Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision, 1997
S.S.Y. Wang, E.J. Langendoen and F.D. Shields, Jr. (eds.)   ISBN 0-937099-05-8

A GEOMORPHOLOGICAL APPROACH TO RESTORATION OF INCISED RIVERS

David L. Rosgen

ABSTRACT

Geomorphological concepts are described as integrated into incised river restoration projects. Restoration is defined as establishing natural stability and proper function of rivers. Methods involve applying morphological relations from natural stable rivers using a stream classification system that describes a stable "reference reach". Evolutionary tendencies associated with stream adjustments leading to their most probable natural state are presented. A range of restoration design concepts are presented including: returning the stream to its original elevation and re-connecting floodplains, widening the belt width to construct a new channel at the existing elevation, changing stream types, and stabilizing the existing incised channel in place. Examples of incised river restoration projects are presented.

INTRODUCTION

The *incised river* is a vertically-contained stream that has abandoned previous floodplains due to a lowering of local base level and is characterized by high streambanks bounded by alluvial terraces. Incised rivers, however, can also be located in certain landforms and valley types that are naturally associated with entrenched rivers. However, the consequence of river channelization, straightening, encroachment, confinement (lateral containment), urban development, major floods, change in sediment regime and riparian vegetation conversion can create incised rivers. The consequences of creating an incised channel are associated with accelerated streambank erosion, land loss, aquatic habitat loss, lowering of water tables, reduced land productivity and downstream sedimentation. To offset these adverse consequences, river improvement through restoration projects has been initiated. The geomorphological approach to stream restoration involves an understanding of the dimension, pattern and profile of natural, stable channels that can occur in specific valley types and landforms, and recreating these conditions on the unstable form. Unsuccessful stabilization projects often involve "patching in place" various reaches or treating symptoms rather than the cause of the problems. Successful restoration solutions often are directed at re-establishing floodplains at various elevations and emulating natural stable channels.

NATURAL STABILITY CONCEPTS

The *graded channel* is described by Mackin (1948) "as one which, over a period of years, slope is delicately adjusted to provide, with available discharge and the prevailing channel characteristics, just the velocity required for transportation of the load from the drainage basin." The definition of the *equilibrium channel* is similar where the average river channel system tends to develop in a way to produce an approximate balance between the channel and the water and sediment it must transport (Leopold and Maddock, 1953). Many combinations of parameters occur, but tendencies lead toward a statistically "probable natural state" through the conservation of energy and distribution of energy expenditure (Leopold, 1994). *Natural stability* of streams is defined as the ability of a stream, over time, to transport the flows and sediment of its watershed in such a manner that the stream maintains it dimension, pattern, and profile without either aggrading or degrading (Rosgen, 1996). The terms *equilibrium*, *graded channel*, *probable natural state* and *natural stability* are synonymous as used in this paper.

RESTORATION CONCEPTS

Restoration in the purest sense is often associated with returning a stream to a pristine or to pre-disturbance condition. Because the sediment and flow regime, as well as many other variables, have been significantly altered in the watershed, returning a stream to a pristine condition is often not possible. Restoration as used in this paper is associated with *restoring natural function, stability and biological condition*. To be implemented properly, restoration designs must consider the *morphological potential* of the stream. A multitude of restoration, enhancement and stabilization methods have been implemented for a wide range of objectives. Often, the objectives have been single purpose, such as to minimize streambank erosion. Other objectives include the improvement of fish habitat. Many of these projects met their initial objectives while other projects, contrary to their goals, created instability and loss of physical and biological function. A study of the successes and failures of a variety of methods can provide a foundation for understanding and improving our restoration efforts. Successful restoration using the geomorphological approach and natural channel design concepts begins with an understanding of the following criteria:

1. The *cause* of the instability or disequilibrium:
   a. Assessment of watershed and river stability
   b. Evidence of change
2. The *potential* or the morphological character of the natural stable form
   a. Stream Classification – must match the appropriate stream type to valley type
   b. The Reference Reach – used as a blueprint for the stable *dimension* (e.g., width, mean depth, width/depth ratio, maximum depth, flood-prone area width and entrenchment ratio), *pattern* (e.g., sinuosity, wavelength, belt width, meander width ratio and radius of curvature), and *profile* (e.g., average water surface slope, pool-to-pool spacing, pool facet slope and riffle facet slope).

An understanding of how rivers work is often learned more from *quantitative* field observations that integrate many disciplines rather than from the theoretical calculations of an individual discipline. Individuals must understand and respect the complexity of the river as restoration is not easily accomplished since many of the interrelated variables that shape and maintain the river are not fully understood. The beginnings, as used in this approach, rely on an understanding of natural stable channels and how to emulate them.

STREAM CLASSIFICATION

The morphological features of a river's stable form are used as the "blueprint" for natural channel design. A stream classification system (Rosgen, 1994) is used to quantitatively describe a combination of river features that integrate mutually adjusting variables of channel form. Stream types are used in restoration primarily to describe and extrapolate data associated with the "*reference reach*" of natural, stable channels. Stream types as grouped by morphological similarity are products of erosional and depositional events, over time, in certain valley types. They reflect similarities in entrenchment, channel form, width/depth ratio, sinuosity, slope and channel materials (Rosgen, 1994). The eight primary stream types are illustrated in **Figure 1**. A more detailed delineation is presented with 41 major stream types that provide quantitative morphological descriptions (**Figure 2**). This level of classification provides information to: a) communicate among those working with rivers, b) predict channel response based on morphological similarity from past observations, and c) stratify and extrapolate data from the appropriate *reference reach* (natural, stable channel).

The entrenched (incised) rivers in this classification system are the A, F and G stream types. To establish a consistent, quantitative field measurement of entrenchment (vertical containment), the entrenchment ratio (flood-prone area width to bankfull width) was developed (Rosgen, 1994, 1996). Flood-prone area width is obtained at an elevation of twice the maximum bankfull depth. When the entrenchment ratio is less than 1.4 (+/- 0.2), the river is entrenched. Degree of incision is obtained by measuring the lowest height bank along a stream reach and dividing by the bankfull stage bank height. As this ratio increases above 1.0, the streambank heights increase indicating a grade control problem and it takes a larger magnitude flood to over-top the banks. Incised streams, characteristically, have high streambanks, which are associated with excessive bank erosion.

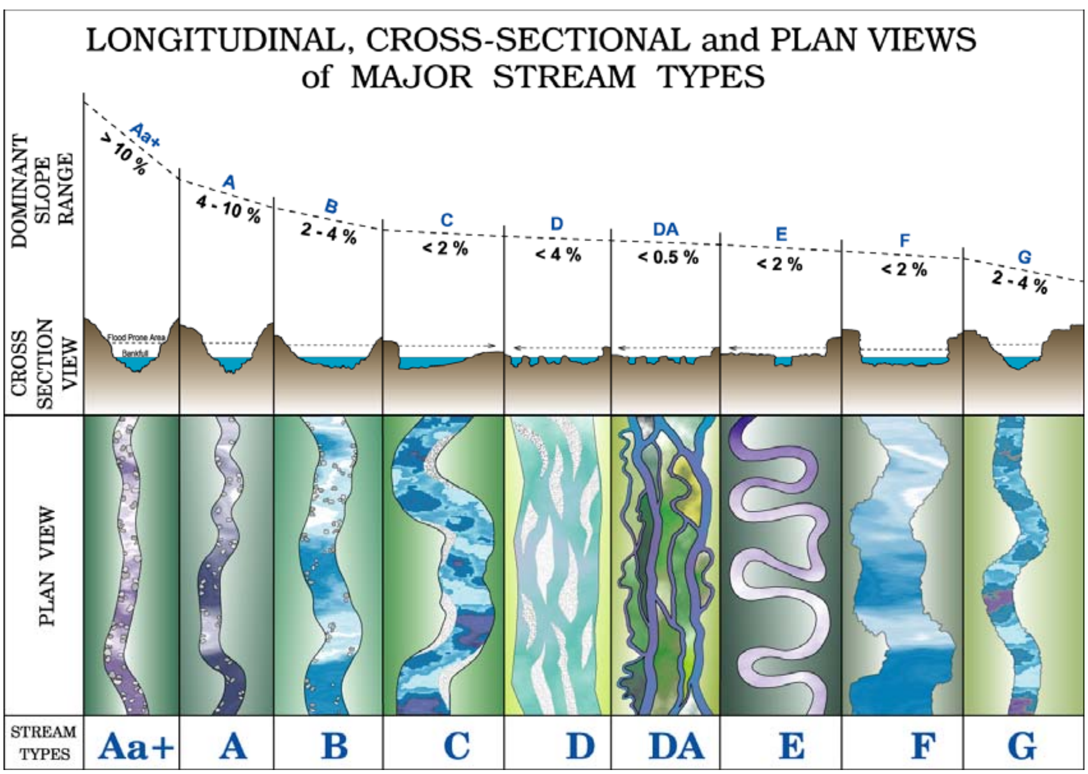

Figure 1. Broad-level stream classification delineation showing longitudinal, cross-sectional and plan views of major stream types (Rosgen, 1994).

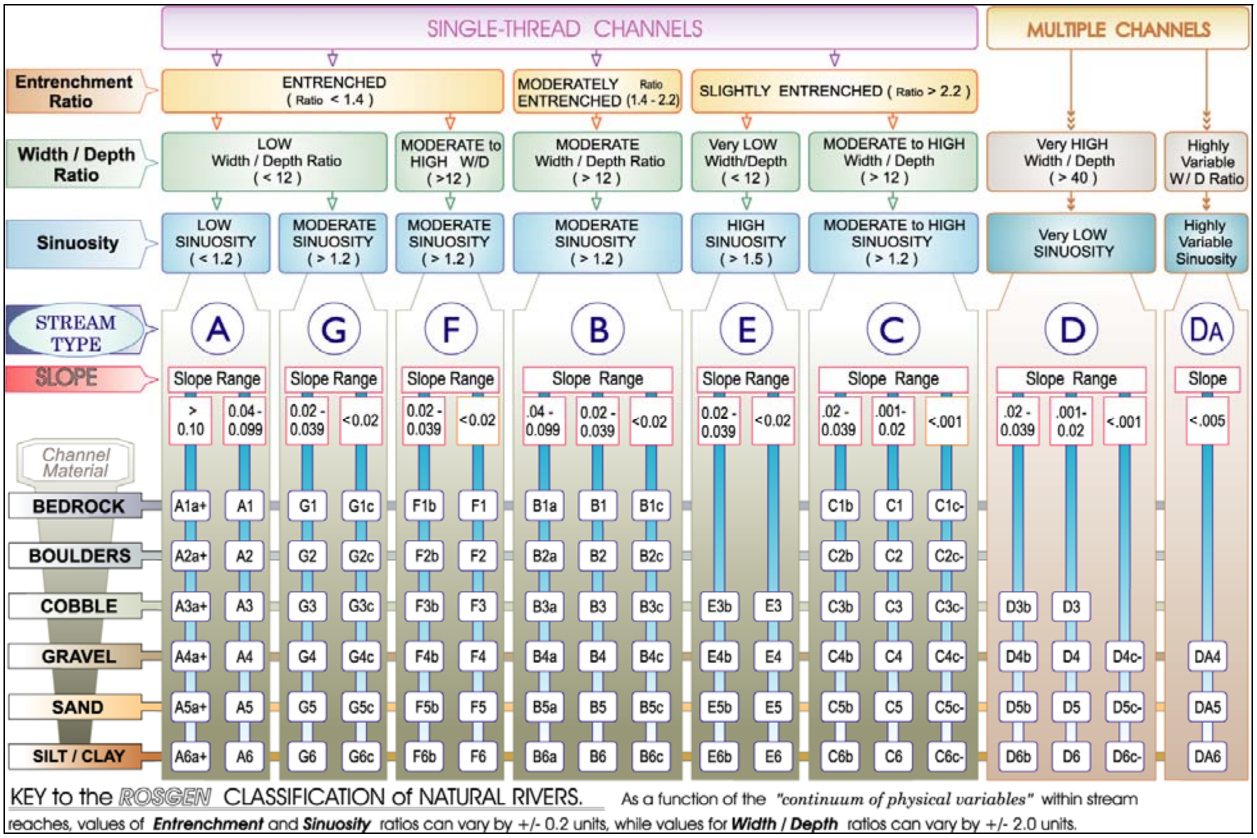

Figure 2. Classification key for natural rivers (Rosgen, 1994).

EVOLUTIONARY TENDENCY OF RIVERS

Rivers, being very dynamic, are subject to change when the variables that shape and maintain their morphological form are altered. These variables include velocity, roughness of the boundary, slope, width, depth, discharge, size of sediment debris, and concentration of sediment (Leopold *et al*., 1964). Rivers have had to accommodate periods of climate change and watershed development. The position of the alluvial river in its valley has changed in relation to climate and development. The changes in the river have affected both the lateral and vertical position. A historical perspective is important in working rivers as the modern river in many cases is still adjusting to events of the past. For example, many rivers in the northeast and southeast United States have aggraded during periods of extensive agriculture over 100 years ago. Today, under a different land use, the same streams are down-cutting in the previous deposition. Holocene terraces, evidence of previous stream and floodplain levels, are remnants of climate change and a corresponding lowering of local base level over time. Cut and fill terraces that reflect these erosional and depositional cycles are shown in **Figure 3** (Leopold *et al*., 1964). Channel evolutionary models for incised channels are shown by Schumm *et al.* (1984) and Simon (1994). These evolutionary observations show stages of channel incision and lateral adjustments as the channel is seeking a new equilibrium. When discussing evolutionary tendency, it is helpful to communicate in terms of particular stream types associated with the various evolutionary stages, and the quantitative channel morphological relations of these stages.

At the initial level of channel formation, the stream incises itself into the deposition initially to the depth of the bankfull discharge. Streamflows greater than this inundate the adjacent valley flat. At this stage of adjustment, the stream type is either a C or an E (**Figure 1** and **Figure 2**). Due to land use, direct disturbance or changes in climate, the stream increases its width/depth ratio, decreases sinuosity and increases slope, leading to chute cutoffs. When these morphological changes exceed a “geomorphic threshold,” stream types change. The scenario presented in **Figure 4** depicts an alluvial channel conversion from stream types E4 and C4 to a G4, or a gully, due to degradation processes. The G4 stream type is an incised channel and the previous floodplain becomes a terrace. The central tendency for this stream is to have a floodplain, a sinuous channel, and lower gradient; thus it will continue to erode its banks to increase the belt width. As this lateral extension of the channel occurs, the stream changes morphology and stream type from a G4 to an F4. The F4 stream type (**Figure 4**) is also entrenched but has a high width/depth ratio, has ceased to downcut and continues to erode its banks at very high levels. When the belt width is sufficiently wide, a new channel is incised in the bed of the F4 stream type, making the previous bed the new floodplain of the C4 and eventually the E4 stream type. Thus, the evolution for this scenario is an E4 to C4 to G4 to F4 to C4 and back to an E4, however, at a new elevation. The stream type changes that reflect geomorphic shifts also reflect the new quantitative values of dimension, pattern and profile (Rosgen, 1994, 1996). This scenario is just one of many evolutionary sequences.

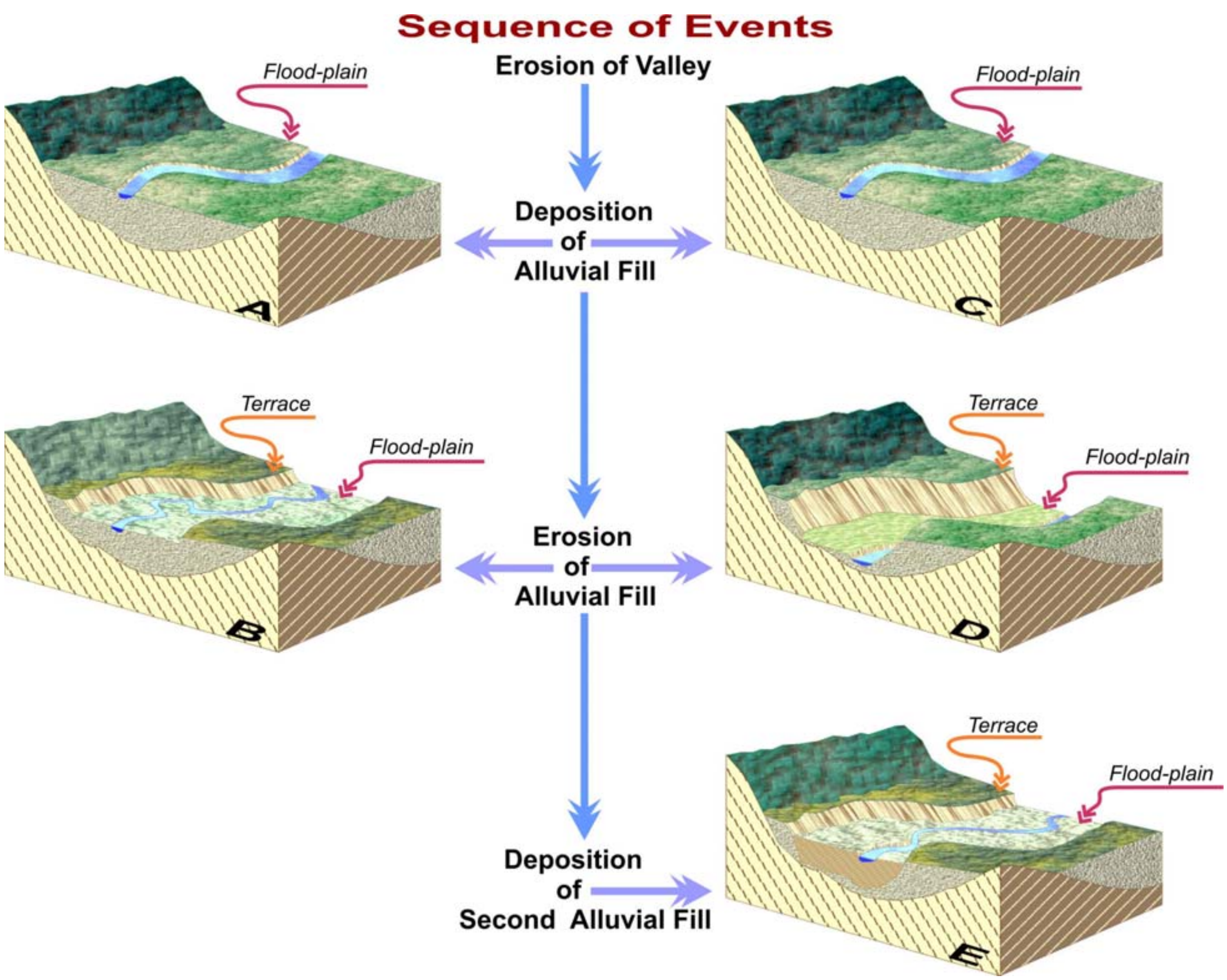

Figure 3. Block diagrams illustrating the stages in development of a terrace. Two sequences of events leading to the same surface geometry are shown in diagrams A, B, and C, D, E respectively (Leopold *et al*., 1964).

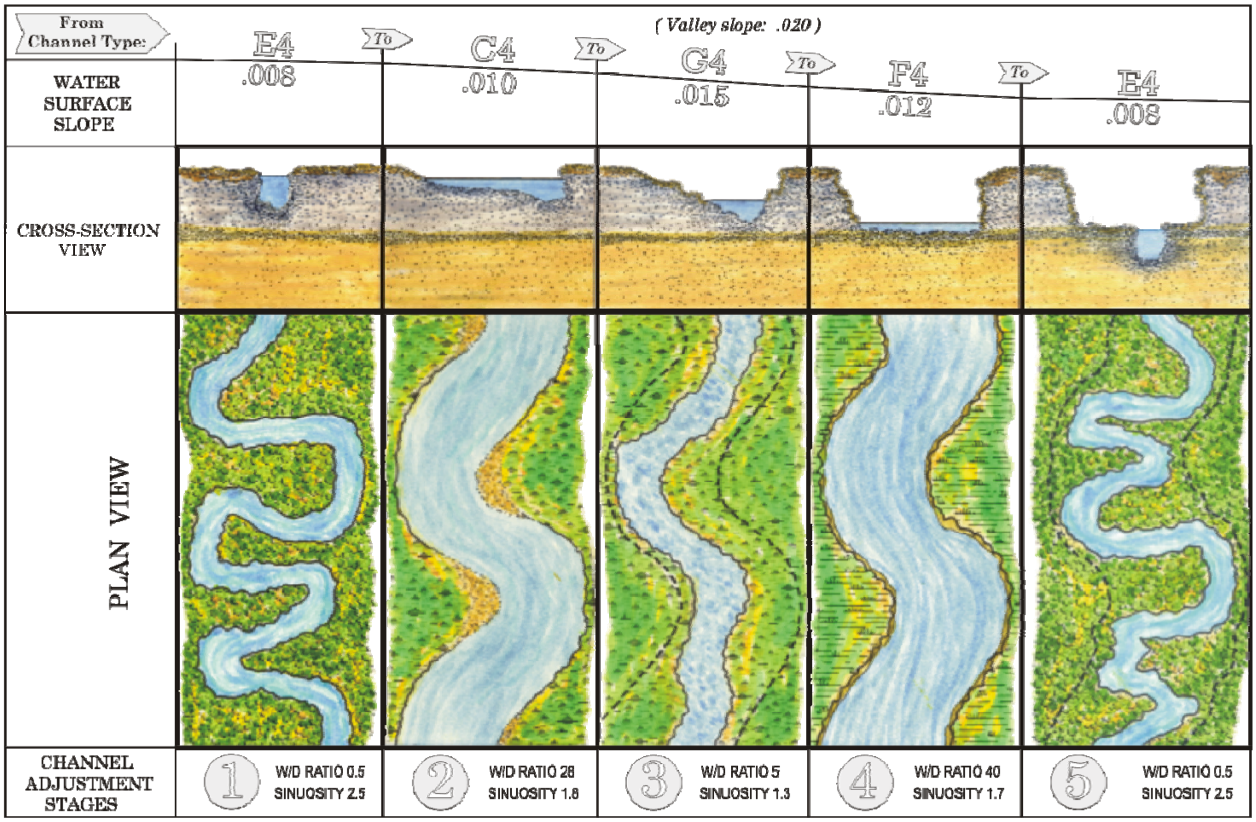

Figure 4. Evolutionary stages of channel adjustment (Rosgen, 1994).

RESTORATION OF INCISED STREAMS

Restoration of incised streams involves an understanding of the *reference reach*, which are stable stream types in similar valley types. Valley types involve a combination of landforms, land types, soils, geology, basin relief, valley gradient, valley width, and depositional and erosional history (Rosgen, 1996). Incised streams are channels that are vertically contained or, in a general sense, have abandoned their floodplains, typical of A, G, and F stream types (**Figure 1** and **Figure 2**).

The incipient point of flooding is one of the definitions of the bankfull stage in rivers. However, in incised rivers, larger magnitude floods are required to inundate the flood-prone area adjacent to the channel; thus the flood-prone areas are flooded less frequently. When the bank height ratio to the bankfull stage is greater than 1.0, it is an indication of degradation (lowering of local base level) initiating abandonment of the active floodplain. Restoration concepts for incised rivers require the use of both the entrenchment and bank height ratios.

A priority system is used by the author when restoring or enhancing the incised river, which considers a range of options based on numerous factors (**Table 1**). Unfortunately, the most common approach in incised channel stabilization is Priority 4, which is often the most costly, highest risk and least desirable from a biological and aesthetic viewpoint. In many instances, however, especially in urban settings, Priority 1 is not feasible because the floodplain has been occupied. Various restoration and stabilization options are depicted in **Figures 5a** through **5f**.

If the existing meander pattern fits the proposed stable stream type, raising the channel back on each riffle reach with grade control to reconnect the floodplain is appropriate. This concept is similar to the discussion in Priority 1 (**Table 1**) illustrated in **Figure 5a** without the need to abandon the incised stream and construct a new channel. Often grade control check dams are used to raise the channel elevation of an F or G stream type; however, if the pattern, width/depth ratio and slope do not match the stable channel tendencies, the structure will not be stable. Because sinuosity is inversely proportional to slope, a flattening of the slope with a grade control structure often induces lateral extension of the channel. “Patching” streams in place often works against the meandering tendency of rivers and leads to high maintenance and eventual failure. If the floodplain has been occupied, then Priorities 2 through 4 (**Table 1**) are often considered. To establish a new stable channel other than at the previous level, Priority 2 provides for a conversion from either a G or F stream type to a C or E stream type (**Figure 5b** and **Figure 5c**). The conversion depicted in **Figure 5b** has the advantage of balancing the cut and fill rather than end-hauling the excavated material from the reach. In natural channels, C and eventually E stream types often develop on the new deposition.

The advantages of the F to C conversion (**Figure 5c**) are a lower flood-stage elevation for the same magnitude discharge and creating the evolutionary progression of stream types that naturally occur. Both increased flood flow and sediment transport capacity result due to the increased cross-sectional area of the flood-prone area and the low width/depth ratio of the C stream type. High boundary stress against the high vertical banks typical of the F stream type is associated with excessive bank erosion rates and sedimentation. The conversion of the F stream type as depicted in **Figure 5b** and **Figure 5c** reduces the high bank erosion rates by decreasing both the high erodibility factors and stress in the “near bank region” (Rosgen, 1996).

The restoration concepts associated with Priority 3 (**Table 1**), as depicted in **Figure 5d** and **Figure 5e**, are implemented where streams are confined (laterally contained) and physical constraints limit the use of Priority 1 or Priority 2 (**Table 1**). Priority 3 also applies to landforms where the natural evolution evolves to the stable B stream type, which is associated with a step/pool bed morphology rather than riffle/pool as in the Priority 1 and Priority 2 conversions. Conversions to a B stream type require streambed profiles that emulate the pool spacing as a function of bankfull width and stream slope. The pool-to-pool spacing ratios are obtained from reference reaches of B stream types on similar gradients and materials. Both the width/depth ratios and entrenchment ratios are increased in the G to B conversion (**Figure 5d**). The conversion from the F to Bc stream type requires a decrease in width/depth ratio and an increase in entrenchment ratio. As shown in **Figure 5d** and **Figure 5e**, the streambanks are sloped and vegetated. Structures are often required to take the stress off of the banks to buy time for the plants to become established.

The stabilization work as described in Priority 4 (**Table 1**) and illustrated in **Figure 5f** is the most common of incised river "improvement." The costs, high risk of failure, loss of natural function and loss of visual and biological value are the reasons this option is presented last on the priority list. Often, however, to protect road fills, homes and historic features, this option is about all that can be done within the existing constraints. The stabilization material used, however, can off-set some of the adverse aesthetic and biological impacts. The use of native materials, such as large boulders, logs, root wads and bio-engineering, and slope stabilization methods that offer a wider range of stabilization objectives are superior to traditional "hard-control" methods. The use of gabion baskets, shown in **Figure 5f**, and concrete lined channels are quite common in engineering application. Their high costs (construction and maintenance) and associated loss of biological and visual values challenge engineers to seek alternative stabilization solutions. Grade control and streambank stabilization methods, however, are essential if Priority 4 is implemented due to the characteristic high streambank erodibility and high near-bank stress of the incised channel.

Table 1. Priority descriptions and the advantages and disadvantages for incised river restoration.

DESCRIPTION	METHODS	ADVANTAGES	DISADVANTAGES
Priority 1 Convert F or G stream types to E or C stream types at the previous elevation with floodplain (*see* **Figure 5a**)	Re-establish channel on previous floodplain using relic channel or construction of new bankfull discharge channel. Design new channel for dimension, pattern and profile characteristic of stable form. Fill-in existing incised channel or with discontinuous oxbow lakes level with new floodplain elevation.	Re-establishment of floodplain and stable channel: 1. Reduces bank height and streambank erosion 2. Reduces land loss 3. Raises water table 4. Decreases sediment 5. Improves aquatic and terrestrial habitats 6. Improves land productivity 7. Improves aesthetics	1. Floodplain re-establishment could cause flood damage to urban agricultural and industrial development 2. Downstream end of project could require grade control from new to previous channel to prevent head-cutting
Priority 2 Convert F or G stream types to E or C by re-establishing the floodplain at the existing level or higher, but not at original level (*see* **Figure 5b** and **Figure 5c**)	If belt width provides for the minimum meander width ratio for C or E stream types, construct channel in bed of existing channel, and convert existing bed to new floodplain. If belt width is too narrow, excavate streambank walls. End-haul material or place in streambed to raise bed elevation and create new floodplain in the deposition.	1. Decreases bank height and streambank erosion 2. Allows for riparian vegetation to help stabilize banks 3. Establishes floodplain to help take stress off of channel during flood 4. Improves aquatic habitat 5. Prevents wide-scale flooding of original land surface 6. Reduces sediment 7. Downstream grade control is easier	1. Does not raise water table back to previous elevation 2. Shear stress and velocity higher during flood due to narrower floodplain 3. Upper banks must be sloped and stabilized to reduce erosion during flood
Priority 3 Convert G stream types to B, or F stream types to Bc that contain a flood-prone area but not an active floodplain (*see* **Figure 5d** and **Figure 5e**)	Excavation of channel to change stream type involves establishing proper dimension, pattern and profile. To convert a G to B stream involves an increase in width/depth and entrenchment ratio, shaping upper slopes and stabilizing both bed and banks. A conversion from F to Bc stream type involves a decrease in width/depth ratio and an increase in entrenchment ratio.	1. Reduces the amount of land needed to return the river to a stable form 2. Developments next to river need not be relocated due to flooding potential 3. Decreases flood stage for the same magnitude flood 4. Improves aquatic habitat	1. High cost of materials for bed and streambank stabilization 2. Does not create the diversity of aquatic habitat 3. Does not raise water table to previous levels
Priority 4 Stabilize channel in place (*see* **Figure 5f**)	A long list of stabilization materials and methods have been used to decrease streambed and streambank erosion, including concrete, gabions, boulders and bio-engineering methods.	1. Excavation volumes are reduced 2. Land needed for restoration is minimal	1. High cost for stabilization 2. High risk due to excessive shear stress and velocity 3. Limited aquatic habitat depending on nature of stabilization methods

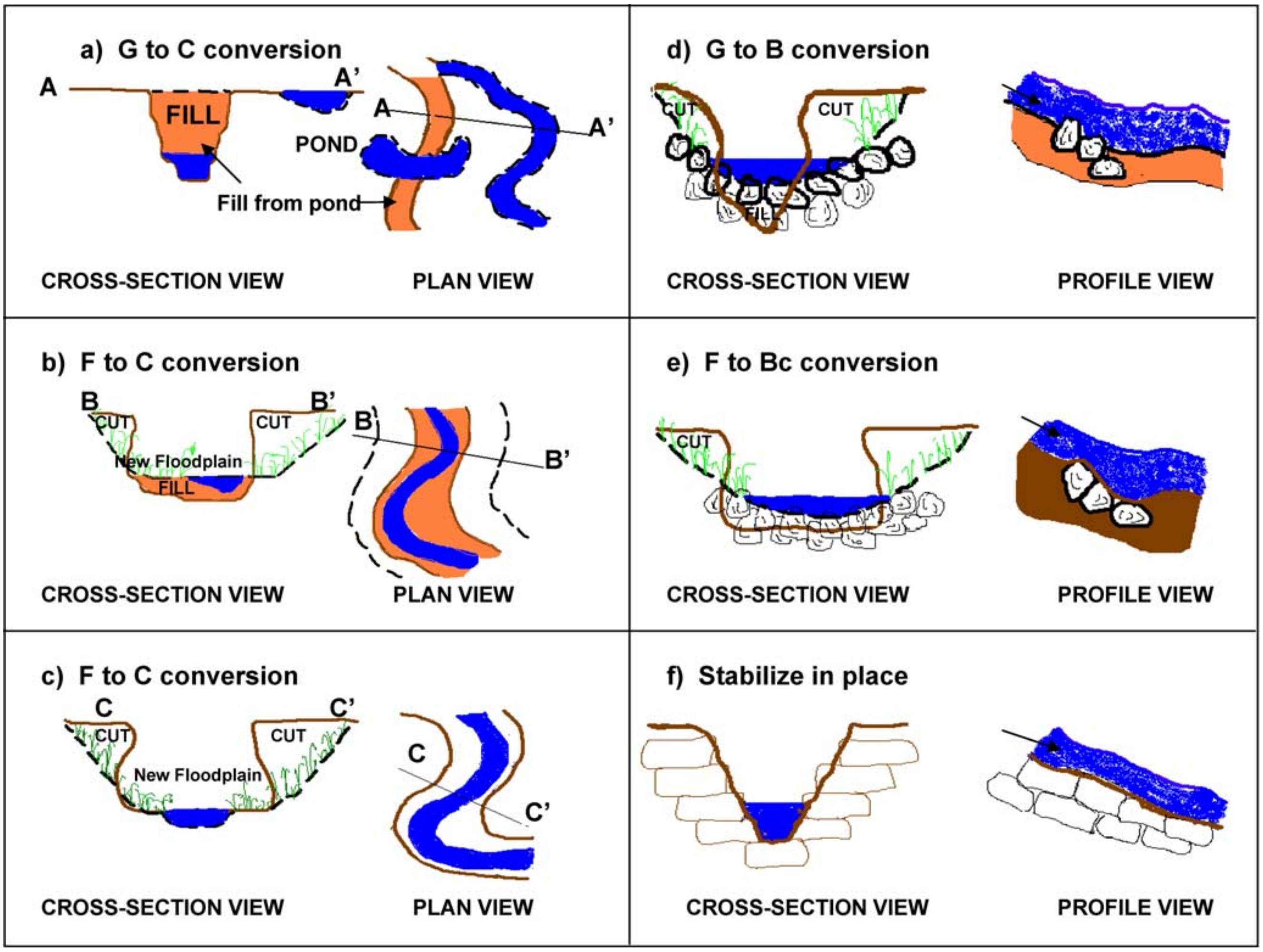

Figure 5. Various restoration and stabilization options for incised channels.

IMPLEMENTATION OF INCISED RIVER RESTORATION CONCEPTS

The author has designed, constructed, provided technical advice, and monitored many restoration and stabilization projects using Priorities 1–4 (**Table 1**), which include the following projects.

Maggie Creek, Nevada

A Priority 1 project was accomplished in 1990 on upper Maggie Creek near Carlin, Nevada, where a government agency cost-shared a project with a private ranch, which resulted in straightening many miles of unstable gravel bed, C4 and D4 stream types. In four years of drought, the stream incised ten meters and created a G4 stream type. The resultant stream type conversion lowered the water table, reduced the productivity of the meadow, created excessive bank erosion and associated downstream sedimentation, accelerated land loss and created loss of fish and terrestrial wildlife habitat. Restoration involved constructing a C stream type back on the original elevation to reconnect the floodplain and creating a series of discontinuous oxbow lakes to obtain sufficient material to fill in the gully (G stream type). This option restored the natural stability of the stream, raised the ground water table back to the original level, and minimized damage from a flood that occurred four months following construction. A key in this restoration was to improve riparian grazing that led to the initial destabilization of the C4 stream.

Lower Weminuche Creek, Colorado

The Lower Weminuche Creek project involved a C4 stream type on private land that was converted to an incised stream type (G4 to F4). Consequently, an avulsion (abandonment of previous channel) occurred and created excessive bank erosion, lowered the water table, decreased meadow productivity, and degraded fish habitat. The restoration solution using Priority 1 options involved blocking the existing F4 stream type, and raising and relocating the channel into an existing, abandoned, meandering channel that reconnected the previous floodplain. This avoided a series of expensive and high-risk streambank and streambed stabilization structures deemed necessary to "patch in place" the incised channel. Abandoned, incised channels need to be converted to oxbow lakes to prevent reoccupation of the previously incised channel during periods of floods. This is accomplished by filling the incised channel headward and downstream to create discontinuous oxbow lakes. Subsequent major flooding has not returned the restored channel to it incised condition.

Quail Creek, Maryland

The breach of a major storm water detention facility created reaches of incised G4 and F4 stream types near Cockeysville, Maryland in 1989–1990. The consequence of this incised river conversion created major downstream sedimentation from streambank erosion and channel adjustment and loss of a brook trout fishery. The restoration involved Priorities 2 and 3, which converted stream types from G4 to B4, F4 to C4, and F4 to B4c- (**Figures 5c**, **5d** and **5e**). Streambed and streambank stabilization measures included the use of native materials of boulders, root wads, logs and vegetation transplants and cuttings. Quail creek has been stable for the six years of post-construction monitoring despite the occurrence of many large floods (including January, 1996). The brook trout have retuned and the channel is self-maintaining.

Wolf Creek, California (Phase II and III)

Excessive watershed disturbance, headward tributary rejuvenation and direct channel impacts near Greenville, California, created incised channels (F4 stream types). Excessive streambank erosion was creating land loss, downstream sedimentation and fish habitat loss. Due to the currently occupied floodplain and constrained belt width (homes and highway), Priorities 2 and 3 were selected to convert the F4 stream type to a C4 and an F4 stream type to a B4c- (**Figure 5c** and **Figure 5e**). Native materials using vortex rock weirs with native boulders, root wads, logs and bio-engineering slope stabilization methods were used as implemented by Plumas Corporation of Quincy, California. A large flood in January of 1995 delivered 145,000 cubic meters of sediment in a 24-hour period through the restored reaches. Minimal damage occurred and little maintenance was required on the F4 to C4 and the F4 to B4c- conversions.

A previous restoration project (Phase I) conducted by the author on the same river in a different reach failed during this flood. This project did not involve an incised river but converted a D4 to a C4 stream type. The flood initiated the failure and a backwater condition was created due to a state highway bridge and the excessive sediment supply from upstream flood sources. Although this restoration had held up during several years of previous floods, the magnitude of the 1995 flood (one of the largest of record) caused both the stream and floodplain to aggrade 1–2 meters.

Wildcat Creek, California

This urbanized stream, as part of the East Bay Regional Park District (Alvarado Park) near Richmond, California, had been channelized and stabilized with old, vertical stone masonry walls, concrete beds and numerous concrete dams (2–3 meters in height). The stream consisted of incised A4, G4 and F4 stream types prior to the restoration. Active landslides impinged on the channel and archeological sites existed amidst eroding banks. The adverse channel condition had eliminated steelhead from migrating upstream, was adding accelerated sediment yields from streambank erosion, and had poor fish habitat. The aesthetics of the concrete structures were not compatible with the park setting. The restoration involved utilizing Priorities 3 and 4. Because the vertical walls were historic, they needed to be maintained in place. This prevented the required change in width/depth and entrenchment ratio to reduce shear stress on the channel. Thus, the restoration varied depending on the location of particular lateral constraints. In several reaches, the G4 stream type was converted to a B4 stream type (Priority 3, **Figure 5d**), and the F4 stream type was converted to a Bc- (**Figure 5e**). The removal of the concrete dams created an A4 stream type, which was made into a series of step/pool reaches with steep channel gradients, a low width/depth ratio and low entrenchment ratio (incised). This reach had to be stabilized in place due to the lateral constraints (Priority 4). Major floods occurred two years later in 1995 and again in 1996, which resulted in four meters of flood stage over the restoration project. Native material was used for stabilization, which included large boulders, root wads, logs and vegetation transplants. The flood created excessive shear stress on the reach of the A stream type next to the stone wall, which created a scour hole below the step/pool structure, dislodging three large rocks. This created local erosion of the toe of the high wall (two meters of width), which needed to be repaired. Other than this problem, the work survived the high floods, protected the streambanks and the archeological site from erosion, provided migration for the cold water fisheries, and restored the stream back to a more natural, stable channel.

SUMMARY

Incised rivers provide a great challenge to initiate various restoration and stabilization solutions. The following items are important to restoring natural stability and function to incised rivers:

- Understand the cause of the incision (entrenchment)
- Analyze watershed conditions, which may not only indicate cause, but may provide the solution
- Select the stable stream type associated with the landform and valley type
- Understand the restoration objectives and make sure they are compatible with the natural, stable morphology
- Obtain data from reference reaches of the stable stream type to be emulated
- Understand the evolutionary tendencies of rivers and recognize where this particular river is in relation to its potential end-point of equilibrium
- Select restoration priorities that allow the stream to speed up the process of natural stability along the evolutionary sequence
- Avoid working against the natural probable state of the river or “patching in place”
- Integrate geomorphology, engineering, biology and botany into the restoration solution

REFERENCES

Leopold, L.B., and Maddock, T. (1953). *The Hydraulic Geometry of Stream Channels and Some Physiographic Implications*. U.S. Geological Survey Prof. Paper 252, U.S. Government Printing Office, Washington, D.C.

Leopold, L.B., Wolman, M.G., and Miller, J.B. (1964). *Fluvial Processes in Geomorphology*. W.H. Freeman, San Francisco, California.

Leopold, L.B. (1994). *A View of the River*. Harvard University Press, Cambridge, Massachusetts, 298 pp.

Mackin, J.H. (1948). Concept of the Graded River. *Bulletin of the Geological Society of American*, Vol. 59, No. 5, pp. 463–512.

Rosgen, D.L. (1994). A Classification of Natural Rivers. *Catena*, Vol. 22, pp.169–199.

Rosgen, D.L. (1996). *Applied River Morphology*. Wildland Hydrology Books, Pagosa Springs, Colorado, 385 pp.

Schumm, S.A., Harvey, M.D., and Watson, C.C. (1984). *Incised Channels: Morphology, Dynamics and Control*. Water Resource Publication, Littleton, Colorado.

Simon, A. (1994). *Gradation, Process and Channel Evolution in Modified West Tennessee Streams: Process, Response, and Form*. U. S. Geological Survey Professional Paper 1470, Washington D.C., U.S. Government Printing Office.