Reconnection of Floodplains with Incised Channels

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Complexity	Environmental value	Cost
Low — Moderate — High	Low — Moderate — High	Low — Moderate — High

OVERVIEW

This technical note describes two alternatives for the reestablishment of floodplain functions on incised streams. The first is to reestablish the hydrologic connection with the historic floodplain by raising the water or bed level on the incised stream. The second alternative is the construction of psuedo-floodplains within the incised channel margin.

BACKGROUND

Incision Processes

Streams are in a constant state of flux. They are ever changing in their physical character, or morphology, which in turn affects their ability to perform important ecological functions. The magnitude of these morphological changes varies considerably, but streams impacted by anthropogenic activities tend to display the greatest changes. Even "stable" streams located in wilderness areas are subject to change. Lewis and Clark's journals, for example, provide vivid accounts of the dynamics of the river systems they traversed.

A "stable" stream is in dynamic equilibrium when, over an engineering time scale, sedimentation processes are balanced so that the channel, while changing locally, maintains the same average morphological character. A stream's morphology is a consequence of its response to the two principal driving, or independent variables - runoff and sediment yield - acting in concert with the channel boundary conditions to determine the channel planform, cross section, and grade. Boundary conditions include the valley slope, geology, resistance, soil type and size, and vegetation character (Figure 1). They also include natural or man-made controls such as dams, bridges, and water levels of receiving water bodies.

Changes in sediment load, flow regime, and boundary conditions can disrupt the balance, resulting in a stream that undergoes rapid morphologic changes until equilibrium is restored. When long- term erosion exceeds sedimentation, channel incision occurs. Channel modification, usually enlargement or straightening for flood control, is probably the most common cause of incision and also results in the most severe cases. Other causes of channel incision include reduced sediment load due to upstream dams and increased peak flows caused by urbanization of the watershed.

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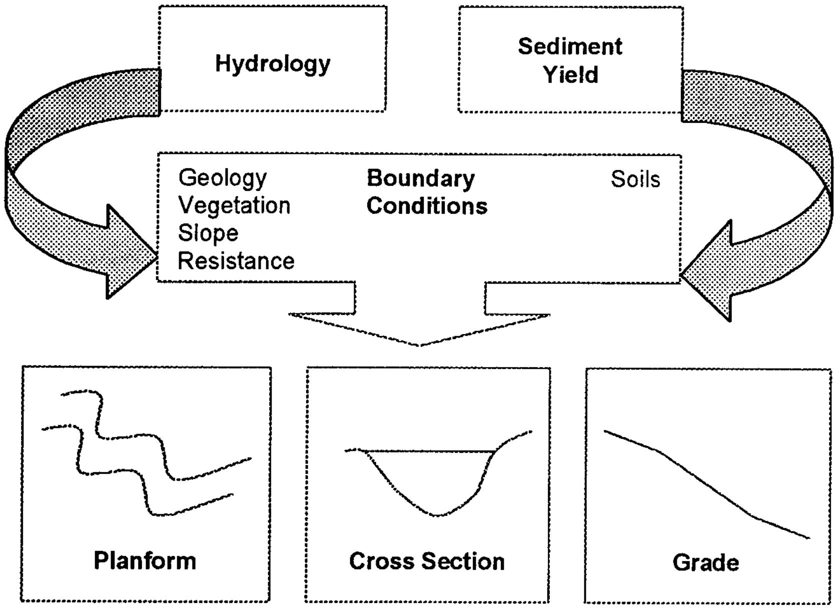

Figure 1. Variables affecting stream morphology

In a typical incising channel, the streambed degrades until the critical bank height is exceeded and the bank fails, increasing channel width and sediment load. In severe cases, nick points and nick zones migrate upstream and destabilize a large part of the system, including tributaries. Over time, the stream will move toward a new equilibrium and incision will cease when one or a combination of the following conditions develops:

1. Changes in the channel slope and geometry alter the hydraulic conditions such that sediment continuity is restored.
2. Fine sediments are selectively eroded, leaving only coarse sediments that armor the streambed and prevent further incision.
3. The degradation is arrested by bedrock or man-made structures prior to the compromise of bank stability.
4. Recovery of riparian vegetation increases streambank stability, and bed stability is provided by one or more of the above factors.

Schumm et al. (1986) presented a model that characterized the incision process for Mississippi streams. The Channel Evolution Model (CEM) describes five stages of channel response. These can be viewed as a temporal process (Figure 2), in which the changes occur at a point on a stream over time, or as a spatial process in which the five stages of the CEM are distributed in a watershed (Figure 3).

The temporal viewpoint is best ascribed to incision initiated by watershed changes that affect the hydrology or sediment yield, in which a new equilibrium may take decades or even centuries to achieve. The spatial perspective is often employed when degradation is initiated by base level lowering or grade changes that initiate headcuts that move upstream, leading to rapid channel incision even in the absence of watershed impacts. Thus, channel incision and evolution can be initiated by a variety of conditions and can be an upstream-down or downstream-up process.

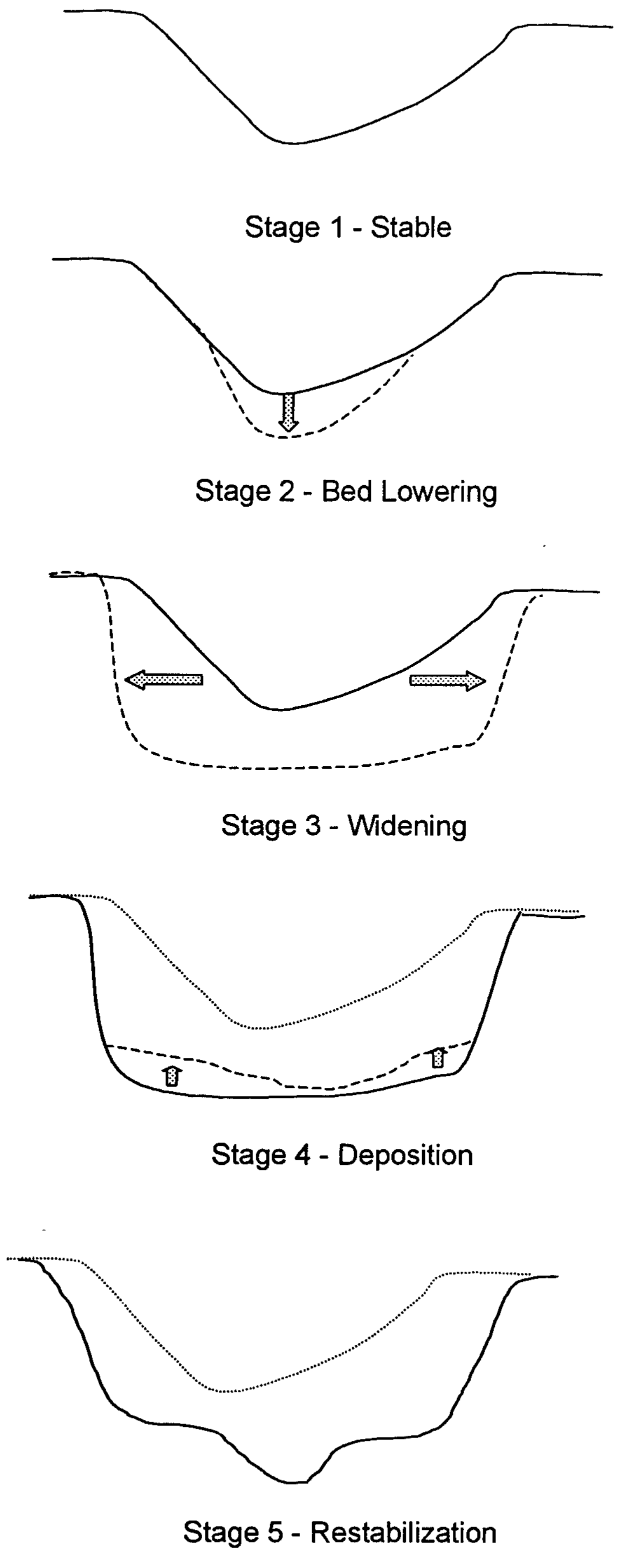

Figure 2. Stages of channel incision in the CEM (temporal view)

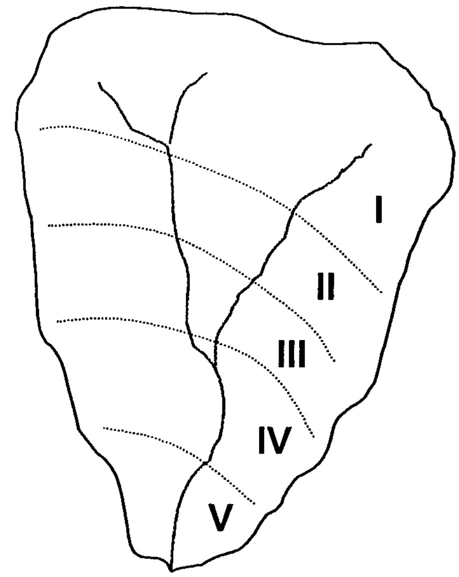

Figure 3. Stages of channel incision presented in the CEM (spatial view)

A typical incised channel is deep, broad, and lacks a defined or stable low-flow channel (Figure 4). The banks are steep and subject to ongoing failure. Pool habitat is usually lacking and riparian vegetation is often rare or absent. The original floodplain habitat may be destroyed by erosion or become hydrologically disconnected from the stream. Incising channels have been a major cause of floodplain and wetland deterioration and loss. Incised channel rehabilitation is a high priority in many areas.

Figure 4. An incised channel that has partially stabilized (Stage 4 or 5)

Characteristics and benefits of alluvial floodplains

Naturally meandering alluvial streams produce floodplains with ridge-and-swale topography and rich soils. Such floodplains have spatially diverse hydroperiods and plant types, and often contain a variety of wetlands. These floodplain wetlands serve many functions and provide important habitats for a variety of fish and wildlife species.

Floodplains are especially important to fishes inhabiting streams and rivers. Due to their high productivity and quickly warming waters in spring, floodplains are important spawning and rearing areas for many fish species, some of which cannot complete their life cycles without access to healthy floodplains and associated wetlands. Species that feed on young-of-the-year fishes and invertebrates that use these habitats or migrate into the stream as floodwaters recede benefit as well. Floodplain wetlands act as nutrient and sediment sinks - improving water quality in the stream. They also provide storage that can decrease magnitude of downstream floods, benefiting stream fishes and riparian landowners. A list of fishes dependent upon floodplains is provided in Table 1 at the end of this technical note.

Animals other than fish also rely on floodplain habitat. Many amphibians and reptiles require floodplain habitats for some or all of their life stages, and floodplain habitat loss has been linked to declines in some species. Neotropical birds rely upon riparian habitats associated with floodplains for feeding and roosting. Much of the migratory waterfowl in the United States could not survive without access to healthy floodplain habitat and many animals that are not generally thought of as wetland species thrive in floodplains because of their natural productivity. This high productivity and great diversity of fish and wildlife species also make floodplains important recreational areas.

Figure 5. Floodplains can provide productive recreational fishing

CHANNEL REHABILITATION

The rehabilitation of an incised or incising channel can follow three general pathways: (1) allow the channel to establish a new equilibrium condition on its own, (2) accelerate the process characterized by the CEM and assist the channel in reaching a new equilibrium, and (3) restore the hydraulic grade of the system to reestablish the hydrologic connection to the historic floodplain.

Options 1 and 2 will result in the reestablishment of floodplains, but within the degraded or enlarged channel. These floodplains provide many functions of the historic floodplain (which becomes a terrace), but often at diminished levels because of their smaller relative size. Option 3 is an attempt to restore the hydrologic interactions between the stream and floodplain, but often fails to restore the physical or hydraulic conditions within the channel.

PLANNING

The first step in the planning process is to conduct a complete geomorphological investigation of the system to determine the causes, extent, and character of the incision processes. The stream channel should be examined visually to identify reaches that are still incising and require stabilization before floodplain rehabilitation can proceed. Space limitations can often be readily identified by visual examination of the stream or of aerial photos, but may also require interviewing land owners or managers. Assessing the historic hydrologic condition and sediment yield of the watershed is useful in determining if restoration of floodplain habitat and associated wetlands is feasible and compatible with the goals of the project.

Failure to create or restore floodplain wetlands may not seem to be a sound rehabilitation technique but under certain circumstances it may be the most prudent course of action. Conditions that may preclude restoration of floodplain wetlands include:

1. The channel is still actively incising. Under most circumstances rehabilitation of riparian and floodplain habitats should not be attempted until the channel has stabilized.
2. Floodplains are highly urbanized, space is limited, and regular flooding is not a viable option. In such systems a stable channel with some riparian vegetation may be all that can be achieved.
3. Streams flow through valuable agricultural lands where space is limited and regular flooding is not economically desirable.
4. Areas are densely populated and cannot tolerate high mosquito populations.
5. Streams have unwanted introduced wetland spawners, e. g., western Salmonid streams with introduced populations of northern pike.

Establishing some form of floodplain wetland function should be a priority objective when the following conditions are present:

1. Wetlands in the area provide important habitat for migrating or nesting waterfowl. This can usually be determined by consulting with the regional office of the U. S. Fish and Wildlife Service.
2. Floodplains are important habitat for endangered species or other high- priority wildlife indigenous to the area. The regional endangered species office of the U. S. Fish and Wildlife Service and the state fish and wildlife agency should be able to determine if this condition may be present.
3. The pre-incised stream contained culturally or economically important fish species that require floodplain wetlands to complete their life cycles. A list of fishes that inhabited the pre-incised stream will be helpful in determining if this condition is present, and can be obtained by researching state or regional fish species accounts or through the state fish and wildlife agency.
4. Floodplain wetlands are important for growth, production, or harvest of sport or commercial fishes in the stream. This can sometimes be determined by surveying sport and commercial fishers. However, more intensive studies will require sampling of sport and commercial fish species, forage fish species, and invertebrates in floodplains.
5. Floodplains will help meet the hydrologic goals of the project. Healthy floodplains can contribute to channel stability, thus decreasing the chance of future incision.

Once it has been established that floodplain restoration is desirable, the type of restoration that is most suitable should be determined. Part of the planning process is determining how the outcome of the three restoration options matches the project objectives.

The endpoint or final channel configuration for option 1 is difficult to predict; the option entails accepting additional bank and bed erosion, and the process may require decades to complete. Option 2 is more determinant, and generally consists of developing a stable low-flow channel with adjoining psuedo-floodplains within the existing channel. These provide similar, albeit diminished, functions to those of the "natural" floodplains. Option 3 restores at least some of the overbank flooding, and can be ruled out if this flooding is intolerable because of adjacent land use.

Accomplishing any of the above options or combinations thereof may involve the use of techniques including modifying the flow or sediment regime, construction of grade control structures, construction of new floodplains to attenuate high flows, increasing or reestablishing channel sinuosity, and armoring streambanks and streambeds. Best results are usually achieved after the problem that initiated the incision has been addressed and the stream has been allowed to adjust toward a new equilibrium and regain some stability.

After implementing option 2 or 3, it may be necessary to accelerate the recovery of habitats that were impacted by destabilization of the channel. This may involve the use of structures to create pool habitat, planting to reestablish riparian vegetation, modifications to the new floodplain to create functional wetlands within the incised channel, or reconnection of the stream to its original floodplain.

OPTIONS FOR FLOODPLAIN RESTORATION

Floodplain rehabilitation.

Under ideal conditions, rehabilitation by reestablishing the interaction between the stream and the original floodplain is the most desirable option. This may not be feasible because:

1. The original floodplain may be damaged beyond the point that rehabilitation is feasible (Williams 1999).
2. The hydrology has changed to an extent that no structural modification will result in a healthy, functioning floodplain system.
3. Current uses of the floodplain are incompatible with flooding.
4. The structures required to raise the stream level may have unacceptable ecological impacts. Such impacts may include blockage of fish migration, destruction of lotic habitat, and harm to riparian vegetation due to prolonged hydroperiod.
5. Reestablishing the connection would be cost-prohibitive.

Streams that are incising due to straightening of the channel are prime candidates for floodplain rehabilitation when most of the original channel is intact. Weirs can be placed at channel cut-off points to reestablish sinuosity, which will reduce the stream gradient, increase flooding potential, and thus restore the interaction between the stream and its floodplain. Because the weirs divert water into the old channel rather than pooling it, the amount of lotic habitat is increased and migrating fishes have unobstructed passage with lower flow velocities.

Streams in which the original bed level has been lowered are more difficult to successfully reconnect to their original floodplain. Weirs used to raise water levels often have ecological impacts such as conversion of lotic to lenthic habitats and blockage of fish migration routes. These impacts can be mitigated somewhat by using more weirs with less head difference.

Floodplain construction

Usually, the most feasible approach to restoring function to an incised stream is the construction of a psuedo-floodplain, complete with floodplain/wetlands and deepwater habitats, within the incised channel. Artificial floodplain wetlands with a single well-defined purpose such as providing spawning habitat for a specific fish species, have the greatest chance of success. Floodplains can be constructed to provide the following:

1. Spawning habitat for fishes.
2. Nesting habitat for waterfowl.
3. Over-wintering habitat for waterfowl.
4. Waterfowl hunting areas.
5. Sport or commercial fishing grounds.
6. Water quality enhancement.
7. Attenuation of high flows.
8. Protection of levees.

Mimicking all the functions of a natural floodplain is usually not a realistic goal for an artificial floodplain constructed within an incised channel. However, floodplains constructed for a single purpose will usually provide several functions in addition to the one for which it was designed.

FLOODPLAIN DESIGN

The goals and constraints of each project will dictate floodplain design, and designs for different purposes vary considerably. Companion technical notes in this series provide details on the design and construction of floodplains (see TN SR-04, for example).

This section presents general design criteria based upon desired functions.

Fish spawning habitat
Floodplains designed for fish spawning habitat should slope gradually with the deepest areas adjacent to the stream channel. This is to ensure that larval and juvenile fishes do not strand as water levels drop. Deepwater areas can be excavated within the floodplain if they are connected to the stream by channels that are flooded during normal low water. The hydroperiod in the shallowest areas of the floodplain should extend at least from the time that the target species spawn until the larvae reach the free-swimming stage and can emigrate to deepwater or transitional habitats. Transitional zones with a hydroperiod sufficient to support emergent aquatic vegetation are usually desirable. These zones should be placed between the stream channel and the shallower floodplain areas if space and hydrologic conditions permit. However, transitional zones can also be constructed within the wetland and connected to the stream with side channels.

The target fish species will dictate the type of vegetation in the wetland. Many fishes spawn in forested wetlands but some, such as northern pike, prefer areas of flooded terrestrial grasses and emergent aquatic vegetation. Size of the floodplain is often not critical from a standpoint of fish spawning, as many fish species will spawn in small floodplains. Small floodplains have the advantage of ensuring that distance to the main channel is not great, thus decreasing the chance of stranding. However, achieving sufficient transitional zones and a sufficient diversity of depth and hydroperiod may be difficult if space is limited.

Figure 6. Larval northern pike in a floodplain designed specifically for northern pike spawning

Waterfowl habitat
Floodplains for waterfowl should retain water after the stream levels drop. To achieve this, they should be relatively flat with a berm adjacent to the stream to retain water. Design and management of such floodplains often utilize systems of levees, water control structures, and pumps to tailor hydroperiod to meet specific needs of vegetation, waterfowl, or user groups.

When feasible, waterfowl floodplains should remain flooded as long as migratory waterfowl are in the area. However, hydroperiod should not be long enough to endanger woody vegetation. Small ponds can be excavated in the floodplain to provide wet habitat long after the rest of the floodplain has dried. These ponds should be small and irregularly shaped to maximize edge effect.

The type or life stage of waterfowl expected to use the floodplain will also influence design. For example, flooded grain fields may greatly benefit dabbling ducks and geese but may have very little habitat value for diving ducks. Likewise, habitat factors that reduce predation, such as lateral and overhead cover may be high priorities in nesting and molting areas, whereas high-energy food sources may be much more important than cover in floodplains along migration corridors.

Water quality improvement
Water quality benefits are a function of the floodplain configuration, its relative elevation,

the vegetation type and density, and the surface area of the floodplain. The larger the area and the longer the contact period with the water, the greater the benefit. Thus, floodplains designed to improve water quality should have a low elevation to ensure a long hydroperiod and abundant growth of submerged and emergent aquatic vegetation. The floodplains should slope gradually with the deepest areas near the stream channel.

Figure 7. Dense vegetation in some floodplains can improve water quality. Here, cattails have overgrown the floodplains within three years following construction

Attenuation of high flows
Floodplains built to attenuate high flows should have levees along the stream with water control structures that allow flooding as water levels rise, then hold the water and release it slowly as levels drop. Areas adjacent to the water control structures should be deep enough to ensure survival of stranded fishes until the structures can be opened sufficiently to allow them to return to the stream. Vegetation should be sufficient to stabilize soils and provide wildlife or fish spawning and rearing habitat, and some of the detention may be derived from backwater caused by dense vegetation.

Floodplains designed to improve aesthetics
Floodplains designed to improve aesthetics should have easy public access in the form of boardwalks or overlooks or should be visible from areas frequented by people. Emergent aquatic plants (sedges, rushes, etc.) are usually best because they often provide good aesthetic value within one growing season. Open water areas can provide habitat for wading birds that add to the aesthetic value of the area. Trees and shrubs should be established along the margins of the wetland to provide habitat for migratory birds. Construction of birdhouses will probably be desirable in most areas. Plans for birdhouses should be available from the state fish and game management agency.

Levee protection
Floodplains designed to protect levees should be heavily forested to stabilize soils and to reduce flow velocity at the levee. The target hydroperiod should be dictated by the species of trees planted. The floodplain should slope gradually from the streambank to the levee to prevent bank failure and stream migration.

SUMMARY
Floodplains habitats are very important in the ecology of most alluvial streams. Human activities often cause incision of streams and have resulted in deterioration of many floodplain habitats as well as loss of many instream habitat features.

Rehabilitation of incising streams is a high priority in many areas and involves abiotic attributes (flow regime, sediment transport, depth, bank and bed stability) and biotic attributes (vegetation, invertebrate communities, fish and wildlife populations).

Rehabilitation of an incising stream may or may not involve construction or restoration of functioning floodplains depending on condition of the stream, condition of the watershed, and specific goals of the project. When it is desirable to construct a new floodplain, specific goals of the project will dictate the design. Although there are many problems associated with reestablishing the interaction of the stream to the original floodplains, it is the most desirable option when it is culturally and ecologically feasible.

APPLICABILITY AND LIMITATIONS
Techniques described in this technical note are generally applicable where primary objectives for incised streams include habitat diversity,

erosion control, and aesthetics, including reestablishment of floodplain-related functions.

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Table 1. Fish Species that Frequently Utilize Floodplain Wetlands[1].

Family and common name	Latin name
Plyodontidae	Polyodon spathula
Paddlefish	
Lepisosteidae	
Spotted gar	Lepisosteus oculatus
Longnose gar	L. osseus
Shortnose gar	L. platostomus
Amiidae	
*Bowfin	Amia calva
Anguillidae	
American eel	Anguilla rostrata
Esocidae	
*Northern pike	Esox lucius
*Muskellunge	E. masquinongy
*Redfin pickerel	E. americanus
*Chain Pickerel	E. niger
Salmonidae	
*Chinook salmon	Oncorhynchus tshawytscha
Catostomidae	
Smallmouth buffalo	Ictiobus bubalus
Bigmouth buffalo	I. cyprinellus
Black buffalo	I. niger
Ictaluridae	
Channel catfish	Ictalurus punctatus
Black bullhead	Ameiurus melas
Brown bullhead	A. nebulosus
Poechiliidae	
Mosquitofish	Gambusia affinis
Centrarchidae	
Warmouth	Lepomis gulosus
Bluegill	L. macrochirus
Redear sunfish	L. microlophus
Largemouth bass	Micropterus salmoides
Black crappie	Pomoxis nigromaculatus

[1]Species may require access to floodplain wetlands to complete its life cycle.