River Restoration Utilizing Natural Stability Concepts

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The rivers of this country have been under siege in the last 75 years. They have been straightened, raised, lowered, lined, narrowed, widened, diverted, and dammed. Their floodplains have been taken over for the good of those who settled the land. Houses and even cities have been located where the high flows of the river were naturally dissipated amongst dense stands of riparian vegetation and associated wildlife habitat.

Well-intended, but misguided efforts toward river control are now starting to show the adverse results of such works. Those who live along the channelized river with the high levees have been watching the elevation of the river bed become higher than the floodplain. As this process occurs, the levees have to be raised to keep up with the rising river. When the stream wants to again seek its historic curves, erosion and breach of the levees occur. When flood waters breach through from an elevated river bed the great velocities and depths of flow create more damage than would have occurred naturally.

Concrete has not added to the aquatic and terrestrial habitats or to the beauty of the river. Engineers were directed to establish expertise at designing trapezoidal, lined, and straightened channels as the people demanded protection from the river. Rather than zoning for certain uses in the floodplain and along the river fringe, the direction has been to control and contain the river.

We are slowly learning from our recent observations and the unfortunate fate of those who are the recipients of the river's wrath. The saying "it's not nice to fool Mother Nature" seems particularly appropriate as we see the river trying to re-establish its natural functioning and pattern. There has recently been a rejuvenation of thought and direction by many throughout the country about the restoration and protection of our rivers. One can observe the loss of habitat, river function, and beauty for only so long before an ethical, as well as a geomorphic, threshold is exceeded.

When an agency such as the U.S. Army Corps of Engineers (COE) begins researching ways of "putting a river back" and integrating environmental engineering into its planning efforts, then indeed, there is a tide of change in the country! Engineers and others are faced with a new challenge— "How do you put a river back?" The traditional control and containment designs don't cover this. In recent years, the author has been working with federal, state, and local agencies, as well as consultant firms to teach and include the application of river restoration principles into their design manuals and procedures.

Can we live in harmony with the river without causing these adverse adjustments? Can we continue to utilize the resources provided by the river without jeopardizing the integrity of the river? The answer is yes! But to do so, we must understand the "rules of the river." We still have many positive examples where we have lived in harmony with the river. In many of these instances, well-managed land use activities adapted to infrequent flooding have contributed to the livelihood of many without adverse affects on the river. In some urban areas, floodplains are maintained in vegetated parks with trails interspersed. When floods occur, as they always will, there is little damage.

General Principles

Channel Variables

Underlying the complexities of river processes is an assortment of interrelated variables that determine the dimension, pattern, and profile of the present-day river. The resulting physical appearance and character of the river are products of channel boundary and slope adjustment to the present streamflow and sediment regime.

River form and fluvial processes evolve simultaneously and operate through mutual adjustments toward self-stabilization. Stream systems are dynamic and their pattern, dimension, and profile are determined by an interaction of process variables, such that a change in one variable sets up a mutual adjustment in the others (Leopold et al., 1964). The variables are width, depth, slope, velocity, flow resistance, sediment size, sediment load, and stream discharge. Because of the complex interactions associated with the individual variables, a stream classification system was developed to describe combinations of the various "integrations" as predictable, morphological stream types (Rosgen, 1985, 1993). The stream classification system is useful in restoration designs to quantify the basic morphological relations for a given river so that the design may better match the potential of the natural, stable channel form.

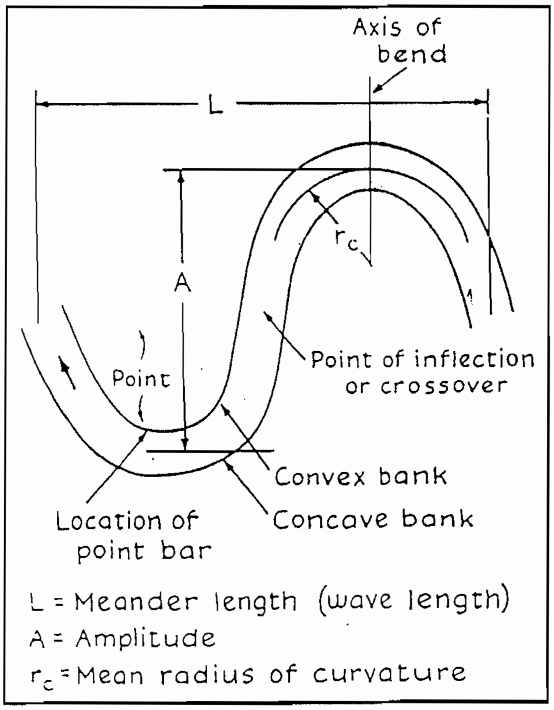


Figure 1. Plan-view sketch of idealized meander (from Leopold et al., 1964).

Successful restoration efforts must utilize established principles of process and function that accommodate a river's predictable response tendencies. Channel stabilization methods that do not follow the known and observable relations are inviting potential long-term problems due to the negative feedback mechanisms from the very streams that we are trying to "help." The basic tendencies of river function and adjustment rely on principles reported by Inglis (1947), Leopold and Wolman (1957, 1960), Leopold et al. (1964), and Langbein and Leopold (1966). The relationship of: meander geometry related to stream size; stream size related to stream discharge; the linear sequence of riffle-pool bed features related to channel width; and hydraulic geometry relations were established by this early research and are used today as the theoretical basis for the restoration design.

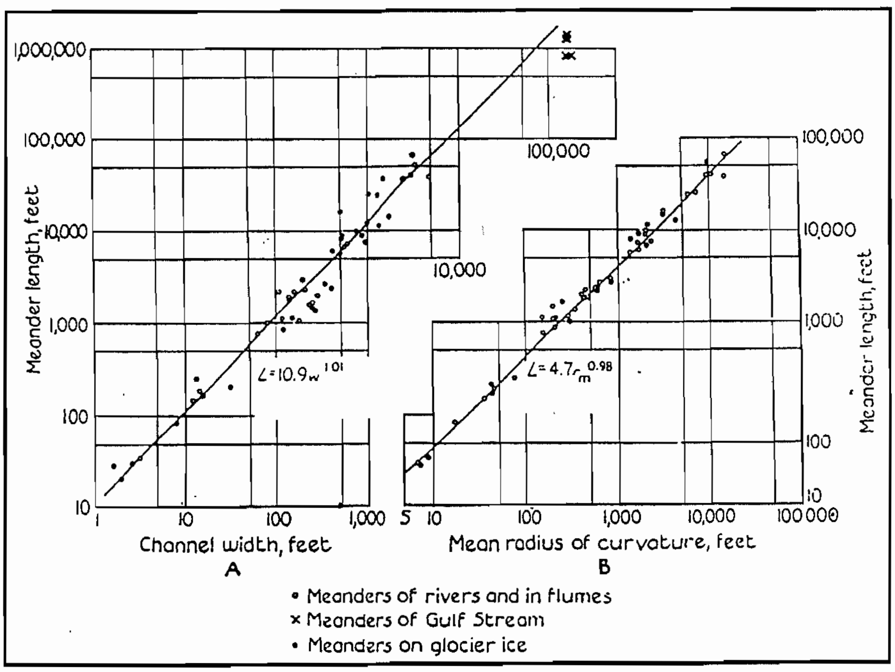


Figure 2. Relation of meander length to width (A) and to radius of curvature in channels (from Leopold et al., 1964).

Specific characteristics of meander geometry are related to channel dimensions and plan features such as meander wave length, radius of curvature, and meander amplitude as described and presented in Figures 1 and 2. The Leopold and Wolman (1960) equations that represent these relations are shown as:

$$L_m = 10.9W^{1.01} \quad (1)$$

$$A = 2.7W^{1.1} \quad (2)$$

$$L_m = 4.7\, r_c^{0.98} \quad (3)$$

where: L_m = meander length (ft)
W = bankfull surface width (ft)
A = amplitude (ft)
r_c = mean radius of curvature (ft)

(Equations published in English units.)

Another useful equation developed by Langbein and Leopold (1966) was that of a sine-generated curve which described meander paths:

$$R_c = \frac{L_m K^{1.5}}{13\,(K-1)^{0.5}} \qquad (4)$$

where: K = channel sinuosity (channel length/valley length)

R_c = radius of bend curvature.

A recent study by Williams (1986) tested the above equations on a data set larger than was used in the original work. Williams found that the application of the equations produced results that agreed quite well with the earlier findings of Wolman and Leopold (1957, 1960), (Figure 3).

A common problem associated with the "traditional designed channel" restoration is that attempts are made to put all of the flow into *one* channel. Most alluvial rivers consist of *three* distinct, but related, channels: the thalweg, or low flow channel; the bankfull, or normal high water channel; and the established floodplain, or channel that carries flows greater than the bankfull discharge. In many river restoration designs, this very basic and important concept is not taken into consideration (Figure 4). As a result, channels designed to contain all the flows in a common width, are constructed "over-width." The consequence of building these over-width channels often leads to aggradation due to a reduction in stream energy or competence of the river necessary to move the sediment associated with the normal, frequent run-off events. Once sediment deposition occurs and bar features form, infrequent flushing flows do not remove these features but start an aggradation process and lateral migration adjustment. Over time, bar features enlarge, extend, and often become islands. This process is more prevalent in the riffle/pool stream types rather than the step/pool types.

Often when grade control structures, such as check dams, are installed in rivers, the local upstream slope is reduced. The width/depth ratio increases, and the stream responds by initiating lateral adjustment. A study of aerial photographs over large areas will show that channel sinuosity is higher on the gentle gradient rivers than the steeper channels. The higher sinuosity occurs as a

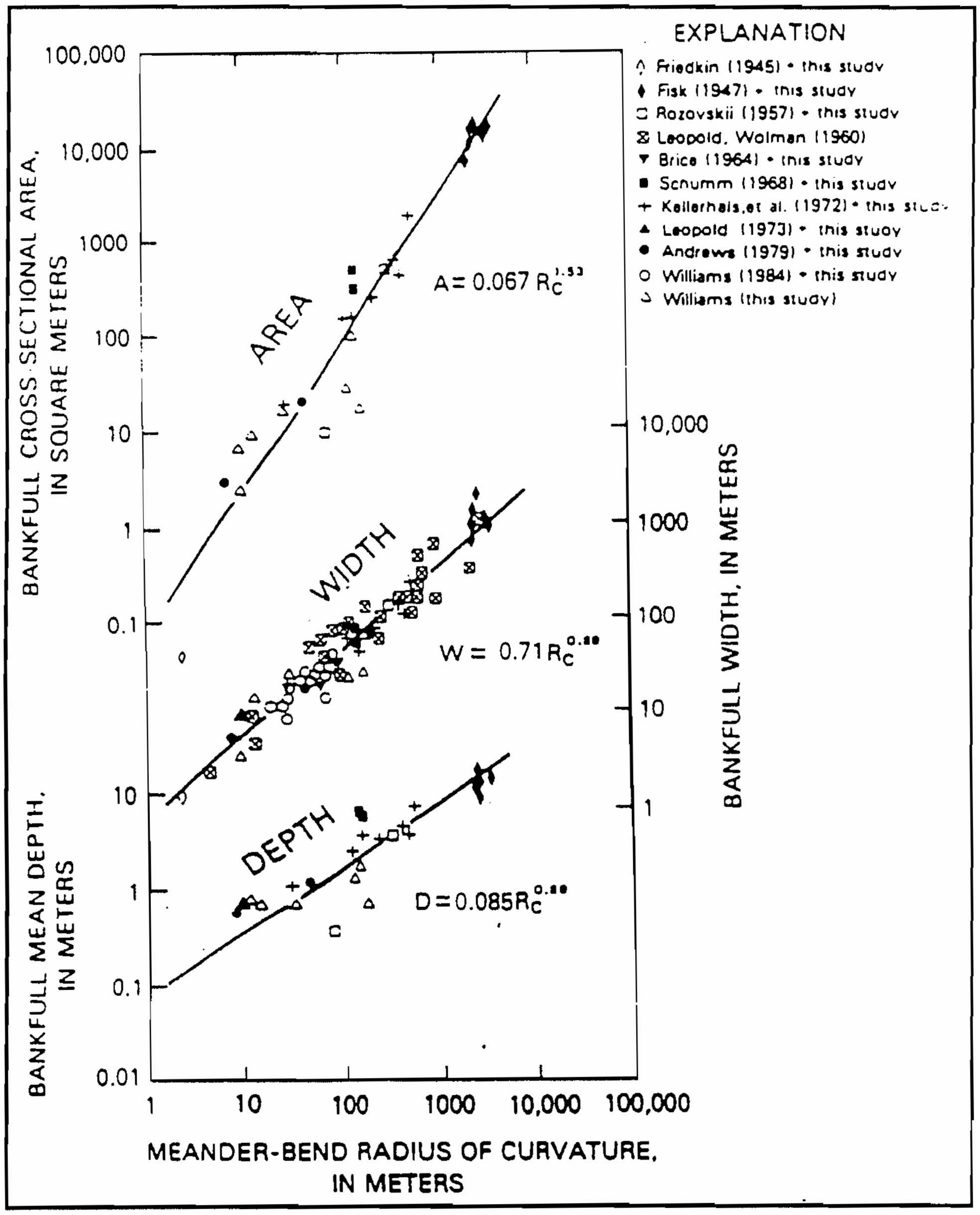


Figure 3. Relation of channel dimensions to meander-bend radius of curvature in meters (from Williams, 1986).

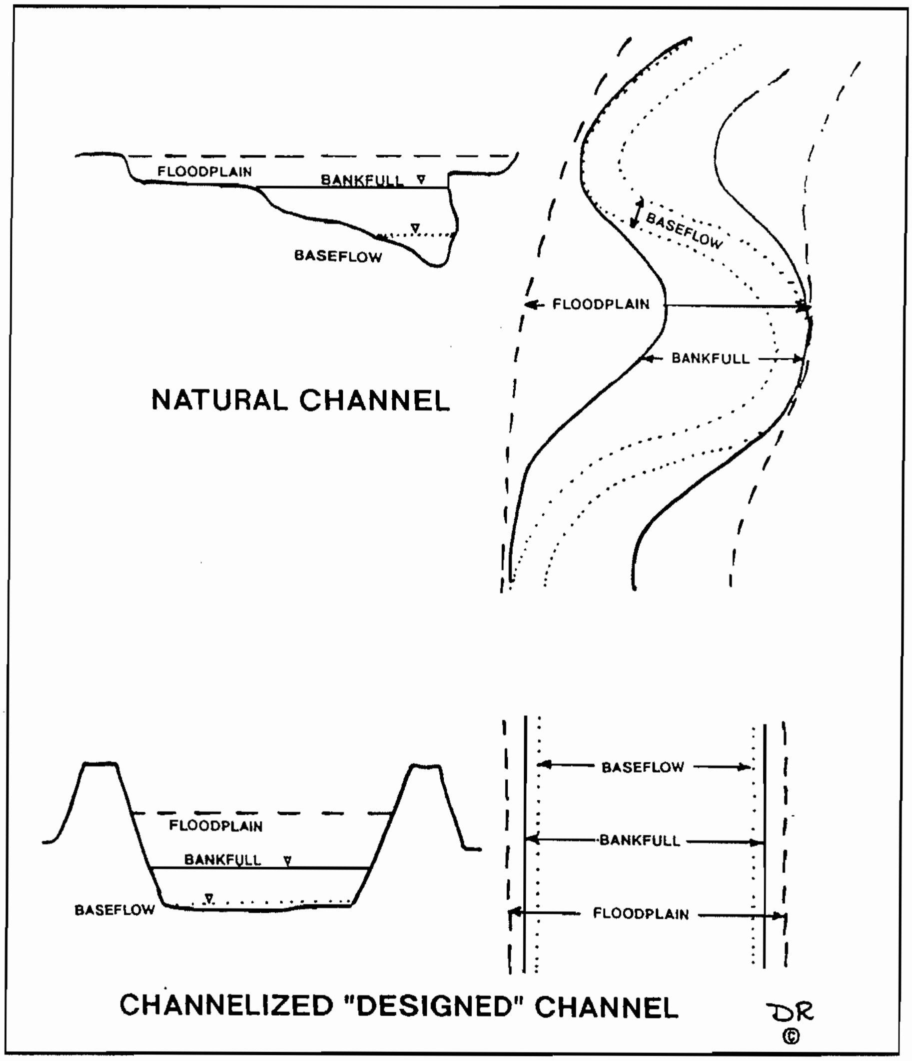


Figure 4. Comparison of "designed" channel dimension and pattern compared to natural channel.

width ratio relations by stream type (Figure 7).

In river restoration design, the meander width ratio is an important morphological feature that must be integrated into the restoration plan. Sinuosity, width/depth ratio, entrenchment ratio, slope, and particle size distribution are not only important for delineation of stream types, but are critical for design specifications for a given river morphology.

Evolution of stream types, caused either naturally due to climate changes or induced due to changes in watershed management, can be observed as a sequential series of channel change. An example of one scenario for a series of channel adjustments and corresponding change in stream type is depicted in Figure 8. Knowing the current state and direction or tendency of channel adjustment is critical to river restoration design. We often try to make a stream into what it "doesn't want to be"! The potential state, or condition, can be inferred by stream type as well as empirical relations for design specifications to emulate the stable morphology.

result of natural bank erosion processes as the river, in an effort to accommodate excess stream energy, naturally adjusts it's form and planimetric configuration. Flattening slopes of rivers, which is often a part of stream restoration projects, usually results in accelerated bank erosion and sediment deposition.

Stream Classification

An arrangement of the morphological variables that can be organized into a common description called "stream types" are shown in Figures 5 and 6. Applications for restoration involve the integration of the variables as stream types into more detailed descriptions involving plan features of the most probable state. An example of this is shown in the meander

Watershed Conditions

Before entering into a major stream restoration project, it is important to *first* understand what caused the instability. Often restoration work is only an exercise in *patching symptoms* rather than working toward a *cure*! Flow regimes that can be altered in magnitude and duration due to vegetation manipulation, urban development, etc. have to be understood and calculated. Changes in sediment supply directly affect the channel stability, and as such need to be determined. Taking care of the problem on-site rather than accommodating sediment supply through in-channel storage is a recommended alternative. However, as logical as this statement appears, there are many ill-fated projects being constructed that are designed to store excess sediment in the active channel.

Structural alternatives can often be minimized or even eliminated if a healthy

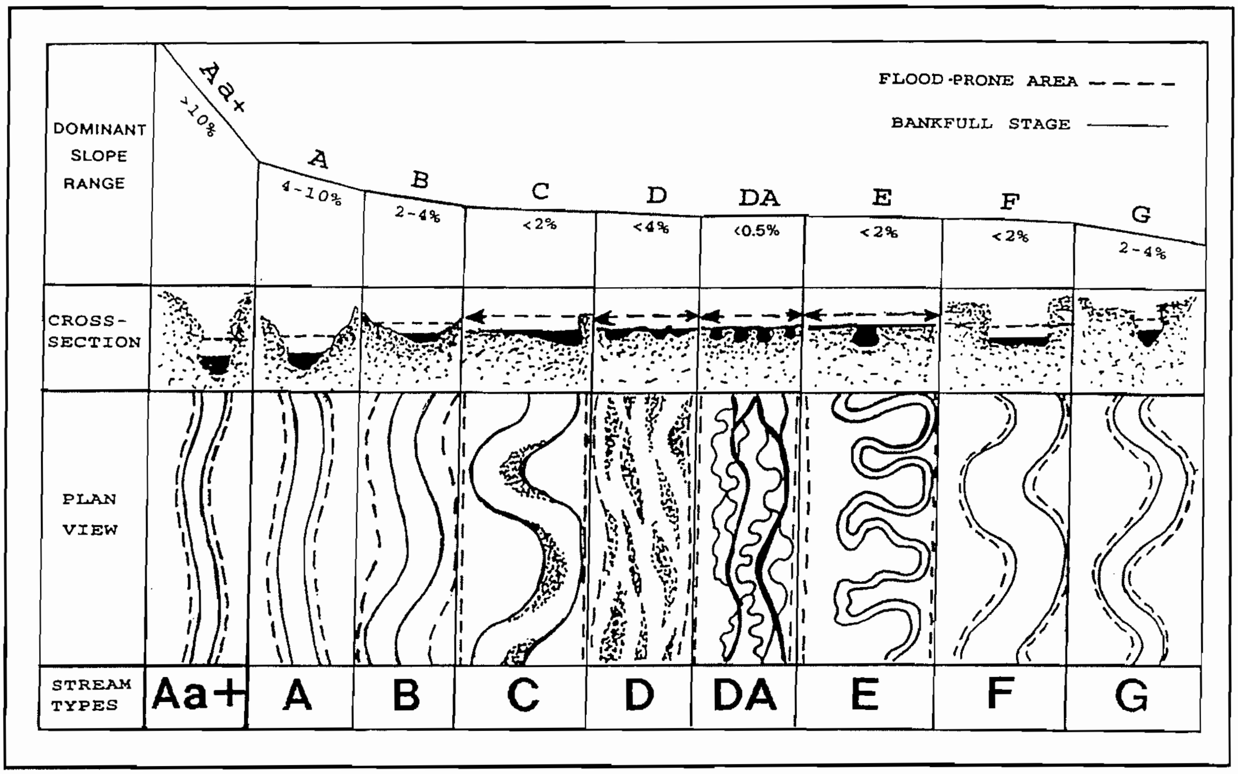
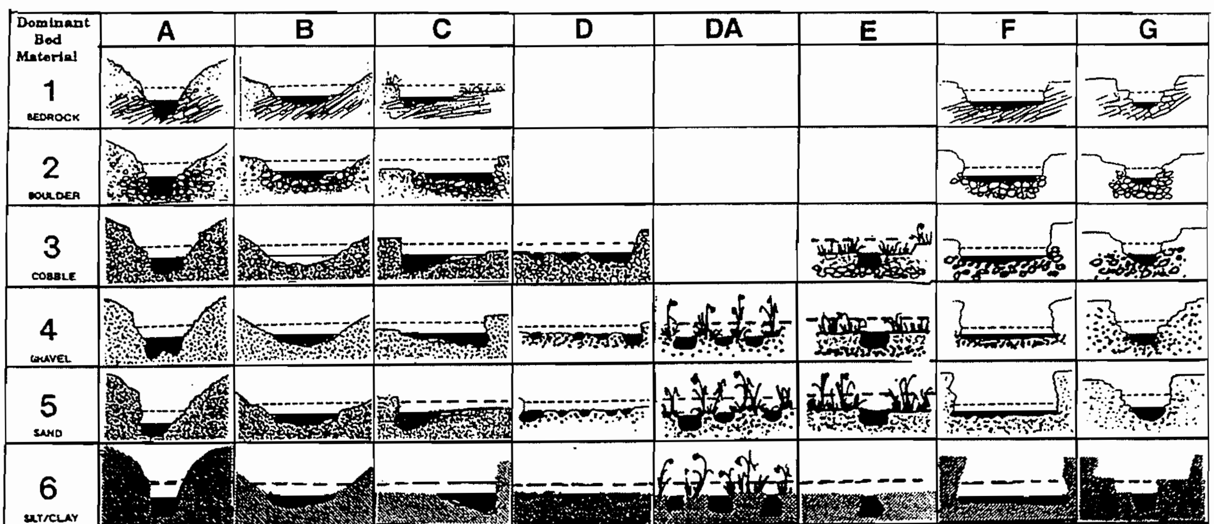


Figure 5. Broad level stream classification delineation showing longitudinal, cross-sectional, and plan views of major stream types (from Rosgen, in review, 1993).



	A	B	C	D	DA	E	F	G
ENTRH.	<1.4	1.4–2.2	>2.2	N/A	>2.2	>2.2	<1.4	<1.4
SIN.	<1.2	>1.2	>1.4	<1.1	1.1-1.6	>1.5	>1.4	>1.2
W/D	<12	>12	>12	>40	<40	<12	>12	<12
SLOPE	.04–.099	.02–.039	<.02	<.02	<.005	<.02	<.02	.02–.039

Figure 6. Illustrative guide showing cross-sectional configuration, composition, and delineative criteria of major stream types (from Rosgen, in review, 1993).

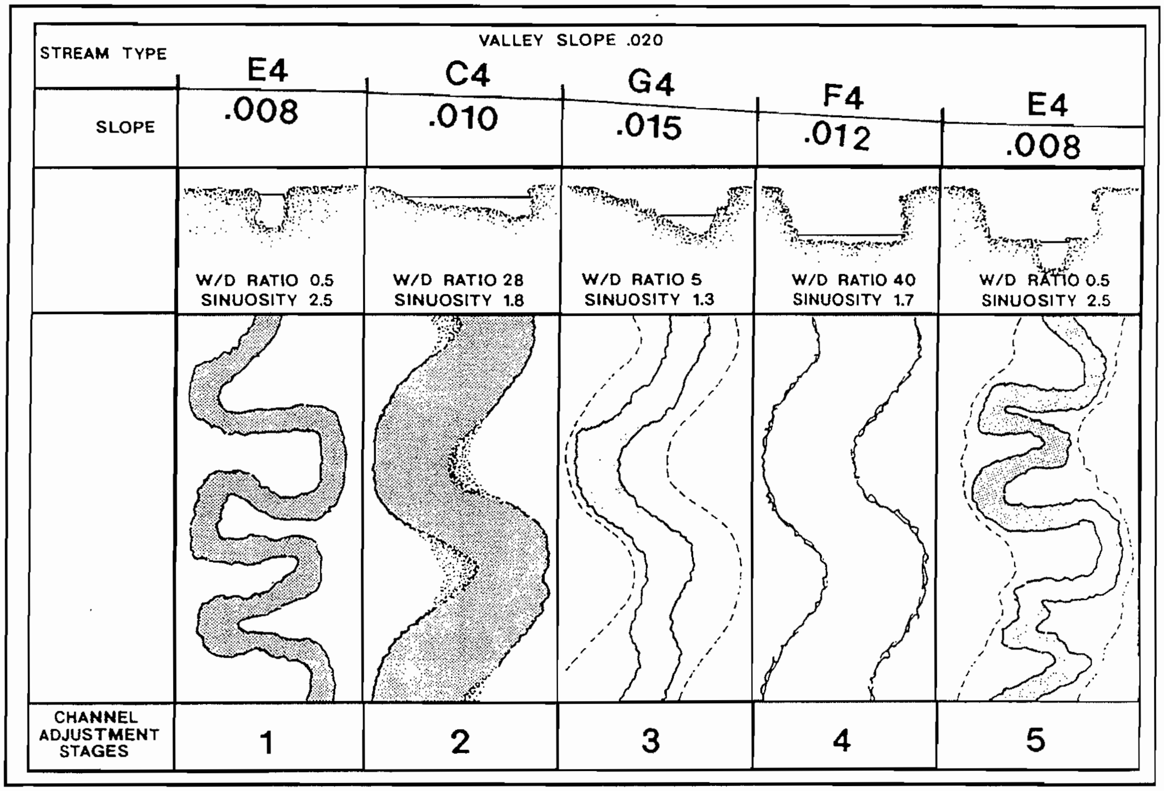


Figure 7. Meander width ratio (belt width/bankfull width) by stream type categories (from Rosgen, in review, 1993).

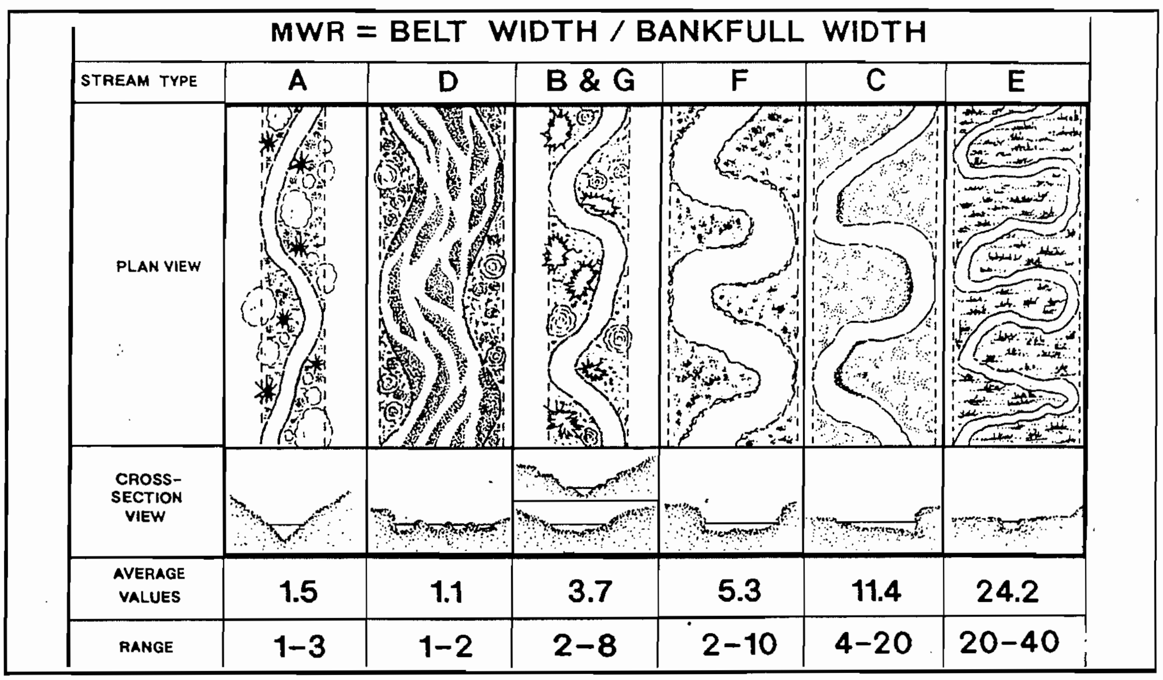


Figure 8. Evolutionary stages of channel adjustment showing corresponding changes in morphology, dimensions, pattern, and slope as indicated by stream type (from Rosgen, in review, 1993).

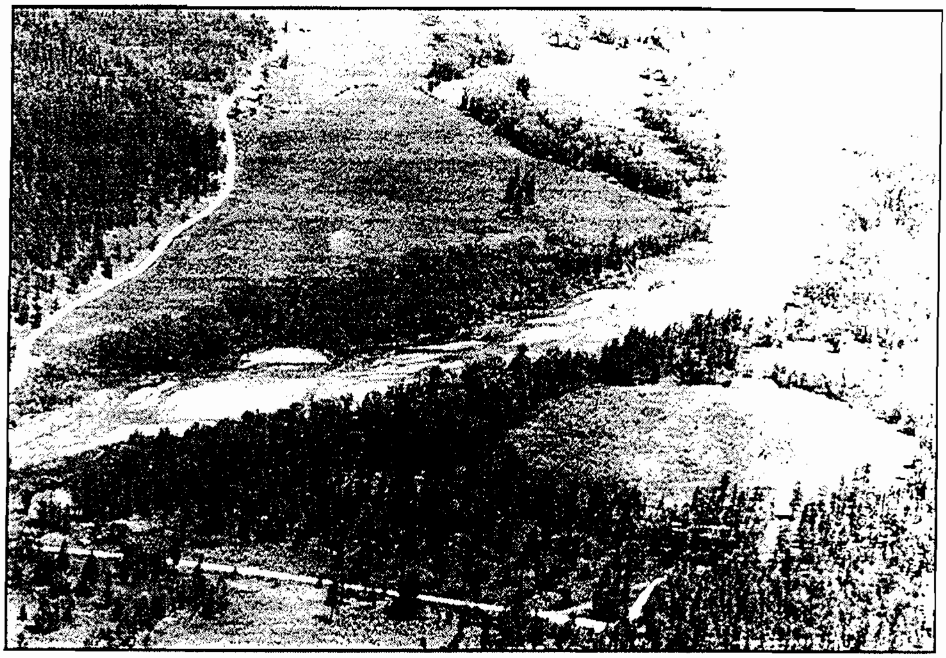
watershed condition can be maintained. *Good* riparian grazing practices can be very effective at reducing bank erosion and improving fish habitat. Fair to poor grazing practices can reverse this process.

Examples

To demonstrate these application principles, a couple of brief examples of large-scale stream restoration projects are summarized.

Rio Blanco—Colorado

A reach of this river was straightened and leveed in the late 1960s. The traditional attempt at river control resulted in the development of a braided (D4) channel; in 1987, a 3.8-kilometer reach was converted to a meandering (C4) stream type. This project is summarized by the National Research Council (1992) and is shown at right.



Aerial view of the braided reach (D4), Rio Blanco, 1986, looking upstream.

Aerial view of Rio Blanco following restoration, showing meandering stream type (C4), 1992, looking upstream.

East Fork of the San Juan River—Colorado

The East Fork naturally converted to a braided channel as extensive willow eradication in the 1930s resulted in accelerated bank erosion and channel widening. The 8 kilometers of existing braided channel, with an average width of 350 meters, was responsible for contributing over 49 percent of the total annual sediment load of the 140-square-kilometer watershed due to accelerated bed and bank erosion. A restoration demonstration study was initiated as part of a section 404 permit through the COE. In 1986, a 1.6-kilometer reach of river was converted from a braided (D4) stream type to a meandering (C4) stream type. The meander geometry relationships and channel dimensions for a stable C4 stream type were emulated on paper, then implemented by constructing a new channel and floodplain. Monitoring has demonstrated that the pattern, profile, and dimensions of the new stream type have been stable. The competence of the river to transport sediment has been improved along with a greatly improved brown trout fishery and visual enhancement. A vegetated floodplain now exists over previous gravel bars. Streambank stability was afforded by the implementation of a bank revetment and fish habitat design using a combination of willow transplants and cuttings, root wads, logs, and boulders. Fish habitat has been improved by increased depths for the same discharge, improved overhead and in-stream cover.

There are many additional restoration projects designed by the author that utilize natural stability concepts including, but not limited to: Wolf Creek, Bull Creek, and the Eel River in California; Quail Creek in Maryland; Lamoille and Maggie Creeks in Nevada; other rivers in Colorado, Idaho, Montana and North Carolina. Unfortunately, space limitations preclude their presentation here.

Summary

Results from monitoring these restoration projects, which have utilized natural stability principles, show the potential of alternative strategies to traditional large-scale river channelization. Rivers can be improved in their stability, visual values, water quality, riparian function, and terrestrial and aquatic habitats. Fish habitat improvement from this approach is greatly improved and becomes a central objective in much of this work.

Continued monitoring with similar projects will help all of us learn and improve our ability to "put something of value back" into our rivers. In this manner, we can demonstrate the ability to regain the stability, integrity, and natural functioning of our inherited fluvial systems for those who follow.

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