# Chapter 3
# Stability Problems with Flood Control Channels

*Section I*
*Types of Channel Modification for Flood Control*

## 3-1. General

*a*. There are many methods of channel modification that may be used to increase channel capacity and thereby provide flood control benefits. The local environment and the desired degree of capacity increase affect the choice of method. Generally, urban areas require more intense investigation than rural areas due to congested developments. Stability and environmental sensitivity must be considered when evaluating alternatives.

*b*. Because of stability and ecological problems that have arisen in many projects, modification of natural channels to provide increased flood capacity has come under increasing attack as an automatic response to flooding problems. Before radical channel modification, consideration should be given to the potential benefits of offstream storage for avoiding or reducing ecological and stability problems. In many basins, natural storage on floodplains has been reduced by agricultural or urban developments and by flood control projects, leading to an increase in flood peaks and severity of flooding and to loss of ecological habitat. Creation of offstream storage basins can reverse this trend, and appears to be a favored policy in parts of Europe (Mosonyi 1983; Schiller 1983; Schultz 1987).

*c*. General methods of channel modification available for consideration include clearing and snagging, cleanout, channel enlargement, channel realignment, levees, floodways, and flow diversions. These are discussed separately in subsequent paragraphs.

## 3-2. Clearing and Snagging

*a*. This method is normally used when the channel is restricted by extensive vegetative growth, accumulation of drift and debris, or blockage by leaning or uprooted trees; and when only a modest increase in hydraulic capacity is required and can be obtained through reduction in channel roughness. The procedure involves removal of log jams, large trees spanning the channel, sediment blockages, underbrush, and miscellaneous debris (Figure 3-1). It is generally advisable to avoid disturbing large stable trees on the banks (larger than 12 in. diam at breast height), as well as all species of special environmental value. Clearing and snagging reduces hydraulic roughness, in some cases increases cross-sectional area, and reduces potential for further blockages and hang-ups of drift. Regular maintenance must be carried out to ensure continued satisfactory operation.

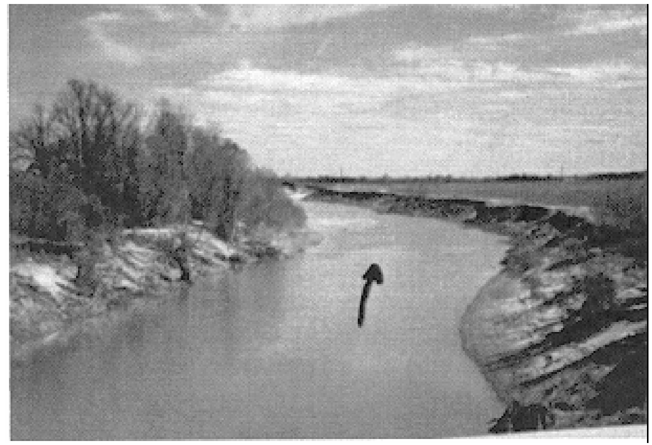

**Figure 3-1. Clearing and snagging**

*b*. Potential stability and sedimentation responses to clearing and snagging are associated mainly with increased velocities and with removal of vegetation that may have acted locally as erosion protection. Effects on stability may be adverse in some places and beneficial in others. Local experience is generally the best guide.

*c*. Retention of tree canopy is usually beneficial to fish and wildlife. Increased light due to reduction in canopy can encourage growth of silt-retaining reeds and willows, which can rapidly neutralize the hydraulic benefits of clearing and snagging.

*d*. Clearing and snagging is also discussed in paragraph 6-8*b*(2). For further details see Nunnally and Shields (1985) and EM 1110-2-1205.

## 3-3. Cleanout

Channel cleanout normally involves removal of a specified thickness of material (usually 1 to 3 ft) around the wetted perimeter of a channel. This method is used when a relatively small increase in capacity is required but cannot be obtained by clearing and snagging. Channel cleanout is also discussed in paragraph 6-8*b*(3). Potential stability and sedimentation responses to cleanout are similar to those for channel enlargement, as discussed in paragraph 3-4.

## 3-4. Enlargement

*a*. Channel enlargement is normally used when hydraulic capacity must be significantly increased (Figure 3-2). Examples include a channel through a formerly rural area that has undergone suburban or urban development, or the upgrading of an urban channel to carry a 100-year flood or of a rural channel designed to minimize flood damages on crops and residences. Modes of enlargement include increased bottom width, flattening of side slopes by excavation, channel deepening, side berm cuts, or a combination of two or more of those.

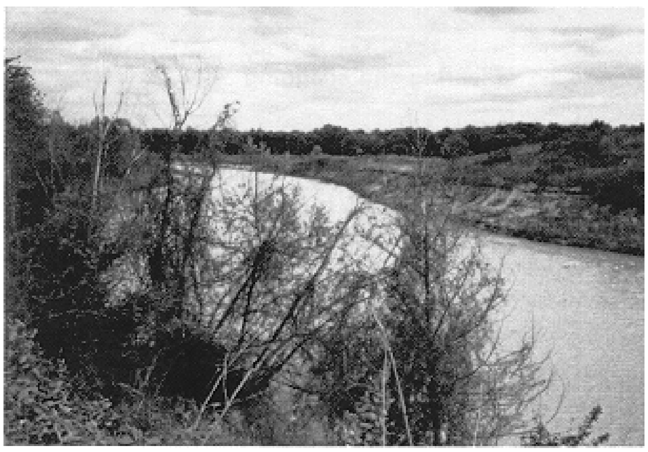

**Figure 3-2. Channel enlargement**

*b*. The extent of enlargement is determined by the desired reduction in flood levels consistent with permissible disturbance of rights of way considering the relationship with the environment and the requirements for maintenance.

*c*. Channel enlargement poses two major potential problems with respect to stability and sediment deposition. Firstly, if depths are increased but the original slope is retained, the bed and banks may erode, especially if bank stability previously depended on cohesive sediment deposits, armoring, or vegetation that was removed in the enlargement process. It may be necessary to provide artificial drop structures to check the velocities. Secondly, if the channel carries substantial sediment loads and if the cross section provided to meet flood control needs is too large (see paragraphs 2-4 through 2-8), the section may partly infill with sediment deposits and the calculated flood capacity may not be achieved without maintenance.

*d*. A method of enlargement that can reduce instability problems is the use of side berm cuts to form a two-stage channel (Figure 3-3). This type of cross section consumes more land than simple enlargement but is more effective for conveying bed material, because higher velocities are maintained at moderate discharges. The preferred arrangement is with the cut on the inside bank as illustrated. In incised channels, the level of the berms should, if possible, correspond to the channel-forming discharge under modified conditions (see paragraph 2-8). (Nunnally and Shields (1985) refer to this form of cross section as a "highflow channel" and suggest that the berm should correspond to mean annual flood.)

## 3-5. Realignment

*a*. Realignment of meandering streams was widely used in the past as a flood control measure to increase hydraulic capacity and to reduce loss of land by meander migration. The realignment sometimes took the form of complete replacement of a meandering length by a straight channel, or alternatively, the elimination of selected meander bends by "cutoffs" (Figure 3-4). The increased capacity results partly from increased slope and partly from reduced eddy losses and roughness.

*b*. The response of a stream to realignment can vary greatly depending on the stream characteristics and the environment. In some environments, streams with stable contorted meanders, flat slopes, and erosion-resistant boundaries can be considerably realigned without serious consequences (Figure 3-5), especially if there are flood-regulating reservoirs. In other environments, straightening of meandering streams to enhance flood capacity has led to serious problems of channel degradation, bank erosion, and tributary incision (Figure 3-6). In such cases realignment may be viable only if accompanied by grade control structures to check velocities and bank protection to control development of new meanders.

## 3-6. Levees

*a*. Levees or embankments are often provided to protect floodplain property, without modifications of the channel itself. A case for levees in place of more radical methods is stated by Ackers (1972) as follows: "the present width and gradient of the river, if it is indeed stable, are the regime values. Consequently, any attempt to make a significant alteration to the cross section may be thwarted by a redistribution of sediment. It is preferable therefore to retain the regime width and slope, up to the level of the dominant discharge, and to provide the increased flood capacity by berms, and flood banks [levees] perhaps, that only come into effect at discharges with a frequency less than the dominant condition."

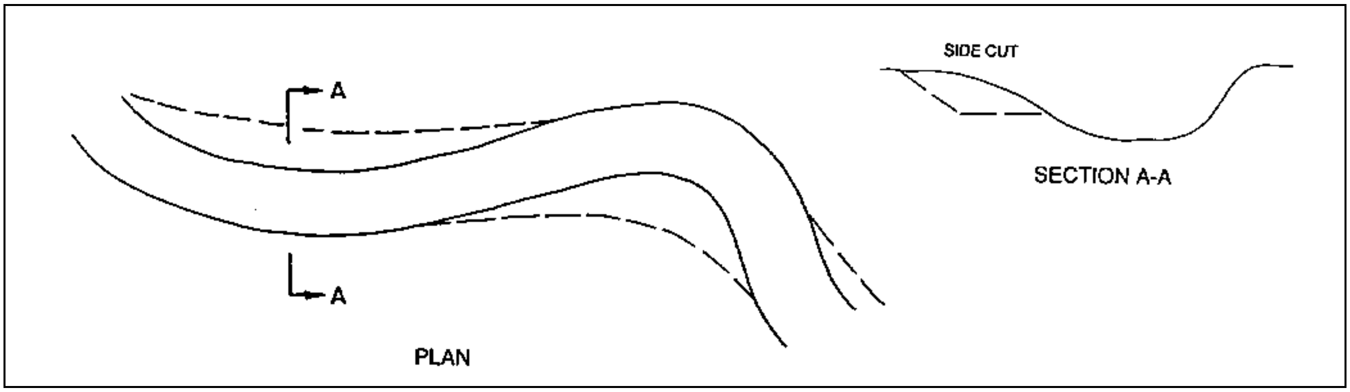


Figure 3-3. Channel enlargement by side berm cut

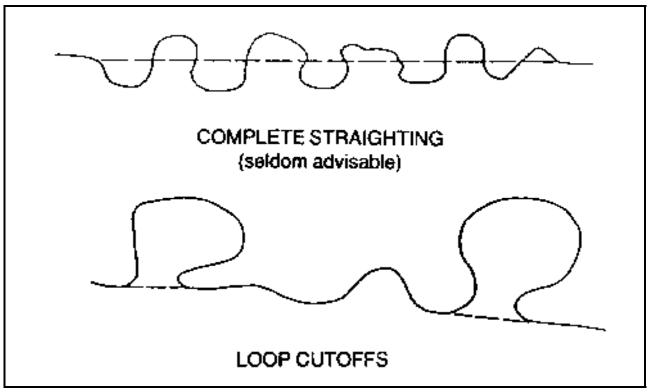


Figure 3-4. Forms of channel realignment

Figure 3-5. Realigned channel without serious instability problems

*b*. Levees are not, however, free from potential instability effects. Unless they are set far back from the channel banks, they may cause increased flood peaks in

Figure 3-6. Lateral instabillity in realigned channel

the channel proper because floodplain storage and conveyance are reduced (Figure 3-7a). This concentrates a higher proportion of flood flows within the channel, tending to initiate channel widening and lengthening of the meander bends. The discharge-increasing effect of levees may be more pronounced in flat deltaic regions where under natural conditions, overbank flows may escape completely from the channel under consideration to reach the terminal water body by other routes (Figure 3-7b). In such cases the levees not only eliminate floodplain conveyance and storage, but prevent the escape flows. Long levee projects in such situations may lead to complete reforming of meander patterns and to slope flattening by upstream degradation and downstream aggradation.

*c*. Levees may also cause sediment deposition in streams with high sediment loads by restricting transport and deposition of sand on overbank areas. More sand is then retained in the channel to deposit farther downstream

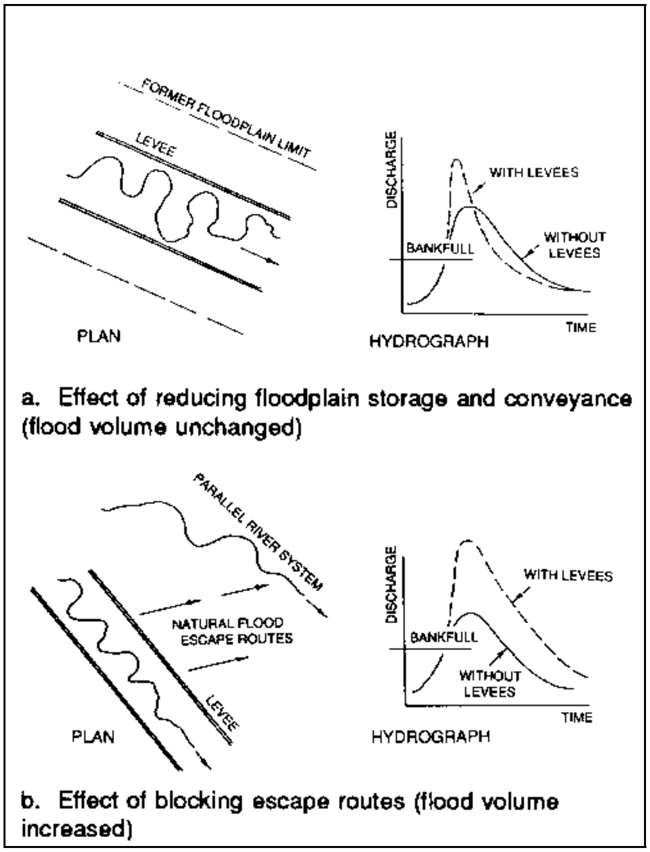


**Figure 3-7. Effects of levees on flood hydrographs**

in reaches of flatter slope. This may initiate a progressive upstream-advancing aggradation of the bed. Also, thick deposition of finer suspended sediment on the berm between the riverbank and the levee (occurring mainly during flood recessions) may overload the bank, causing slump failures.

*d*. In actively meandering channels, the danger exists that continued meander migration, perhaps aggravated by increased in-channel discharges, will encroach on levee setback distances and attack the levee itself at various points. If populations depend on the levees for security, this may pose a critical situation in large floods. As time passes, levee projects in this type of situation tend to require ever-increasing vigilance and maintenance. Eventually large portions of the stream may be effectively canalized by bank protection of one form or another (Figure 3-8).

## 3-7. Flood Bypass Channels

*a*. A flood bypass channel is usually completely separate from the existing channel whose capacity it is

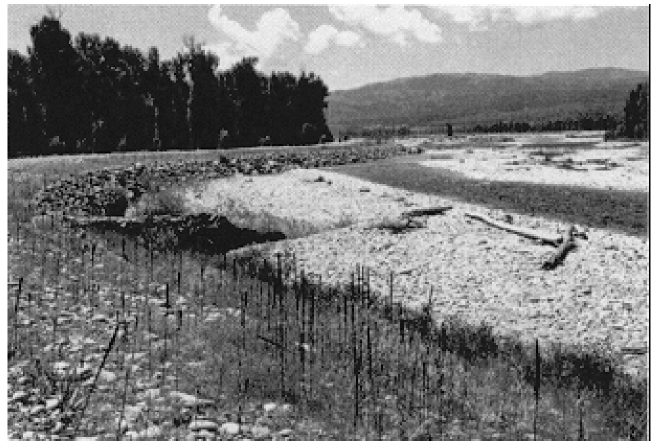

**Figure 3-8. Bank protection necessitated by encroachment on levee setback**

designed to supplement. In some cases the two channels may intersect at intervals as in the case of high-level bend cutoffs (Figure 3-9).

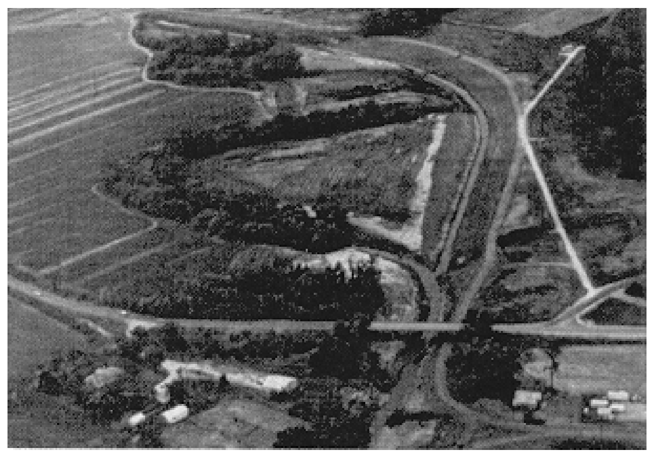

**Figure 3-9. Flood bypass channel formed by high-level bend cutoffs**

*b*. The most appropriate application of bypass channels is usually for streams with relatively low bed material loads. In other cases they may cause sediment problems if the division of sediment between the original channel and the bypass channel does not match the division of flow. Bypass channels should normally be provided with control structures at entrance and exit. A channel may be modified for flood control by diverting flow out of it to another system or into it from another system.

## 3-8. Flow Diversions

*a*. When flows are diverted out, erosional problems are normally reduced downstream of the diversion. Sediment deposition may occur in the main channel or in the diversion or in both as the combined sediment-carrying capacity of both is likely to be less than that of the existing channel. The division of sediment between the two channels is not necessarily proportional to the division of flow. Further deposition problems may arise if there are substantial downstream inflows of sediment that the reduced flows are unable to transport.

*b*. When flood flows are diverted in but the channel is not deliberately modified to accommodate the increased discharges, serious erosional problems may ensue. The channel tends to respond by widening and deepening, and by flattening slope through upstream degradation and downstream aggradation. A spectacular example is illustrated in paragraph 3-16.

*Section II*
*Case Examples of Stability Problems*

A number of cases of channel instability in flood control projects are summarized to illustrate the range of problems that can be encountered. All these cases have been investigated or analyzed to some degree; but a full diagnosis of the problems is not always possible, especially where the stream or channel in question has a history of previous interventions. Cases are drawn from several regions of the United States and involve various types of channels.

## 3-9. Twenty Mile Creek

*a*. Twenty Mile Creek is a tributary of the Tombigbee River in mixed woodland and farmland in northeast Mississippi. The creek flows through easily erodible sandy-silty alluvial deposits underlain by clay at variable depths, typical of streams in northern Mississippi. Most of the creek was apparently cleared and straightened to some extent by local agencies at various periods between 1910 and 1940, but it was probably not substantially enlarged at that period. A length of 12 miles upstream from the mouth was channelized by the U.S. Army Corps of Engineers between 1965 and 1967: the lower 9 miles was widened and deepened and the upper 3 miles was cleared and snagged. The combined effect was to increase the average cross-sectional area by about 200 percent, the slope by 50 percent, and velocities by 50 percent or more. The magnitude of flood peaks at given return periods increased greatly, partly because the enlarged channel captured flood runoff that had previously flowed overland, and partly because of increasing intensity of agricultural land use in the basin.

*b*. Instability response to the project was rapid and extensive. The main changes documented up to 1982 were as follows:

(1) The channel widened substantially over a large part of the project length, especially by increase of bed widths (Figure 3-10). As-constructed side slopes of 1V:3H steepened substantially by toe erosion.

(2) The longitudinal slope flattened substantially over the project length by bed aggradation at the lower end and degradation at the upper end (Figure 3-10). Bed material deposited at the lower end was derived from widening and meandering farther upstream. Dredging was required near the mouth to maintain channel capacity.

(3) The bed degraded by headcutting, the channel widened, and meanders developed over a length of stream extending at least 7 miles upstream of the head of the project (Figure 3-11).

(4) Headcutting was initiated in several tributaries as water levels in Twenty Mile Creek were reduced by the enlarged cross sections and bed degradation.

Remedial measures were applied to check the instability. Grade control structures were installed at several points on Twenty Mile Creek and on several tributaries. Riprapping and planting of vegetation was done for bank protection.

## 3-10. Puerco River

*a*. The Puerco River is an ephemeral stream in arid uplands in northwest New Mexico. The history of response to historical land use and climatic changes is somewhat obscure, but there is evidence of substantial regional changes in channel characteristics after the introduction of cattle around 1880. Some reaches of the channel are deeply entrenched (Figure 3-12); others are not. The plan and profile are constrained locally by rock ridges, but the channel has mostly a flat, smooth bed of fine to medium sand. The natural banks are mostly of stratified fine sand and silt with occasional layers of cemented sand and gravel. Floods are extremely flashy, lasting 24 hr or less, but carry very high concentrations of sand and silt. The bed is active only during a few flood events each year.

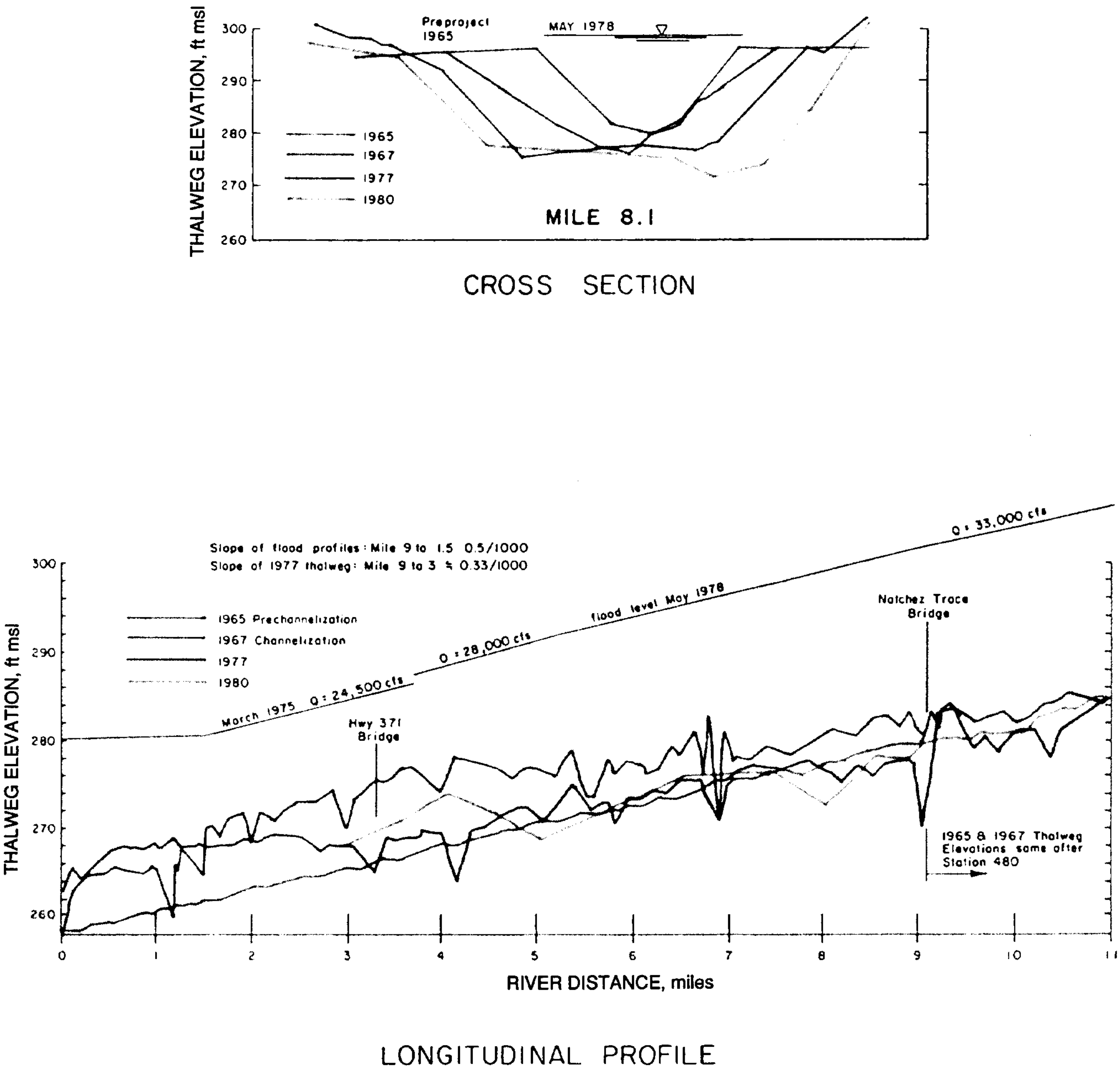


**Figure 3-10. Cross-section and profile responses to channel enlargement, Twenty Mile Creek**

*b*. Various works have been constructed to control the channel through the town and reduce flooding of urban land. Two lengths each about 2 miles long were channelized in the 1970's in connection with an interstate highway project. The main features and responses were as follows:

**Figure 3-11. Induced instability upstream of channel enlargement, Twenty Mile Creek**

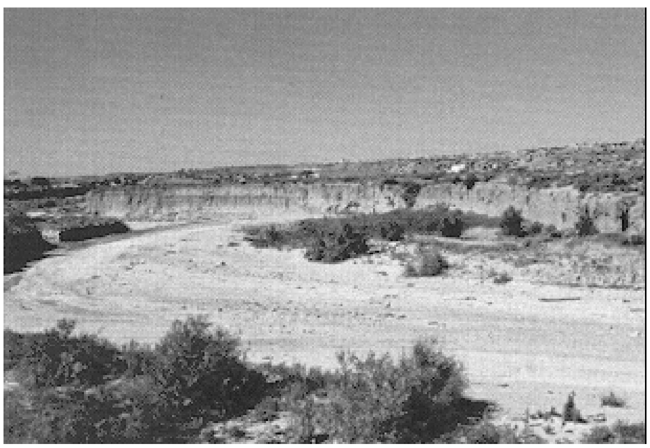

**Figure 3-12. Entrenched reach of Puerco River**

(1) Upper channelization. The channel was straightened and shortened rather severely. Channelized cross sections appear on average considerably wider than natural sections. Limited bank protection using jacks was installed, and the excess slope was partly compensated by installing grade control structures. The main response seems to be a trend to resumption of a meandering pattern.

(2) Lower channelization. The river was fixed in a sinuous planform using concrete side slopes. The width provided was about 50 percent greater than the natural width. The main response seems to have been deposition of sand and a consequent rise of 3 to 5 ft in bed levels. Clearance under bridges was seriously reduced (see Figure 5-12).

*c*. Analysis of the instability problems of the Puerco River is hampered by incomplete information and by the special characteristics of ephemeral arid-land channels with high sediment inflows. In the lower channelization, the enlarged channel appears unable to transport all the inflowing sand, presumably because of lowered velocities. The observed aggradation might, however, be caused in part by a deficiency of larger floods. This cannot be checked because of lack of reliable streamflow data.

## 3-11. Grapevine Spillway Channel

*a*. Grapevine Lake is a flood control, water supply, and conservation reservoir on Denton Creek northwest of Dallas, Texas, completed in 1952. The spillway, designed for a Probable Maximum Flood flow of nearly 200,000 cubic feet per second (cfs), discharges into what was originally a small creek. A moderate spillway discharge episode in 1981, the first major overtopping since construction, lasted about 3 weeks with a peak flow of about 10,000 cfs. This episode produced dramatic enlargement and downcutting of the creek channel over a 3,000-ft length (Figure 3-13). The erosion is partly into silty-sandy overburden but extends well down into a horizontally bedded shale or sandstone that is apparently highly susceptible to disintegration by weathering and to hydraulic erosion.

**Figure 3-13. Grapevine Spillway Channel after erosional episode**

*b*. The main point demonstrated by this case is the potential for extremely rapid enlargement and downcutting, even in partly consolidated materials, when a channel is subjected to flows grossly in excess of the channel-forming discharge. The damaging flows exceeded the channel-forming discharge of the creek by one to two orders of magnitude.

*c*. Rehabilitation involved construction of a $10 million concrete chute and stilling basin to carry flows from the end of the existing spillway slab down to the new base level of the creek.

## 3-12. Snake River

*a*. The Snake River near Jackson Hole in western Wyoming is a braided gravel river in a wide floodplain (Figure 3-14). Bed material transport is moderately high. Upstream of the town of Jackson, the active braided system is bounded by flood control levees built in the 1960's. Downstream of Jackson, there is an intermittent system of short levees and other flood protection works. The total length of river wholly or partly protected is about 25 miles. The main instability problem (as of 1987) was the heavy cost of emergency maintenance of the existing system during and after flood events: the river continuously shifted the location and orientation of its main channel and attacked the levees at new points. Damage to existing riprap protection is usually caused by the main flow impinging more or less at right angles against the banks and undermining the toe as it turns abruptly and produces a deep scour hole. Heavy driftwood and tree trunks add to the force of the attack. Original riprap protection seemed to be deficient in size and thickness and especially in toe protection.

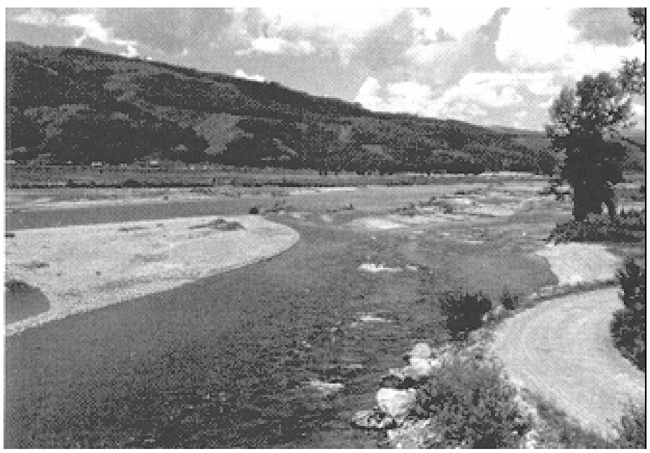

**Figure 3-14. Snake River near Jackson Hole**

*b*. The main form of instability exhibited by the Snake River is an irregular and more or less unpredictable shifting of the main channel during floods. This type of shifting is characteristic of active braided rivers.

## 3-13. Little Tallahatchie River

*a*. The Little Tallahatchie River is a meandering sand-bed tributary to the Yazoo River basin in north-central Mississippi, discharging to a leveed floodway in the Mississippi/Yazoo floodplain (Biedenharn 1984).

*b*. About 85 percent of its drainage area is controlled by Sardis Dam, constructed in 1939 for flood control and located about 22 miles above the present mouth. A certain amount of channel improvement was done downstream of the dam in the form of clearing and snagging and cutoff of a few meander bends. As a result of the dam, downstream flood discharges were greatly reduced: whereas predam floods had frequently exceeded 20,000 cfs, postdam floods were generally limited to 6,500 cfs, more or less the bank-full capacity of the channel (see Figure 2-9 in Chapter 2).

*c*. The initial instability response of the river below the dam was slope flattening by downstream-progressing degradation, resulting from trapping of the bed material load in the reservoir. This is a typical response downstream of reservoirs that trap bed material (see Table 2-1). As a result of the combined effects of smaller flood discharges and bed degradation, the water levels at the mouths of tributary streams were substantially lowered, so that the tributaries were "rejuvenated" by augmentation of their hydraulic gradients. Bed degradation started progressing up the tributaries, followed by bank failures and meandering; and quantities of coarse sand and gravel bed material were delivered to the Little Tallahatchie Channel. The reduced flows in the Little Tallahatchie were unable to transport all of this material; therefore, as a secondary response to the project, the channel started to aggrade, except for a 3-mile reach immediately below the dam (Figure 3-15).

*d*. As a result of this complex response, dredging has been required on the Little Tallahatchie Channel to maintain flood capacity and flood control benefits, and erosion protection and grade controls have been required on several tributaries to reduce loss of land and delivery of coarse sediment. The case demonstrates how initial and final instability responses may operate in opposite directions, and how tributaries may degrade when main stem flood levels are lowered by flood control.

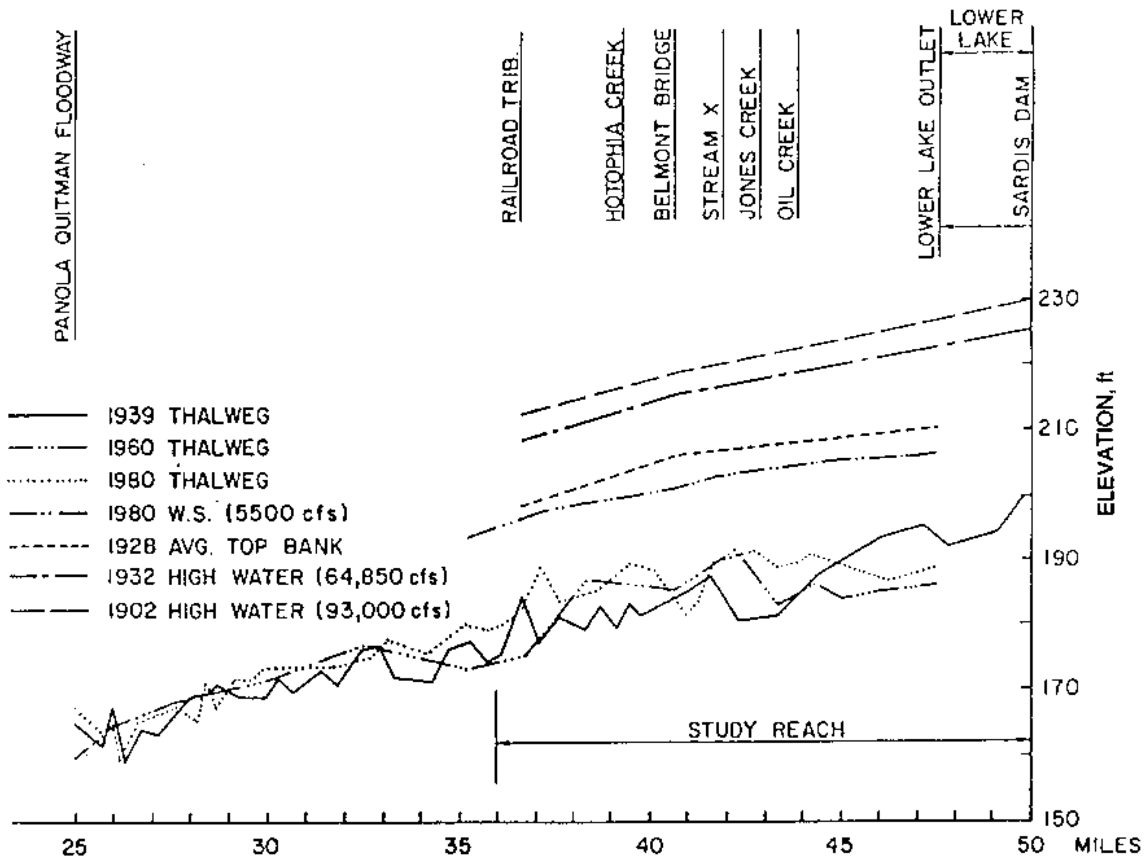


**Figure 3-15. Response of Little Tallahatchie River profile to upstream reservoir**

## 3-14. Red River

*a*. The Red River, one of the major streams in the southern United States, has its source in New Mexico and flows generally east along the Texas-Oklahoma border and through Arkansas to join the Atchafalaya River in east-central Louisiana. The Red River is a dynamic river, continually shifting its planform through bank caving and meandering (Figure 3-16). The sediment load is relatively high.

*b*. A historical phenomenon that affected the river system was the formation and subsequent removal in the mid-19th century of a huge series of log jams called the Great Red River Raft, which at its greatest extent covered a length of about 160 miles in Louisiana. The raft was removed in 1873, and further accumulations were cleared periodically. The river has been affected in more recent times by various works for flood control and navigation. Nearly 60 percent of its drainage area is controlled by Dennison Dam, located about 500 miles above the mouth and constructed in 1943. Base levels at the mouth have been lowered by channel improvements on the Atchafalaya and Lower Mississippi Rivers, and the river itself has been trained and shortened in various places for flood control and navigation.

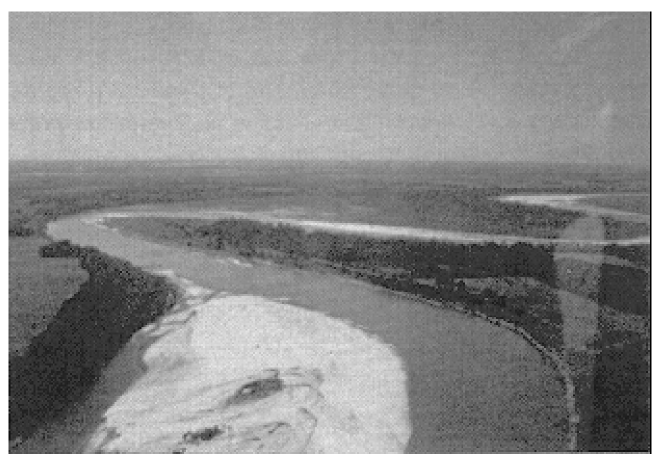

**Figure 3-16. Red River**

*c*. The combined response to all these developments includes a marked incision of the lower river, such that a 50-year flood is now contained within banks in many places, and widening of the channel by a factor of up to 2 or 3. The incision is illustrated by Figure 3-17, which shows "specific gauges" at Shreveport in western Louisiana over the period 1890-1986.

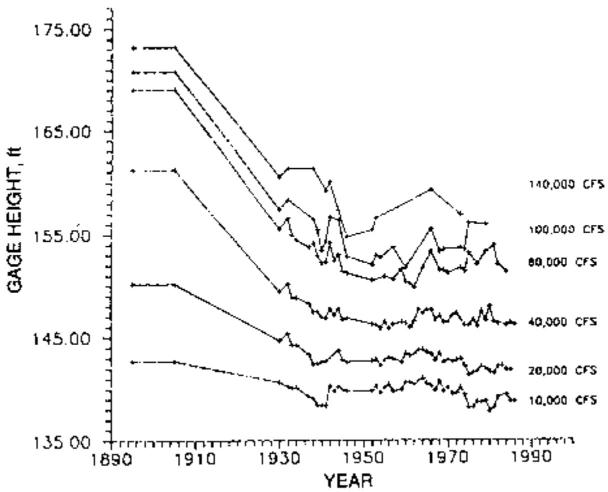


**Figure 3-17. Specific gauge plot for Red River at Shreveport, Louisiana, over period 1982-1986. Datum for gauge height is mean sea level**

*d*. The Red River case illustrates the difficulty of sorting out responses to a series of historical events and developments. For example, it is not immediately clear to what extent the incision illustrated in Figure 3-17 represents a response to removal of the log raft or to subsequent base level lowering. There is no evident response to construction of Dennison Dam in 1943.

## 3-15. Sacramento River

*a*. The Sacramento River flows south through over 200 miles in the Central Valley of California. It is a meandering sand-bed river in its lower part but has a significant content of gravel bed material in its middle and upper reaches. It is regulated by Shasta Dam in its upper reaches and affected by irrigation diversions and bypass floodways in the lower valley. Considerable lengths are bordered by flood protection levees that follow the margins of the meander belt. Historically, the river was greatly disturbed by hydraulic mining operations in the mid-19th century. This supplied large quantities of coarse sediment to the river and caused aggradation of up to 30 ft in certain reaches. This temporary slug of sediment has by now largely worked through the system.

*b*. Recent studies show no systematic trend of changes in the longitudinal profile. Rates of bank erosion apparently reduced by about 25 percent after construction of Shasta Dam in 1943, but remain troublesome for security of the levees and loss of valuable agricultural land. Various methods have been tried for bank protection in response to environmental concerns over use of riprap, but success with alternative systems has been limited (Figure 3-18).

*c*. The main instability problem affecting flood control works on the Sacramento River is bank erosion associated with systematic shifting of meanders. This is essentially a continuation of predevelopment trends, and there is no evidence of aggravation by recent developments. Bank attack could be reduced by further storage regulation to reduce flood peaks and bed material loads. In the absence of such measures, there is little alternative but to focus on bank protection.

## 3-16. Long Creek Basin

*a*. Long Creek near Oxford in northern Mississippi is a tributary of the Yocona River, which since 1953 has been regulated by Enid Dam located about 7 miles upstream of the mouth of Long Creek. Like many other basins in the Yazoo Basin uplands east of the Mississippi Valley, Long Creek basin was devastated by exploitative cotton agriculture in the mid-19th century. Many of the present stream channels have cut through "post-settlement alluvium:" this valleywide deposit is derived from severe hillslope and sheet erosion during the early cotton period. The post-settlement alluvium and the underlying older alluvial and lacustrine deposits are generally very susceptible to hydraulic erosion.

*b*. The recent history of basin changes, in-stream works, and instability responses is complex. Starting in the 1930's, considerable lengths of stream channel were straightened and rechannelized for flood control. Base levels were lowered by regulation of the Yocona River and also by flood control in the Mississippi Valley. Some reforestation and soil conservation have been done in the upper watershed, and some land has reverted from cultivation to woodland. Grade control structures and lengths of bank protection have been installed in parts of the watershed to arrest bed degradation (incision) and bank erosion.

**Figure 3-18. Flanking of experimental bank protection on Sacramento River**

*c*. The main instability responses to 20th century developments appear to be a general incision that has advanced to the middle and upper parts of the basin by upstream migration of nick zones (Figure 3-19), and re-formation of meanders in reaches that had been straightened for flood control. The incision process has been checked by installation of grade control structures, or in some cases by road culverts. The meander development has been checked by provision of various forms of bank protection. Experience with Long Creek and similar basins in Mississippi shows the potential for widespread channel incision when base levels are lowered in areas of highly erodible soils. Incision is followed by bank failures, channel widening, and transport of sediments to downstream locations of deposition.

## 3-17. Tanana River

*a*. The Tanana River is a tributary of the Yukon River, which rises in the Alaska Range in central Alaska and forms the south boundary to the city of Fairbanks. Upstream of Fairbanks, it is an active braided river with a gravel bed. Some distance downstream, it changes to a more or less meandering river with a sand bed. In the vicinity of Fairbanks it displays a transitional planform consisting of several channels with large semistable islands (Figure 2-15).

*b*. Flood control works were constructed in the 1970's to protect Fairbanks. The Chena River tributary, which passes through the city, was controlled with a dam and floodway so that flood flows are diverted to the Tanana upstream of the city. A setback levee was built along the right floodplain for a distance of approximately 20 miles, with occasional groins to resist specific threatened encroachments by the river. At the downstream end of the levee, it was found necessary to build the levee out into the river because no land was available between recently eroded riverbanks and valuable existing developments. This in-river length of the levee was provided with several long groins that project out into the river to deflect the main flow away from the levee (Figure 3-20). The in-river construction was a matter of local controversy and generated public concerns, but was eventually approved and implemented.

*c*. The main observed response of the river to the flood control project was from the in-river construction. During construction a pilot channel had been excavated to encourage the river into a new channel outward of the groins (Figure 3-20). Alluvial material from the pilot channel excavation, instead of being removed, was stockpiled alongside. In the following high-water season the river removed most of this material, plus additional

**Figure 3-19. Incised channel in Long Creek basin**

material eroded from the pilot channel area, and deposited much of it downstream in the form of new channel bars. Dredging was required initially to safeguard navigational access to the mouth of the Chena River, but the problem more or less resolved itself over subsequent seasons.

*d*. Prior to and contemporaneous with the flood control project, other developments interfered with natural evolution of the river to some extent. These were mostly connected with gravel extraction from midriver islands and associated access roads. One access road that closed off a minor channel probably triggered rapid shifting of a sharp main-channel bend. It was this shifting that more or less forced in-river construction of the downstream end of the levee.

*Section III*
*Causes and Forms of Instability*

## 3-18. General

*a*. The information provided in this section is intended to supplement more general information on channel response contained in Chapter 2, as well as case examples described in Section II. Extensive information on past problems is contained in a Congressional record on stream channelization (U.S. Congress 1971). A nationwide inventory of flood control channels (McCarley et al. 1990) indicated that bank instability and channel siltation were the most common stability problems. Table 3-1 summarizes common potential problems associated with various types of channel modification.

*b*. Although the following discussions focus on individual causes and forms of instability, these seldom occur singly. It may be very difficult to determine the exact causes of an observed complex pattern of instability, or to forecast exactly what forms can be expected from a specific project proposal.

## 3-19. Continuation of Pre-existing Processes, e.g., Meandering

*a*. In many cases an existing channel to be used for flood control will already display instability, which may be aggravated under postproject conditions. Probably the

**Figure 3-20. Tanana River at Fairbanks showing in-river levee and groins**

most common form of instability is meander migration, which if untreated may impact on project levees. Meandering is discussed at length in a conference proceedings (Elliott 1984). Following are some significant points:

(1) Although erosion tends to occur along outer concave banks and deposition along inner convex banks, this can reverse at certain locations under certain forms of meandering.

(2) Meanders can start in straight channels as a result of side bar deposition from bed material transport (Figure 3-21), but the question of whether bed material transport is necessary for initiation of meanders is unsettled. Meander development and migration involve sediment exchange between eroding and depositing locations (Figure 3-22).

**Table 3-1**
**Potential Stability Problems from Flood Control Modifications**

| Forms of Channel Modification | Potential Stability Problems: Within Reach Directly Affected | Upstream | Downstream |
|---|---|---|---|
| Clearing and snagging | Bank erosion and bed scour | Headcutting | Sedimentation |
| Cleanout or enlargement | Bank erosion; sedimentation | Headcutting | - |
| Realignment | Bank erosion and bed scour; meandering | Headcutting | Sedimentation |
| Levees | Meander encroachment on setback | - | Increased flood peaks |
| Floodways and bypasses | Sedimentation of original channel | - | - |
| Diversions out | - | - | Sedimentation |
| Diversions in | - | - | Bank erosion and bed scour |
| Base level lowering (parent stream) | - | Bed scour, widening, tributary degradation | - |
| Storage reservoir or sediment basin | - | Delta formation; aggradation | Bed degradation |

**Figure 3-21. Side bar deposition and sub-meandering in straight channel**

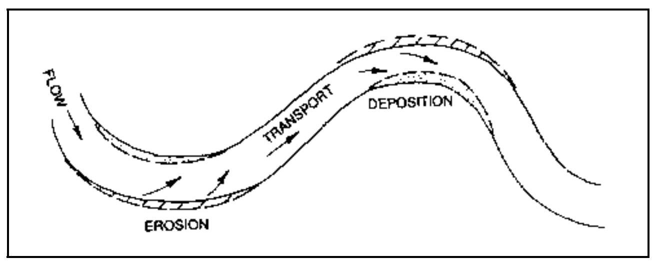


**Figure 3-22. Sediment transport associated with shifting of meander bends**

(3) Initial meander development is often self-reinforcing because the generated sediment transport tends to feed the process. It is easier to check at an incipient stage than later.

(4) Analytical prediction of whether a straight channel will start meandering is seldom practicable. It is better to rely on related local experience and to conduct post-project monitoring.

(5) Design of sinuous rather than straight channels is frequently advocated on environmental grounds (Keller and Brookes 1984, Rechard and Schaefer 1984; Nunnally and Shields 1985). It is sometimes claimed that

meandering channels can be more stable, but quantitative guidance is lacking.

*b*. The braiding form of instability (see also paragraph 2-3) occurs naturally in channels with relatively high slopes and bed material loads, but may be induced by a flood control project. In a case reported by Gregory (1984), a meandering channel widened and braided after the effective slope was increased by flood control measures.

## 3-20. Increased Discharges

*a*. Various basin developments and project features such as deforestation, urbanization, channelization, and diversions may increase inflow discharges of given frequencies. Increased discharges tend to cause cross-section enlargement, accelerated meander migration and eventual lengthening of meanders, and longitudinal profile changes. If profile changes include upstream incision, in-channel flood discharges may continue to increase after project completion.

*b*. In general, increased discharges tend to cause an eventual flattening of slope through upstream degradation (otherwise described as incision or headcutting) and downstream deposition. Such changes may be masked in the short term by the complexity of erosional and depositional responses and by other project changes such as straightening. Degradation and the longitudinal response of channelized streams are discussed in detail by Galay (1983), Schumm, Harvey, and Watson (1984), and Neill and Yaremko (1988). Incision tends to be most severe with fine bed materials; in coarser materials with a wider range of sizes, it is often limited by armoring. Longitudinal profile response can be studied using the one-dimensional computer program HEC-6 (U.S. Hydrologic Engineering Center 1993): see EM 1110-2-4000 for further guidance.

*c*. Cross sections and their response are discussed in paragraphs 2-3 and 2-6. In general, increased discharges tend to cause widening and deepening. Some additional points about cross-sectional stability are as follows:

(1) Severe cross-sectional changes may follow longitudinal incision as banks are undercut. The section may go through a complex cycle of changes (Schumm, Harvey, and Watson 1984; Thorne 1988).

(2) Provision of a very wide section does not necessarily ensure bank stability. An inner meandering channel may form and attack the banks.

(3) Narrow, deep channels, which may appear attractive for hydraulic conveyance, are maintainable in erodible materials only with very flat slopes and low velocities. In nature, they are found mainly in very fine grained or organic materials with very low bed material loads.

## 3-21. Realignment and Channel Improvement

*a*. Straightening in past projects was designed to increase hydraulic conveyance and sometimes to reduce loss of land by bend erosion. However, unless grade control structures are used, which tend to negate the hydraulic advantage, straightening may have severe effects on channel stability, resulting in greatly increased sediment loads with downstream siltation and deposition and loss of fishery habitat. Although bank erosion and meander migration may be relieved temporarily, many straightened channels tend to revert to a meandering state unless bank protection is provided.

*b*. Modifications such as clearing and snagging and cleanout (usually employed in relatively small channels) often entail some removal of vegetation and reduction of roughness. This tends to increase velocities while reducing erosional resistance, and may increase bank erosion and sediment transport unless the operations are carefully planned, conducted, and monitored.

## 3-22. Flow Regulation by Reservoirs

*a*. Upstream effects of a reservoir include delta formation, gradual raising of stream levels in the backwater zone, and more pronounced meandering.

*b*. Downstream effects result from altered outflows and retention of sediment. The purpose and mode of operation, and the degree of control over runoff at the reach of interest determine the magnitude of the flow effects. Reservoirs usually reduce downstream flood flows and increase low flows (Figure 3-23). Such changes tend to improve stability in the main stream, but tributaries may be destabilized because of lower water levels at their mouths - as in the case described in paragraph 3-13.

*c*. Storage reservoirs generally capture all the incoming bed load and a high proportion of the suspended load (Figure 3-24). The downstream channel profile tends to degrade in the form of a wedge starting at the dam (Figure 3-25). Theoretically this process continues indefinitely, but in practice a near-equilibrium condition is

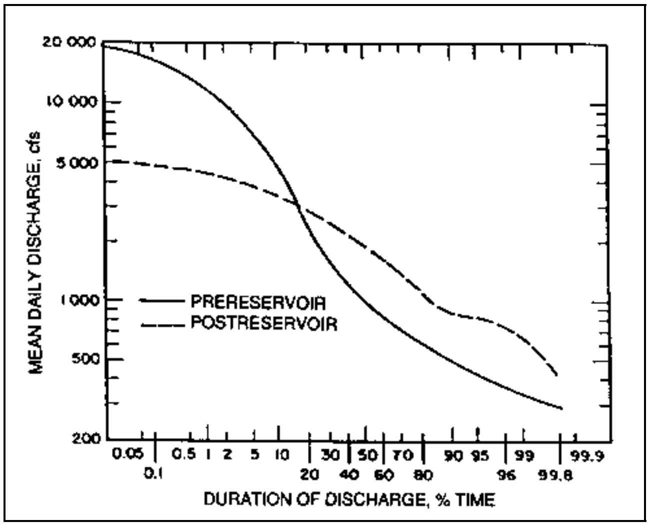


**Figure 3-23. Effect of storage reservoir on downstream flow-duration curve**

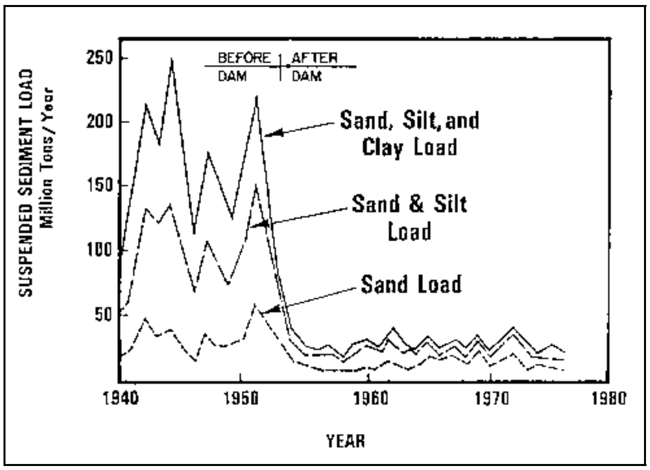


**Figure 3-24. Effect of storage reservoir on downstream sediment transport (Missouri River average annual suspended sediment load at Omaha, Nebraska)**

eventually attained after a time and distance that differ widely from case to case. In the North Canadian River below Canton Dam, Oklahoma, the distance was more than 100 miles and possibly up to 300 miles (Williams and Wolman 1984). As in the case of upstream incision, downstream degradation tends to be deepest in fine material and to be limited by armoring in coarser materials.

*d*. Reduced flood peaks and reduced bed material load may have partly compensating effects on the downstream channel. If the flood peak reduction is great enough, degradation may be insignificant. The profile

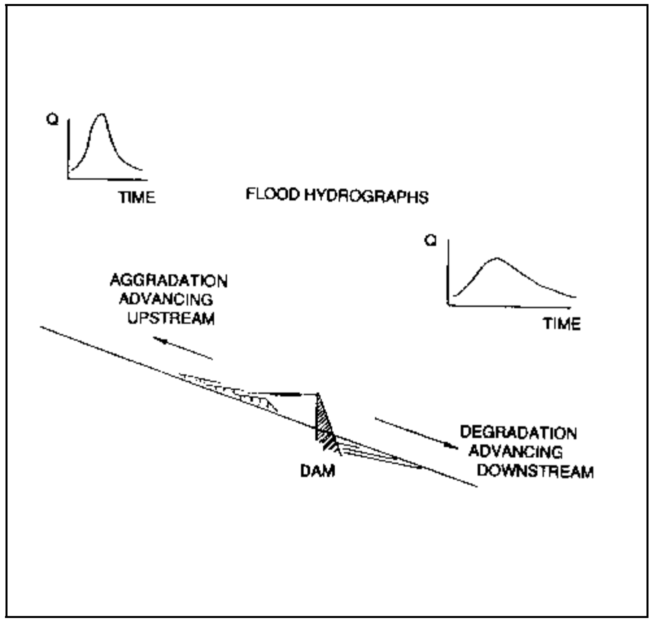


**Figure 3-25. Effects of storage reservoir on profile stability.**

effects of altered hydrology and sediment supply can be studied using HEC-6 (U.S. Hydrologic Engineering Center 1993).

*e*. Downstream effects on channel widths are variable. Studies of 17 cases found widening in 50 percent of cross sections, narrowing in 25 percent, and no change in 25 percent (Williams and Wolman 1984).

*f*. In some cases the effects of storage reservoirs may be opposite to those implied above. If bank-full discharges are released for longer durations than occurred in the natural stream, bank erosion may be aggravated. If bed material inflows from downstream tributaries are high relative to those captured by the reservoir, the downstream channel may actually aggrade because the reduced flood peaks are unable to transport the inflows.

## 3-23. Sediment Transport and Channel Stability

*a*. Sediment transport can be both a cause and a result of instability. Bed material load and wash load have different effects on stability: increasing bed material transport tends to increase instability, but heavy wash loads of fine material may promote stability by depositing cohesive layers on banks and encouraging vegetation. Contrary to popular belief, bank erosion associated with meander migration does not necessarily cause high sediment loads, if erosion on one bank is balanced by deposition on the other, as in lowland floodplains.

*b*. The designed slope and cross section for a project channel must be capable of maintaining transport of incoming bed material; otherwise deposition and loss of hydraulic conveyance will occur.