# ~ 3. Principles of Stream Science ~

**Fluvial Geomorphology:** *the study of riverine landforms and the processes that create them*

**Hydrology:** *the science dealing with the properties, distribution, and circulation of water on and below the earth's surface and in the atmosphere (Merriam-Webster Online 09/12/07)*

An understanding of both hydrology and fluvial geomorphology is essential when approaching stream management at any level. This section is intended to serve as an overview of both aspects of stream science, as well as their relation to management practices past and present.

**Figure 3.1 Stream Ordering (NRCS) and the Depiction of a Dendritic Stream System**

Applied fluvial geomorphology utilizes the relationships and principles developed through the study of rivers and streams and how they function within their landscape to preserve and restore stream systems. In landscapes unchanged by human activities, streams reflect the regional climate, biology and geology. Bedrock and glacial deposits influence the stream system within its drainage basin. The "dendritic" (formed like the branches of a tree, **Figure 3.1**) stream pattern of the East Branch Delaware River watershed developed because horizontally bedded, sedimentary bedrock had a gently sloping regional dip at the time the initial drainage channels began forming[16]. The bedrock's jointing pattern (the pattern of deep, vertical fractures) also influence stream pattern formation. The region's geologic history has favored the development of non-symmetric drainage basins in the East Branch basin.

As rivers flow across the landscape, they generally increase in size, merging with other rivers. This increase in size brings about a concept known as stream order. Stream order identifies the position in a hierarchy of tributaries occupied by a stream segment. As described by Strahler (1964) and shown in **Figure 3.1**, any clearly defined (ephemeral)

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[16] Ritter, 1978, p. 171.

channel without tributaries is designated as a 1st order channel; where two 1st order channels join they form a 2nd order channel; where two 2nd order channels join they form a 3rd order channel, and so on. The stream network thus formed is a drainage system and is often dendritic, but may adopt other patterns depending on the regional topography and underlying geology.

## Watershed Characteristics

*Stream flow* patterns affect *aquatic habitat*, flood behavior, recreational use, and water supply and quality. Although it may not be obvious, the water flowing through the East Branch drainage system reflects the integrated net effect of all the watershed characteristics that influence the hydrologic cycle (**Figure 3.2**). These characteristics include the climate of the drainage basin (type and distribution patterns of precipitation and temperature regime), geology and land use/land cover (permeable vs. impermeable surfaces, materials affecting the timing and amount of runoff, constructed drainage systems), and vegetation (uptake of water by plants, protection against erosion, and influence on infiltration rates).

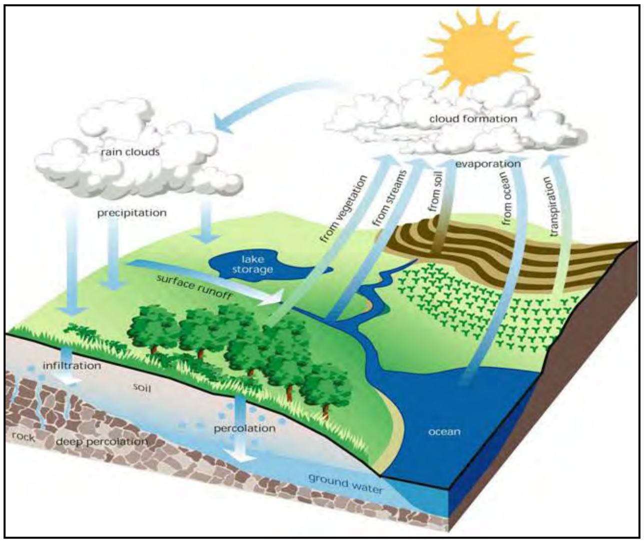

**Figure 3.2 The Hydrologic Cycle**

Climate conditions are variable both globally and in a given region. Climatic changes can noticeably affect seasonal rainfall and stream flow is derived from rainfall or snowmelt (Leopold, 1997). Varying rainfall amounts and soil moisture conditions prior to a rainfall event (or series of events) can have a direct effect on flooding frequency and magnitude. Therefore, it is necessary to have an understanding of climate to fully understand how stream systems function. For a basic description of climate in the East Branch Delaware River watershed and the surrounding area, refer to **Section II** in **Volume 1**.

Drainage area or watershed size is also part of the physical characteristics of the watershed. The size of the watershed is defined by the amount of land area that has the potential to drain stormwater runoff into the stream network. The shape of the watershed also plays a key role in the stream network; if two watersheds have the same size but different shapes, they will have different *peak discharges* and *times of concentration* resulting from the same storm event. Travel time for runoff to move through the stream network varies with watershed topography. A steep watershed typically exhibits a higher peak discharge than a flatter watershed.

The above factors (climate, geology, topography, vegetation, etc.) affect timing and amount of stream flow, referred to as the stream's hydrologic *regime*. Streams flow at many different levels over the course of a year, ranging from the small trickle of a dry summer to the raging torrent associated with the rapid thaw of a thick snowpack. There are essentially two basic types of stream flow: storm flow and base flow. Storm flow appears in the channel in direct response to precipitation and/or snowmelt. Base flow, on the other hand, sustains stream flow during inter-storm (between storms), subfreezing, or drought periods.

The graph below is an example of a *daily mean discharge curve* for the stream gage at Margaretville, NY for the period from September 2006 to August 2007. Note that the brown line indicates the average daily mean discharge (stream flow measured in cubic feet per second) for the 69 years of gage records, and the light blue line shows the daily mean discharge for the 2006-2007 period. This graph also shows that most of the runoff for the watershed above Margaretville occurs between mid March and mid May, with a second period of runoff in the fall in November and December. This is a period when the ground is often bare and *evapotranspiration* from plants is low. The precipitation that falls during this period quickly runs off and the streams are full.

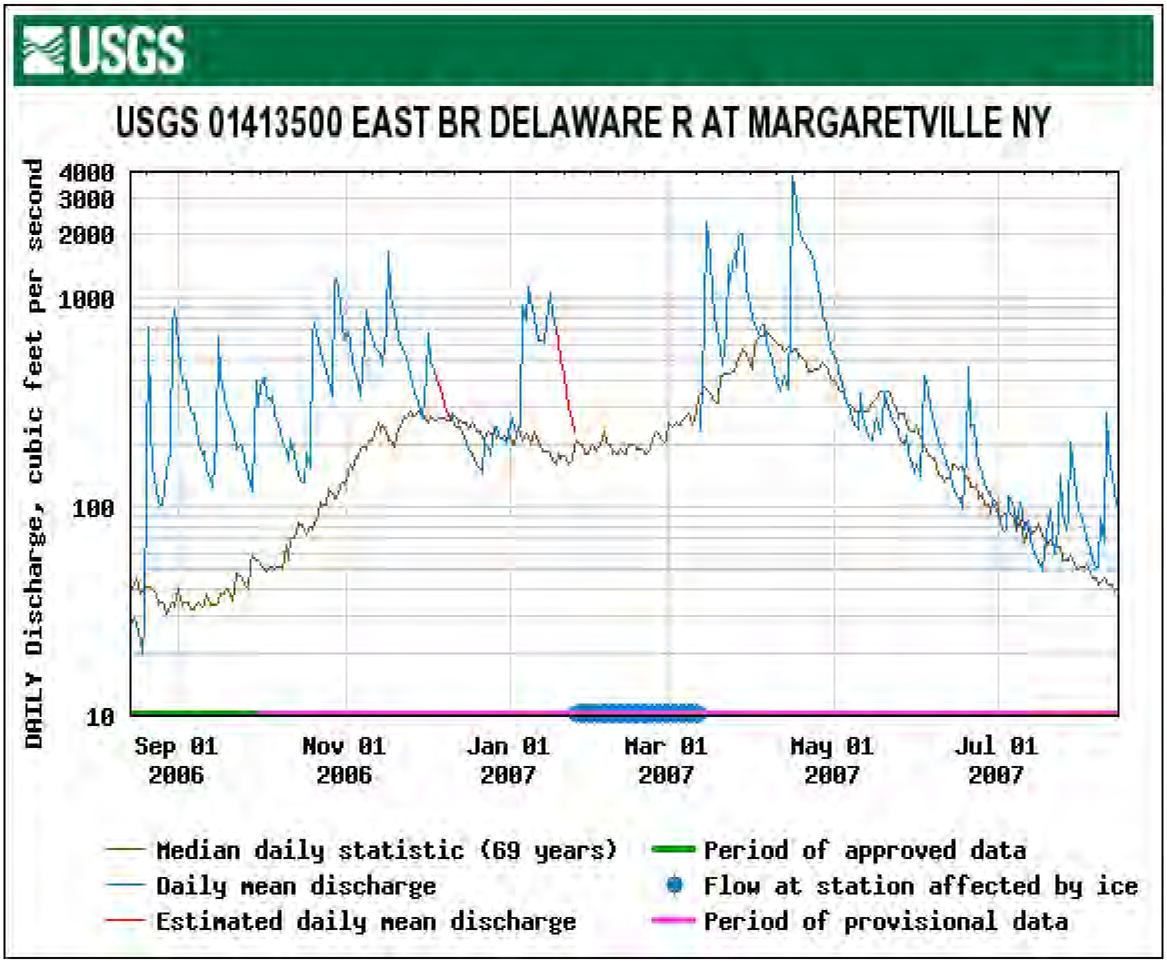

**Figure 3.3 Daily Mean Discharge Curve**

Because the climate, topography, geology and vegetation of a region usually change very slowly over time, the stream flow *regime* is fairly consistent at any given location.[17] This stream flow regime, in turn, defines when and how much bedload will move through the stream channel from year to year. Together, the movement of water and bedload carve the form of the stream channel into the landscape. Because the stream flow regime is fairly consistent year after year, the form of the stream channel changes relatively slowly, at least in the absence of human influence. Over the 120 centuries since glaciers covered the region, the stream and the landscape conditions have evolved into a dynamic balance.

Streams that are in dynamic balance with their landscape adapt a form that can pass the water and bedload associated with both small and large floods, regaining their previous form after the flood passes. This is the definition of stream stability. In many situations, however, stream reaches become unstable when some management activity has upset that balance, altering the stream's ability to move its water and bedload effectively.

The form of a stream that is considered "stable" varies with topography. When it is in balance with mountainous terrain, a stable stream will look different than one that is in balance with rolling hills or broad floodplains. Stable streams are less likely to experience bank erosion, water quality and habitat problems. The maintenance of a stable stream *morphology* and vigorous *riparian* (streamside) vegetation is essential to "healthy" streams. The condition and types of riparian vegetation play crucial roles in stream health, and thus are important to sound stream stewardship and management.

## Sediment Balance

Essential to the maintenance of a stable stream is the preservation of a "sediment balance." The following paragraph sums up the importance of sediment transport in the formation of rivers:

> "Sediment transport processes have a major control on channel morphology since rivers can only develop if sediment is eroded and transported. Not only are the overall dimensions of the river influenced by sediment transport, but local temporal and spatial variations in transport capacity within a reach result in the formation and maintenance of *pools*, *riffles* and bar forms which are so characteristic of alluvial channels"
> (R. D. Hey, 2003).

Sediment discharge has long been recognized as one of the primary variables that determine the characteristics of a stream. **Figure 3.4** below illustrates the inversely proportional relationship between a set of four primary physical variables (sediment size, sediment load, stream discharge and stream slope) and two opposing processes (stream bed aggradation and *degradation*) that determine stream sediment and channel characteristics and balance. The figure suggests that a change in one of four physical

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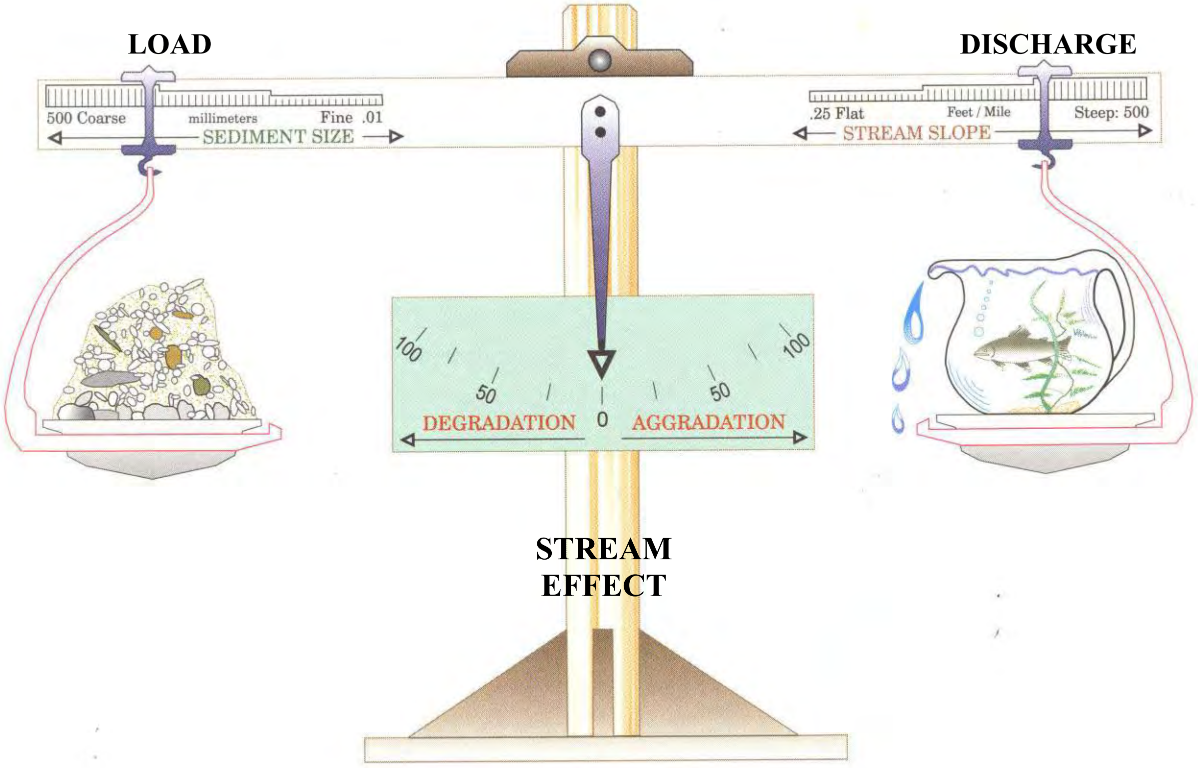
[17] One exception is when the vegetation changes quickly, such as can happen during forest fires, catastrophic geologic events, or rapid commercial or residential development.

variables will trigger a response in the two process variables. This in turn creates changes in river characteristics.



**(Sediment LOAD) x (Sediment SIZE) is proportional to (Stream SLOPE) x (Stream DISCHARGE)**

**Figure 3.4 Sediment Balance (Rosgen, 1996)**

If the supply of sediment decreases (for example, an impoundment leading to reduced sediment load downstream) or the supply of water increases (for example, increase in impervious area or decrease in vegetative cover in the watershed leading to increased runoff), the stream will begin to erode downward or *degrade*. The most noticeable manifestations of this will be incision (the stream depth will increase), and the stream slope will become less steep. Incision could lead to undermining of the streambanks as they become over-steepened and bank height ratio increases. As banks fail, this feedback mechanism provides additional sediment and results in a widening of the stream channel, bringing sediment transport capacity and sediment supply back into equilibrium. An increase in sediment transport capacity by increasing slope or decreasing width will have similar effects as increasing discharge or decreasing sediment supply (**Figure 3.4**).

Conversely, if the supply of sediment increases (for example, due to removal of bank vegetation causing increased erosion) or the supply of water decreases (for example due to water diversions or increasing vegetation on floodplain or watershed areas) the stream will begin to *aggrade* or fill in. Noticeable manifestations of this include a localized increase in stream slope and a reduction in stream depth often followed by further increase in stream width. Frequently the supply of sediment increases while the supply of water remains constant. This leads to a stream becoming too shallow from increased deposition, which can cause greater frequency of flooding due to a lack of channel capacity for its available water. Alternatively, the stream may erode its banks to become wider and achieve the necessary cross-sectional area to transport its available water. This process is temporary, because the increase in width encourages additional deposition. Eventually, the stream channel will develop a flow concentration between deposits, and a new channel will develop within the over-widened channel.

Stable streams can be considered to be "operating at their full potential." A number of factors can change the stability of streams such as changes in flow input, sediment, and land use. Channelization of the stream, berms, culverts and bridges can also have a negative impact on stream stability (potential). Departure from potential —stream potential is defined as the best channel condition, based on quantifiable morphological characteristics, for each stream type (Rosgen, 1996) — can be measured at different sections of a stream and can be compared to stable reaches (reference reaches). This comparison allows us to determine the departure from potential, understand causes, predict and plan future changes.

## Stream Features

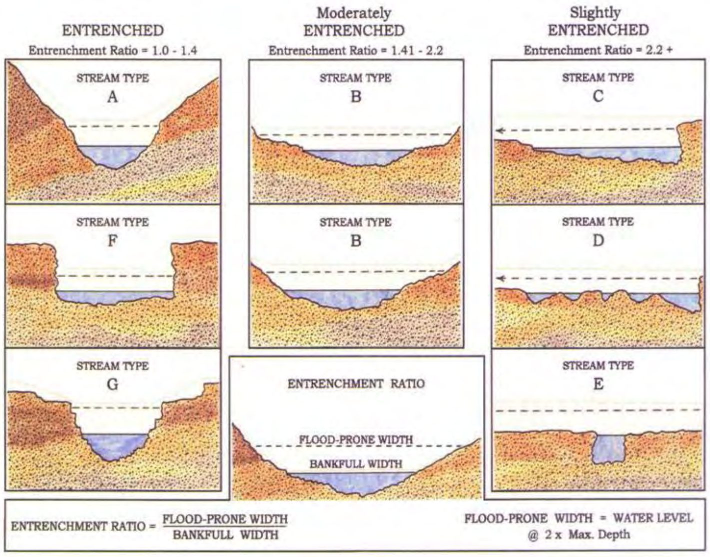


**Figure 3.5 Entrenchment of Various Stream Types**

The features of a stream are described in terms of their cross-section dimension, their planform dimensions and their longitudinal dimensions.

In terms of its cross-sectional dimension, a stream has a primary channel that conveys most of the flow throughout the year. Another feature of the stream that moves flow is the floodplain. Floodplains are the flat area of a stream system located above the top of the stream bank that is inundated with flowing water during and following storm events. Streams can have split or multiple channels that may move flood flows. If a stream has more than three channels, it is commonly referred to as a "braided" stream. Storm flows in some streams may not rise over the top of the banks and therefore may lack or are disconnected from their historic floodplain. Such stream channels are commonly called entrenched channels (**Figure 3.5**).

DCSWCD and NYCDEP have developed Regional Hydraulic Relationship Curves (see page 150) to aid in determining a stream's cross-sectional area, width and depth for a give drainage area. This information is used during assessments to determine if a stream's dimensions are within an acceptable range of values. As shown, stream dimensions and flow usually change significantly below a tributary confluence.

Consequently, it is important to know when two or more stream orders occur in an impacted or study stream reach as there are impacts on its hydraulic function and how we interpret our Regional Hydraulic Relationship Curve data.

Longitudinal dimensions of a stream are used to describe how the stream changes from the top of the watershed to the mouth of the stream. The most important factor is the slope of the stream. Slope is a critical contributor to the energy of the stream. The energy of water flowing down a slope is needed to move sediment. A stream's slope can vary from high gradient (slope greater than 4%) to medium gradient (2%-4%) to low gradient (less than 2%). The slope of the stream typically is greatest at the top of the watershed (high gradient stream) and gradually declines as the stream flows down the valley (medium gradient stream) and makes its way to the bottom of the watershed (low gradient streams). Within a reach, the slope of the stream can vary as the water moves through riffles (steep sections), runs (steepest sections), pools (flat sections), and glides (transition sections from flat to steep). The illustration below (**Figure 3.6**) shows a profile of the stream through one riffle – pool sequence. Pools are important features in stream since their low slope acts to slow the velocity (hence reduce the energy of the stream). Typically a stable stream reach will maintain a balance in the ratio of the length of riffles to the length of pools.

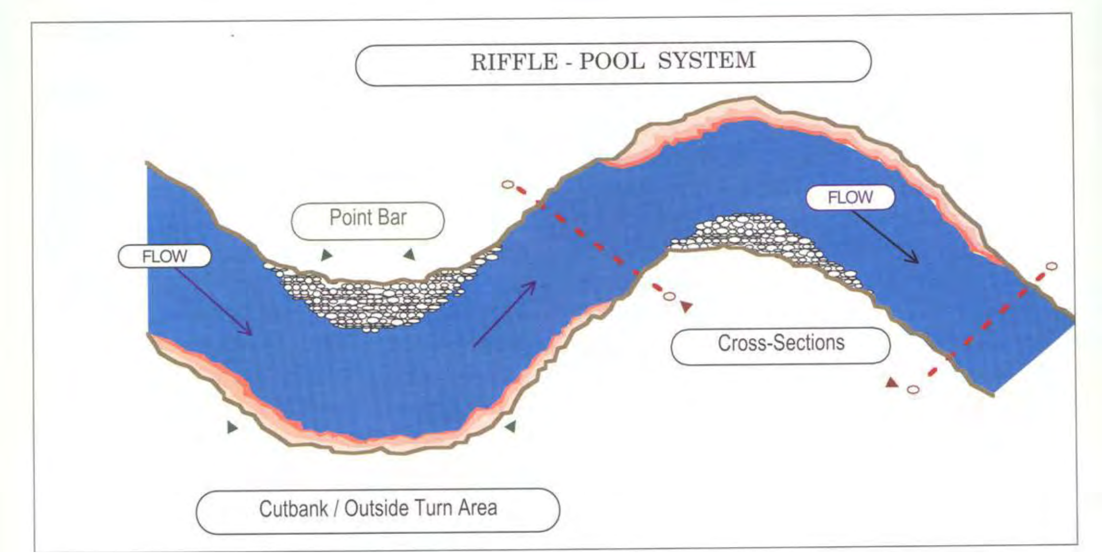


**Figure 3.6 Typical Riffle-Pool Sequence**

The overhead or "planform" view of the stream focuses at the winding nature of the stream within its valley. Stream managers speak of a stream's *sinuosity* as they describe the extent the stream meanders across the valley. Sinuosity is related to slope and energy. A sinuous stream is longer than the straight line distance between an upstream and downstream set of points and associated elevations. Therefore the greater the sinuosity the lower the average slope. The sinuosity of a stream is generally greater at the lower end of the valley closer to the mouth of the watershed. Additional information on stream features and the relevance of their dimensions is provided in "Stream Morphology and Classification".

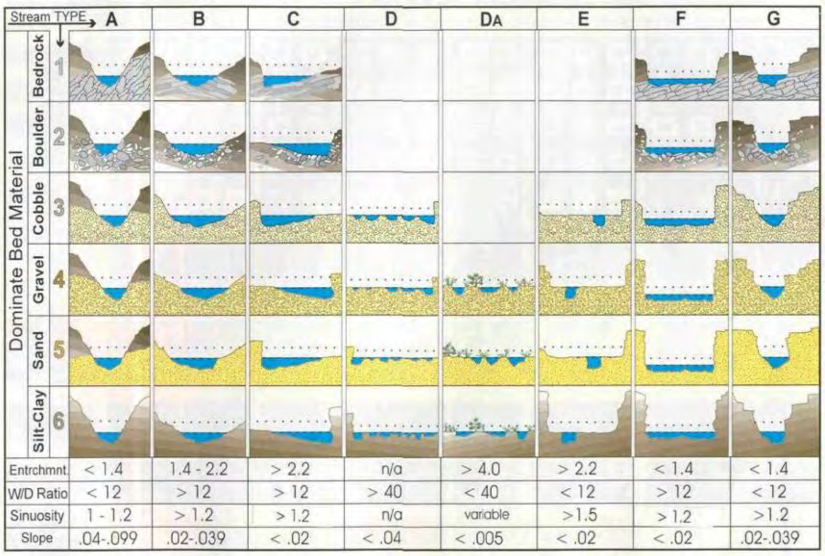
# *Stream Morphology and Classification*

**"The river is the carpenter of its own edifice"   - Luna Leopold, 1994**

One useful tool for stream managers, developed by Dave Rosgen (1996), is a system for classification of different stream reaches based on their form. Rosgen's system gives letter and number designations to different stream types, depending on their combination of five *bankfull* channel characteristics:

1) Entrenchment ratio
2) Ratio of width to depth
3) Slope
4) Sinuosity
5) Bed material size (D50)

Different combinations of these characteristics result in a great number of different stream types, from A1 through G6 (see **Figure 3.7**; read letter designation across the top, particle size number down the left side). These letter/number designations provide a sort of shorthand for summing up the form of a stream reach. By classifying the different types of streams in a watershed different management strategies can be targeted to each section of stream. These and other characteristics come together to influence how a stream "makes itself" and whether is it stable or unstable in a given setting. These include[18]:



| Stream TYPE | 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 |

**Figure 3.7  Stream Type Delineative Criteria (Rosgen, 1996)**

**Stream flow (Q) –** Usually represented as cubic feet or cubic meters per second, stream flow is also called stream *discharge*. Stream flow changes from hour to hour, from day to day, from season to season, and from year to year.

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[18] Each characteristic is followed (in parentheses) by the symbol commonly used to represent it in hydraulic equations.

Some stream flows play a more significant role than others in determining the shape of the stream. The bankfull flow is considered most responsible for defining the stream form. For this reason, bankfull flow is also sometimes called the *channel-forming flow*. This flow typically recurs every 1-2 years. It may seem surprising that very large floods aren't more important in forming the channel. While they may induce catastrophic changes in a stream—severely eroding banks and washing countless trees into the channel—these major floods are rarer, occurring on the average every decade or so. The flows that have the most effect on channel shape are those that come more frequently (**Figure 3.8**), but which are still powerful enough to mobilize the gravel and cobble on the streambed: the smaller, bankfull flows.

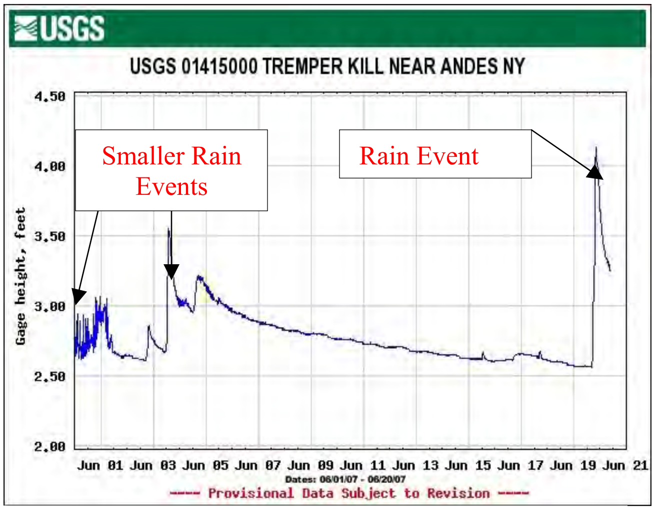

**Figure 3.8 Flow Responses to Precipitation**

The height of the water in the channel is called the *stage*. When a stream overtops its banks, it is in *floodstage*. *Bankfull stage* — when the stream is just about to top its banks — is used as a benchmark for measuring stream dimensions for classifying different *stream types*.

**Slope (S)** – The distance that the stream channel drops divided by the distance over which that drop occurs. Slope is one of the two main determinants of a stream's potential force for erosion of the streambed and banks. The slope of a stream usually refers to the average slope of the water surface when the stream is running at bankfull flow, though can be measured as a low flow water surface slope for use in stream classification.

**Bankfull depth (d)** – The depth from the elevation of water surface at the *bankfull discharge* to the deepest point in the channel. ***Depth*** is the other primary determinant of potential force, and is measured from the streambed to the water's surface at the bankfull stage elevation. Again, this will depend on the level of the stream flow. When used to compare one stream reach to another in *stream classification systems* (see above), the average depth of the stream during a bankfull flow is used.

**Bankfull width (W)** – The width of the water surface at the bankfull discharge. Together with average depth, channel *width* determines the *cross-sectional area* (Area (A) = width x depth). Channel width is measured from bank to bank at the bankfull elevation. One principle important to understanding stream morphology is that whenever outside influences change a stream's channel dimensions, the stream usually adjusts itself to maintain a cross-sectional area that will pass normal bankfull flows.

From the above two measurements, the following two ratios are calculated:

**Entrenchment ratio –** Entrenchment ratio is equal to the floodplain width at two times the bankfull depth divided by bankfull depth. When a reach of stream is either straightened or narrowed, the power of the stream flow is increased. The stream may then cut down into its bed, so that flood flows are less likely to spill out into the floodplain. When this happens, we say that the reach has incised, and that the channel has become *entrenched*, which can occur to varying degrees of severity. When large flood flows are confined to the narrow channel of an incised stream, the water becomes very deep and erosive; the stream may gully down even deeper into its bed. Eventually the banks may become so high and steep that they erode away on one or both sides, widening the channel. This in turn can change previously stable areas downstream, having a significant impact on road and bridge infrastructure.

**Width/depth ratio –** Bankfull width divided by bankfull depth. Stream channel morphology is often described in terms of a width/depth ratio related to the bankfull stage cross-section. Width/depth ratio varies primarily with the dimension of the channel cross-section for a given slope; the boundary roughness as a function of the stream flow and sediment regime; bank erodibility factors including the nature of streambank materials; degree of entrenchment; and the distribution of energy in the stream channel (Rosgen, 1996).

**Sinuosity (k)** – The ratio of the linear valley floor length to the stream length measured along the *thalweg*. A different kind of roughness that slows water flow has to do with whether the channel runs straight, or curves. The flow of a stream is slowed as it moves around a bend as a result of *form roughness*. The overall "curviness" of a stream is called its *sinuosity*. In natural channels, as a rule of thumb, lower slopes produce more sinuous streams.

**Particle size distribution (Dxx) –** The statistical distribution of stream bottom material sizes measured in the stream channel below the bankfull depth. It takes more force for a stream to move material on the streambed if it consists of large cobbles than if it is sand or silt; the smaller the particles, the more easily they will be moved. To characterize the sediment in a stream reach, 100-300 particles are randomly selected and measured, and the median size particle determined. Although a time-consuming task, this procedure determines the $D_{50}$ of the reach: meaning that 50% of the particles in the stream are smaller, and 50% are larger. The $D_{50}$ is used in overall stream reach classification while the $D_{84}$ is used for hydraulic calculations.

| Name | Particle Size | |
|---|---|---|
| **Silt** | < 0.062mm | < 0.002 in |
| **Sand** | 0.062mm - 2mm | 0.002 in - 0.08 in |
| **Gravel** | 2mm - 64mm | 0.08 in - 2.52 in |
| **Cobble** | 64mm - 256 mm | 2.25 in - 10.08 in |
| **Boulder** | 256mm - 2048 mm | 10.08 in - 80.63 in |

**Channel roughness (n)** – Although flowing water develops potential to erode streambeds and banks, other stream characteristics combine to slow the water down. One of these is the channel roughness: there is more resistance to flow where a stream reach contains boulders and cobbles than through a reach with a smooth, silt-bottomed bed and no obstructions. Similarly, water flows more slowly across a floodplain filled with trees and dense brush, and so is less likely to cause erosion, than it does across a smooth, newly mown lawn or parking lot. This characteristic is also referred to as *bed roughness*.

**Sediment discharge (Qs)** – In general, the term "sediment" is used to describe the silt, sand, gravel, cobbles and even boulders that are moved by stream flow. Sediment discharge is the amount of sediment moving past a particular point over some interval of time, usually measured in tons per year. Bedload is sediment that moves along the bottom of the channel, while washload is sediment that is suspended within the water. Measuring sediment discharge helps determine if a stream reach is stable. If the amount of sediment entering a reach doesn't roughly equal the amount leaving it, the form of the reach is changing or unstable.

**Bed and Bank Cohesiveness** – Some soil types hold together better than others, or are more *cohesive*. Some streambeds have their gravel and cobbles bound together in a *matrix* of finer material that resists movement by stream flow; those that do not can erode more easily. The roots of trees and shrubs can reach deep into streambanks, and the web of fine root fibers can add much strength to otherwise erosive soils. This creates a balance between water forces the bed and banks to resist erosive power. When changes in streambank vegetation affect soil erosivity, stream morphology will change in response until a new *equilibrium* is reached.

**Radius of curvature (Rc***)* – *Radius of curvature* describes the "curviness" of the stream at a single curve, and is measured as shown in **Figure 3.9**.

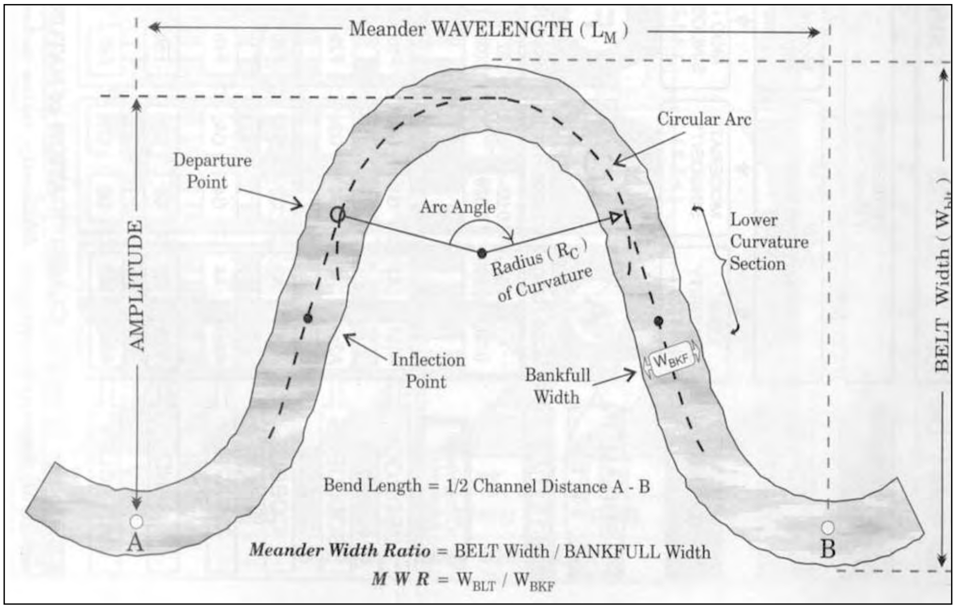

**Figure 3.9 Radius of Curvature (Adapted from The Reference Reach Field Book, D. Rosgen.)**

## Channel Disturbance and Evolution

Channels that have been disturbed by dredging, incision, or channelization follow a systematic path to recovery. This process has been documented by Simon and Hupp (1992), and is illustrated in **Figure 3.10**.

- Class I, is the channel in its natural pre-disturbed state.
- Class II, is the channel immediately after being disturbed (in this case, channelized, presumably straightened and steepened in addition to over-widened).
- Class III, is the channel eroding down (degrading) due to the flood waters being confined because channel is lower and out of contact with the former floodplain.
- Class IV, the channel continues to degrade, the banks become unstable, and the channel erodes laterally.
- Class V, the channel begins to deposit eroded material in the over-wide channel, and the newly developing floodplain continues to widen.
- Class VI, and a new channel is established and becomes relatively stable. A new floodplain is established within the original channel, and the former floodplain becomes a *terrace* (abandoned or inactive floodplain).

The six classes would temporarily occur at a single cross-section, but they can be seen to occur spatially as well when viewed along the stream profile, most typically in the downstream direction from Class I at the headwaters to Class VI at the mouth.

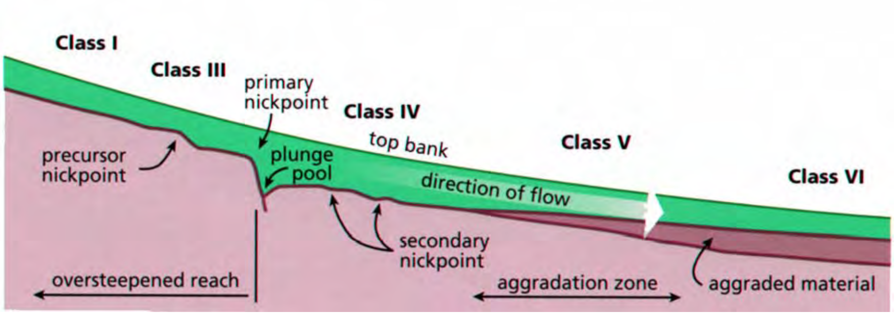

**Figure 3.10 Profile View of Channel Evolution Sequence (Simon and Hupp, 1992)**

**Figure 3.10** shows this process occurring along the stream profile. The profile view illustrates the changes a stream goes through in adjustment to disturbance or to natural stream processes over geologic time. Bank erosion is a symptom of change within the watershed. Focusing on stabilizing short reaches of eroding bank (*rip rap*) does not address the issue of change within the watershed. It ignores the effect that excess sediment form upstream will be deposited, and that this in turn triggers rapid channel migration and additional bank erosion. The causes of erosion must be addressed and this requires looking at the watershed as a whole.

Dave Rosgen (2001) has described nine evolutionary scenarios using his stream types which are illustrated below in **Figure 3.11** (below). These are not theoretical evolutionary scenarios; each has been observed by Rosgen in the field. A common evolutionary sequence in this region is number nine. A C type stream degrades to a G, then widens to an F. Eventually a new C is formed inside the wide F channel. Note that in this case a new floodplain has been created. The old floodplain is at a higher elevation relative to the streambed, and becomes a terrace.

The evolutionary sequence can be used on any particular stream to tell scientists, engineers, or hydrologists something about the stream's former and present state, or to determine what the stream's former condition (type) and what it should be to be in balance with the current setting.

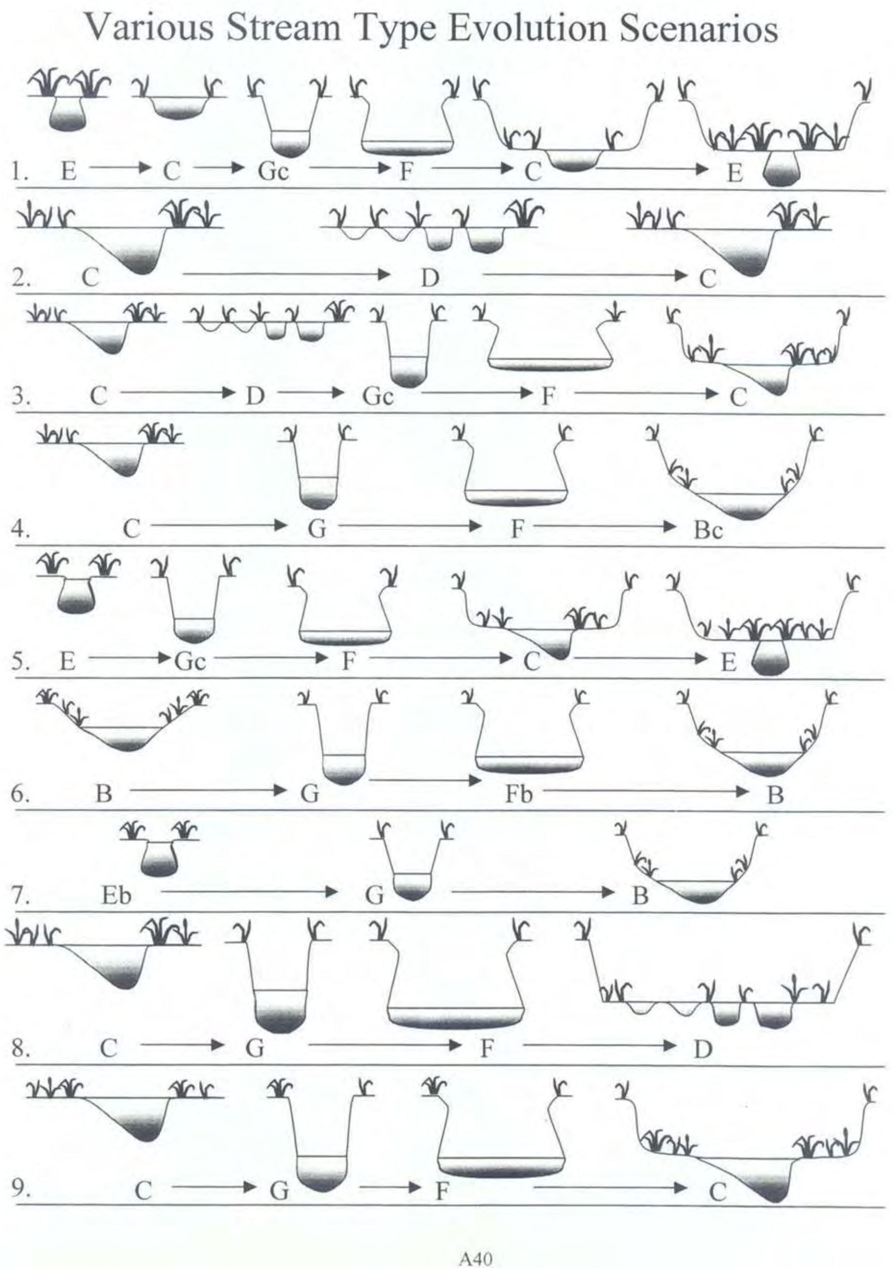

**Figure 3.11 Stream Evolutionary Sequence (Rosgen, 2001)**

# *Human Activities and Impacts on Stream Health*

The distinction between natural and human disturbances is important to understand. The effects of ice floes, pests, and disease can cause widespread damage to riparian vegetation but these effects are usually temporary (see **Volume 2, Section 5**). Human disturbances, however, often significantly alter natural conditions and can have a longer lasting impact on the capability of riparian vegetation to survive and function. These disturbances can include logging practices, livestock overgrazing, cropping practices, construction and maintenance of highway infrastructure, real estate development, gravel mining, dredging, channelization, berming, and introduction of non-native species in the riparian corridor. All of these practices have impacted stream stability on a watershed scale.

## Agricultural Influence

**Figure 3.12 Streambank Impacted by Cattle**

Continuous access to streams by livestock has a significant impact on the vigor, mortality and diversity of riparian vegetation. Grazing can reach an intensity that will keep grasses and forbs at a height too low to effectively uptake nutrients and impede storm runoff, which increases environmental contamination and streambank erosion (see Figure 3.12). Intensive riparian grazing also inhibits the growth, establishment and/or regeneration of shrubs and trees while hoof shear (cattle-eroded stream access points) on streambanks exacerbates erosion. Cultivating row crops and mowing haylands to the stream's edge or the top of the streambank also result in decreased species diversity and riparian buffer width. These practices significantly increase runoff and associated nutrient contamination and streambank erosion.

Agriculture is a notable land use in the East Branch watershed, and it is linked to the land management changes that may be needed in the future to enable successful stream corridor management. Soil characteristics must be evaluated in order to design conservation practices that limit the loss of excess *nutrients* and eroded sediments from farmland and keep them from entering surface water.

The United States Department of Agriculture's (USDA) Conservation Reserve Enhancement Program (CREP) is a voluntary program that protects environmentally sensitive agriculture land with vegetative riparian buffers often associated with exclusionary livestock fencing. This program provides numerous environmental benefits and has met with great success in the West Branch Delaware River watershed and is expanding into the East Branch watershed. More information on CREP is included in the Watershed Programs section at the end of this volume.

## Highway/Public Utility Infrastructure Influence

Some of the most easily visible impacts to stream stability result from the construction or maintenance of highway infrastructure. Use and maintenance of state and local highways impacts the vigor of riparian vegetation where narrow buffers exist between roads and streams. These areas receive runoff containing sediment and road chemicals that stunt vegetative growth or increase stress and mortality. Highway maintenance activities that regularly disturb the soil along shoulders and cut banks can welcome undesirable *invasive plants*. In areas where public utility lines parallel or cross streams, riparian areas are disturbed by the practice of keeping vegetation trimmed to near ground level. This is another contributor to accelerated runoff and increased streambank erosion.

**Figure 3.13 Dry Brook Road Culvert**

Roads are commonly located close to streams, especially in the Catskill region with its narrow and winding valleys. Road encroachment has narrowed and deepened many streams, resulting in increased velocity. This causes the bed of the stream to *degrade* and, ultimately, to become *incised,* like a gully in its valley. This means that the stream reach has become unstable, which can lead to rapid streambank erosion as well as impairment of water quality and stream health. Worse yet, these local changes can spread upstream and downstream, causing great lengths of stream to become unstable. Roads near streams can also introduce pollutants or garbage to the stream system from stormwater runoff which effects aquatic habitat. Stormwater runoff is recognized as a significant water quality concern in Delaware County. As overland flow from impervious surfaces, such as roads and parking areas, stormwater runoff contains contaminants and nutrients that are delivered directly into stream system. A good streamside buffer along roads could help minimize excess pollutants and garbage from entering the stream system.

Roadside ditches collect stormwater runoff, carrying it away from the road and sometimes directly into streams. Without retention and/or filtration, resulting stream issues are often contamination, excess sediment, and excess nutrients in the stream. Ditch maintenance without re-seeding can increase sediment (turbidity) in the stream system. This can exacerbate gravel deposition problems. Proper culvert installation and sizing is also important for stream stability. Culvert installation that utilizes improper size, slope, and headwall can lead to streambank erosion and/or gravel deposition both upstream and downstream of the culvert.

**Figure 3.14 Bridge at Erpf Road**

In addition to roads and ditches, bridges have had a considerable impact on stream system stability. Bridges built wider than the stream's natural dimensions will lead to the deposition of sediment under and near the structure during periods of low or base stream flow. Localized scour may also be present. Sediment that deposits under the bridge will affect the flow capacity of the channel beneath the bridge. In many instances, the sediment is dredged out to maintain design capacity. Bridges built narrower than the stream's natural dimensions will exhibit a depositional wedge upstream of the structure. This can lead to water backup behind the bridge, resulting in local flooding upstream. Bridge approaches are sometimes built across floodplains in order to have a gradual rise unto the bridge. These become floodplain encroachments. Bridges can force water that would normally be on the floodplain through a narrow opening, concentrating energy that can cause problems downstream of the bridge, such as streambank and stream bed erosion.

## Residential Development Influence

Residential land use and development of new homes can have a significant impact on the watershed and ecology of the riparian area. Houses require access roads and utility lines that often have to cross streams. Homeowners who enjoy their stream and desire to be close to it may clear all the trees and shrubs along it to provide views and access. They may replace natural conditions with an un-natural mowed lawn that provides little benefit to stream health or local wildlife. These practices can lead to new streambank erosion or increase existing erosion issues.

Many people live close to a stream and have access to the water without destabilizing the bank. Careful selection of a route to the stream and locating access where the water's force on the bank is lower, a landowner can minimize disturbance to riparian vegetation and the streambank. Minimizing disturbance in the flood prone area and promoting a dense natural buffer provide property protection, aesthetic value and wildlife habitat. Riparian gardeners must know which riparian species are appropriate for planting. More information can be obtained by contacting the Delaware County Soil & Water Conservation District, 44 West Street, Suite 1, Walton, New York, 13856, (607) 865-7162. The following websites also offer information on riparian buffers:

USDA Natural Resources Conservation Service backyard tree planting -
http://www.nrcs.usda.gov/feature/backyard/TreePtg.html (Verified September 27, 2007)

USDA Natural Resources Conservation Service wildlife habitat - http://www.nrcs.usda.gov/feature/backyard/WildHab.html (Verified September 27, 2007)

Connecticut River Joint Commission, Inc. - http://www.crjc.org/riparianbuffers.htm (Verified September 27, 2007)

The National Wildlife Federation – http://www.nwf.org/backyardwildlifehabitat/ (Verified September 27, 2007)

## A Look to the Future

Many past and current human attempts at fixing streams have been "band-aid solutions" for spot problems and these attempts often create additional problems downstream. To combat stream problems, fluvial geomorphology techniques can help stream managers understand natural and human-induced stream problems on a larger (watershed) scale and prioritize severely unstable stream reaches for treatment. By carefully measuring the characteristics of stream form described in the preceding sections, stream managers can get a fairly good idea about the relative stability of a stream, reach by reach, over its whole length. Stable stream reaches *(reference reaches*) are identified and surveyed, and the stable form characteristics are used as a design template for restoration projects. A variety of management strategy options can then be provided to address these problems on both short and long-term bases.

Practices consistent with fluvial geomorphology (natural stream channel design) include:

- **Proper sizing of channels when undertaking stream work**.
    - As previously mentioned, the DCSWCD and NYCDEP have put considerable effort into the development of Regional Hydraulic Relationship Curves. This has been accomplished through the calibration of USGS Stream Gaging Stations to bankfull parameters. These curves are extremely useful for determining if a stream's bankfull dimensions are within an accepted range of values for a given drainage area. As an example, picture a stream reach with a 25 square mile drainage area, a bankfull width of 80 feet, and an average depth of 1.3 feet. By interpolating from the Regional Hydraulic Relationship Curves or by using the formulas, the chart below (**Figure 3.15**) indicates that the average width should be 56 feet and the average depth should be 2.5 feet. This means that the reach in question is both too wide and too shallow, and it will likely aggrade, widen, and become shallower. More frequent flooding is also likely. The stream will probably become multi-channeled at some point, creating the potential to relocate itself during a major flood. Such a reach would be noted as being "impacted" and, as part of developing a mitigation plan, DCSWCD staff would further examine the watershed to determine the cause of these issues.

      Conversely, DCSWCD staff can determine whether a stream reach is functioning well. A reach that is functioning really well can be used as a "reference reach" for future mitigation projects. (See "Using Stable Stream Feature Dimensions" later in this section.) In a case where recent floods totally destroyed the stream, DCSWCD staff were able to reconstruct streams using the Regional Curves. The curves are also useful in performing emergency stream mitigation. In emergency situations, streams can be returned to a somewhat natural dimension so they have a chance to recover naturally until more permanent work can be planned and implemented.

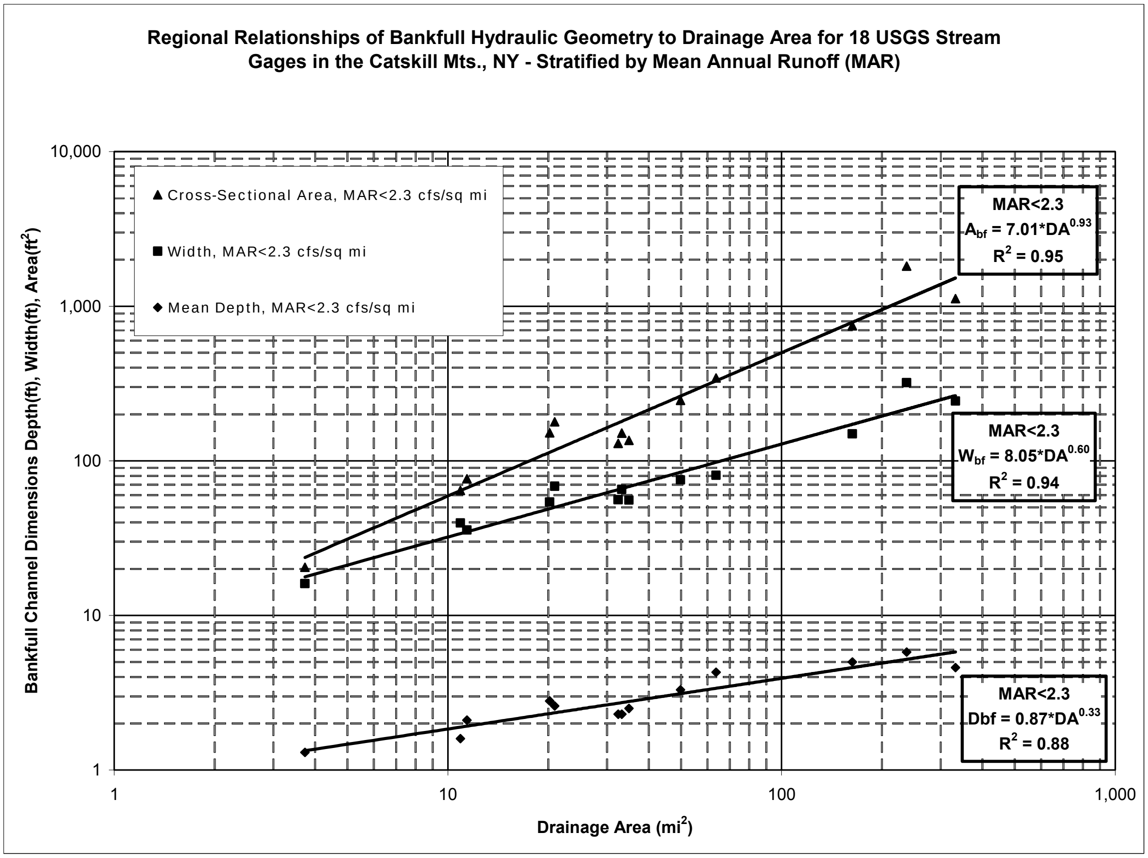

**Figure 3.15 Regional Hydraulic Relationship Curves**

- **Identifying the desired stream type as part of a project design process**
    - Part of stream classification involves determining the stream type of a given stream reach. Stream type is often dependant on the type of valley through which it flows. For example, headwater streams in the Catskills are typically in steep narrow valleys and tumble from one pool to the next. These are commonly called an "A" or "Aa+" type stream (**see Figure 3.16**). As the stream continues to descend down the valley, it flattens out and becomes a "B" type stream ending in a "C" stream in the valley bottom. The occasional "E" stream type is a very stable stream. Other stream types that may be encountered in the Catskills are "D", "F", and "G". These stream types are usually unstable.

      Knowing the stream type helps stream managers in determining stream stability. When planning a restoration project, it is important to restore a stream to the correct stream type. As depicted in **Figure 3.16**, A and B type streams are fairly straight while the C type stream exhibits some sinuosity. Sinuosity plays a role in energy reduction. If a straighter B type stream were constructed where a C type stream should be, the stream would be over-steepened and would crash and thrash about until the correct stream slope is attained.

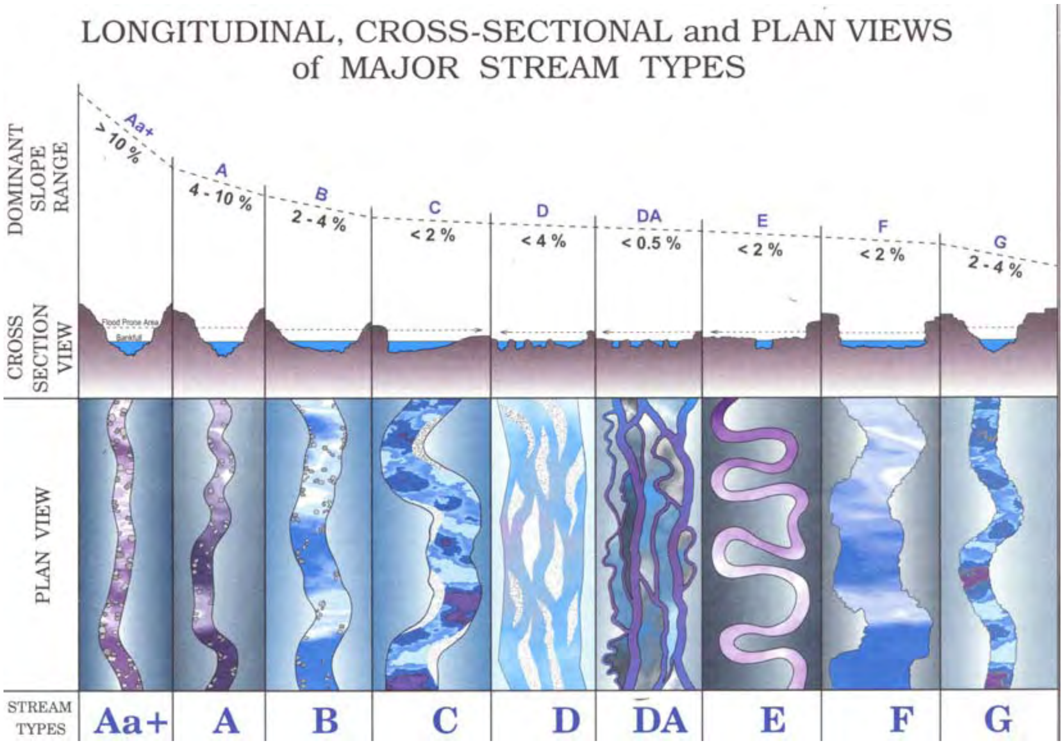

**Figure 3.16 Stream Types**

Another look at **Figure 3.11** on page 145 shows stream evolutionary scenarios. Scenario 9 is fairly common in Delaware County. If a stream in a valley bottom is a G or F type, and it is known that the stream was once a C type, it is reasonably certain that it will eventually build another C type stream at a lower elevation. While the stream is lowering its elevation, excessive erosion and deposition patterns and loss of property can be expected. This evolutionary sequence can migrate upstream and/or downstream and create the same effect in the stream's tributaries. This information must also be taken into consideration when planning and designing a stream restoration project.

- **Re-connecting floodplains**
    - "The floodplain is defined as the flat area bordering a stream, constructed by the river in the present climate and inundated during periods of high flow" (Leopold, 1997). The floodplain is a critical component of stream function. The floodplain serves as an energy dissipater and depository of finer sediments during high flows. When streams are disconnected from floodplains by berming, dredging or other means, this natural balance is disrupted – often with undesirable impacts. Additionally, floodplain obstructions like bridge approaches and buildings can restrict floodplain flow or concentrate flow elsewhere – again with undesirable impacts. It is, therefore, an important component of any restoration project to give prioritization to floodplain re-connection.

- **Using stable stream feature dimensions**
    - As previously mentioned, a stream reach that is functioning well (stable) can be used as a "reference reach". Every aspect of a reference reach is accurately surveyed and measured and data compiled with specialized computer software. Data collected and compiled include all the features and information described in the "Stream Morphology and Classification" on pages 106. The watershed drainage area is also documented. The drainage area is important because as a rule-of-thumb, stream managers do not extrapolate more than ten percent above or below the reference drainage area for design. For example, if the drainage area of a reference reach is 60 square miles, that data is only good for projects between 54 and 66 square miles. However, replicating "reference dimensions" in a stream restoration project reach helps ensure project success.


SEP 18 2004

**Figure 3.17 Functioning Floodplain Along NYS 30 North of Margaretville, September 18, 2004**

- **Consideration of upstream and downstream impacts**
    - Impacts upstream and downstream of a stream restoration project always need to be considered. For example, if a stream bank is armored with riprap or other hard material, consideration is given to increased velocities and erosion potential on an opposing downstream bank. Likewise, if a restoration project is designed to improve sediment transport through a reach, deposition potential downstream must be assessed. It is a goal with fluvial geomorphological design to not only improve an impacted reach but to *not* create undue stress elsewhere in the stream system. This also includes not creating any situation that may increase upstream deposition or negatively alter flood flows.


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**Figure 3.18 Root wad Installation Taken After the September 18, 2004 Storm**

- **Using vegetation and natural channel design structures**
    - Re-establishing or enhancing streamside vegetation is a crucial component of a natural stream channel design restoration project. A planting plan can range from simple to complex. However, it is important to plant wet-adapted plants near the water and phase to dryer-adapted species from the top of the bank back. Streamside vegetation serves to help stabilize the stream bank with their root masses, slow down higher flows and trap sediments, regulate water temperatures, and provide habitat for both aquatic and upland fauna.
    - Natural channel structures are designed to reduce stress on the stream bank by re-directing stream flow toward the center of the stream. These typically include single arm rock vanes, rock cross-vanes and root wad structures. Rock vane structures are built with large rock, well-footed below the stream bed, and well-tied into the stream bank. The vane arm slopes from the top of the stream bank to the stream bed. A rock cross-vane is simply two single arm vanes with a throat in the center (**Figure 3.19**). Root wads are similarly used. A root wad is a large tree devoid of limbs but with the entire root system attached. They have typically been used in Delaware County for post-flood mitigation to take advantage of the large woody debris left on floodplains. There is, however, a standard design for using them in restoration projects. Plantings are done around both at the ends of the vane arms (where they are tied into the stream bank) and all around a root wad. **Figure 3.18** shows a typical root wad installation prior to stream bank plantings (which are done in the fall during their dormancy).

**Figure 3.19 Rock Cross-Vane**

- **Limiting gravel removal**
    - Gravel removal at a project site should be given careful consideration. Generally, only deleterious gravel bars, such as transverse bars (those bars across a stream that direct flow toward a stream bank), center bars (those in the center of a stream with flow on both sides) or deposition near or around drainage structures should be considered for removal. Point bars (those on the inside of a bend) actually serve a hydraulic function primarily by providing a definable stream channel during lower flows. They are actually formed by lack of stream energy on the inside of a bend and are partially eroded away during flood events, being re-deposited as flood flows subside. Removing point bars will reduce stream energy at low flows, thereby creating potential for increased deposition.

- Point bars are formed in the following manner. "As a flowing stream enters a bend in its channel (see **Figure 3.20**), the water surface, being swifter than that near the bottom, moves toward the concave bank and tends to erode it. Continuity requires, then, that the surface water plunge downward near the concave bank and that some bed water emerge at the surface near the convex bank (point bar). This circulatory motion in the cross-sectional plane of a channel, which was first observed and explained by Thomson in 1879, is a result of the larger centrifugal force that is exerted on fast-moving surface parcels than on slower-moving ones near the bed. The motion gives to an individual water parcel a path resembling a helix." (Leopold, 1997).

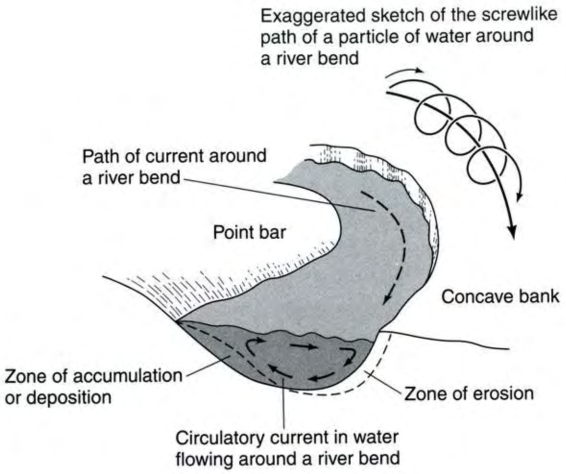

**Figure 3.20 Effect of a curved channel on water flow creating point bars**

**Figure 3.21 Looking upstream at a point bar in the Tremper Kill Sub-basin**