel, A1 for downstream segment of natural channel. The critical factor in the localized bank erosion and failure of the riprap was apparently the height and steepness of the embankment, which probably slumped when undercut at the toe.

SITE FACTORS--Lat 40°59', long 75°14', at I-80, 3.5 km west of Stroudsburg, Pa., on Stroudsburg 7.5' map. Pocono Creek is perennial, drainage area of 105 km^2; channel width, 25 m, channel slope, 13 m/km. Semi-alluvial stream, valley relief of 50 m, narrow flood plain about 100 m in width, tree cover along banks greater than 90 percent. Bed material is cobble-boulder.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--Although the relocated channel is 670 m in length, bank erosion occurred only at one bank, for a length of about 50 m, where there is no bend in the channel. This suggests that the toe of the riprapped bank was undercut, and that failure occurred by mass movement. The size of the failed riprap is not specified in the plans, but remnants of half-ton (500 kg) size are in the channel.

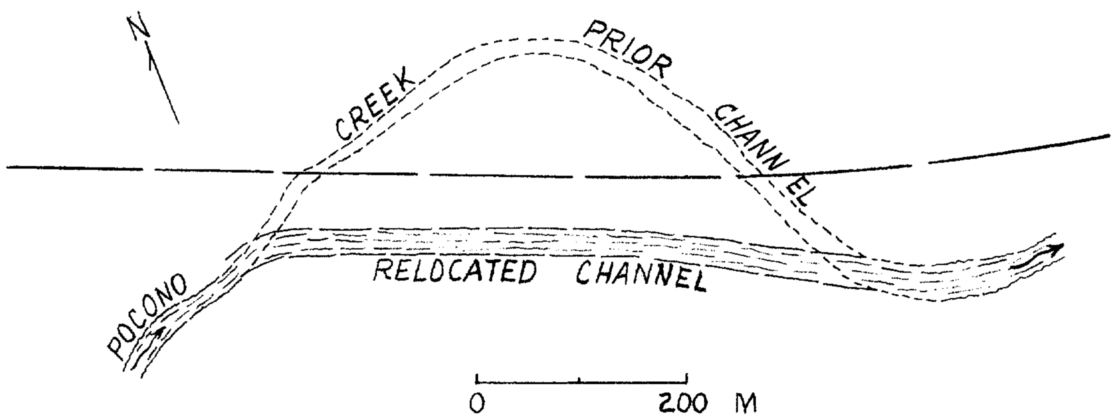


Figure 181. Plan sketch of Pocono Creek channel relocation.

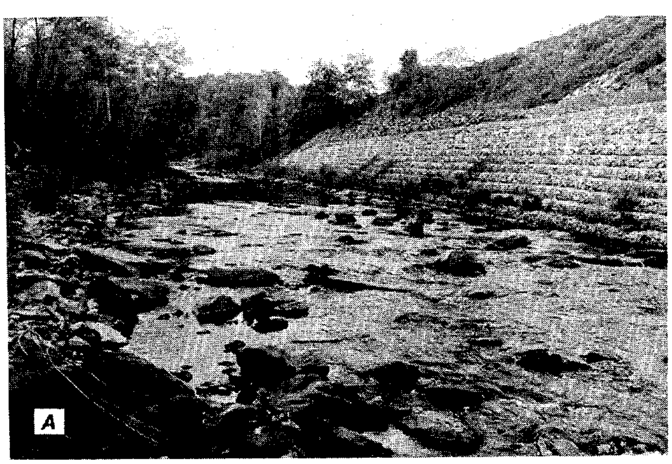


Figure 182. Pocono Creek at site 90. A, View upstream toward gabions on left bank, in 1978. B, View of natural channel downstream from relocation, in 1978.

SITE 91. SAWMILL RUN AT I-80 NEAR TANNERSVILLE, PA.

SYNOPSIS--Channel relocation, reach 715 m in length straightened and shortened to 555 m, for purpose of alining flow through concrete arch culverts beneath dual highway (figs. 183; 184A and B). Performance period, 16 yr (1962-78). Relocated channel was subjected to a major flood in 1969. In the median area between high embankments of the dual highway, the relocated channel has a rectangular cross section with vertical concrete side walls and a concrete bottom (fig. 184A). No failure of the concrete or other problems with the channel were observed in 1978. Downstream from the relocation, the natural channel is stable.

Stability class A1 for relocated channel and downstream segment of natural channel. No erosion of the relocated channel would be expected because of the concrete lining, and aggradation has not occurred in the culverts.

SITE FACTORS--Lat 41°04', long 75°22.5', at I-80, 7 km west of Tannersville, Pa., on Mount Pocono 7.5' map. Sawmill Run is perennial, drainage area of about 5 km^2; channel bottom width is about 6 m, slope is 50 m/km. Stream is semi-alluvial, valley relief of 50 m, very narrow flood plain, tree cover along channel greater than 90 percent. Bed material is cobble-boulder.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

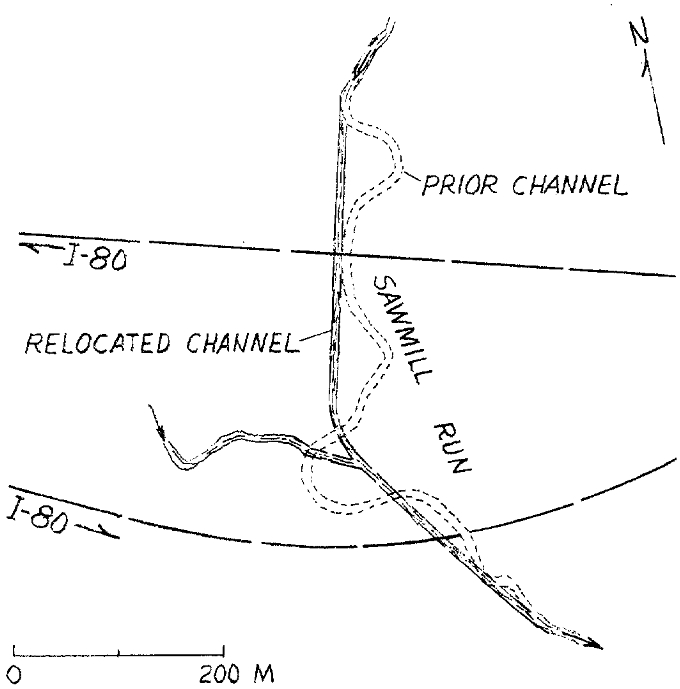


Figure 183. Plan sketch of Sawmill Run channel relocation.

DISCUSSION--Except for minor accumulation upstream from the tributary entrance in the median (figs. 183 and 184A), the concrete-lined channel contains little bed material. Its width, about 4 m, is somewhat narrower than the bottom width of the natural channel, and water velocities consequent upon its width and slope (about 50 m/km) have proved sufficient to transport coarse bed material without aggradation.

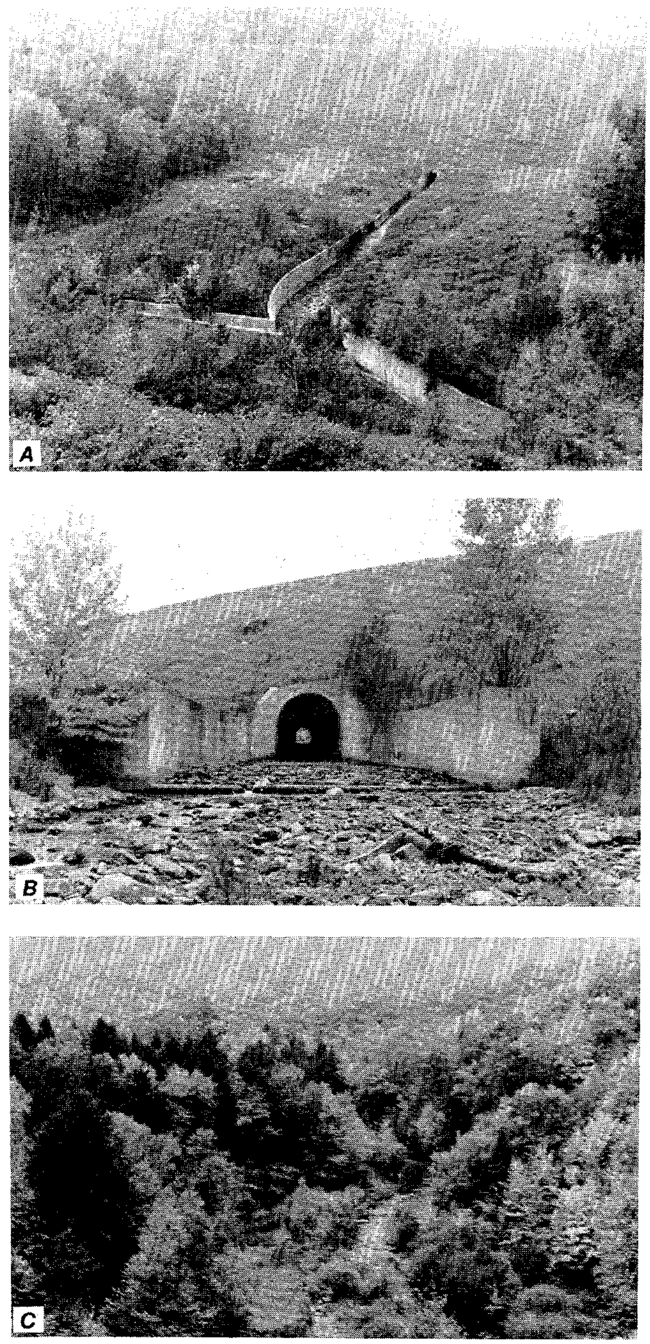


Figure 184. Sawmill Run at site 91. A, Upstream view of concrete-lined channel in highway median area, in 1978. B, Upstream view of culvert, near end of relocation. C, Natural channel downstream from relocation.

SITE 92. MOUNTAIN RUN AT
I-81 NEAR SCOTLAND, PA.

SYNOPSIS--Reach 245 m in length relocated, with no change in length, for purpose of channel alinement at interstate crossing (fig. 185). Performance period, 15 yr (1963-78). The stream is ungaged, but a major flood affected streams of this region in 1972. The relocated channel was trapezoidal in cross section with a bottom width of 6.7 m at the bridge; bottom width elsewhere is not specified in the available plans, but field study in 1978 indicates that it tapered to 2.3m upstream and downstream from the bridge. No countermeasures were used except for a short length of riprapped bank at the upstream junction with the backfilled prior channel. In 1978, the relocated channel was grassed (fig. 186), the banks were generally stable, and only minor previous erosion of bed or banks was evident.

Stability class A1 for relocated channel and adjacent segments of natural channel. Design of the relocated channel with the same slope and length as the cut-off section of natural channel was probably a factor in channel stability. However, the major factor is probably the effect of bedrock geology on streamflow. The natural channel is small and shallow in relation to the area of its drainage basin, and it lies within a hydrologic region in which floods are reduced by underground storage in limestone (Tice, 1968, p. 5).

SITE FACTORS--Lat 38°58', long 77°35', at I-81, 1 km northeast of Scotland, Pa., on Scotland 7.5' map. Mountain Run is intermittent, drainage area of 18 km^2; bottom width of channel is in the range of 3-4 m. Channel is alluvial, slope of 8 m/km, valley relief of 10 m. Bed material is cobble-boulder, bank material is moderately coherent clay-silt. In area of relocation, channel is in a pasture, and there are few trees along the banks.

ALTERATION FACTORS, POST-ALTERATION FACTORS, DISCUSSION--(See "Synopsis")

Figure 186. View upstream along relocated channel of Mountain Run.

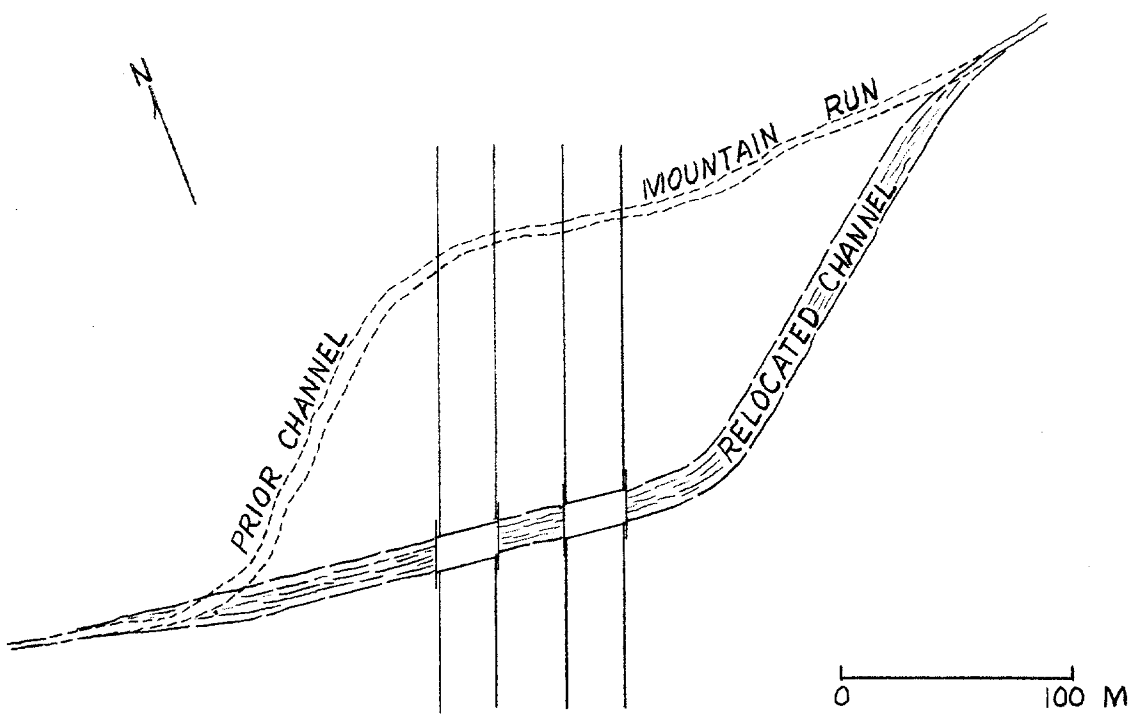


Figure 185. Plan sketch of Mountain Run channel relocation.

SITE 93. BLACK CREEK AT
SR-625 NEAR BOWMANSVILLE, PA.

SYNOPSIS--Channel relocation, reach 302 m in length straightened and shortened to 140 m, apparently to prevent migration of meander against roadway. Performance period, 47 yr (1931-78). Black Creek is ungaged; but at the nearby gage on Conestoga Creek the largest flood of record occurred in 1972, and the second largest, in January of 1978. Scour at the upstream footing of the left bridge abutment (figs. 187 and 188A) caused subsidence and consequent closure of the bridge in January of 1978. This scour is mainly localized at the outside of the curve in the relocated channel, although some degradation has occurred. Upstream progression of the degradation has evidently been halted by large boulders in the channel just upstream from the bridge.

According to the plans, the relocated channel was trapezoidal in cross section, with a bottom width of 6-9 m, 1.5:1 side slopes, and a depth of 1.4 m. In 1978, the bottom width of the relocated channel (fig. 188B) was within the range of 6-9 m, and the maximum depth was about 2 m. Thus the relocated channel has not widened or deepened much, and the failure of the bridge abutment is attributed to a combination of local and general scour at the bridge. Downstream from the bridge, the right bank in 1978 was eroded for a distance of about 20 m (fig. 188B) but the erosion does not appear to be progressive.

Stability class B2 for relocated channel. Although the bridge failed because of large floods, placement at a bend, and spread footings, the performance and stability of the relocated channel is not bad. Lateral erosion has been held in check by resistant bank materials, consisting of gravel and boulders in a coherent silt-clay matrix; and degradation, by large boulders and possibly by a concealed bedrock outcrop in the channel.

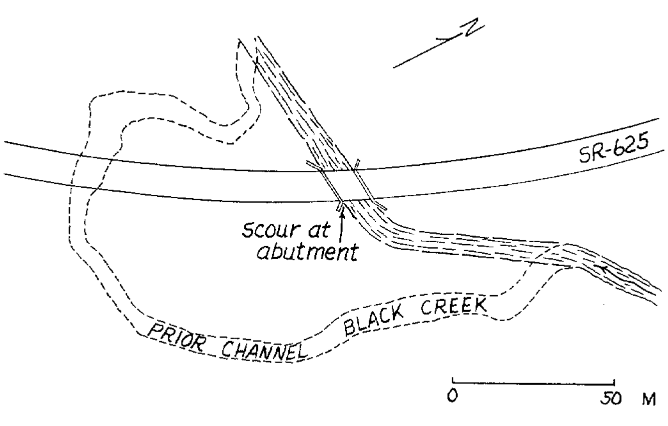


Figure 187. Plan sketch of Black Creek channel relocation.

SITE FACTORS--Lat 40°10', long 76°0.5', at SR-625, 3 km south of Bowmansville, Pa., on Terre Hill 7.5' map. Black Creek is perennial, alluvial, with a drainage area of 16.5 km^2. Bottom width of channel is 4.5-6 m and channel slope is 7 m/km. Bed material is of boulders, cobble, and gravel size; bank material is also of this size, but with a coherent red silt-clay matrix.

ALTERATION FACTORS, POST-ALTERATION FACTORS, DISCUSSION--(See "Synopsis")

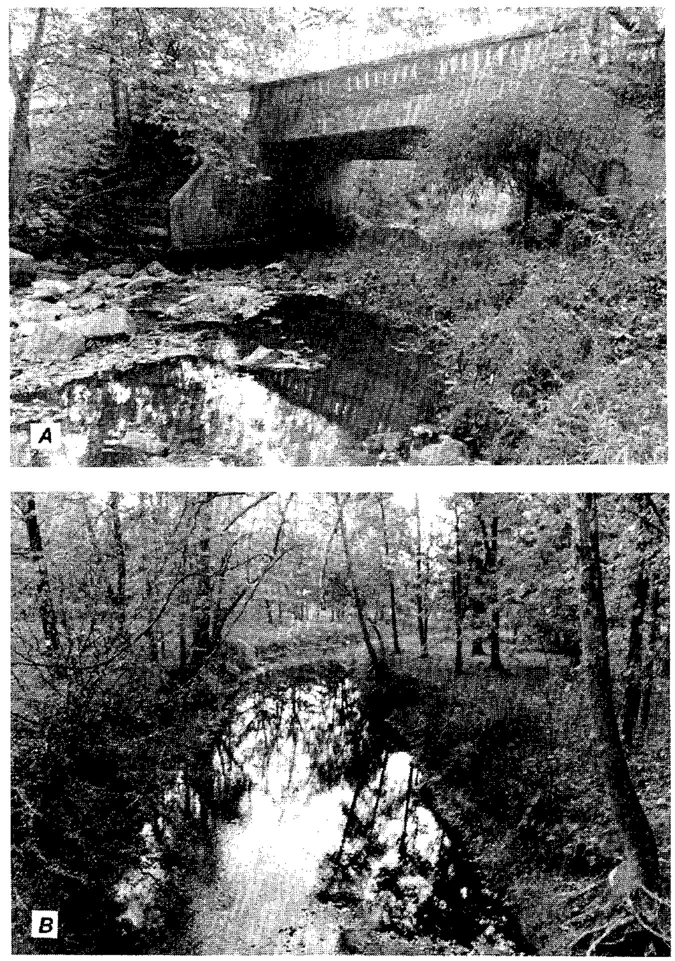


Figure 188. Black Creek at site 93. A, View downstream toward failed left bridge abutment in 1978. B, View from bridge, downstream along relocated channel, in 1978.

SITE 94. SHADE CREEK AT
US-522 NEAR SHADE GAP, PA.

SYNOPSIS--Channel relocation, reach 625 m in length straightened and shortened to 480 m (fig. 189 to avoid a stream crossing on new road, which is less sharply curved than old road. Performance period 10 yr (1968-78). The relocated channel was subjected to a major flood in 1972, and to a lesser flood in 1975. The relocated channel was trapezoidal in cross section, with a bottom width of 15 m, 1.5:1 side slopes, an average depth of 1.2 m, and a longitudinal slope of about 15 m/km. The left bank, along the highway embankment, was revetted with dumped rock riprap on a 1.5:1 slope, that extended a vertical distance of 1.6 m above the channel bottom. In 1978, the revetted bank was stable (fig. 190A) and the right bank was generally stable except for minor bank erosion near the downstream end of the relocation. Rapids at the downstream junction of natural and relocated channel (fig. 190B) suggests that a small amount of degradation has occurred, but upstream progression of the degradation has been inhibited by boulders in the streambed. The channel of a tributary to Shade Creek was also relocated (fig. 189), and this relocated channel was stable in 1978, as was the natural channel of Shade Creek (fig. 190C).

Stability class B1 for relocated channel of Shade Creek, and class B1 for adjacent segments of the natural channel. Critical factors in channel stability are the large boulders in the bed and banks, and the use of riprap along the highway embankment.

SITE FACTORS--Lat 40°11.5', long 77°53', at US-522, 1.5 km west of Shade Gap, Pa., on Orbisonia 7.5' map. Shade Creek is perennial, drainage area of 52 km^2; channel width, 7-8 m, bank height, 1-1.25 m, channel slope, 14 m/km. Equiwidth stream, no point bars, locally anabranched; semi-alluvial, sinuosity, 1.1-1.2. Valley relief, 200 m; width of flood plain at site, 400 m; tree cover along channel, greater than 90 percent. Bed material is in the size range of gravel to large boulders; bank material consists of gravel and boulders overlain by weakly coherent silt-clay. Shade Creek was only moderately stable prior to relocation, as cut banks are visible on a 1967 airphoto.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--Shade Creek is generally similar in form and setting to Wilson Creek (site 89), and the length and degree of shortening by relocation is also similar; yet it has remained stable and Wilson Creek has not. The bottom of Shade Creek has a rather continuous armor of boulders; but the bottom of Wilson Creek is less well armored and its banks are less bouldery and more erodible. No other factors are apparent to account for the differences in stability.

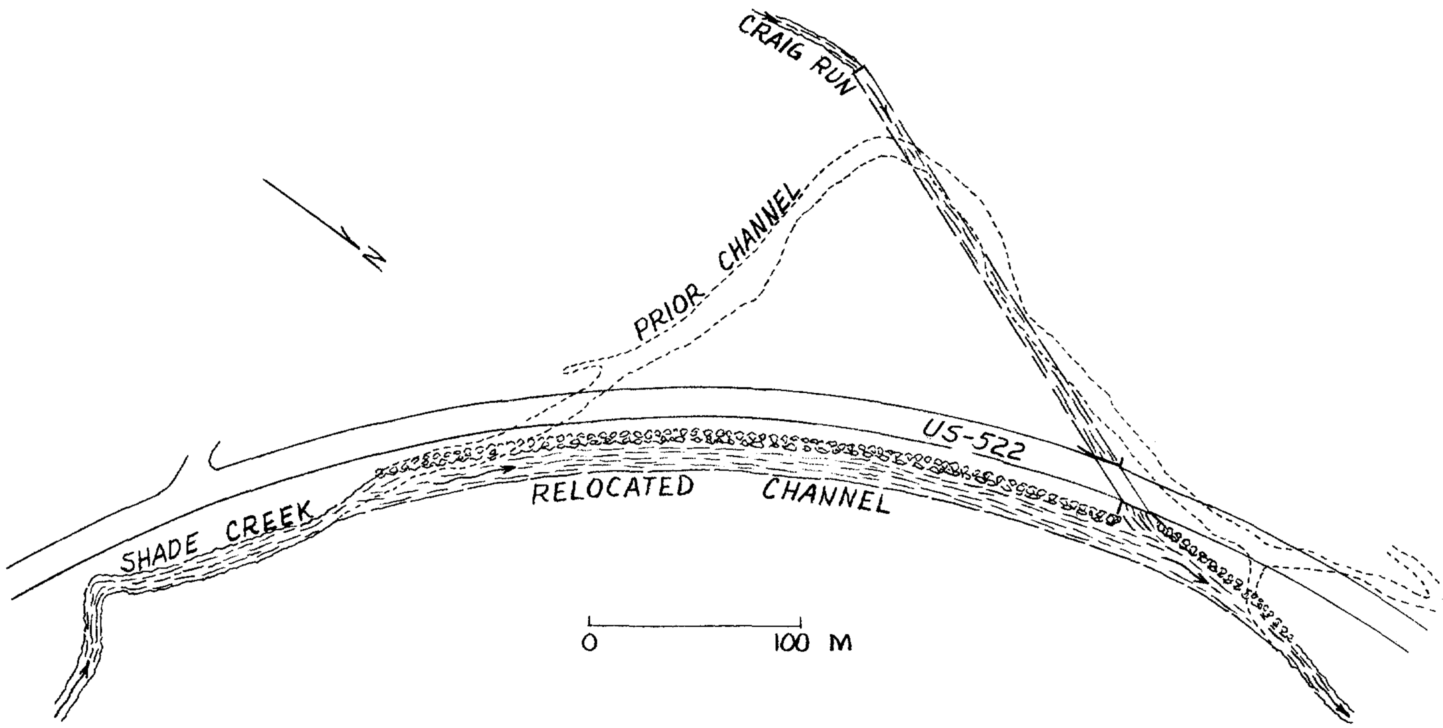


Figure 189. Plan sketch of Shade Creek channel relocation.

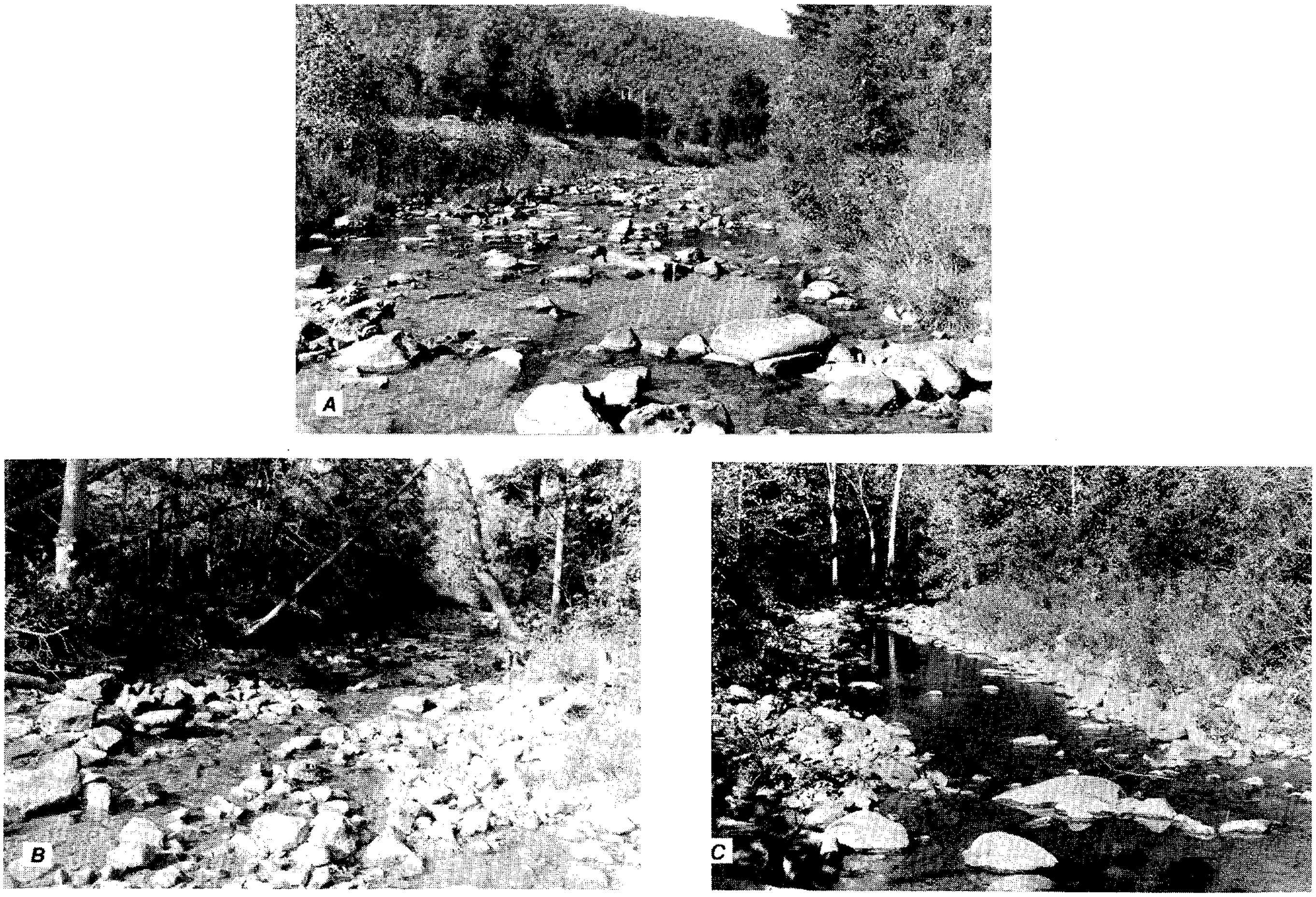


Figure 190. Shade Creek at site 94. A, Downstream view of relocated channel, in 1978. B, Downstream junction of relocated channel with natural channel, in 1978. C, Natural channel downstream from relocation, in 1978.

SITE 95. LITTLE MILL CREEK AT I-80 NEAR BROOKVILLE, PA.

SYNOPSIS--Channel relocation, reach 450 m in length shortened and straightened to a length of 400 m, to accommodate roadway alinement and to improve entrance angle of flow at culvert (fig. 191). Performance period, 15 yr (1963-78). Relocated channel has been subjected to a very large flood in 1972 and a lesser flood in 1977. The relocated channel was built to a trapezoidal cross section, with a bottom width of 7.5-12 m, 1.5:1 side slopes, and a longitudinal slope of about 8 m/km. No bank protection measures were installed. In 1978, the relocated channel was stable except for an unvegetated high bank (fig. 192A) just upstream from the crossing; this bank was probably eroded during past floods, but erosion did not appear to be progressing at the time of inspection. Downstream from the relocation, one cut bank was observed (fig. 192B). Stability class B2 for relocated channel and adjacent segments of natural channel. The eroded bank of the relocated channel, although not a serious stability problem, is attributed to the rather sharp curve upstream from the crossing.

SITE FACTORS--Lat 41°10', long 79°02', at I-80, 1.5 km east of Interchange 14 at Brookville, Pa., on Brookville 7.5' map. Little Mill Creek is perennial and has a drainage area of 22 km^2, a bottom width of 6-8 m, and a channel slope of about 8 m/km. The channel is alluvial, with a sinuosity of about 1.3 and a narrow flood plain and a valley relief of about 50 m. Bed material ranges in size from gravel to boulder and bank material consists of gravel in a moderately coherent silt-clay matrix.

ALTERATION FACTORS, POST-ALTERATION FACTORS, DISCUSSION--(See "Synopsis")

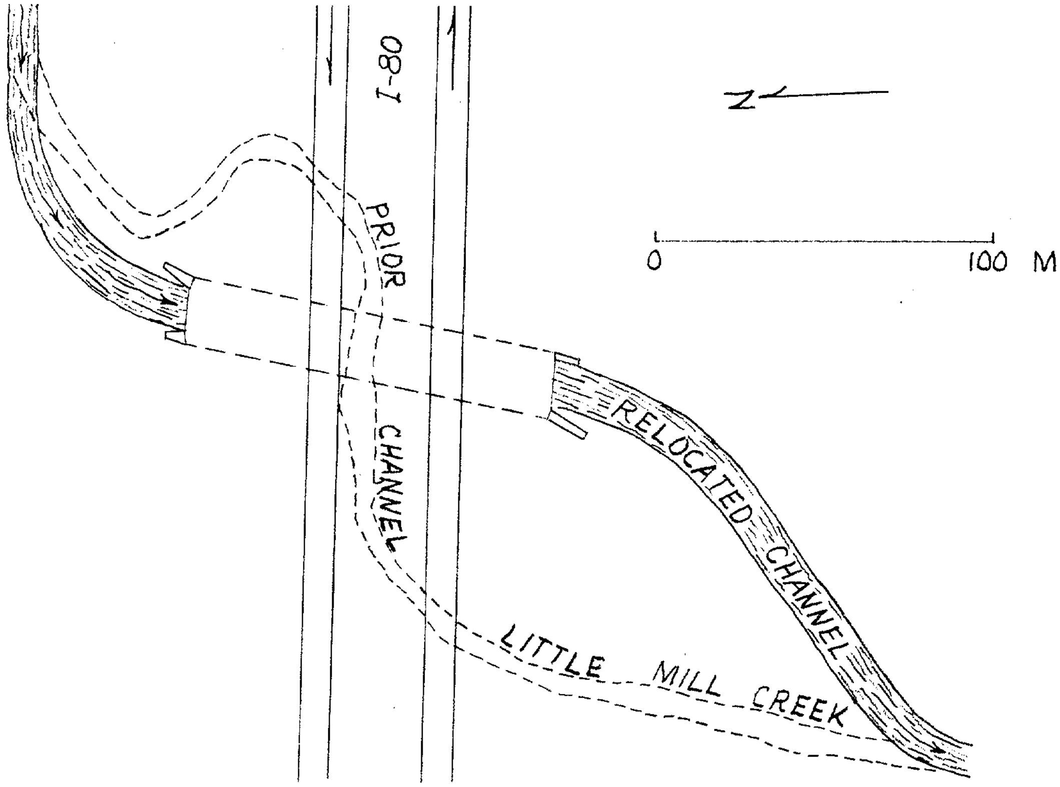


Figure 191. Plan sketch of channel relocation, Little Mill Creek.

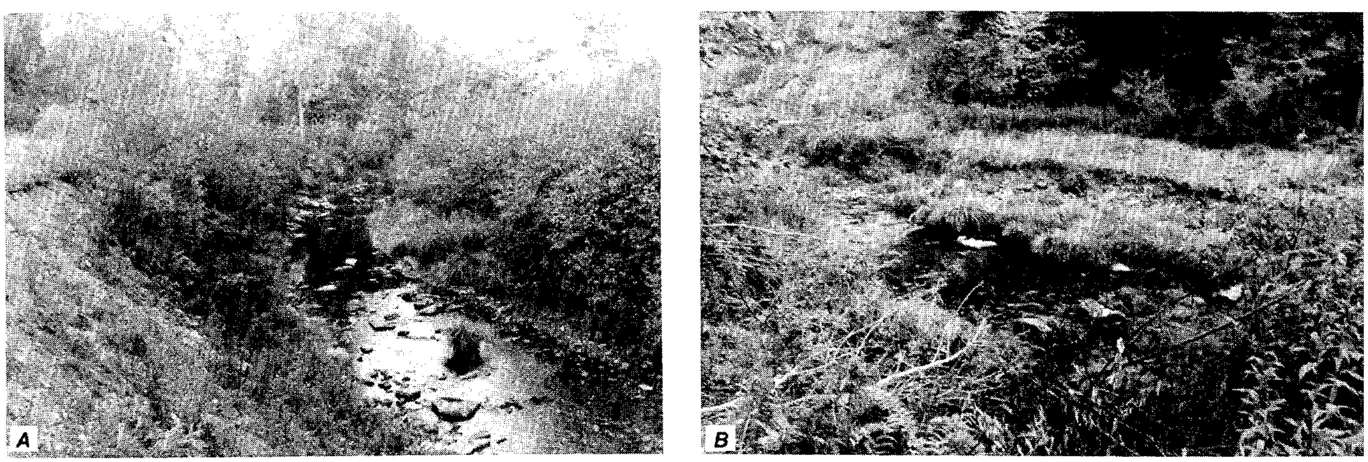


Figure 192. Little Mill Creek at site 95. A, Unvegetated bank at curve in relocated channel, upstream from I-80 crossing of Little Mill Creek, in 1978. B, Natural channel about 100 m downstream from crossing, in 1978.

SITE 96. MILL CREEK AND FIVE MILE RUN
AT I-80 NEAR BROOKVILLE, PA.

SYNOPSIS--Channel relocation, anabranching reach of Mill Creek 535 m in length, was shortened to 420 m and combined into a single channel. In addition, Five Mile Run was relocated and its confluence with the relocated channel of Mill Creek was moved upstream (fig. 193). The purpose of the relocations was to avoid stream crossings and to combine multiple channels into a single channel. Performance period, 15 yr (1963-78). The relocated channel has been subjected to a very large flood in 1972 and a lesser flood in 1977. The relocated channel of Mill Creek, as built, had a bottom width of 15 m, 1.5:1 side slopes, and a longitudinal slope of about 10 m/km. The relocated channel of Five Mile Run also had a trapezoidal cross section, with a bottom width of 7.3 m. In 1978, the relocated channel of Five Mile Run had a bottom width of about 11 m at the bend upstream from the confluence, and the outside bank was actively eroding (fig. 194A). The channel bed dropped by a vertical distance of about 1 m near the confluence, forming a rapids (fig. 194B). Bank erosion was also noted on the relocated channel of Mill Creek, at the outside of the bend downstream from the Interstate 80 bridges (fig. 194C); otherwise, the banks were stable (fig. 194D).

Stability class C3 for relocated channel of Five Mill Run, and class B2 for relocated channel of Mill Creek. Bank erosion is attributed to the rather sharp bends in the relocated channels, together with the erodibility of bank materials and the lack of bank protection. Adjacent segments of natural channel were not studied in the field, but no effects of relocation are apparent on airphotos made in 1969 and 1973.

SITE FACTORS--Lat 41°10', long 79°00', at I-80, 4 km east of Interchange 14 at Brookville, Pa., on Brookville 7.5' map. Mill Creek is perennial and has a drainage area of approximately 110 km^2. At the site, the channel was anabranched (fig. 193, the major branch having a bottom width of 11 m and the minor branch of 7.5 m. Slope of the major branch was about 8 m/km. Mill Creek is semi-alluvial, with a sinuosity of 1.1, a valley relief of 60 m, a very narrow flood plain, and greater than 90 percent tree cover along the bankline. Bed material is in the size range of gravel to boulders, and bank material is of gravel and boulders overlain by moderately coherent finer alluvium. The channel of Five Mile Run is smaller (bottom width of 6 m) and more sinuous than that of Mill Creek, and it is not anabranching.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--In view of the magnitude of the 1972 flood (recurrence interval of about 100 yr), bank erosion at bends on the relocated channels is not regarded as an indication of poor performance, although the banks have remained steep and unvegetated. The drop in bed elevation of Five Mile Creek at the confluence is attributed to aggradation, which has resulted from bank erosion and minor degradation along the lengthy relocation 4-6 km upstream (site 97).

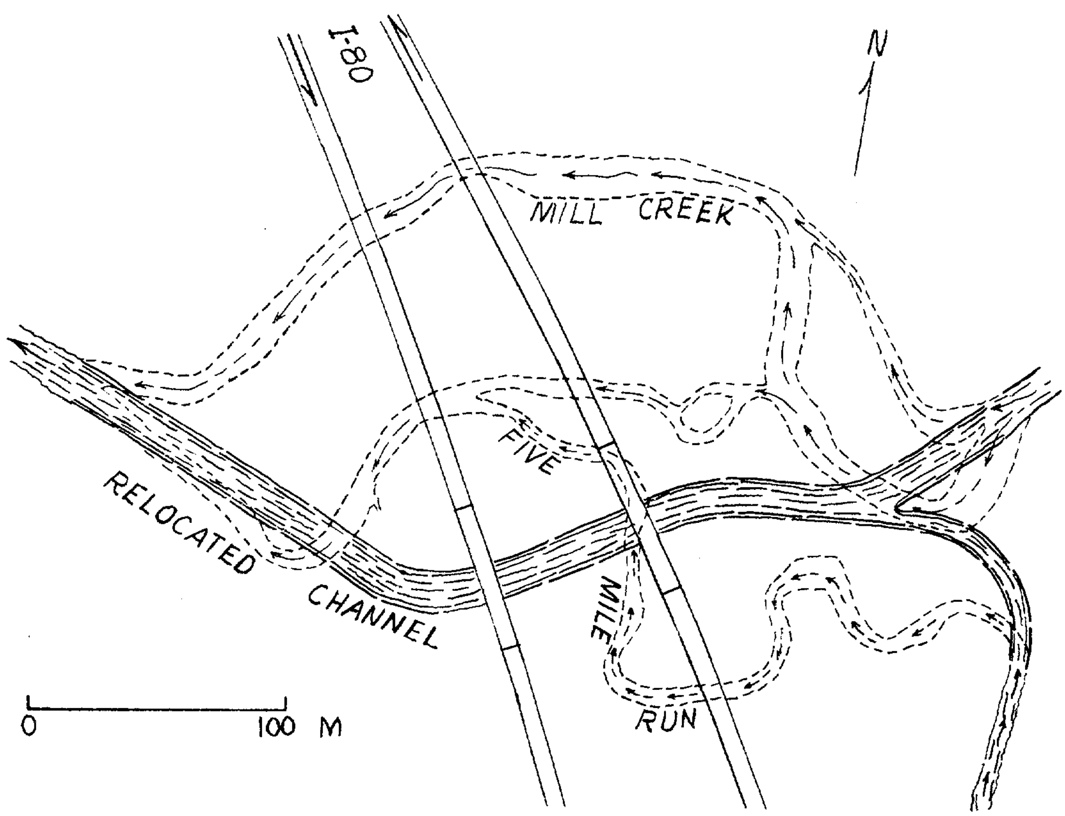


Figure 193. Plan sketch of Mill Creek channel relocation.

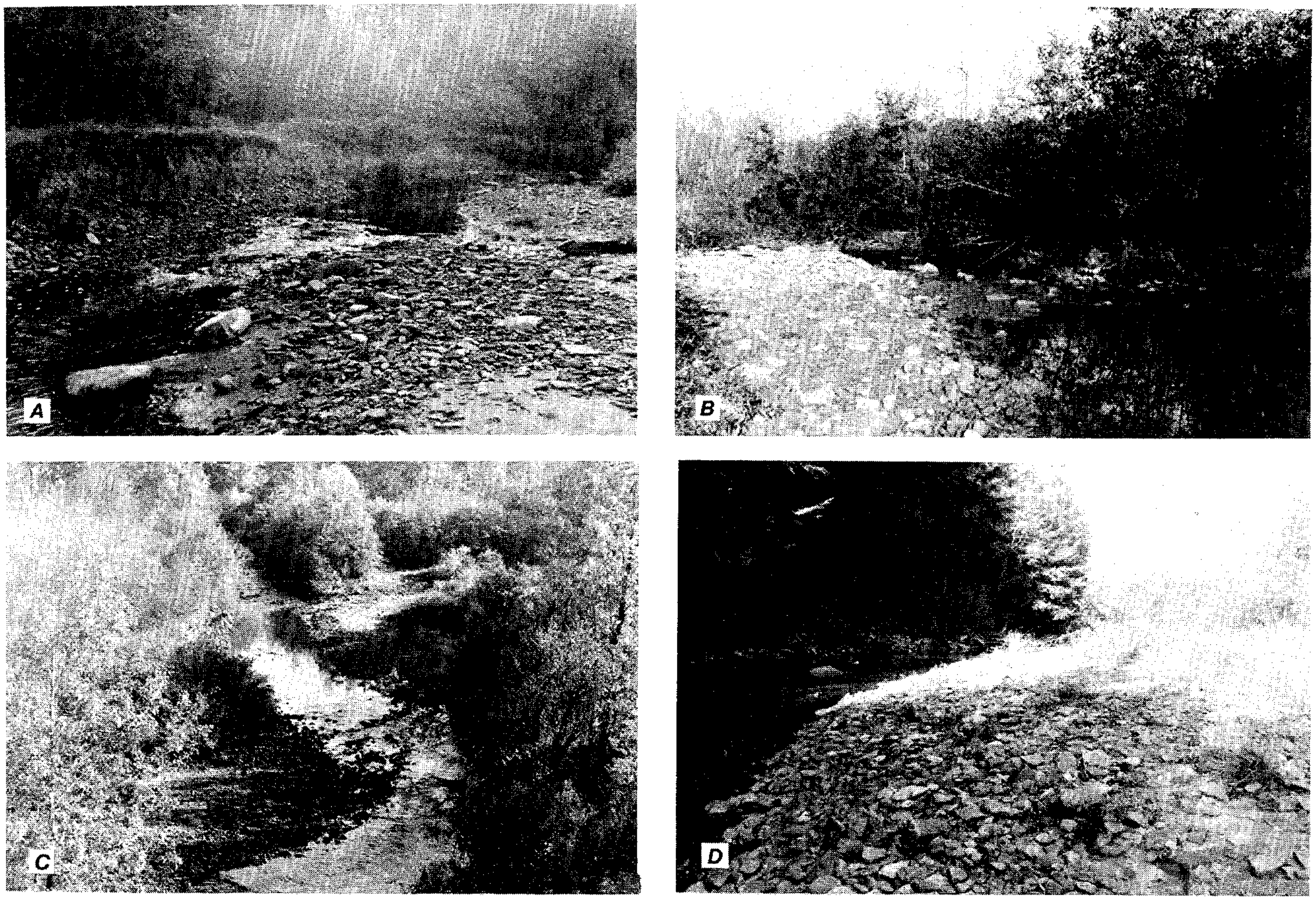


Figure 194. Mill Creek and Five Mile Run at site 96. A, Bank erosion at bend in relocated channel of Five Mile Creek, in 1978. B, Rapids in Five Mile Creek at confluence with Mill Creek, in 1978. C, View along Mill Creek upstream from I-80 bridge, in 1978. Mouth of Five Mile Creek is in background, at right. D, View of bend in relocated channel of Mill Creek, downstream from I-80 bridge, in 1978.

SITE 97. FIVE MILE RUN AT I-80 NEAR BROOKVILLE, PA.

SYNOPSIS--Reach 1,930 m in length relocated to median area of Interstate 80 and shortened to 1,245 m, for purpose of avoiding crossings and to accommodate roadway alinement (fig. 195). Performance period, 15 yr (1963-78). The relocated channel has been subjected to a very large flood in 1972 and to a lesser flood in 1977. Because the relocation is lengthy in relation to the size of the stream, drainage area increases significantly along the relocated channel, which has a bottom width of 4.2 m at the upstream end and 8.5 m at the downstream end. The channel cross section, as built, was trapezoidal with 1.5:1 side slopes and depth that ranged from about 1 m to 4.5 m, depending on local differences in terrain altitude. In 1978, the relocated channel was generally stable, with well vegetated banks (fig. 196A) for a distance of several hundred meters upstream from sta. 770. However, bank slumping was noted at several places, where the banks were high, in the vicinity of sta. 795 (fig. 196B). Degradation could not be assessed because of a lack of benchmarks, but a small amount of degradation is probable, upstream from a bedrock outcrop in the channel near sta. 770. Downstream from the relocation, the natural channel is generally stable, and the cut banks that occur at bends may have been present prior to relocation (fig. 196C).

Stability class C2 for upstream part of relocation, B1 for downstream part and for adjacent segments of the natural channel. Channel degradation has probably been inhibited by boulders on the streambed. Bank erosion, mainly by slumping, is restricted to places where the banks are higher than about 2 m, and elsewhere has been controlled by vegetation and by boulders along the bankline.

SITE FACTORS--Lat 41°08', long 78°58', at I-80, 8.5 km east of Interchange 14 at Brookville, Pa., on Hazen 7.5' map. Five Mile Run is perennial, drainage area of 9 km^2 at downstream end of relocation. Channel width was 4.5 m at downstream end of relocated reach, and 2.5 m at upstream end; bank height is variable, about 1.2 m to narrow flood plain. Wide-bend point-bar stream, locally braided, mostly alluvial, sinuosity of 1.5, valley relief of 100 m; tree cover along channel, greater than 90 percent. Bed material is in the range of gravel to boulders, bank material consists of angular gravel and cobbles in a weakly coherent silt-clay matrix. Small strip mines occur from place to place on the valley side slopes.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--In view of the degree of shortening (by a factor of 0.65), the erodibility of the banks, the lack of countermeasures, and the large magnitude of the flood to which it has been subjected, a substantial amount of instability might have been expected along the relocation. Instead, bank instability is restricted to places where the banks are high, and the amount of degradation is estimated to be less than 0.5 m. Vegetation is particularly important in controlling bank erosion along a small stream, and the major flood did not occur until 10 years after relocation and after the time that small trees had become established along the bankline. Where banks were high, the vegetation was not effective and slumping occurred.

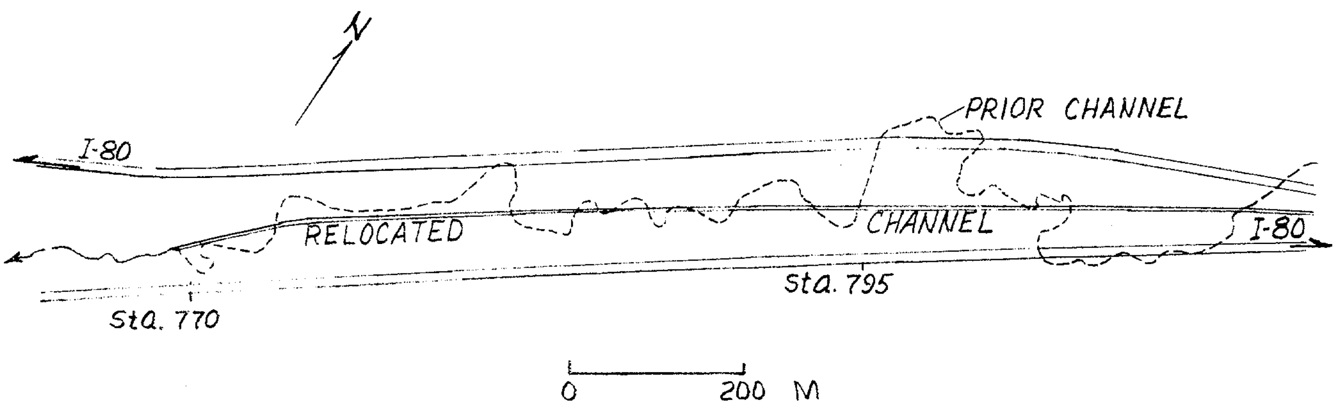


Figure 195. Plan sketch of channel relocation, Five Mile Run.

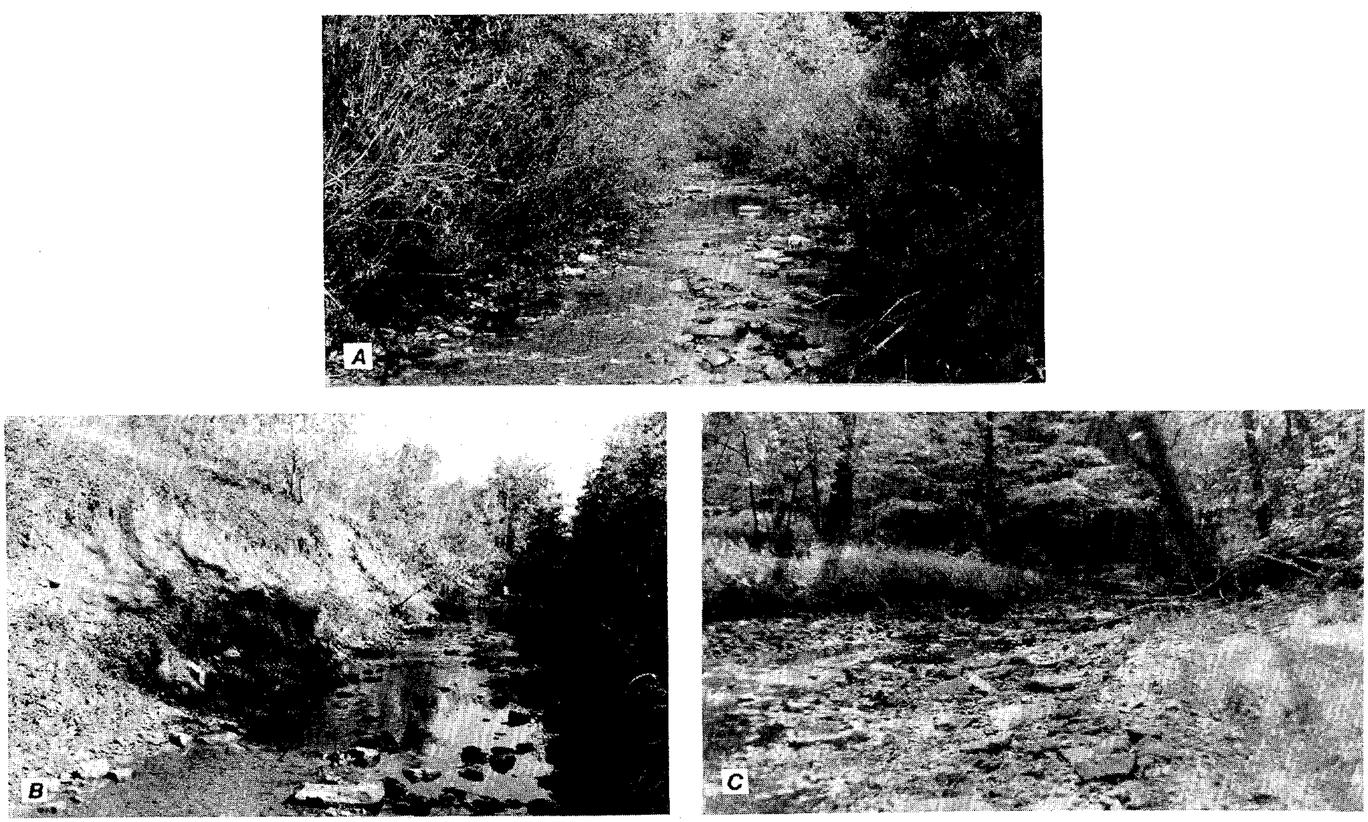


Figure 196. Five Mile Run at site 97. A, View upstream along relocated channel in vicinity of sta. 770. B, Unstable bank along relocated channel in vicinity of sta. 795. C, Natural channel just downstream from sta. 770.

SITE 98. HUNTERS RUN AT SR-38
NEAR MOUNT HOLLY SPRINGS, PA.

SYNOPSIS--Anabranching channel segment, 134 m in length, was relocated as a single channel and lengthened to 143 m, to avoid a second crossing and to improve channel alinement at bridge (fig. 197). Performance period, 50 yr (1926-1976). Relocated channel was subjected to a 30-yr flood in 1970 and a 70-yr flood in 1972. Because of difficulties in changing the alinement of the roadway, which is in a narrow valley, the relocated channel was built with a sharp bend upstream from the bridge. As observed on a 1968 airphoto, this bend had migrated downstream by a few meters, but the alinement of the approach channel with the bridge was not significantly changed. During the 1972 flood, the bend moved downstream and a large area was eroded at the right abutment. This area was backfilled and the channel was, by 1975, fixed with riprap at the alinement indicated in figure 197 (see also fig. 198).

Stability class C3 for relocated channel. Critical factors in instability are the sharp bend, erodibility of the bank materials, the lack of tree cover, and the magnitude of the 1972 flood.

SITE FACTORS--Lat 40°95', long 77°12', at SR-38, 4 km south of Mount Holly Springs, Pa., on Mount Holly Springs 7.5' map. Hunters Run is perennial, with a drainage area of 13.6 km^2, a channel width of 3.7-4 m, and a channel slope of 13 m/km. Equiwidth stream, locally anabranched, alluvial, low sinuosity. Valley relief is 150 m, tree cover along channel at site, less than 50 percent. Bed material is in the gravel to cobble range, bank material is weakly coherent gravel and sand.

ALTERATION AND POST-ALTERATION FACTORS--The relocated channel had a bottom width, as built, in the range of 7.6-8.5 m (about twice that of the natural channel) and a longitudinal slope of 13.5 m/km (about the same as that of the natural channel). Bank protection with rock riprap was recommended in early bridge reports, but there is no record or evidence of installation. On an airphoto taken in 1968, the banks of the relocated channel, particularly at the bend, appear to be cut and tree cover along the channel is scant. During the flood of 1972, a large area was eroded at the bend, and the right approach roadway was nearly breached.

DISCUSSION--The nearly parallel trends of stream and roadway, in a narrow valley, presented a difficult problem in crossing location and it was difficult to avoid the bend in the relocated channel. In spite of the sharpness of the bend, it did not erode seriously until the major floods in 1970 and 1972. The damage that resulted could probably have been prevented, or greatly diminished, by bank protection and the establishment of vegetation.

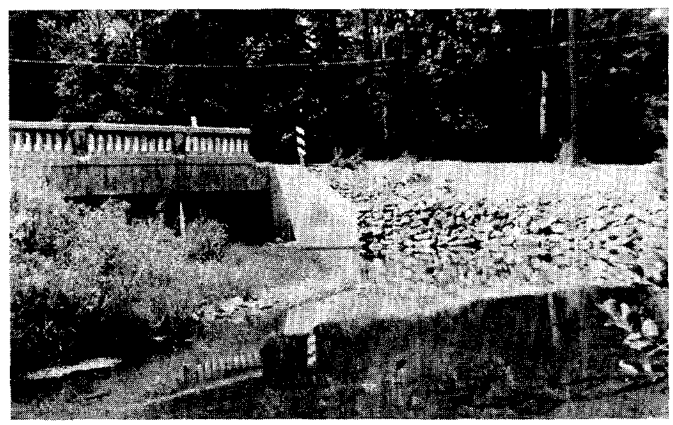


Figure 198. Bankline of Hunters Run as protected with hand-placed riprap and as established after the flood of 1972 (Photograph of July 1976).

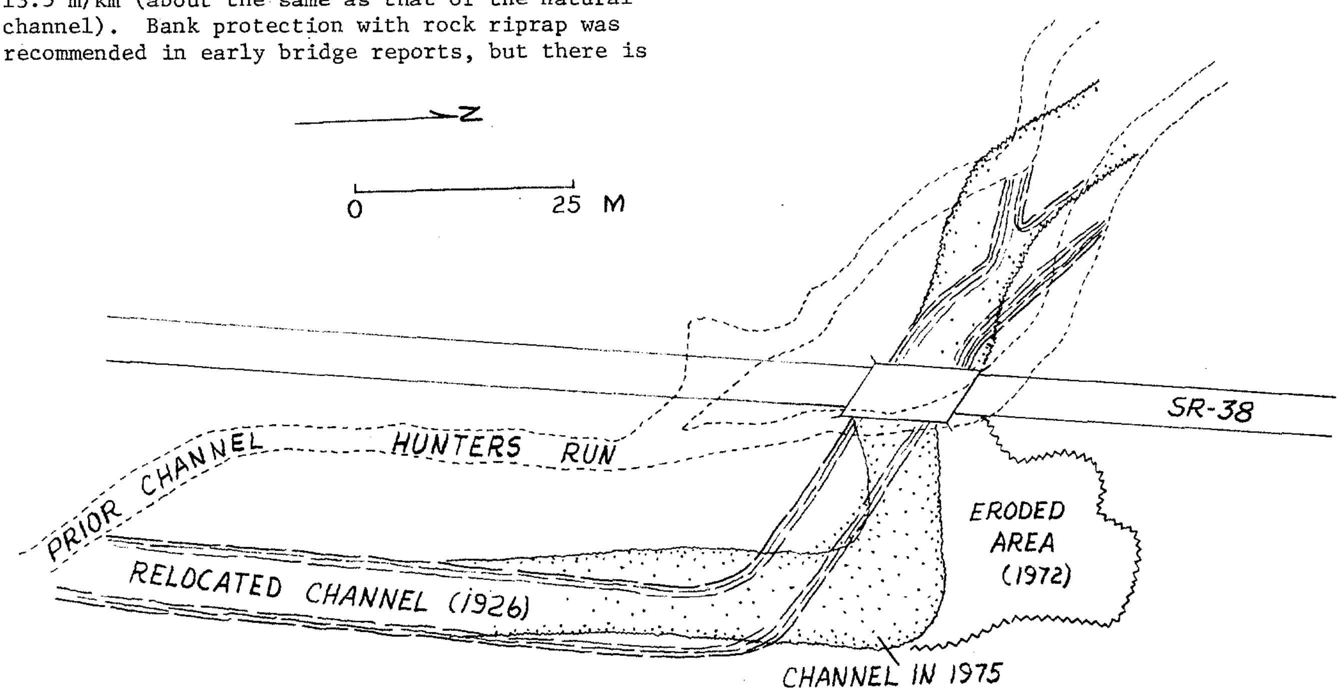


Figure 197. Plan sketch of Hunters Run channel relocation, and of bank erosion that occurred during the flood of 1972.

SITE 99. GILLS BRANCH AT SR-21 AT BASTROP, TEX.

SYNOPSIS--Channel segment 457 m in length was relocated and shortened to 417 m, evidently for purpose of combining stream crossing with railroad overpass (fig. 199). Performance period, 21 yr (1956-77). Relocated channel was subjected to a flood of substantial magnitude during the period 1973-74. As built, the relocated channel was trapezoidal in cross section, with a bottom width of 7.5 m, 2:1 side slopes, and a longitudinal slope of 5.5 m/km. Both bed and banks were lined with concrete pavement (fig. 200A). In connection with the flood, a section of the bottom lining was raised, evidently by hydrostatic pressures, and a scour hole was formed at downstream junction with the natural channel (fig. 200B). Subsequently, the raised section of bottom lining was broken up and left in place as riprap. A comparision of airphotos taken in 1966 and 1977 indicates that some deterioration of adjacent segments of the natural channel has occurred by bank erosion (fig. 200C).

Stability class A1 for relocated channel, B2 for adjacent segments of natural channel. Concrete lining has prevented erosion of relocated channel, but relocation has, by an increase in slope, evidently induced some instability in adjacent segments of the natural channel.

SITE FACTORS--Lat 30°06', long 97°19', at SR-21, near southern limits of Bastrop, Tex., on Bastrop 7.5' map. Gills Branch is intermittent, with a drainage area of 5.5 km^2, a bottom width of 3-4 m, and a slope of 5.1 m/km. Equiwidth stream, somewhat incised, alluvial, sinuosity of 1.4, on flood plain of Colorado River. Vegetal cover along the channel is mainly shrubs and grass.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis").

DISCUSSION--Local failure of the concrete channel lining is tentatively attributed to the lack of weep holes for relief of hydrostatic pressures. Upstream and downstream transitions between a natural channel and a concrete-lined channel are potential problem areas because there can be no adjustment, either in slope or cross-section, of the lined channel.

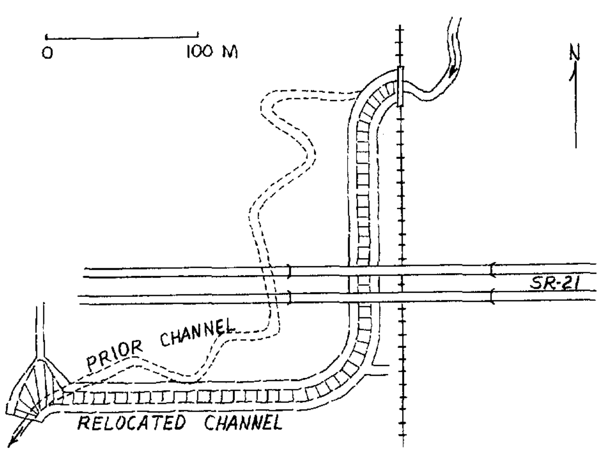


Figure 199. Plan sketch of Gills Branch channel relocation.

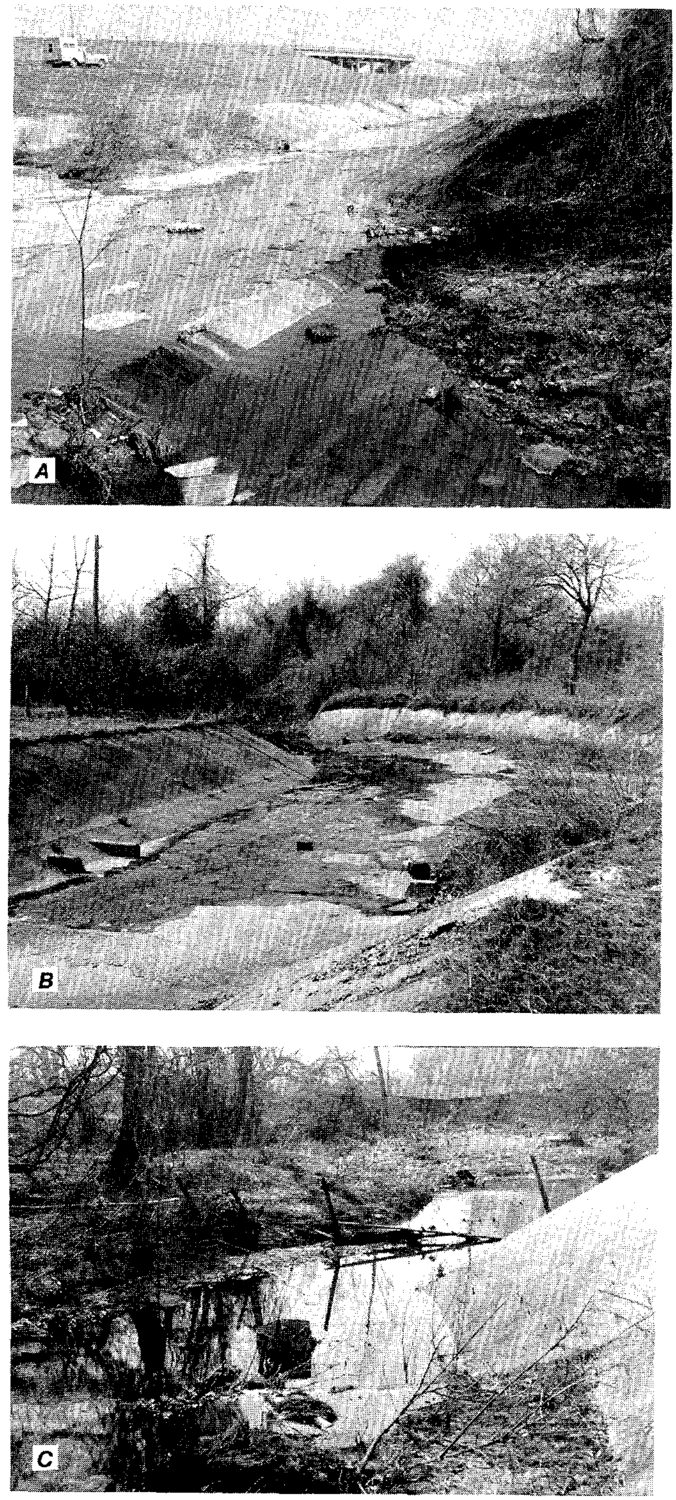


Figure 200. Gills Branch at site 99. A, View along relocated channel, upstream toward bridge, in 1977. B, View downstream toward end of relocated channel, in 1977. Scour hole is at terminus of concrete pavement. C, Natural channel downstream from relocation, in 1977.

SITE 100. LEWIS RIVER AT I-5 AT WOODLAND, WASH.

SYNOPSIS--Channel was relocated by cutting off a meander, which shortened the channel segment from a length of 2,800 m to 840 m; the purpose was to avoid a river crossing (fig. 201). Performance period, 39 yr. (1940-1979). Since relocation, several large peak discharges have been recorded at the U.S.G.S. gage at Arial (21 km upstream), but the river has been regulated since 1931 and is not subject to overflow at Ariel. As built, the relocated channel was trapezoidal in cross section, with a bottom width of 152 m, 2:1 side slopes, and a longitudinal slope of 0.6 m/km. According to the plans, the right (west) bank was riprapped to a thickness of 0.6 m and to a height of 4 m above low water; the toe of the riprap blanket was thickened but not extended below the streambed. In 1979, riprap was also observed along the left bank, but the date of placement is not known. Both banks of the relocated channel were stable (fig. 202A), and trees were well established along the riprapped right bank (fig. 202B). As measured on a 1970 airphoto, taken at low river stage, the water surface width of the relocated channel ranged from 157 m to 172 m, which is the same, or slightly greater, than the as-built channel width at average water stage. Adjacent segments of the natural channel showed little change in width or configuration during the period 1951-1979, as determined by comparison of airphotos, but cut banks occur at bends.

Stability class A1 for relocated channel and class B1 for adjacent segments of natural channel. The channel stability is unexpected in view of the erodibility of the banks, and it is tentatively attributed to the low channel slope and to regulation. On the relocated channel, the bank revetment has no doubt contributed to stability.

SITE FACTORS--Lat 45°54', long 122°45', at I-5, near south limits of Woodland, Wash., on Woodland 7.5' map. Lewis River is perennial, with a drainage area of about 2,000 km^2 at the site, and an average discharge of 138 m^3/s at Ariel, 21 km upstream. Channel bottom width is in the range of 80-110 m, bank height is 3.4 m, and channel slope is about 0.2 m/km. Equiwidth point-bar stream, locally braided or anabranched, alluvial, sinuosity of 1.3, valley relief of 300 m; tree cover along bankline is 50-90 percent. Bed material is gravel, and bank material is weakly coherent silt, clay, sand, and gravel. Since 1931, flow has been regulated by two upstream reservoirs.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--At the relocated segment, channel length was reduced by a factor of 0.3, and channel slope was correspondingly increased. Comparable meander cutoffs that occur on natural channels are commonly accompanied by a local increase in width and by an increase in growth rate of adjoining meanders; but neither of these effects is apparent at this site. The site is on the flood plain of the Columbia River, about 7 km upstream from the confluence of the Lewis and Columbia Rivers; and the generally low channel slope is probably the main factor in channel stability.

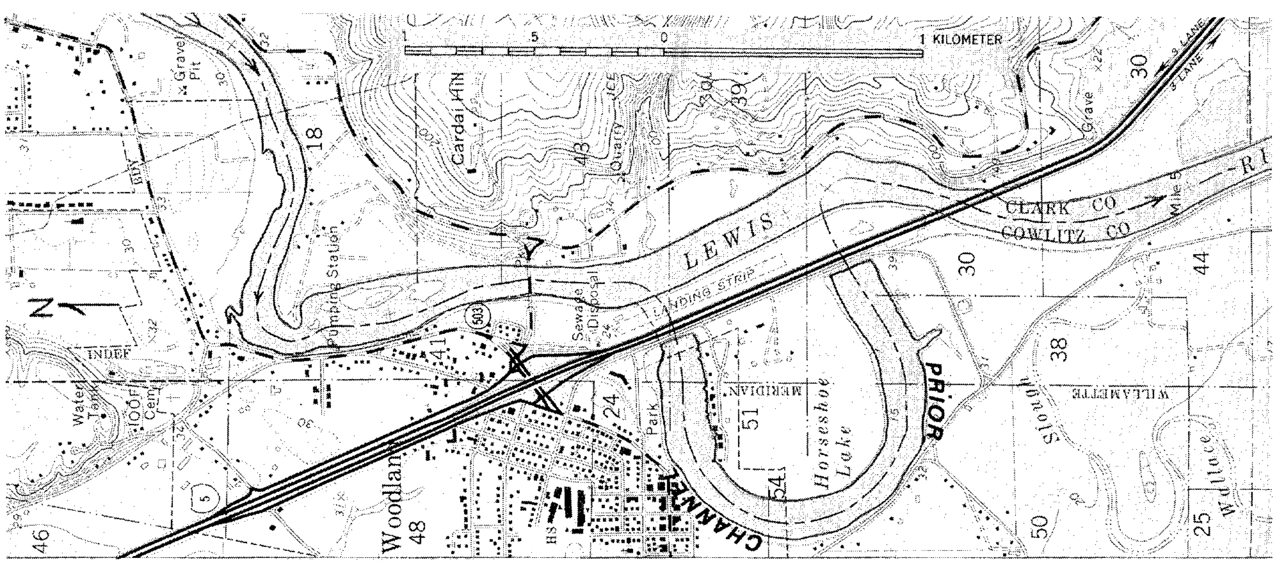
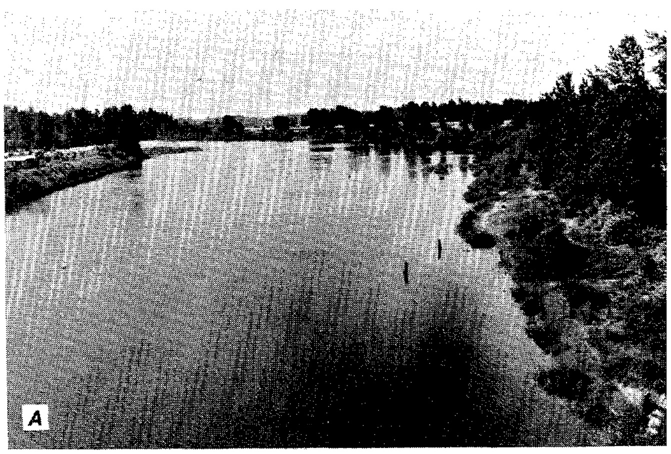


Figure 201. Topographic map of channel relocation, Lewis River. (From U.S. Geological Survey Woodland, Wash., 7.5' quadrangle, contour interval 20 ft, from aerial photographs taken in 1952 and 1970)



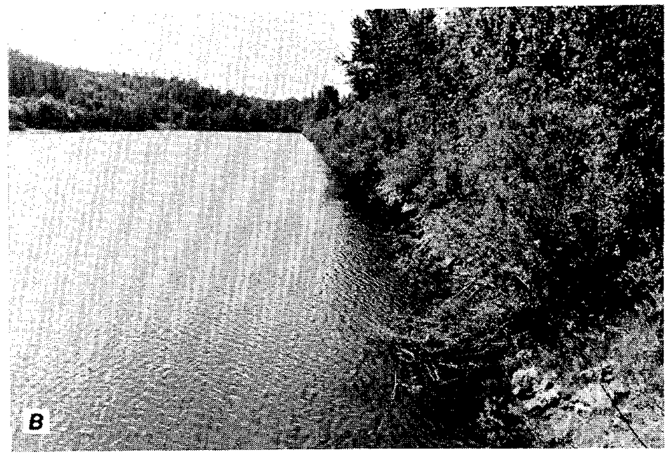


Figure 202. Lewis River at site 100. A, Relocated channel as viewed downstream from bridge at Woodland, in 1979. B, Growth of vegetation on riprapped right bank of relocated channel, in 1979.

SITE 101. SKOOKUMCHUCK RIVER AT I-5 AT CENTRALIA, WASH.

SYNOPSIS--Anabranched channel segment 1,340 m in length was relocated and shortened to 565 m, apparently to avoid crossing of an anabranch and to accommodate excavation of a borrow pit (fig. 203). Performance period, 23 yrs(1952-79). At the nearest U.S.G.S. gage, 19 km upstream, the maximum flood in a 42-yr period of record occurred in 1953. The relocation was connected with a borrow pit operation, and a berm was maintained between the borrow pit and the river channel until diversion of the stream through the south end of the borrow pit and under the I-5 bridge. Thus the south bank of the relocated channel was the south embankment of the borrow pit; and the north bank was indefinite except in the vicinity of the bridge, where the channel was trapezoidal in cross section, with a bottom width of 40 m. As shown on an airphoto taken in 1960 (fig. 204A), the relocated channel was largely blocked with gravel bars and much of the flow was apparently diverted into the water-filled borrow pit. In 1979, boundaries of the relocated channel were more definite and tree-lined, and the channel was somewhat natural in aspect (fig. 204B). Channel degradation has apparently been inhibited by a massive riprap check dam, which extends to a depth of 10 ft below the channel bottom (fig. 204-C). Rapid bank erosion occurred along the natural channel at the first bend upstream from the relocation (fig. 204A) during the period 1948-1960, but in 1979 the banks had been stabilized with riprap.

Stability class A2 for relocated channel, which has narrowed in width since relocation; and class B3 for adjacent segments of natural channel. Critical factors in channel performance are the check dam, which has reduced channel degradation; and the flow regimen of the stream, whose annual peak flow does not vary greatly from one year to the next and does not include any extremes during a 42-yr period of record.

SITE FACTORS--Lat 46°44', long 122°58', at I-5, near western limits of Centralia, Wash., on Centralia 15' map. Skookumchuck River is perennial, with a drainage area of about 450 km^2 and an average discharge, at a gage 19 km upstream, of 7.2 m^3/s. Channel width is 15 m, and channel slope is roughly 6.5 m/km. Wide-bend point-bar stream, locally anabranched, alluvial, sinuosity of 1.5, valley relief of 60 m. Tree cover along the bankline was in the range of 50-90 percent in 1960, and had increased within this range by 1979. Bed material is in the size range of gravel to small boulders, and bank material is non-coherent gravel overlain by silt and clay.

ALTERATION AND POST-ALTERATION FACTORS--(See "Synopsis")

DISCUSSION--Relocation by diversion through a borrow pit is an uncommon procedure, which created an artificial lake and a rather indefinite stream channel. Backwater flooding was precluded by the large bridge opening, which had a bottom width about 2.5 times greater than the natural channel. Despite the sharp reduction in channel length, with consequent increase in slope, major degradation was prevented by a massive riprap check dam. Flexible check dams of this sort are probably preferable to rigid structures, in that they are less likely to induce scour and bank erosion at the overfall. As built, this dam in cross section had a surface width of 8 m, which tapered to a width of 1.8 m at a depth of 3 meters below the streambed. Nevertheless, some degradation (estimated at 1 m or less) occurred, which evidently induced bank erosion at upstream bends.

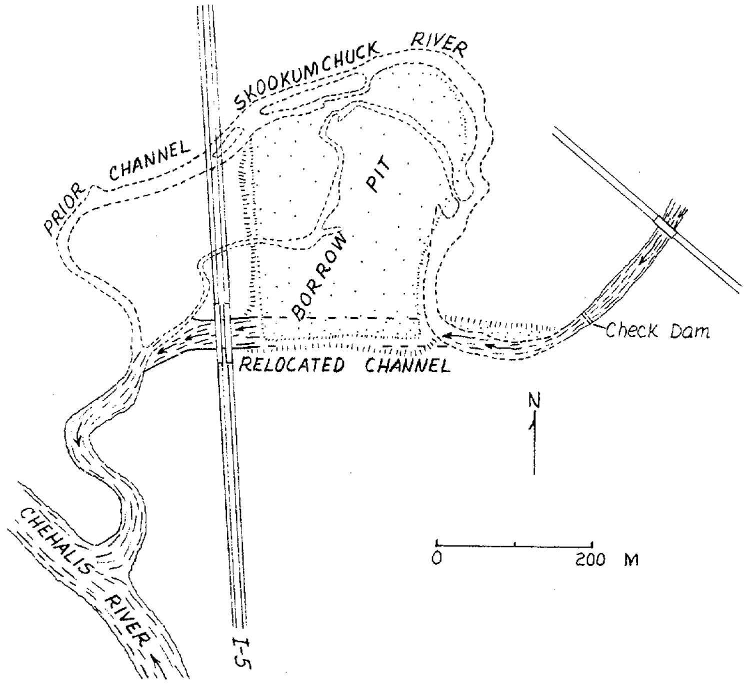


Figure 203. Plan sketch of channel relocation, Skookumchuck River.

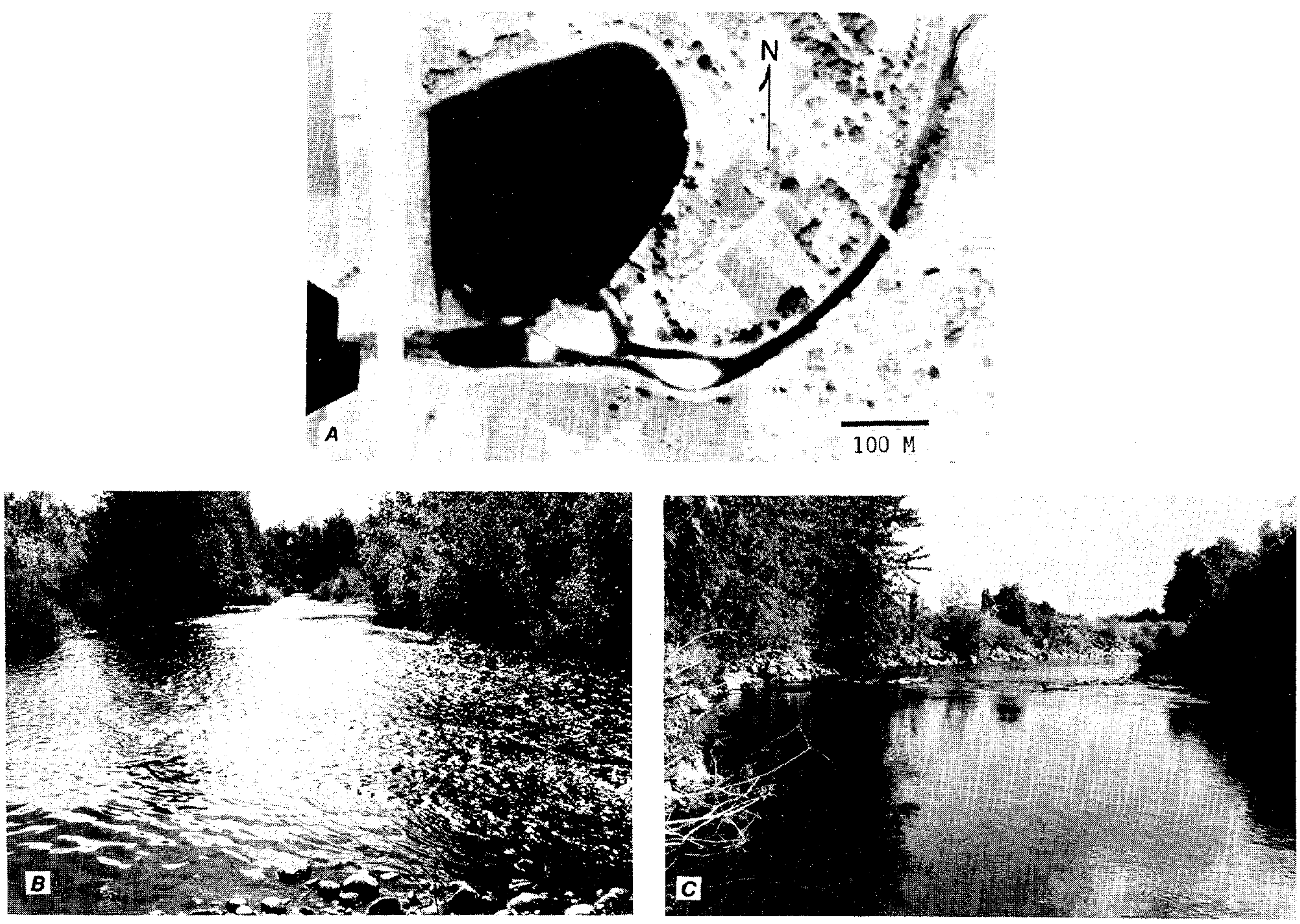


Figure 204. Skookumchuck River at site 101. A, Airphoto of relocation in 1960. Dark area is water-filled borrow pit. (From U.S. Dept. of Agriculture) B, View downstream in 1979 along relocated channel, which follows south end of borrow pit. C, Natural channel just upstream from relocation. Check dam forms riffle in background.

SITE 102. SALZER CREEK AT I-5 NEAR CENTRALIA, WASH.

SYNOPSIS--Channel was relocated by shortening a bend, thereby reducing its length from 110 m to 60 m, for purpose of improving alinement of channel at bridge and to accommodate roadway location (fig. 205). Performance period, 23 yr (1952-79). Salzer Creek is ungaged, but a high peak flow was recorded in 1972 at a nearby gage on the Newaukum River. No data were obtained on the as-built cross section of the relocated channel, but the bottom width as observed in 1979 was about 5 m, which is the width of the natural channel. The banks were stable and grassed (fig. 206) and it is unlikely that any significant widening has occurred. No bank protection measures were observed.

Stability class A1 for relocated channel. Critical factors in channel stability are the small size of the stream, its low slope, coherence of the bank materials, and the establishment of grass on the banks.

SITE FACTORS--Lat 46°41.5', long 122°58', at I-5, 2 km south of Centralia, Wash., on Centralia 15' map. Salzer Creek is perennial, with a drainage area of about 45 km^2, a bottom width of 5 m, and a channel slope of 1 m/km. Equiwidth point-bar stream, incised, alluvial, sinuosity of 1.3, valley relief of 100 m. Bed and bank materials are silt-clay at site.

ALTERATION FACTORS, POST-ALTERATION FACTORS, DISCUSSION--(See "Synopsis")

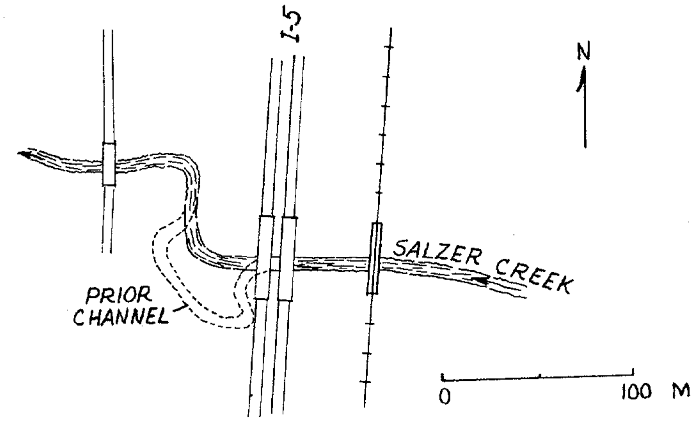


Figure 205. Plan sketch of Salzer Creek channel relocation.

Figure 206. Upstream view of bend in relocated channel, Salzer Creek.

SITE 103. NORTH LARAMIE RIVER AT I-25 NEAR WHEATLAND, WYO.

SYNOPSIS--A channel segment about 1,900 m in length was relocated and shortened by a factor of 0.7, for purpose of improving channel alinement at bridge and apparently to facilitate relocation of irrigation ditches (fig. 207). Performance period, 15 yr (1964-79), during which one 10-yr flood occurred. The relocated channel has a bottom width of 15 m and is bordered by dikes (fig. 208-A). Riprap was placed along the banks at the upstream end, and at the curve downstream from the bridge. In 1979, no bank erosion was seen along the relocated channel (figs. 208A and B), and bank stability of adjacent reaches of the natural channel was similar to that observed on an air-photo taken in 1949.

Stability class A1 for relocated channel and adjacent segments of natural channel. Stability is attributed to a good growth of vegetation (dense grass along the relocated channel, cottonwood trees downstream from bridge), and to suitable measures at both transitions to the natural channel: riprap at the upstream end, and a floodway at the downstream end.

SITE FACTORS--Lat 42°09', long 105°00', on I-25, about 8 km north of Wheatland, Wyo., on Dwyer 7.5' map. North Laramie River is perennial, drainage area about 1,025 km^2 at site, bankfull discharge estimated at 15 m^3/s for design purposes, 50-yr flood estimated at 274 m^3/s. Channel bottom width, 8 m; bank height, 2-3 m to flood plain, but higher where channel is bordered by terraces; valley slope, 2.8 m/km; channel slope, about 2 m/km. Equiwidth point-bar stream, alluvial, incised into alluvium; abandoned channels on flood plain are common. Maximum sinuosity in vicinity of site 2.1; sinuosity at site about 1.3. Valley relief, about 30 m; flood plain wide, about 300 m. Banks grassed, tree cover less than 50 percent. Bed material is sand and gravel (largest size about 10 cm diameter). Natural channel had low rate of lateral migration, as indicated by comparison of 1949 and 1966 air-photos. Works of man that may affect channel stability are irrigation diversion dams and irrigation ditches along stream.

ALTERATION FACTORS--Relocated channel segment was shortened from an original length of 1,900 m to a length of 1,400 m. Bottom width of the relocated channel was 15 m, and slope was about 3 m/km. At upstream end of the relocated channel, there is an irrigation diversion dam, and a rather sharp bend in the natural channel upstream from this dam is controlled by a riprapped dike. The downstream end of the relocated low-water channel meets the natural channel at an abrupt angle, but the floodway of the relocated channel has a smooth transition. The low-water channel was designed to convey a flow of 15 m^3/s at a velocity of about 1.2 m/s; the floodway, to convey a flow of 274 m^3/s at a velocity of 2 m/s. Dumped rock riprap was placed along the banks of the relocated channel at the upstream end, and at the outside of the curve downstream from the bridge. The floodway and dikes of the relocated channel were seeded with Brome grass and alfalfa.

POST-ALTERATION FACTORS AND DISCUSSION--(See "Synopsis")

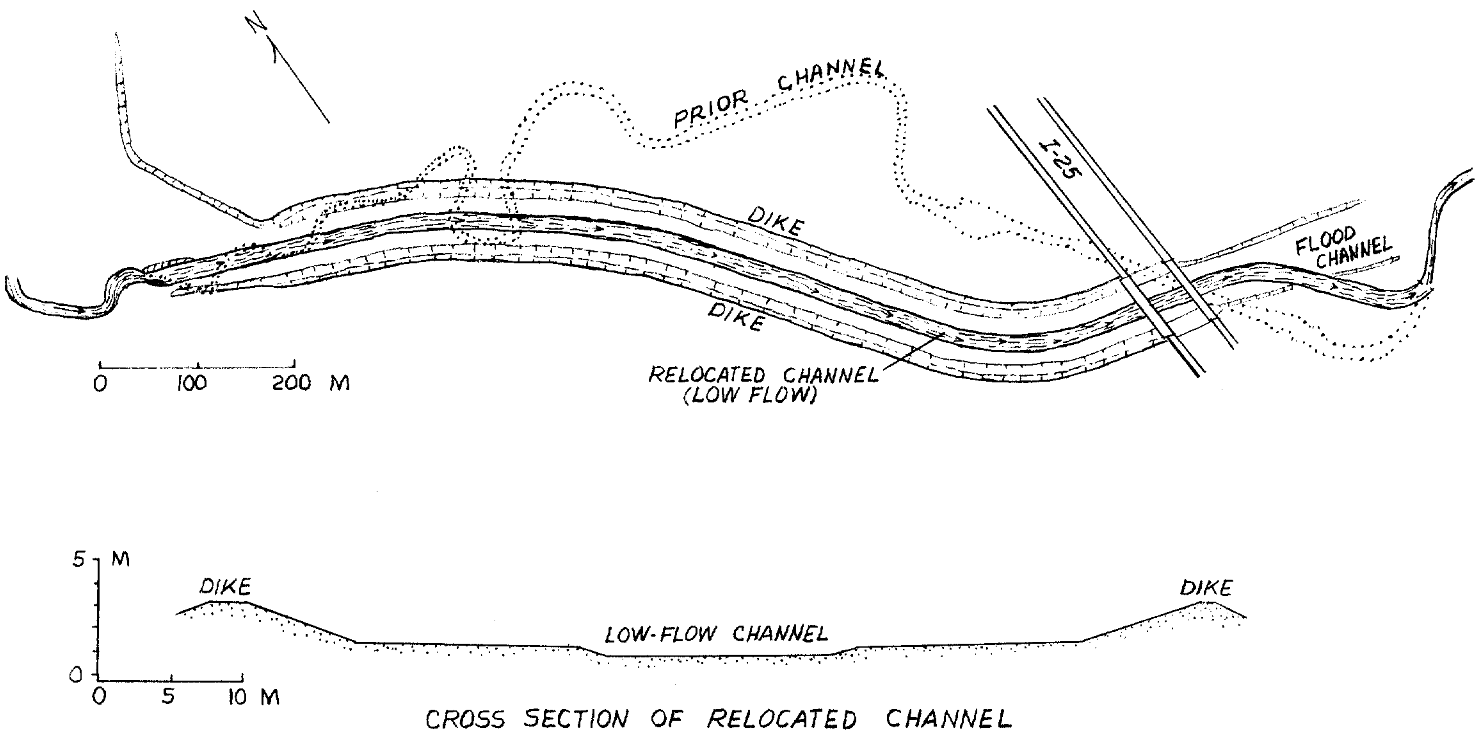


Figure 207. Plan sketch of channel relocation, North Laramie River.

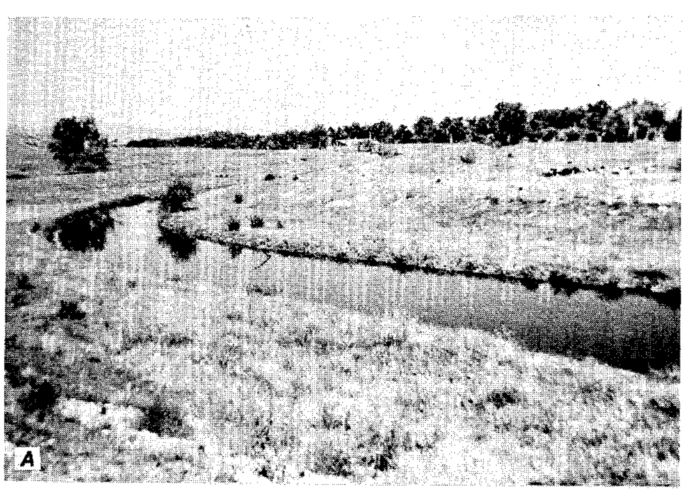


Figure 208. North Laramie River at site 103. A, Relocated channel, as viewed upstream from I-25 bridge, in 1979. B, Relocated channel as viewed from upstream end, in 1979.

SITE 104. CLEAR CREEK AT
I-25 AT BUFFALO, WYO.

SYNOPSIS--Channel relocation, reach 663 m in length shortened to 417 m, to avoid two stream crossings and to improve alinement of channel with culvert (fig. 209). Performance period, 18 yr (1962-79). At the gaging station on Clear Creek 6.5 km west of Buffalo, a flood having a recurrence interval greater than 100 yr was recorded in 1963, and a 25-yr flood was recorded in 1968. Minor bank erosion has occurred at upstream bend in relocated channel (fig. 210A), but no significant change in channel dimensions. No effect of relocation on adjacent segments of the natural channel could be discerned (fig. 210B).

Stability class B1 for relocated channel, class B for natural channel. In view of the rather small radius (about 45 m) of bends in the relocated channel, and the erodibility of the bank materials, a critical factor in the stability of the relocated channel is the rock-and-wire mattress along its banks. In addition, the relocated channel for most of its length has a lower slope than does the natural channel, the elevation difference due to channel shortening being taken up by a sloping concrete apron at the culvert entrance.

SITE FACTORS--Lat 44°21', long 106°41', at I-25 about 0.5 km east of Buffalo, on Buffalo 7.5' map. Clear Creek is perennial, drainage area of 337 km^2 at site, 50-yr flood estimated by U.S. Geological Survey at 80 m^3/s. Channel bottom width, 10-12 m; bank height, 1-2 m to flood plain; channel slope at site, about 8 m/km. Equiwidth point-bar stream, alluvial, sinuosity about 1.5. Valley relief about 50 m, flood plain narrow, bordered by terraces. Narrow strip of trees along channel, tree cover less than 50 percent. Bed material is in the size range of gravel to small boulders.

ALTERATION FACTORS--The increase in channel slope that would have resulted from shortening of the relocated channel segment was eliminated by a 3.5 m drop at the culvert entrance, such that the relocated channel had a slope of 7 m/km as compared with 8 m/km for the natural channel. As-built bottom width of the relocated channel was 24 m, as compared with a bottom width of 10-12 m for the natural channel. In order to conform in alinement with the natural channel, the relocated channel was constructed with two curves of rather small radius at either end. The 2:1 side slopes of the relocated channel were protected with rock-and-wire mattress.

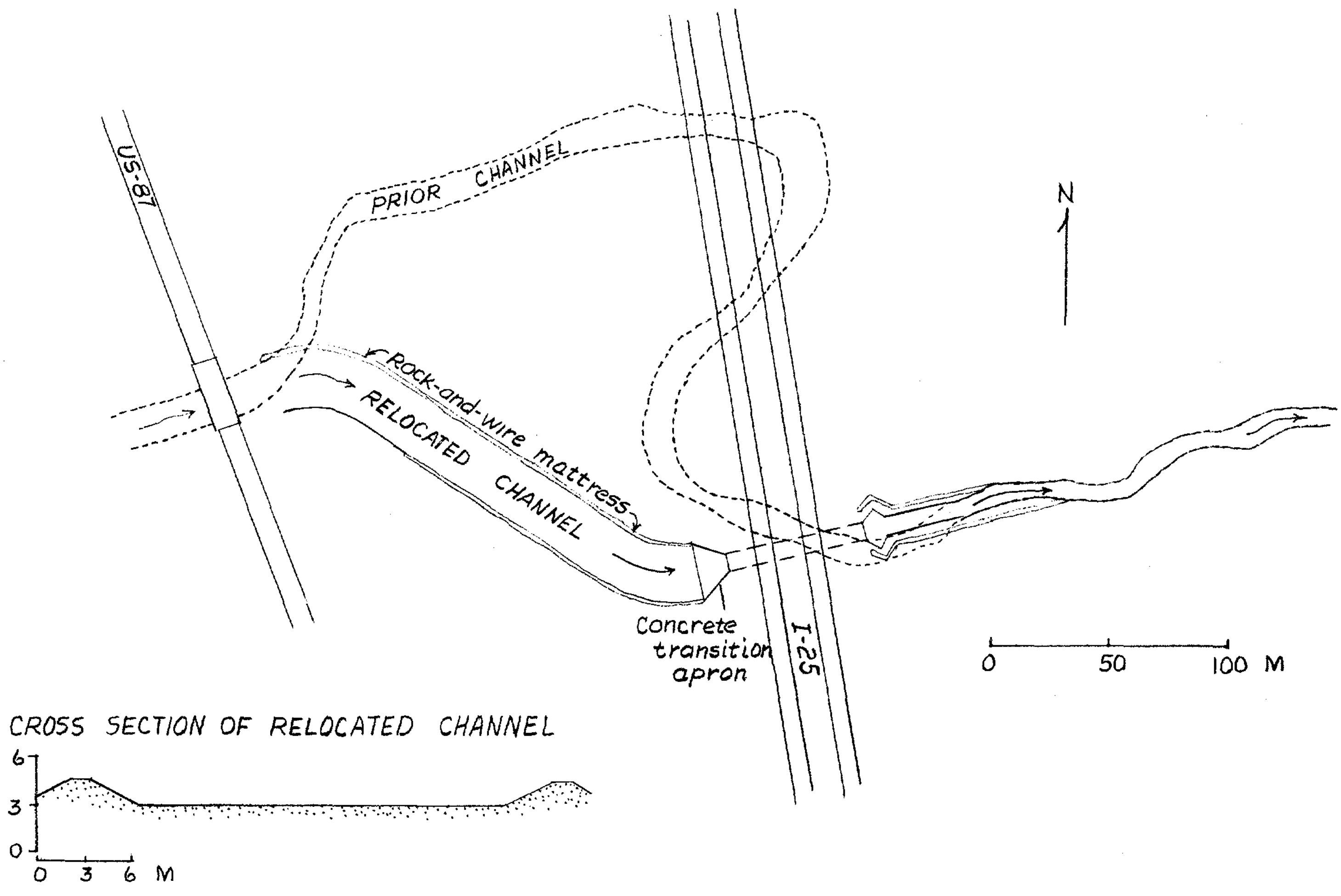


Figure 209. Plan sketch of Clear Creek channel relocation.

POST-ALTERATION FACTORS--A flood having an estimated recurrence interval of 100 yr occurred shortly after construction. At the culvert transition, bank material was washed out behind the rock-and-wire mattress. To remedy this problem, the mattress was pressure grouted and the wingwalls were extended into the dikes along the sides of the relocated channel. A line of trees, which appear to have been planted, extends along the relocated channel except at the outside of the upstream curve. Here, bank erosion has progressed about a meter beyond the mattress. In addition, a well-defined point bar has developed at the inside of the bend.

DISCUSSION--The relocated channel has performed well, but bank erosion and meander development may progress at its upstream curve unless the rock-and-wire mattress is maintained.

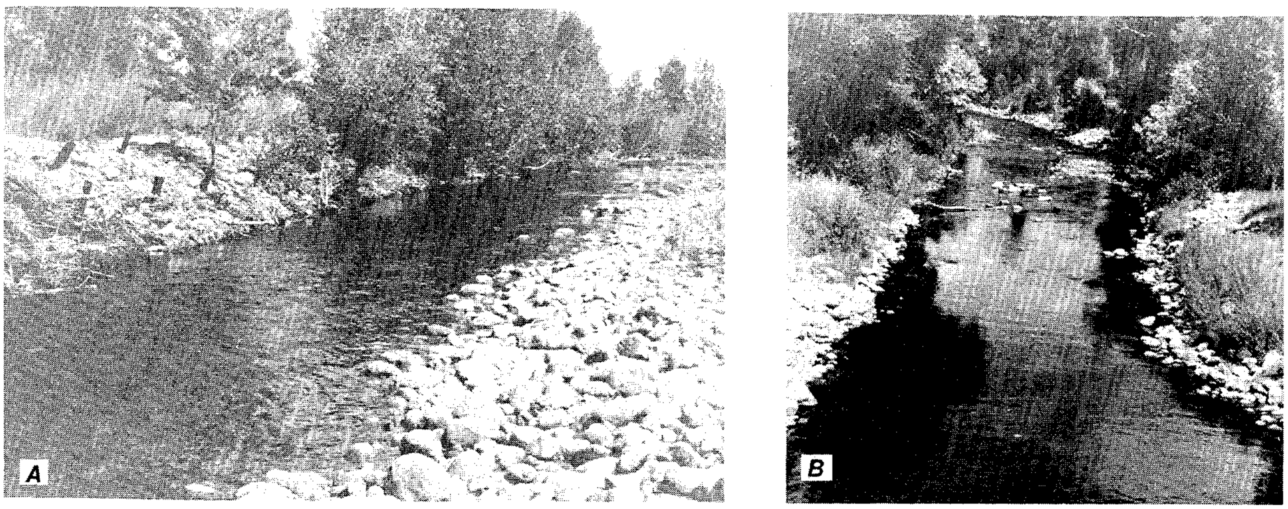


Figure 210. Clear Creek at site 104. A, View of relocated channel downstream from US-87 bridge, in 1979. B, View of channel downstream from culvert beneath I-5.

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

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This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.