CHAPTER 3

Rivers and Streams

USDA Forest Service

Billions of years ago, rivers were formed by runoff flowing towards low elevations and coalescing to form rivers that sculpted and eroded paths towards the lowest points on Earth. Huge lakes were formed and eventually they joined to create our oceans. These processes continue today, albeit, in somewhat subdued fashions (Mount 1995).

This chapter discusses how balance in river systems is achieved by certain forces and how these forces dictate the physical behavior, size, and shape of a river. The river profile, the channel patterns, and the loci of deposition and erosion all reflect a river's attempts to balance energy expenditures, develop a least-work design, and process the discharge and sediment supplied to it by its watershed.

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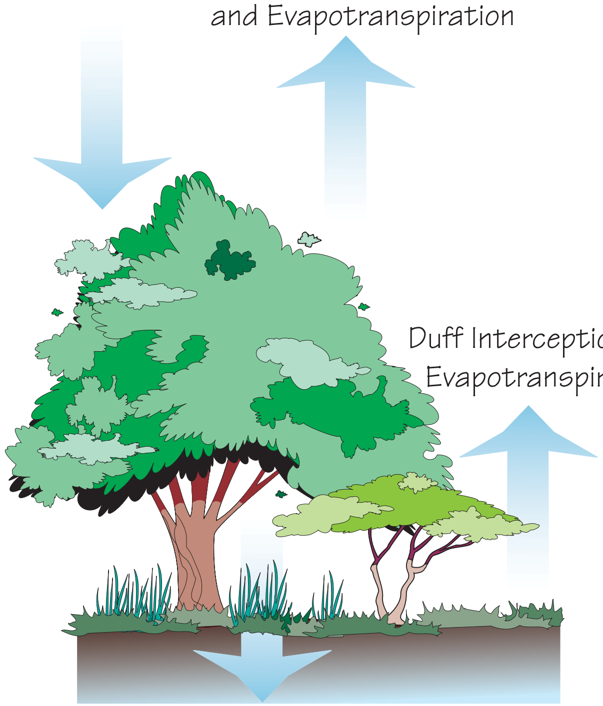
Only a portion of precipitation ends up as runoff. More often plants intercept it and evapotranspiration occurs or precipitation is infiltrated into the ground to moisten soil and feed aquifers. Moisture not intercepted, evaporated from plants and soil, or infiltrated becomes runoff and is driven by gravity towards the sea.



Captured from mountaintops, hills, and sloping watersheds, water is energy that runs the river's engine and "gravity is the driving force behind the water, accelerating it at a rate of 32.2 feet per second toward the center of the Earth. Given this acceleration, one could easily envision that a river should be constantly increasing in velocity as it flows down hill. Yet in any given reach of stream over any short period of time, current velocity varies little. The fact that water does not continuously accelerate reflects the balance between the forces that drive water (gravity), keep it in motion (momentum), and try to stop it from moving (friction)" (Ibid.).

Distributing the Work

Regardless of the variation in size, shape, and complex composition, rivers are the predictable product of interaction between physical, chemical, and biological processes.

According to Mount (1995),

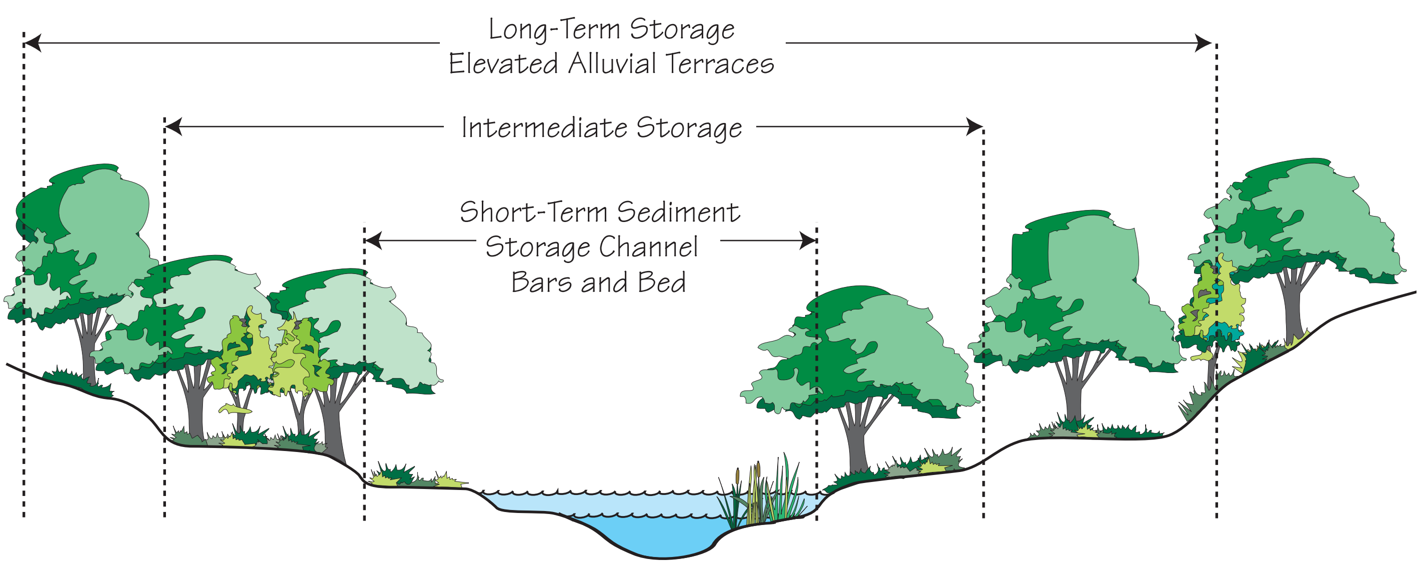
"One prominent school of thought about rivers is based, in part, on the concept of grade or equilibrium. Grade assumes that the present morphology and behavior of a river reflects a balance of the forces that operate through it and upon it. In natural systems that move energy and matter, there is a tendency for the system to arrange itself in a manner that both reduces the amount of work and distributes that work as evenly as possible. These two tendencies are often in conflict with each other in rivers. The energy and matter that flows into and through a river system is the discharge and sediment load provided to it by its watershed. Intuitively, the most efficient means for a river to route this energy and matter to the sea would seem to be to develop a perfectly straight channel of uniform slope. However, because water accelerates under the influence of gravity, energy expenditures (work) would not be equally distributed along the entire straight channel. In addition, since tributaries add water to a river, the amount of energy and matter in the system progressively increases down slope. Rivers deal with this tendency for nonuniform distribution of work by adjustments in profile, channel cross section, and channel pattern. ...The concave-up longitudinal profiles of rivers and their alluvial floodplains with meandering channels and associated riffles and pools are all the product of the rivers' attempts to minimize the amount of work performed and to spread that work out as evenly as possible. In this manner rivers are self-regulating, evolving just the right pattern and profile to handle the amount of discharge and sediment delivered to them. This balance is termed *grade* (not to be confused with slope or gradient) and records a state of *equilibrium* within a river system.

The Shape of Rivers

"Most of the business of a river is conducted through its channel. The day-to-day task of handling discharge, the year-to-year task of eroding, transporting, and depositing sediment, and the long-term adjustments toward some equilibrium are all dependent on processes that occur within or immediately adjacent to a river's main channel. The morphology and behavior of channels have long been considered a sensitive indicator of the 'state' of any river as well as a record of processes acting within a watershed.

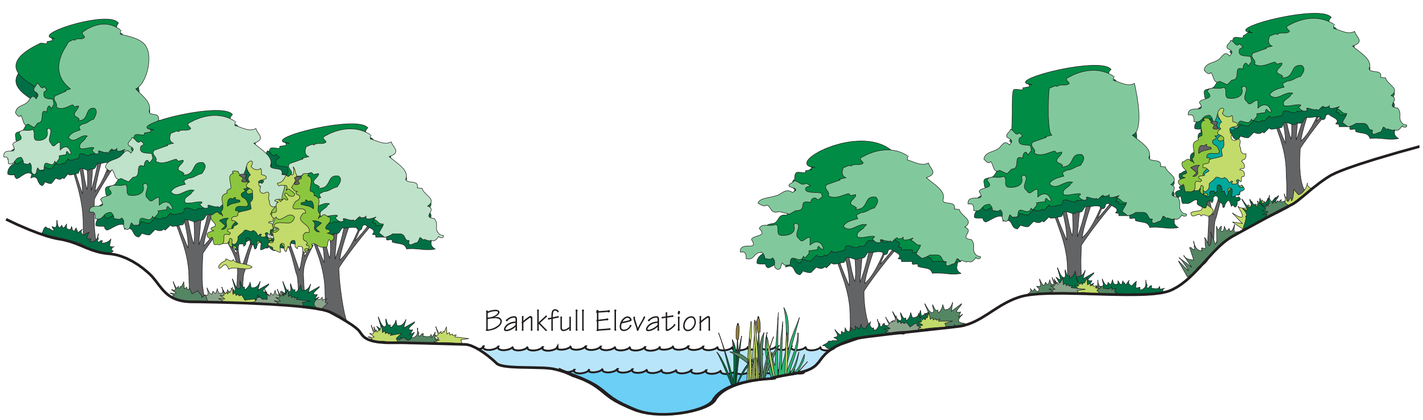
"The maximum grain size that a flow can transport is its competence; the total amount of sediment that can be transported is a river's capacity... . Rather than routing all sediment through quickly, rivers will typically store sediment within a variety of depositional sites. Short-term storage occurs in channel bars and in the channel bed. Intermediate storage occurs within the floodplain. Long-term storage occurs within elevated alluvial terraces. Declines in capacity and competence lead to deposition within all of these sites. Excessive stream power or declines in sediment supply can cause a river to selectively erode material in these sites.

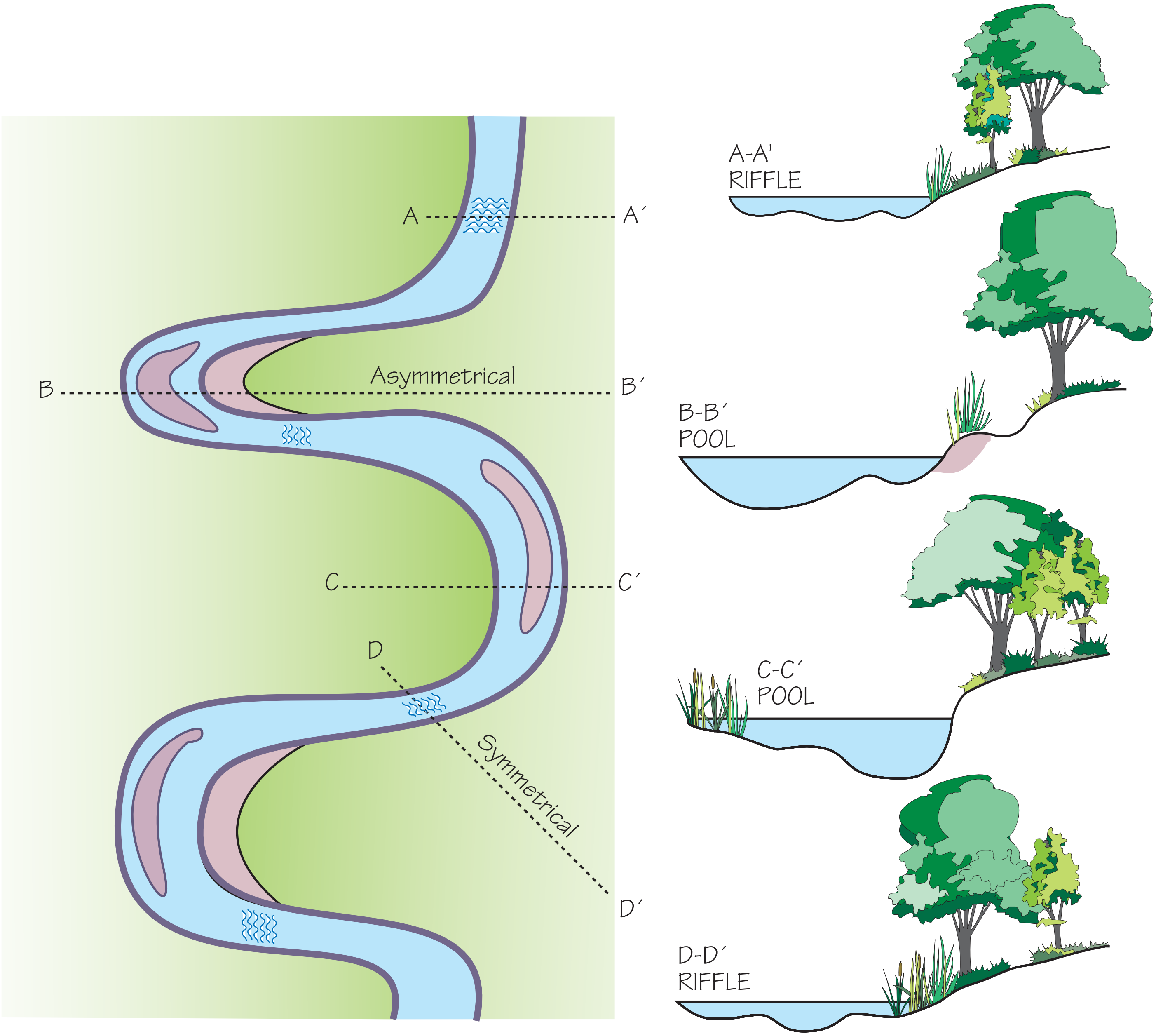
"A river balances and minimizes its energy expenditures through adjustment of its channel cross section. Along the entire length of a river the shape and size of an infinite number of cross sections are in constant variation, adapting to the discharge and sediment load that is delivered to it by the channel reach that lies immediately upstream. In aggregate these adjustments produce the distinctive channel patterns that record the establishment of dynamic equilibrium within the overall river system.



"Rivers construct channel cross sections that are best adapted for the wide range of discharges delivered by their watersheds. [Studies have shown] that although unusually large discharge events are capable of greatly affecting river channels and river geomorphology, their occurrence is so rare that, when viewed in the long term, their effects are usually masked by intermediate, more frequent discharges. The ability of intermediate flows to erode, transport, and deposit sediment allows them to eventually undo the effects of the larger events and to control the equilibrium configuration of the channels. The intermediate discharge that appears to exert the greatest influence on the shape and size of channel cross sections and thus on the overall geomorphology of the river is generally known as *bankfull stage* or *bankfull discharge*. For most rivers, bankfull stage occurs when discharge fills the entire channel cross-section without significant inundation of the adjacent floodplain.

"Bankfull stage or bankfull discharge... usually occurs with a frequency of 1.5 to 2 years for natural, undammed rivers.... Apparently, bankfull discharges meet two key criteria for shaping channel cross sections: (1) the flows contain sufficient stream power to erode bank materials and to transport and deposit large volumes of sediment; and (2) they occur often enough that their effects are not muted by the weaker, but higher-frequency, smaller-discharge events. The interaction between bankfull discharge and its channel produces a wide range of channel cross sections. The causes of these variations are numerous but are usually tied directly to interaction between the flow and the bank [and bank] materials [and riparian vegetation. For example,] within any given channel reach, the cross-sectional profile of the river varies from symmetric to asymmetric.... This variation is due primarily to the tendency of a river to develop meanders rather than a perfectly straight channel.... Within meander bends that are tightly curved, the cross-section profile becomes strongly asymmetric. In the relatively straight stretches between meander bends, the profiles are more symmetric." (Mount 1995)




A
A´
B
B´
Asymmetrical
C
C´
D
D´
Symmetrical
A-A'
RIFFLE
B-B´
POOL
C-C´
POOL
D-D´
RIFFLE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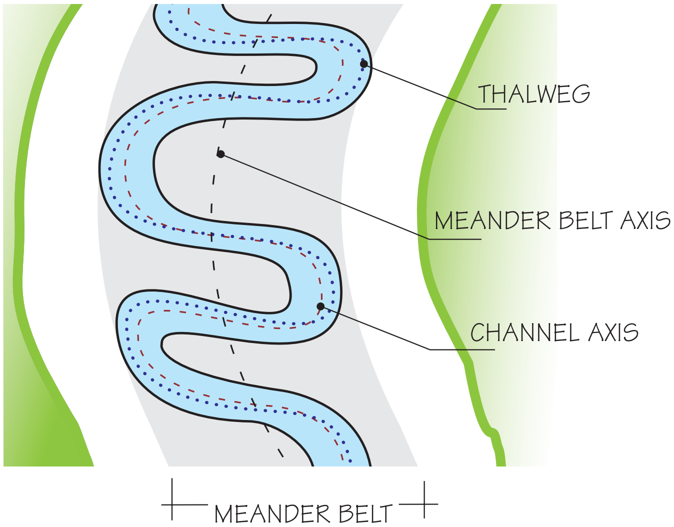
Channel Pattern

"River and stream channel patterns can be grouped into two general classes: single channel and multichannel. The flow in single channel rivers is restricted to a discrete, sinuous channel… . The differences between single and multichannel rivers reflect contrasting watershed onditions.

"When examining single channel rivers in map view… the greatest variation appears to be in the way they snake across the landscape. This snakelike property is termed channel *sinuosity*. The sinuosity of a river is variably defined but is generally a reflection of the channel length required to cover a given point-to-point or straight-line distance. [Other natural influences on sinuosity include geology, fault lines, and topography. ("Stream Corridor Restoration" includes more information on this topic. See the Bibliography for more details.)]

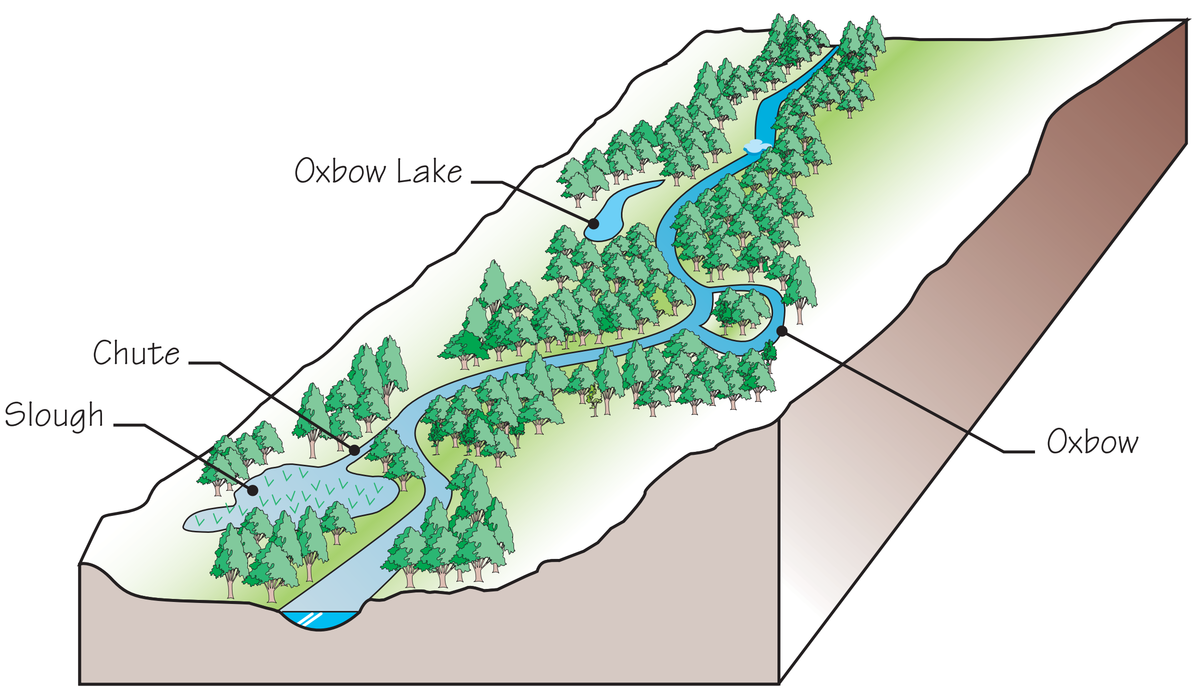
"[As shown in the drawing], the irregular course of a river usually occupies a portion of a valley, termed the *meander belt*. A line drawn down the center of this meander belt is referred to as the *meander belt axis*. In large valleys… the meander belt axis does not always parallel the valley walls and thus tends to be longer than the valley itself. There are two possible axial measurements within the river channel: the *thalweg*, which is the deepest portion of the channel, and the *channel axis*, which is equidistant from the channel walls.



"The 'urge' to meander involves interaction between sediments that make up the bed and bank material [including riparian vegetation] and the oscillatory nature of flow within a channel. The longitudinal bed profile of most rivers and streams is broken into a series of alternating segments of high and low gradient. These segments form the *riffles* and *pools*, respectively, that are evident at low water levels. Riffles are the topographic high points on a bed profile. They are typically spaced five to seven channel widths apart and are composed of the coarsest bedload that is being transported by the river. Pools, the haven of most river fish, are deep-water areas between the riffles. During high flow events, the pools are usually scoured, leaving a coarse gravel lag or channel armor and depositing material on the riffles.

"Downstream as well as lateral expansion of meanders will eventually cause meander channels to intersect, temporarily reestablishing a shorter and straighter channel and cutting off the channel that originally made up the large meander bend... . Where both ends of these abandoned meander channels are cut off from the newly established channels, they form horseshoe-shaped lakes, known as *oxbow lakes*. These lakes become the sites of accumulation of fine overbank sediments and vast quantities of organic material such as peat. When the lakes fill with sediment, they commonly become swamps or wetlands. If one end of the abandoned meander continues to receive flow directly from the channel, *sloughs* are formed. These, too, eventually fill with sediment but are less likely to accumulate large quantities of peat. A second and perhaps more common cause of abandonment of meanders is associated with the development of cutoffs. During flooding events, flow across the inside of the point bar can establish chutes or channels. Intense scouring of these chutes can lead to the establishment of a new channel across the point bar and abandonment of the meander.

"The tendency for deposition during overbank flooding events to be concentrated near the river can, in the long term, lead to a buildup of the meander belt itself. During very large floods, a river will occasionally abandon its meander belt entirely and establish a new channel in the surrounding lower-lying areas of the valley. Termed *avulsion*, large-scale channel abandonment is a common feature of most large and intermediate river systems... .



"…many of the world's greatest rivers…do not occupy a single, sinuous channel. During moderate to high [floods] these *braided* rivers establish multiple channels that repeatedly diverge and join.

"An important characteristic of braided rivers is the instability of their channels. Channel abandonment can occur on time scales varying from hours to months and can involve either gradual or sudden changes. The reason for the dynamic nature of braided river channels is rooted in their varying discharge, overall coarse sediment load, and unstable bank materials. During rapidly rising river stage, [river turbulence quickly increases in intensity causing] the coarsest material being transported to accumulate within the center of the channel. In coarse bedload systems, these accumulations initiate the formation, growth, and downstream migration of channel bars. As a channel bar grows, it deforms or splits the flow, increasing bed shear stresses in channels or chutes on either side of the bar. Because the river is bedload dominated, the bank materials tend to be relatively coarse-grained and erosionally nonresistant" (Mount 1995).

All rivers and streams naturally change course. Knowledge and awareness of how this process occurs can make a difference in management and in deciding what should be stabilized and how.

Stream Channel Morphology

Stream or river morphology is included to make the reader aware of the classification systems. These systems can be useful in analyzing a stream and resolving a problem, especially if one's interest is in channel redesign.

Schumm (1997) relates the type of channel to the predominant type of bedload in a channel. For example, stable straight channels and meandering channels have cohesive banks and primarily carry a suspended sediment load. Braided channels move primarily bedload sediment and have noncohesive banks.

Montgomery and Buffinton's (1993) work reflects research done in the Pacific Northwest for alluvial, colluvial, and bedrock channels. Their system is similar to Schumm's. They look at the channel's responses to sediment throughout the watershed.

To date, the most widely practiced approach in the Forest Service to river morphology, form, and structure is the Rosgen classification system. It can be used to predict the expected stream type and floodplain features of a specific stream based on a hierarchical analysis system.

According to Harrelson, Rawlings, and Potyondy (1994), "Stream classification provides ways to look at stream channels, to group those that are similar, or to identify features that are different. As we expect streams of similar types to act in similar ways, classification offers a powerful tool for selecting streams for comparison. This classification allows:

- prediction of a river's behavior from its appearance,
- comparison of site-specific data from a given reach to data from other reaches of similar character, and a
- consistent and reproducible system of technical communication for river studies across a range of disciplines.

"Rosgen's classification scheme initially sorts streams into the major, broad stream types (A-G) at a landscape level…. At this level, the system classifies streams from headwaters to lowlands with stream type:

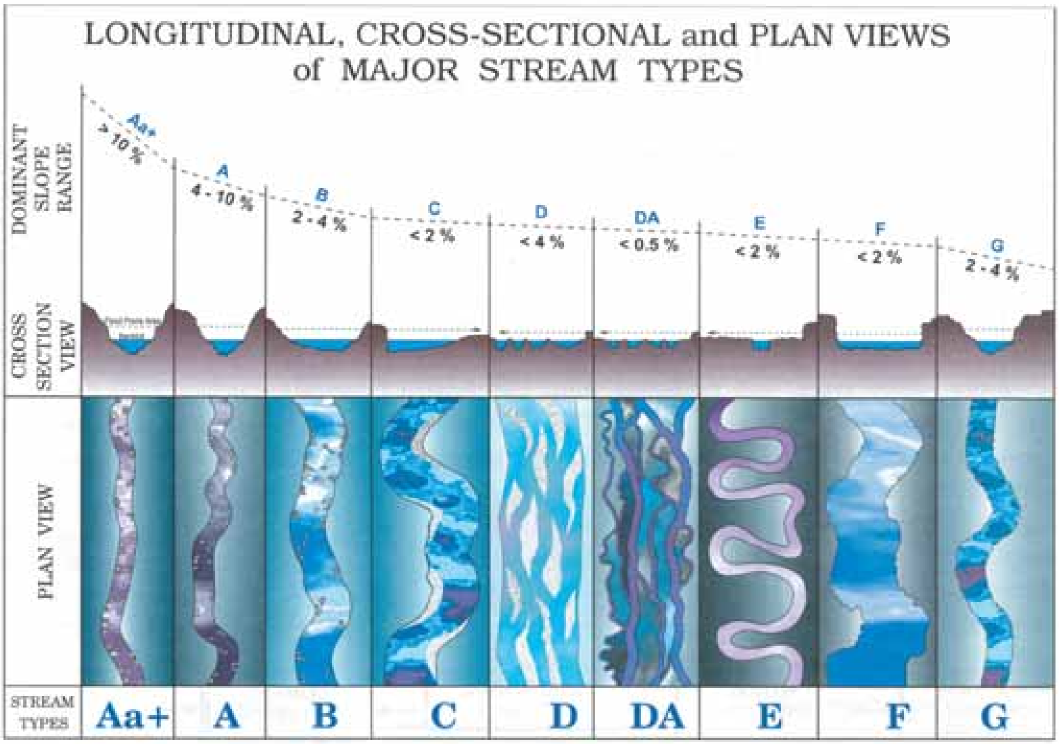
A–headwater	B–intermediate
C & E–meandering	D–braided
F–entrenched	G–gully.

"The Rosgen system breaks stream types into subtypes based on slope ranges…and dominant channel material particle sizes… . Subtypes are assigned numbers corresponding to the median particle diameter of channel materials:

1 = bedrock	2 = boulder
3 = cobble	4 = gravel
5 = sand	6 = silt/clay.

"The above provides a simplified description of the Rosgen system… . For more complete information about the classification and associated inventory procedures, see Rosgen (1994). Ultimately, stream classification helps to distinguish variations due to stream type from variations in the state or condition of sites."

Additional information on Great Basin geomorphology and plant materials is in appendix B.



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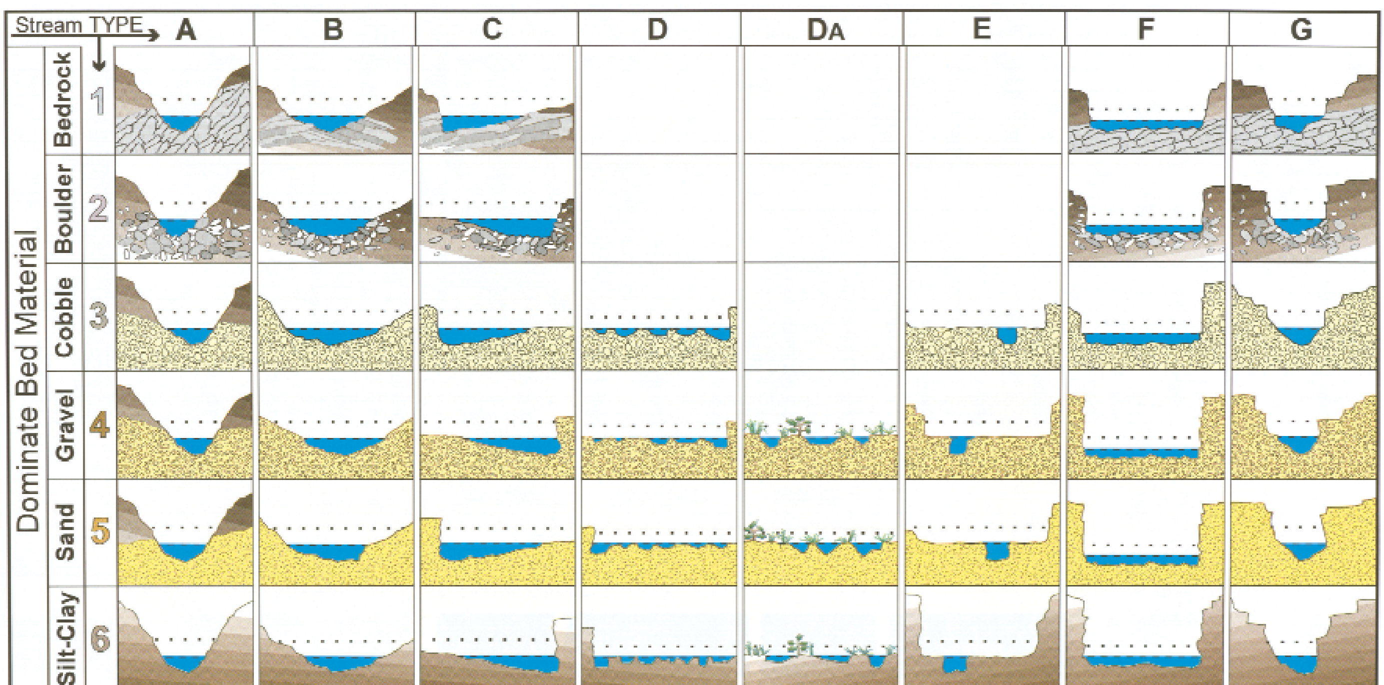

	A	B	C	D	DA	E	F	G
Entrchmnt.	< 1.4	1.4 - 2.2	> 2.2	n/a	> 4.0	> 2.2	< 1.4	< 1.4
W/D Ratio	< 12	> 12	> 12	> 40	< 40	< 12	> 12	< 12
Sinuosity	1 - 1.2	> 1.2	> 1.2	n/a	variable	>1.5	> 1.2	>1.2
Slope	.04-.099	.02-.039	< .02	< .04	< .005	< .02	< .02	.02-.039

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