III. Introduction to Stream Management

While many people look at streams as being random, chaotic systems, in reality their behavior is highly predictable. Knowledge of the many factors that impact stream systems is essential if effective management strategies are to be adopted and, more importantly, implemented. To assist readers of this SMP, the following section is provided to give the reader a basic understanding of stream dynamics and the emerging science of fluvial geomorphology.

A. STREAM HYDROLOGICAL REGIME

One of the most important factors that stream managers must understand is the hydrological regime of the watershed, and how it is manifested in stream flow. Flow patterns in any given stream system may be an important factor in fisheries management, flood protection, recreational uses, water supply uses and other issues which stream managers must address. A stream's flow regime is important not only in terms of the amount of flow, but also the timing of the flow.

1. Flow Levels

Streams generally flow at many different levels, from a small trickle during a dry summer to a raging torrent during flood events. The level of stream flow is dependent on a wide range of factors, but is primarily influenced by the amount of water that drains from the streams watershed as direct runoff, the type and distribution patterns of precipitation and water that enters the system from groundwater. Typically, there are three general flow levels of interest to stream managers.

> **Base Flow** - The base flow (average low flow) is associated with the lowest stage of the stream, and is generally representative of the stream's influence from groundwater contributions. Base flow is a critical consideration in stream management, as it has a strong influence on fisheries habitat conditions during critical periods of the year when both water quantity and thermal conditions are primary concerns. Groundwater inflow is primarily influenced by soils and geology, and it can be highly variable within a given stream system. In most cases, a stream may be classified as an effluent or influent reach. An effluent or "gaining" stream reach actually receives inflow from groundwater. An influent or "losing" reach loses a portion of its base flow to the groundwater table.

Bankfull Flow - From a stream management standpoint, bankfull flow is defined as that flow which fills the stream channel to the point of incipient flooding. In some cases, this could be the stream stage at the point when the stream flow starts to move onto the adjoining floodplain, but in many other cases it may represent a stage associated with a lower, slope break feature, in the channel cross section. The bankfull flow is often referred to as the "effective", "dominant" or the "channel forming" flow and it is a primary consideration in the study of the morphology of stream channels. The bankfull flow is that flow which has the primary influence on overall stream form, and is discussed in greater detail in other sections of this SMP.

Flood Flow - Generally, flood flows can be defined by conditions where the water in the channel exceeds its capacity, overtops its banks and enters the flood plain. This flow is mostly overland flow, and in the Catskill Mountains is generally associated with large storm events, or in the worse case scenario a rainfall event which occurs concurrently with snow melt. While most people are familiar with the concept of a "100 year flood", stream managers consider a wide range of flood flows when undertaking activities on the stream. Flood flows occur with variable frequency which is discussed in greater detail later in this section.

2. Flow Timing

While flow level is critical to many aspects of stream management, the temporal characteristics of the stream hydrologic regimes is equally important. The relationship between stream discharge and timing must be examined both over the long term, such as in flood frequency analysis, and in the shorter time span of individual storm events, to fully understand the dynamics of any given stream system.

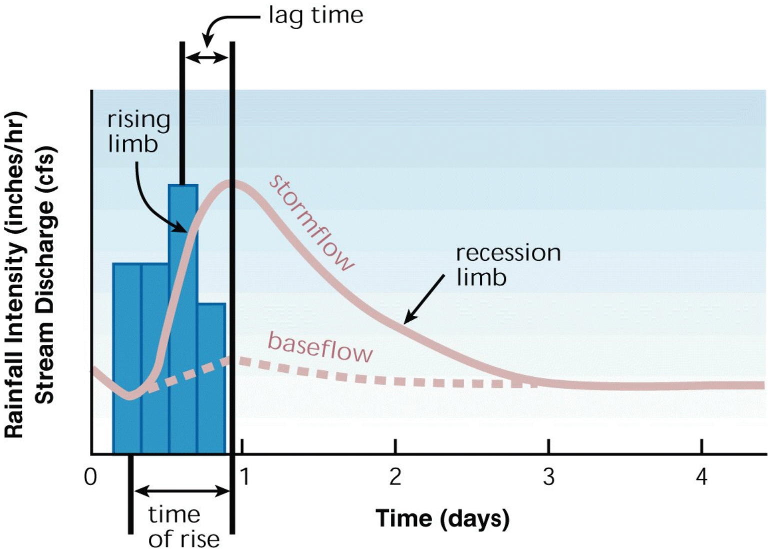


Figure III-1: Typical Storm Hydrograph. *Stream Corridor Restoration Principles, Processes, and Practices, 10/98, the Federal Interagency Stream Restoration Working Group (FISRWG)*

The relationship between flow and timing is expressed in the form of a hydrograph as shown in **Figure III-1**. A hydrograph developed for single discrete storm events, as shown here, demonstrates a stream's response to a single precipitation event. Streams typically respond with a rapid rise in stage from the base flow condition present at the onset of the storm (rising limb), peaks at some level associated with total precipitation and multiple basin characteristics, and finally slowly recedes (recession limb).

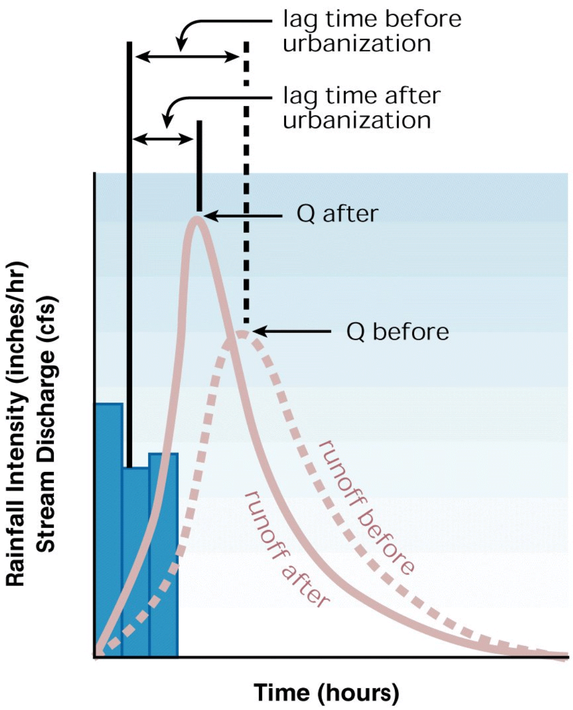


Figure III-2: Comparison of hydrograph for pre and post urbanization of a typical watershed. *Stream Corridor Restoration Principles, Processes, and Practices, 10/98, the Federal Interagency Stream Restoration Working Group (FISRWG)*

As a watershed undergoes changes, such as an increase in development, corresponding changes in a stream's hydrologic regime can be demonstrated by examining storm hydrographs. **Figure III-2** shows a comparison of typical rural and urbanized watersheds. As you will note, an increase in urbanization causes peak flow to increase and lag time to decrease. Lag time is the period of time between the onset of the storm event and the hydrographs peak. Modification of runoff due to urbanization will impacts a streams natural hydrological regime, often resulting instability problems. The impact of urbanization is often addressed using stormwater retention/detention ponds which modify effect.

When stream gages have long periods of record available, hydrographs can be an effective tool for assessing or monitoring a stream's response to changes in watershed conditions. As shown later in this document **(Section VI-B Watershed Assessment),** hydrographs can indicate trends which are important in stream management.

3. Flood Frequency

Understanding the probability of how often a flood of a certain magnitude may occur is important to stream managers for a number of reasons. On one hand, knowledge regarding the frequency of larger flood events has a direct impact on landowners and community planners in relation to the regulations which govern those areas prone to flooding. On the other hand, stream managers require solid information on the frequency of smaller flood events, such as the bankfull stage, which are critical to an understanding of stream process. Flood frequency curves illustrate both low and high stream flows, stream response to rainfall, flood volumes and elevations as well as reservoir levels, and are critical criteria in the design and construction of bridges, culverts and other physical features.

The primary objective of flood frequency analysis is to utilize probability distributions to estimate the flood magnitude, corresponding to various return periods. Flood frequency curves represent predictions, derived through statistical analysis of data from the watershed, or by comparisons with watersheds having similar attributes. The curves are derived from the relationship between the streams stage (height) and its discharge (flow) at stream gages and calibrated to a specific region to allow estimates of flood magnitude. These statistical analyses focus on the frequency, or the likelihood, that stream discharge (and subsequently stream water surface elevation) will be equaled or exceeded and are referred to as recurrence intervals. **Figure III-3** shows a flood frequency curve developed for the USGS stream gage on the Schoharie Creek at Prattsville.

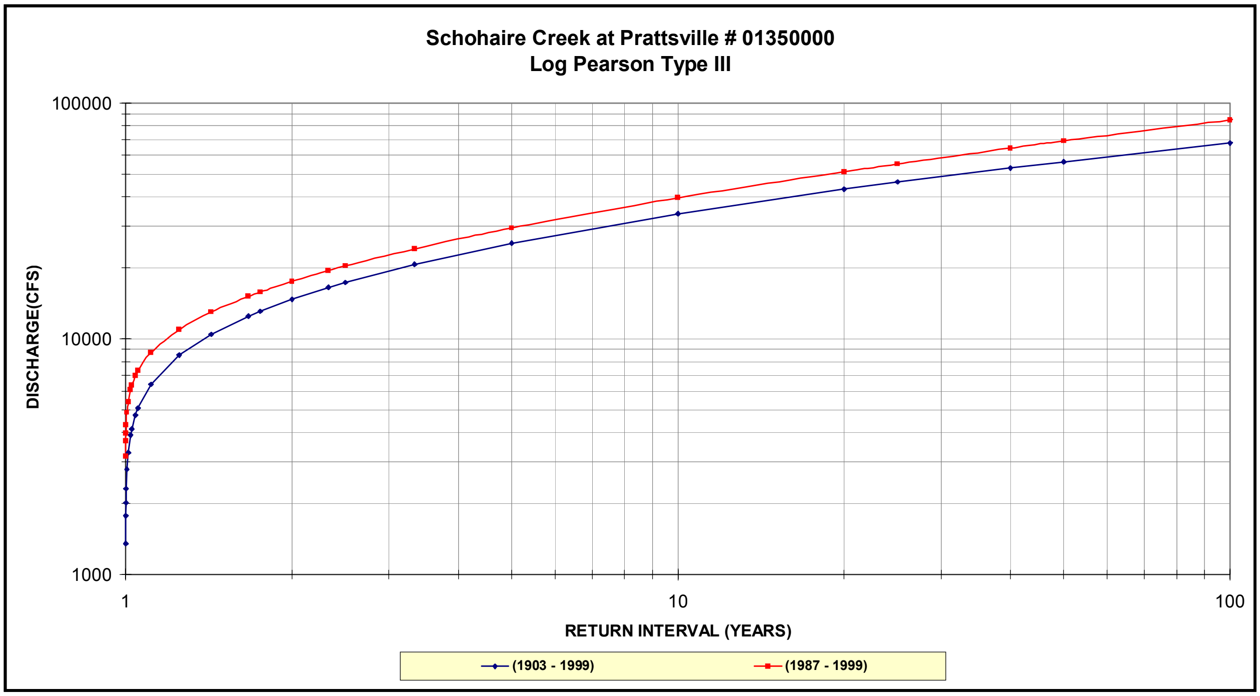


Figure III-3: Flood Frequency Curve for Schoharie Creek at Prattsville New York.

It must be noted that there is a common misconception regarding flood recurrence intervals. While many people are aware of the term “100 year flood”, most incorrectly interpret this designation to mean that a flood of this magnitude will occur only once every 100 years. Statistically, what this really means is that the there is a 1% chance of this magnitude of flooding occurring in any given year. As discussed in the following section on the Fluvial Form, the bankfull stage has been shown to have a typical recurrence interval of 1-2 years. This does not mean that the bankfull stage can be expected only once every 1-2 years, but rather that there is a 50% chance that a 2 year storm (66.6% chance for a 1.5 year stage) stage will occur in any given year.

B. THE FLUVIAL FORM

It has been demonstrated that the morphology, or shape of alluvial streams, is largely an expression of a dynamic equilibrium between the stream’s attempt to maintain a stable form and the evolution of the stream channel form in response to changes in the streams sediment load or stream flow. Sediment characteristics and flow regime, coupled with other factors such as channel materials, topography and the broader features of the valley morphology, all contribute to the form and stability of stream systems.

Fluvial geomorphology, or the science that describes the form and function of streams, involves the integration of many disciplines including, hydrology, geology, biology and other specialities to understand how streams relate to their landscape.

While some observers of stream activities associated with the ravages of the larger flood events would claim that stream processes are chaotic and unpredictable, the opposite is actually true. Streams, to the practiced eye, are often very predictable in regards to their form and their response to change.

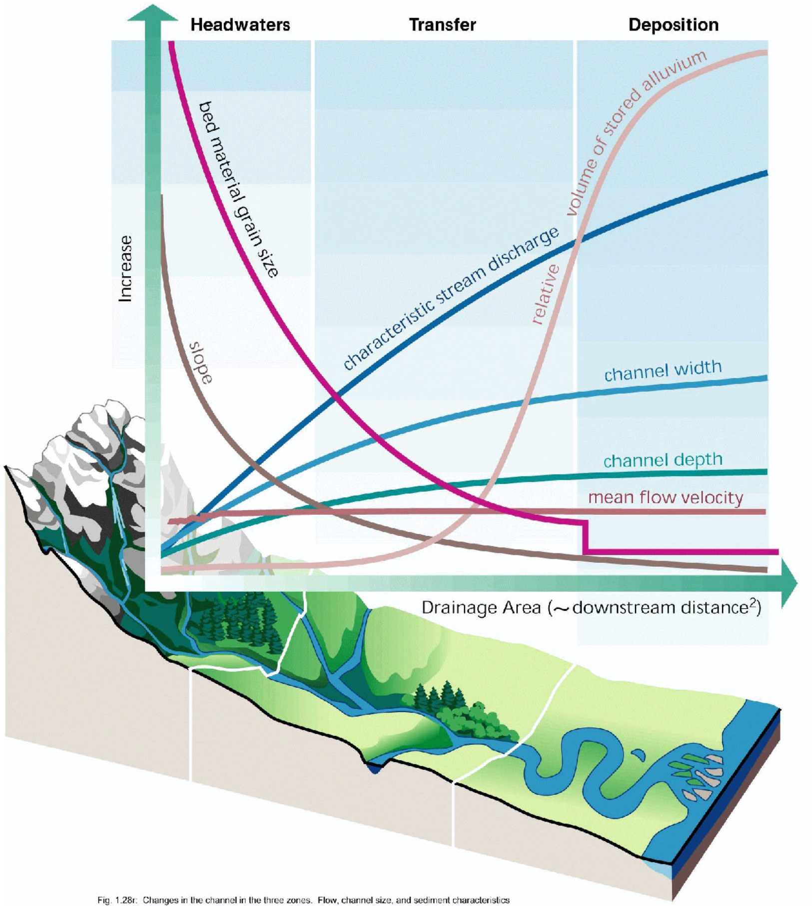


Fig. 1.28r: Changes in the channel in the three zones. Flow, channel size, and sediment characteristics change throughout the longitudinal profile. In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98, by the Federal Interagency Stream Restoration Working Group (FISRWG) (15 federal agencies of the US government).

Figure III-4: Relationship between stream form and function on the watershed scale. *Stream Corridor Restoration Principles, Processes, and Practices, 10/98, the Federal Interagency Stream Restoration Working Group (FISRWG)*

On the broader watershed scale, stream morphology and function is characterized by several general features. As shown in **Figure III-4**, as a stream flows down its watershed, characteristics related to slope and bed materials both decrease, while discharge, sediment storage and the morphological form all increase. The rate of change in these features is representative of a wide range of watershed factors such as hydrologic regime, soils, land use and valley morphology. While researchers have studied the fluvial form of streams for many years, the broad application of fluvial geomorphology to stream management activities was not commonly practiced until more recently when hydrologists, such as Dave Rosgen (Principle Hydrologist, Wildland Hydrology), developed practical methodologies which incorporated these principles.

The development of a geomorphically based stream classification system by Rosgen (1995), as well as practical assessment protocols and restoration design methods, provided practitioners with valuable new tools for changing the direction of stream management. To understand the form of alluvial streams, fluvial geomorphology considers three primary categories of stream form, the stream's dimension (cross sectional relationships), planform (pattern) and profile (slope). Each of these features is discussed in further detail in the following sections, on stream form and function.

1. Bankfull Discharge

For stream managers, a working understanding of the stream stage (elevation) related to the bankfull discharge is the single most important factor in application of the Rosgen Stream Classification System. An effective understanding of stream evolution and its current state of stability is also important. As discussed earlier, the bankfull discharge dictates the overall morphological form and represents the most active stage of the stream system. Correct field identification of the bankfull stage is critical to making accurate and reliable interpretations of the various relationships between a stream's morphological form and the stream's function, as well as the application of the Rosgen Stream Classification System.

Typically, field indicators associated with the active channel and correlated to flow and morphology data collected at stream gaging stations determine the bankfull stage. While these indicators are often fairly consistent and easy to read in a stable reach, they can be non-existent or at best difficult to decipher in severely unstable stream reaches.


Figure III-5: North Settlement Creek, at Ashland, at bankfull stage December 17, 2000.

The field indicators which may be used to identify the bankfull stage may include, the presence of a well defined floodplain at the point of incipient flooding, the elevation associated with the top of point bars, slope breaks or changes in particle size within the active channel, and evidence of inundation as characterized by small benches. In some cases, there may be less reliable indicators present, such as staining of the rocks in the active cannel, exposed roots indicating exposure to erosive flow, the presence of some plants or lichens, and a change in vegetation type. At all times, stream managers must follow four basic principles when determining the bankfull stage:

1. Use indicators in locations which are appropriate for the stream type being evaluated.
2. Know the recent stream history; do not be misled by features associated with events such as floods or recent management activities.
3. Use multiple indicators when possible.
4. When possible, calibrate determinations based on field indicators using stream gages.

2. Stream Channel Dimension

A primary consideration in stream channel morphology is the relationship between a stream's cross section form and the surrounding landscape. Stream dimension addresses not only the cross section of the active stream channel, but also the stream's adjoining floodplain (**Figure III-6)**. Stream dimension related to the bankfull stage is extremely important in understanding the fluvial form of a given stream channel and is central to the application of geomorphically based classification, assessment and restoration methods.

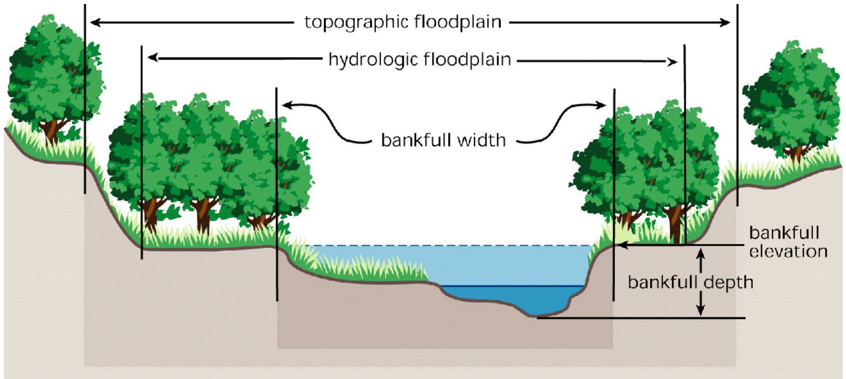


Figure III-6: Typical stream channel dimension features. *Stream Corridor Restoration Principles, Processes, and Practices, 10/98, the Federal Interagency Stream Restoration Working Group (FISRWG)*

Bankfull Width (W_{bkf}), is the horizontal distance across the stream channel at the elevation of the bankfull discharge, while the bankfull depth (d_{bkf}) is the vertical distance between the channel bottom and the water surface at the bankfull stage. Bankfull depth is examined using both the maximum (deepest) depth and the mean (average) depth depending on what features of the stream channel dimensions are being studied. Based on the bankfull stage dimensions, stream managers can characterize a stream's general shape by using the width to depth ratio, and the relationship between the active channel and its adjoining floodplain by using the entrenchment ratio. As seen later in this document, stream dimension relationships are an important consideration in both the classification and assessment of alluvial stream systems.

Width to Depth Ratio (W_{bkf} / $d_{bkf\ mean}$), the relationship between the stream's bankfull width and the mean (average) depth, is a good indicator of a stream channel shape. A lower W/D ratio indicates a channel which exhibits a more confined form, with a narrow and deep channel. Streams with higher W/D ratios are characterized by channels that are both broad and shallow.

Entrenchment Ratio (W_{fpa} / W_{bkf}) is an expression of the degree of vertical containment of stream channels as represented by the relationship between the width of the active bankfull channel and the immediate floodplain. To evaluate a stream's entrenchment ratio, one must first determine the channel's flood prone width. The flood prone width is identified as the width of the floodplain at the stream stage (elevation) which is twice the maximum bankfull depth. Bankfull is first determined, and the maximum depth at bankfull doubled to determine the elevation of the flood prone area. In some streams, the flood prone area is represented by large, broad floodplains typical of the flatter valley floors. In other streams, the flood prone width may be narrower, or more confined due to valley morphology or in many cases manmade features. The ratio of the flood prone channel width to the bankfull channel width is expressed as the entrenchment ratio.

3. Stream Channel Pattern

In nature, stream systems seldom exhibit straight conditions in their planform, rather they follow a sinuous or meandering course as they travel from their headwaters and down the watershed. Due to a common misconception that the water cab be made to “move faster” through a straight channel traditional management strategies have often sought to straighten stream courses, but in reality these changes to the stream’s morphology are done at the risk of setting in motion stream adjustments which can rapidly destabilize a stream.

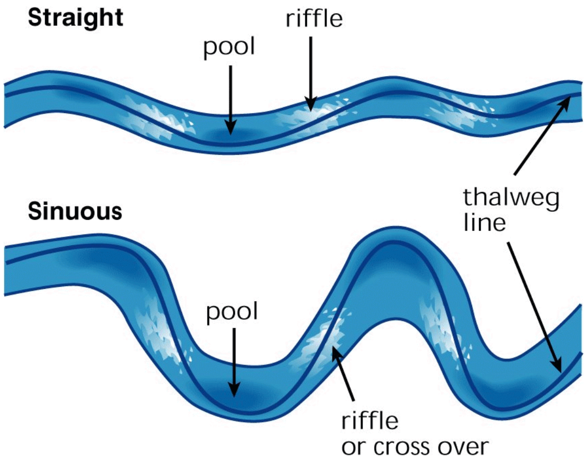


Figure III-7: Comparison of typical sinuosity between straight and meandering stream planform. *Stream Corridor Restoration Principles, Processes, and Practices, 10/98, the Federal Interagency Stream Restoration Working Group (FISRWG)*

Natural stream systems develop a planimetric form which dissipates stream energy and minimizes the work expended during sediment transport. Generally, stream meander geometry is broadly categorized as straight, meandering or braided, with planform features of stream morphology evaluated in terms of the stream’s sinuosity.

Sinuosity is an indication of a stream’s adjustment to its valley, and is expressed in terms of the relationship of stream length to valley length **(Figure III-7)**. Sinuosity is an important delineative criteria in Rosgen’s stream classification system as well as an effective tool for assessing stream conditions. Sinuosity is simply determined by dividing the length of a specific section of the stream, by the corresponding valley length through which the section of stream flows. A sinuosity value of 1.0 would indicate a completely straight stream where the channel length is equal to the valley length. Streams with moderate sinuosity exhibit values of 1.2 to 1.4, with sinuosity values of 1.5 and greater typical of highly meandering streams.

Other quantitative parameters which can be used to characterize a streams planform are meander wave length, radius of curvature, amplitude and belt width. While these features are not used in Rosgen’s stream classification system (**Figure III-8**), they are critical to an understanding of a stream’s stable form. These features are used by stream managers when evaluating a stream channel’s departure from the stable form and when collecting data from stable reference reaches that will be used for restoration designs.

4. Stream Channel Profile

The final broad category of stream morphological form relates to the stream channel's longitudinal profile and characterizes how streams change in response to elevation, discharge and bed material size over a given distance.

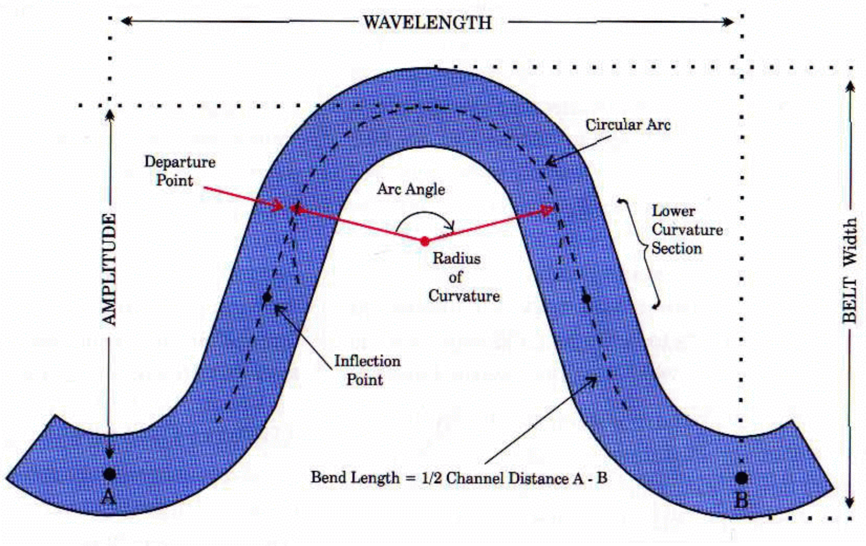


Figure III-8: Stream Planform Features. *Applied River Morphology, 1996, Wildland Hydrology*

Typically, streams exhibit steeper slopes in their headwaters, gradually flattening as the stream flows down the valley (**Figure III-4**). In natural streams, stream gradient is directly related to the streambed material particle size, with increases in bed material size as slope increases. Conversely, stream flow is inversely related to stream slope, with slope decreasing as flow increases. Stream profiles can be categorized by four common forms:

Regime: generally low gradient (<1%) sand bed channels with planar bed, ripples, dunes and antidunes.

Pool-riffle: moderate gradient (1-3%), have an undulating bed that forms a series of pools, riffles and gravel bars. Riffles are the high points topographically with accumulations of relatively coarse sediments. Pools are topographic low points with finer sediments and are usually spaced every 5-7 channel widths. Riffles are characteristic of the straighter reaches of stream while pools are a feature of the outside of stream meanders.

Step-pools: high gradient (3-8%), large material organized across the channel that form a series of steps separating pools. Pool spacing is 1-4 channel widths.

Cascades: high gradient (8-30%), large disorganized bed material, stair-step appearance, pool spacing less than one channel width.

Stream slope is a delineative criteria used in the Rosgen Stream Classification System, and it is also an important consideration in evaluating stream instability as well as design parameters for restoration.

C. HYDRAULIC GEOMETRY RELATIONSHIPS

It has been demonstrated that certain features of stream morphological form and function tend to increase in a linear fashion as drainage area increases (Leopold et al. 1964). Bankfull width, mean depth and cross sectional area, as well as bankfull discharge typically increase as drainage area increases. The relationship between the change in these features and drainage area can be used to develop regional hydraulic geometry curves that can be used to estimate bankfull form and function in streams that do not contain a stream gaging network (**Figure III-9**).

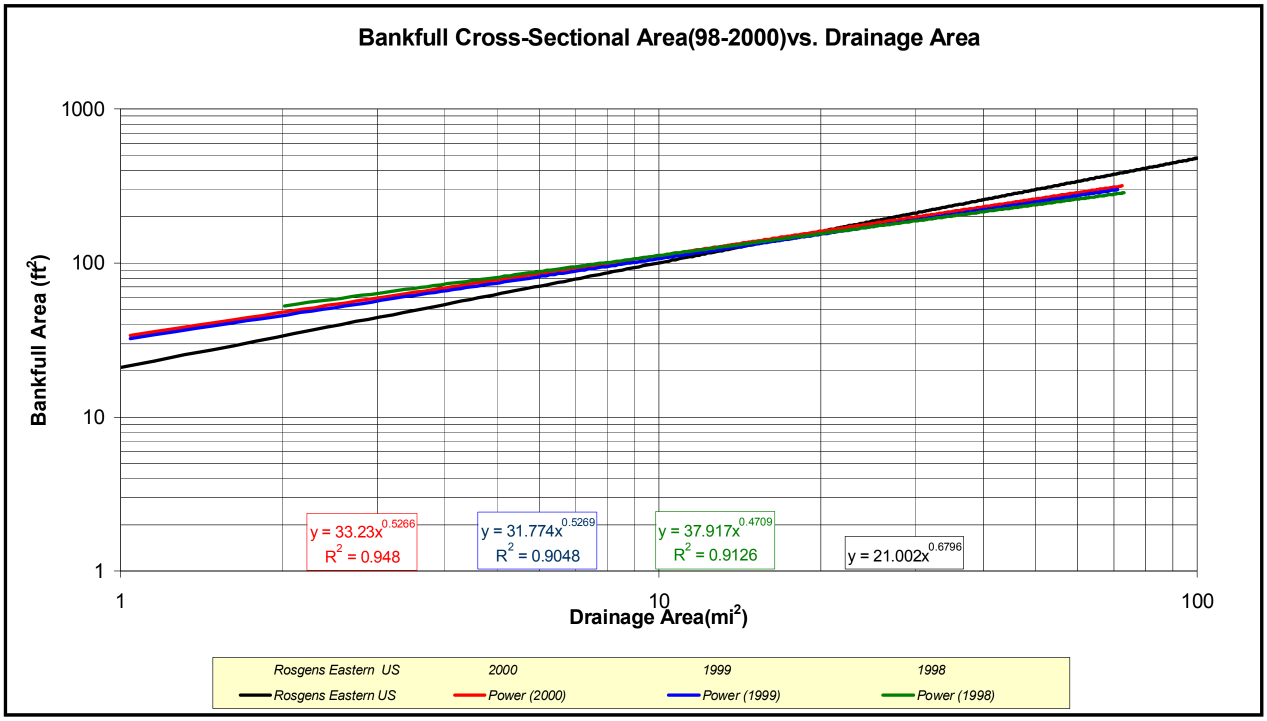


Figure III-9: Regional Hydraulic Geometry Curve for bankfull area.

Using measurements of stream form and function at gage stations, stream managers can develop a database for the refinement of estimates related to bankfull in streams that are not monitored by gages. Typically, these curves are developed for identified hydro-physiographic regions which are characterized by similarities in topography, geology, as well as hydrologic regimes. In New York State, the United States Geological Survey (USGS) has delineated eight broad hydro-physiographic regions; the region covering parts of the Catskill Mountains (region 4) has two subdivisions region 4a and 4b.

To develop these curves, detailed measurements of stream channel morphology (cross section, width, depth) are taken at stream gaging stations, which allow for calibration of these measurements to the bankfull stage. When the morphological dimensions taken at stream gages are plotted as a function of drainage area, regional curves can be developed and used in many aspects of stream management. Regional curves are a critical tool for stream managers as determination of the bankfull stage is often difficult, particularly when assessing unstable stream reaches which often lack well delineated bankfull indicators. The NYCDEP SMP is currently researching the consistency of bankfull discharge and bankfull channel morphology within the Catskill/ Delaware watershed area. The development and use of regional curves is discussed in greater detail later in this document (section VI -A.3)

D. STREAM CLASSIFICATION

While stream classification systems have been around for more than 100 years, many were unable to adequately describe a stream system and could not be applied universally. Recently, Rosgen (1995) developed a method to classify streams that is consistent, quantitative and easily reproducible. His method has become very popular with stream managers and a wide range of disciplines such as hydrologists, geomorphologists and biologists. There are four objectives associated with the Rosgen Stream Classification System.

1. Predict a stream's behavior from its appearance.

2. Develop specific hydraulic and sediment relationships for a given stream type and its state.

3. Provide a mechanism to extrapolate site-specific data to stream reaches that have similar characteristics.

4. Provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines and interested parties.

As seen in **Figure III-10**, the Rosgen classification system uses several delineative criteria to sort streams into distinct classes. Application of the Rosgen classification system requires a working understanding of the bankfull channel. Classification can be conducted at the broadest scale, using maps and aerial photographs (Level I classification), or refined, based on field measurements of the morphological form and bed particle characterization (Level II classification). Rosgen's classification is supplemented by two additional levels of assessment and verification. Rosgen's Level III protocols are used to determine a stream reach's condition, or level of departure from the stable form, while Level IV methods provide for verification of a stream's current state and potential for change from or towards a stable form.

At the broadest scale, stream classification involves an examination of the stream channel form to determine whether it is a single or multiple thread channel. Further classification is made based on four primary delineative criteria which includes the stream reach's entrenchment ratio, width/depth ratio, sinuosity and slope. Additional refinements in the classification system allow for characterization of the stream channel's dominant materials, such as bedrock, boulder, cobble, gravel, sand or silt.

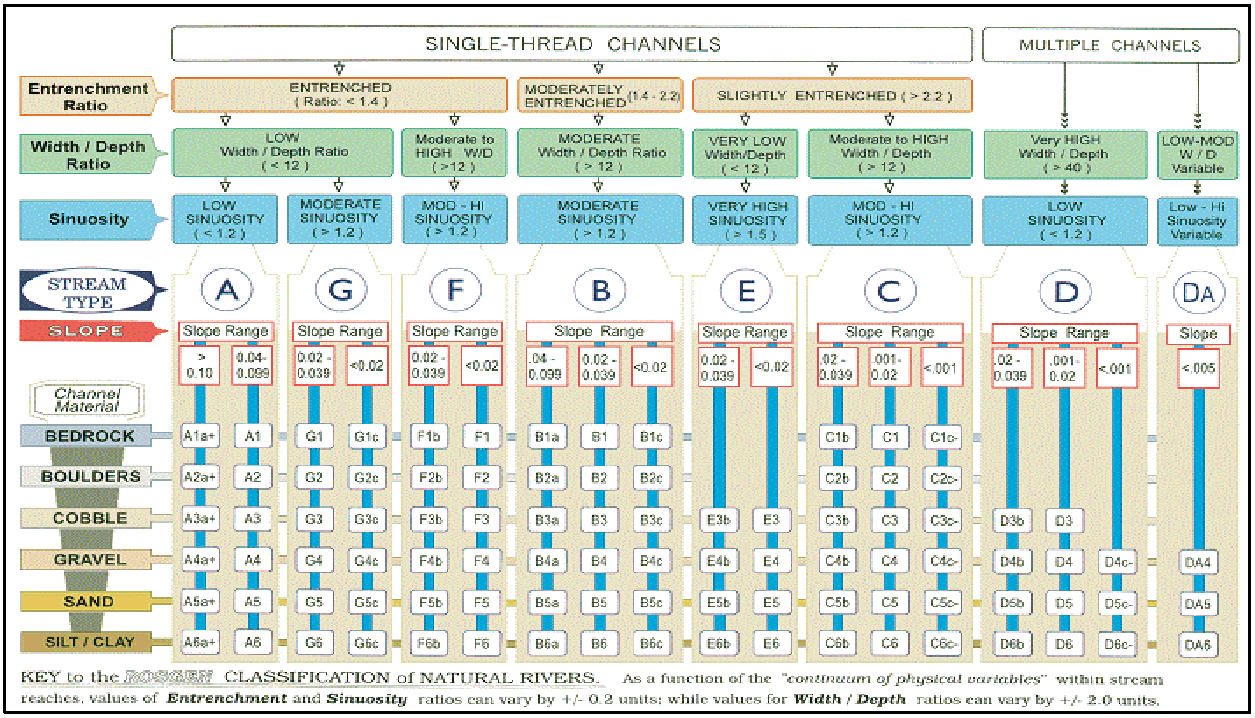


Figure III-10: Rosgen Stream Classification System, *from Applied River Morphology, 1996, Wildland Hydrology.*

Stream managers need to be aware that stream form exists on a continuum, with few natural systems exhibiting all of the delineative criteria values for a specific stream designation. Occasional deviations of measured values from those described in the classification do not necessarily signal a change in stream type. Rosgen's system allows for leeway between measured values and typical values. Measured values for entrenchment ratio and sinuosity can vary by +/- 0.2 units, while values for width/depth ratio can vary by as much as +/- 2.0 units without the stream changing type.

E. FLUVIAL PROCESS

In order to fully understand fluvial process, a basic understanding of the energy of motion, gravity and friction is needed. Potential energy is the energy a mass has by raising above the lowest point to which it can move. The higher it is, the more potential energy, or energy of position, it has. Water that is precipitated in high elevations has high potential energy. Gravity acts on this water to move it downslope, converting the potential energy to kinetic energy or energy of motion.

Figure III-11: Large gravel deposition, at the confluence of North Settlement Creek and the Batavia Kill, after Hurricane Floyd September 1999.

Kinetic energy erodes stream banks and transports sediment and debris. Friction opposes this motion in the form of turbulence and contact with the channel. There are two main causes for flow resistance, surface resistance (impact of vegetation, particle size and in-stream structures) and form resistance (impact of channel bed form and planform). The relationship of friction and gravity determines the ability of the flow to erode stream banks and to transport material shaping and maintaining channels.

The term dynamic equilibrium (Leopold, 1954) refers to a stream system's tendency to develop in such a way as to produce an approximate equilibrium between channel morphology and its function in moving water and sediment. Streams are continuously trying to evolve to an energy balance (continuity) which is stable. This energy balance suggests that streams adjust by shaping and changing their channel bed and banks in order to accommodate the range of flows occurring in the system, as well as changes in the system's sediment characteristics. These adjustments can be the result of climatic changes, watershed disturbance and anthropogenic impacts.

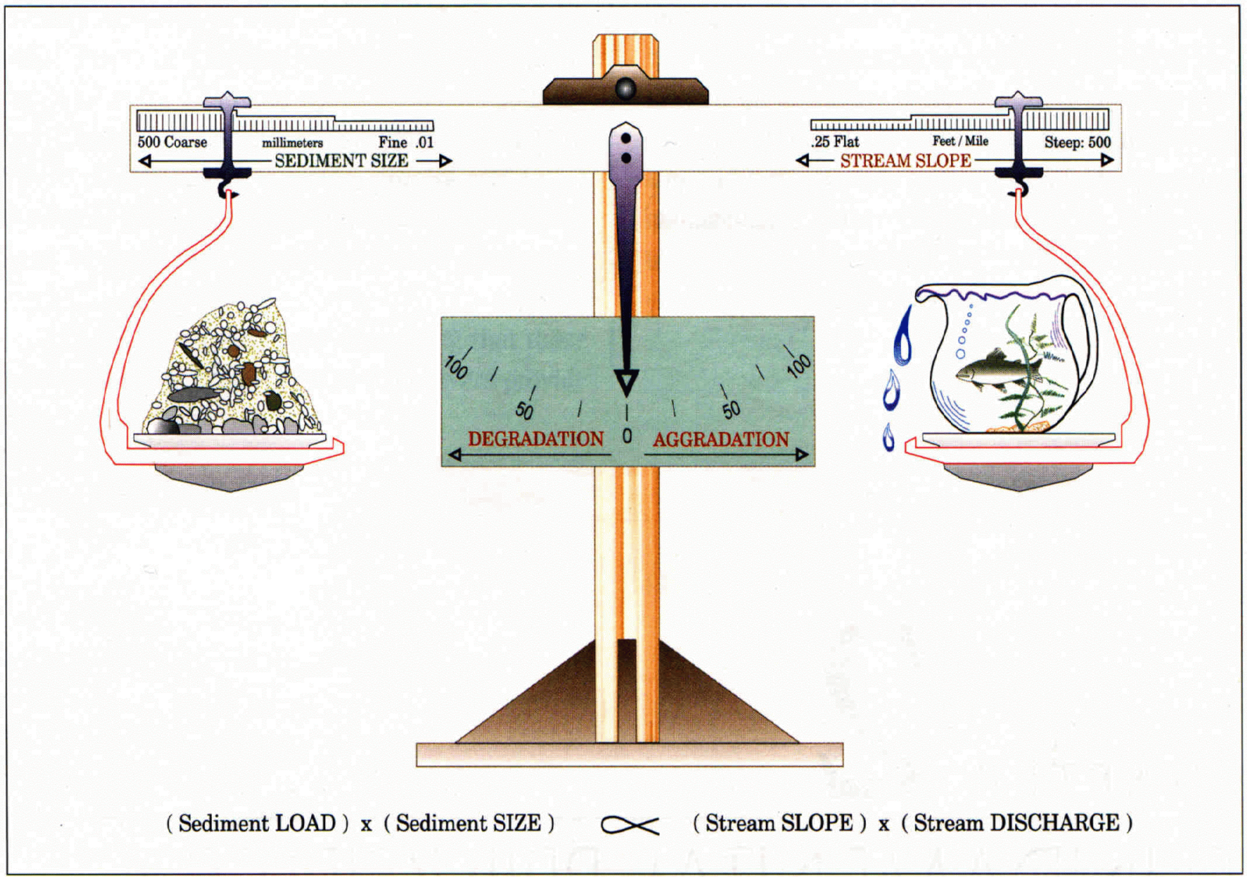


Figure III-12: Lane's stream relationship model. *Stream Corridor Restoration Principles, Processes, and Practices, 10/98, the Federal Interagency Stream Restoration Working Group (FISRWG)*

Lane (1955) proposed a generalized relationship demonstrating the balance between sediment load and size and stream slope and discharge. Upsetting the balance on either side of this imaginary scale will result in a corresponding reaction on the opposite side of the scale until conditions evolve to a new point of stability (**Figure III-8**).

To clarify this relationship, a common practice in stream management in the Catskill Mountains provides an example of negative stream response to management activities. Consider a public bridge which experiences upstream deposition of gravel during a flood event. A traditional response to this condition is to get in the creek and remove the gravel with bulldozers and loaders. During the gravel removal process, the grade of the stream channel is typically left at a steeper slope than the previous channel, and the channel is often straightened. These changes in the channel's morphological conditions for stream response are set in motion. As shown in Lane's model, if the stream slope is steepened, it will initially tip the balance to the right side of the scale resulting in down cutting (degradation) of the stream channel. This process will continue until balance is restored by the combination of forces, such as the stream slope becoming flatter, coarsening of the dominant particle size or an increase in the sediment supply. Unfortunately, as stream systems undergo adjustments in their quest for stability, damage to streambanks, private property, infrastructure, and fisheries habitat, are often the result.

It should also be noted that fluvial processes in any given stream system can be characterized as being system wide, localized or a combination of both. In some instances, fluvial process may be occurring on a broad, watershed scale as may be typical of a stream's response associated with changes in the character of the watershed. For example, rapid changes in the land use/land cover, such as increased development or deforestation, could significantly impact both the stream's flow and sediment regime. As a result, adjustments in the morphological form and stream function may occur throughout the entire stream system or at least over significant sections of the stream. System wide fluvial process is most commonly associated with urbanization of watersheds where the stream experiences both an increase in flow and a loss of sediment supply as soils are covered by impervious surfaces.

On the other hand, fluvial process may be observed as a result of some form of localized disturbance which results in a change in the stream form or stream function over a shorter, more stream reach. Typically, localized fluvial process may be associated with in-stream structures such as bridges which may cause either aggradation or degradation of a stream channel depending on the relationship between the bridge's hydraulic opening and the bankfull channel. Localized stream process is most often representative of undesirable stream management practices such as dredging, straightening, deepening or filling of the channel. In general, fluvial process can be characterized by three basic forms which includes lateral migration, aggradation or degradation. In natural stream systems, seldom do these processes occur independently.

1. Lateral Migration


Figure III-13: Lateral migration of meander bend in Ashland as shown in 1959 (blue), 1995 (purple) and 2000 (photo).

Lateral migration is a natural process whereby streams continuously adjust their planform and move across their flood plains. Typically, this migration of the stream channel is characterized by erosion at the outer bend of a stream meander, with deposition of sediment on the inside area of the meander (point bar). If a stream cannot expend its energy by down cutting (degradation), then the energy will be expended in lateral erosion.

This process is strongly influenced by geology, loss of riparian vegetation and anthropogenic (manmade) impacts, such as over-widening or removal of vegetation, which can cause accelerated rates of erosion and introduce excess sediment into the system. The introduction of additional sediment from migrating streambanks further contributes to lateral migration.

Lateral migration typically becomes a problem when infrastructure or property is threatened by the erosion. While all natural stream systems experience some degree of lateral migration, under stable conditions the lateral migration of a stream channel may not be measurable on a management time scale.

The problems result when streams that demonstrate stable conditions and unperceivable migration rates are suddenly destabilized, and migration rates accelerate to as much as a few hundred feet in a given storm event. Rapid lateral migration can result in excess sediment entering the stream system, and damage to aquatic health and water quality.

2. Channel Aggradation

Aggradation is a process which occurs due to a stream channel's loss of ability to transport the sediment supply from its watershed. Aggradation occurs when the stream channel does not have the force to move the available sediment through the system, the sediment drops it out of the water column and the stream channel builds up or aggrades. If the total stream energy is less than the energy required to transport the sediment, the streambed will aggrade.

Figure III-14: Central bars indicate a loss of a stream's ability to transport sediment.

Over-widened stream channels typically exhibit the signs of aggradation. Over-widened streams are characterized as having a width to depth ratio higher than the stable range for the particular stream type and are generally pretty shallow for the width of the active channel. Once a stream segment experiences aggradation, the conditions can be compounded due to a transfer of the stream's shear stress to the outer stream banks. When the stream power is reduced, sediment deposition increases, which in turn increases shear stress in the near bank region (or against the outer streambanks). The transferred shear stress results in accelerated streambank erosion, with even more sediment being introduced to the stream channel. Aggradation commonly causes a stream to continue to become over-widened and braided (D stream type). Aggrading systems have poor fish habitat and, in many instances, summer baseflow may become completely subsurface in the aggraded reach.

3. Degradation

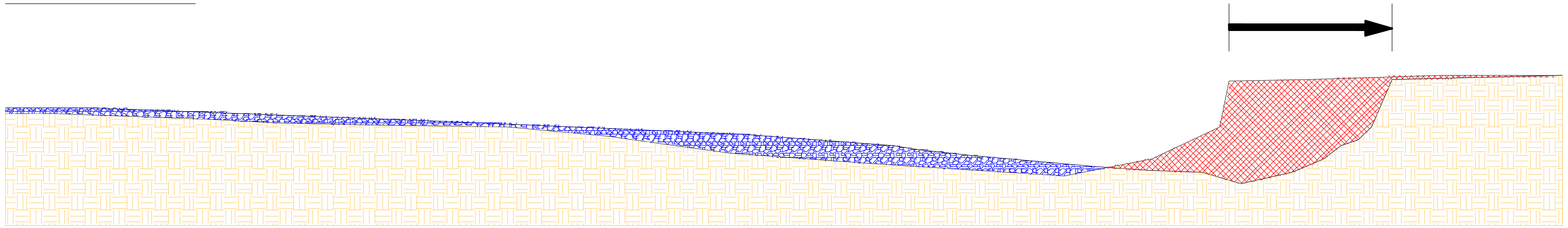
The final general form of fluvial process relates to a stream's incision (down-cutting) into the landform referred to as channel degradation. An incised stream is characterized by a lowering of the streambed elevation and the stream's abandonment of its floodplain. Degraded stream systems are typically characterized by high streambanks, bounded by alluvial terraces which are no longer active at the bankfull stage. An incised condition has a bank height ratio beyond a stable range for the stream type. The streambed will degrade if total stream energy is greater than the energy required to transport

Figure III-15: Typical degrading stream reach in the Catskill Mountains. Deposition feature on left shows multiple terraces associated with the stream's attempt to establish a new bankfull channel as it became incised.

Lateral Migration - "Kastanis Site"

(Note that the general base elevation of the channel has not changed and the cross sectional dimensions have remained constant; erosional area below bankfull is equal to depositional area)

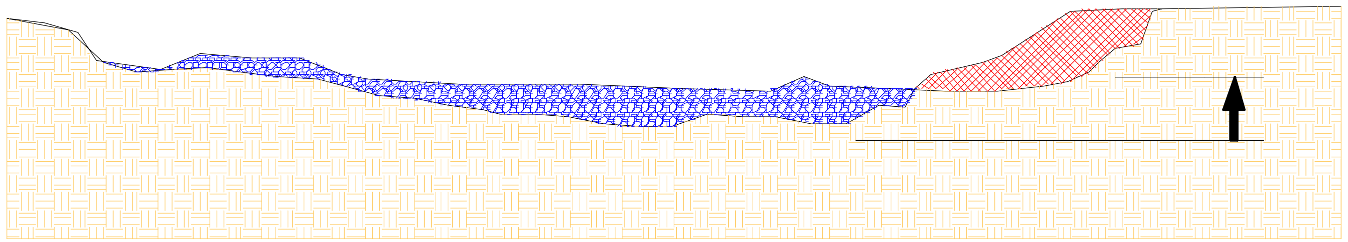
Cross Section #7



Aggradation - "Headwaters"

(Note the increase in channel width as a result of the sediment deposition)

Cross Section #5



🟥 EROSION

🟦 DEPOSITION

Degradation - "Peck Road"

(Note the multiple terrace formation, on the right side of the cross section, as historical evidence of the degradation process)

Cross Section #8

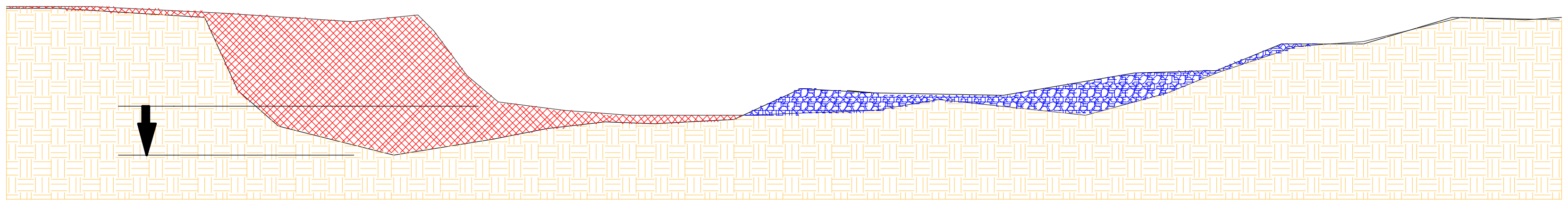


Figure III-16
Primary Stream Instability Process

sediment, and may be caused by activities which increase stream flow or stream velocity.

Degradation is caused by many factors including channelization, straightening, encroachment, confinement (lateral containment), urban development, change in flow or sediment regime, and riparian vegetation conversion. Problems with incision include accelerated bank erosion, land loss, lowering of water tables, land productivity reduction, and accelerated downstream sedimentation. Incised conditions can cause a loss of stream access to the flood plain, losing the benefits from over bank flows. Typically, degradation processes are often overlooked by stream managers.

Many times, activities taken to "stabilize" a stream may in fact result in stream channel degradation. For example, rock rip-rap is frequently used to address streambank erosion. In most cases, the rip-rap streambank protection is used with little attention to existing degradation processes. The rock rip-rap can divert stream energies to the channel bottom, further accelerating the degradation process. Continued incisement leads to structural failure of the rip-rap as the base erodes away. A visual summary of lateral migration, degradation and aggradation is shown in **Figure VI-16**.

F. STREAM CHANNEL EVOLUTION MODELS

Stream managers can use morphological form and stream function to make determinations regarding stream system stability in its current state, as well as predictions regarding future changes to the stream system. By comparing the current state of an unstable stream segment to a stable stream segment of the same type, stream managers can make very accurate predictions of future change as the unstable stream continues to adjust to those changes which have upset its equilibrium. By understanding the response of a stream system to changes in flow or sediment supply, or changes in the channel's morphological form, stream managers can often accurately predict a stream's response to a wide range of natural phenomena or other activities in its watershed. Changes to either the channel's form or function will conversely set in motion processes that will impact the other. Channel evolution models are useful in describing the sequence of changes which can be expected as the stream responds to changes in form or function.

Simon (1989) proposed one scenario for stream channel evolution, begining with a predisturbance condition of a channel that is vegetated and stable (class I) **Figure III-17**. A disturbance in the stream system, such as channelization, serves as the "trigger" (class II), and the stream system responds by degrading (class III). The channel degradation leads to exposed, steep banks and a localized steepening of the stream slope. The exposed banks begin to fail when they reach a critical height and slope. As the channel degradation moves in an upstream direction, a process commonly referred to as a "head cut", the channel will begin widening on the lower sections of the stream reach (class IV), as the banks fail and the stream attempts to reduce the steeper slope caused by the head cut. Eventually, the over-widening channel is characterized by reduced stream power, and the loss of the channel's ability to transport its sediment supply through the reach. The over-widened channel is then subject to aggradational processes, with sediment deposited in the reach (class V). In the final stages of the stream evolution, the channel will reach a new equilibrium, with the channel exhibiting the ability to move its water supply and bedload with out change, and the stream re-vegetates itself (class VI). In the final stage of the channel evolution model a new bankfull channel is formed at a lower elevation than the original channel.

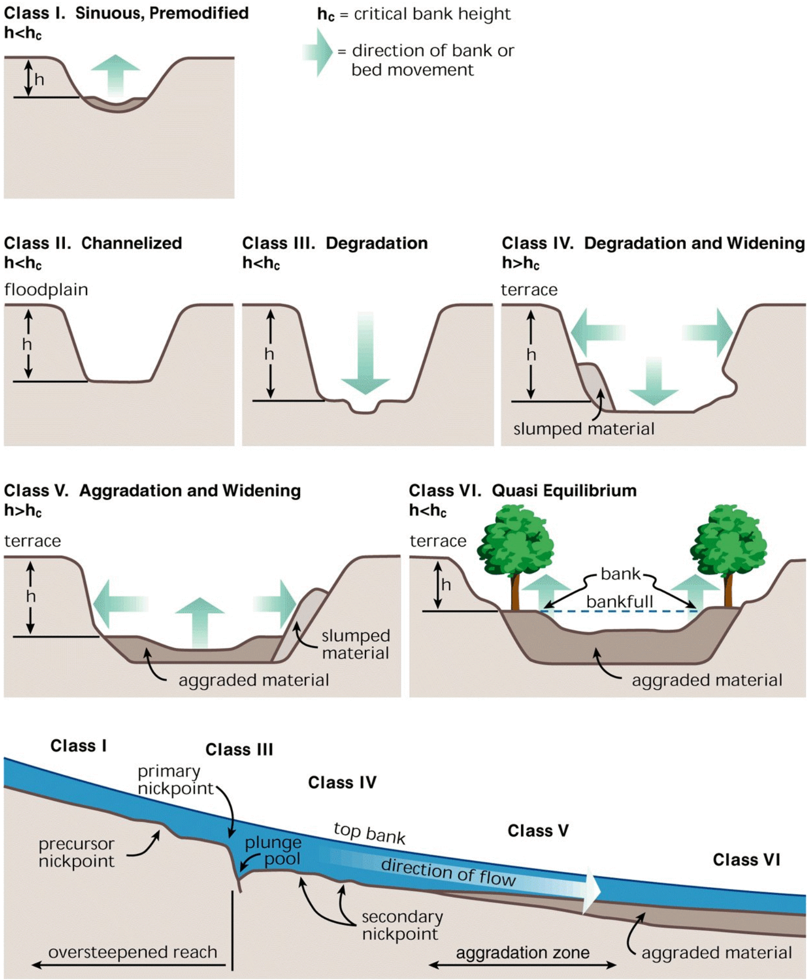


Figure III-17: One channel evolution model scenario, Simon 1989.
Stream Corridor Restoration Principles, Processes, and Practices, 10/98, the Federal Interagency Stream Restoration Working Group (FISRWG)

A general understanding of channel evolution models can be helpful in stream management. By determining the current state of the stream, and understanding the on-going evolution process within a given reach, stream managers can often predict what the next stages in the stream channel's instability will be, therefore, allowing for restoration efforts to be tailored to most effectively fix the problem. Understandably, limitations to the application of channel evolution models due to unforeseen changes in flow and sediment supply exist, as well as additional disturbances which can interrupt the channel evolution process.

G. TRADITIONAL MANAGEMENT ACTIVITIES

Mankind has been manipulating stream systems to one degree or another for centuries. In ancient time, aqueducts were constructed to carry stream flow from mountain brooks to thirsty settlements. Later, humans learned to harness the energy of natural stream systems to power mills and power plants. On all scales, mankind has developed a strong tendency to manipulate the natural form and process of its rivers and streams. Unfortunately, it has only been in recent times that humans have come to try and understand stream systems, and to realize that many activities they undertook, were in themselves responsible for additional stream stability problems.

While stream management activities are often undertaken with the best of intentions, in reality these activities have only increased the level of instability in stream systems. Traditional management activities, such as stream maintenance for protection of bridges and roads or impoundments for flood protection, have been conducted by stream managers that often lack a good understanding of the fluvial process and the consequences of these management activities. The following section describes some of the more common stream management activities and gives examples of how they result in additional stream problems. While these in no way represent the full range of activities which can impact streams, nor the wide array of stream problems they can cause, we hope they will give the reader a better awareness of the fragility of stream systems.

1. Stream Crossings

Bridges and culverts that are constructed without proper consideration of fluvial process often have a negative impact on stream systems. These impacts are most commonly associated with inadequate sizing of the bridge opening. Bridges with an inadequate opening to accommodate the stream's morphological form result in a loss of stream function. First, when a bridge opening is undersized, a backwater condition is often created above the bridge. The backwater results in a reduction in stream velocity and sediment deposition (aggradation). In addition to the aggradation causing a loss in channel capacity, the deposited sediment also causes the stream to insert stronger erosional forces on the streambanks causing erosion at the bridge abutment. A second impact is associated with an increase in stream velocity, as flow passes through the bridge opening (funneling effect) leading to scour and undermining of the bridge pillars and

Figure III-18: Failure of bridge abutment due to localized degradation of the stream channel caused by inadequate bridge opening.

abutments. It is far too common in the Catskill Mountains to see multiple scour walls poured around bridge abutments in response to local degradation and undermining of the bridge structure.

2. Stream Channelization

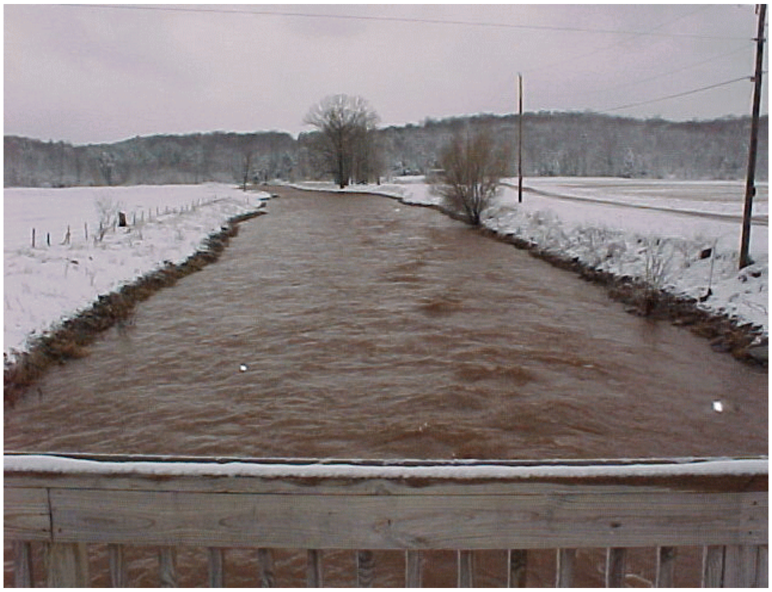


Figure III-19: Channelized and straightened stream reach

Traditionally, activities to straighten, widen, embank, or deepen stream channels have been undertaken to aid in flood water conveyance, provide for navigable waterways, improve irrigation and drainage, or to "protect" eroding streambanks. Any of these stream channelization activities can significantly impact stream channel slope, depth, width, roughness, and or sinuosity. These modifications typically lead to over-widened channels, increase in channel slope, decrease in low flow water depth, decrease in channel roughness, decrease in meander pattern. In addition to the undesirable stream responses to channelization discussed below, these stream modifications generally require routine maintenance which are not only costly, but also results in a continued disturbance to the stream channel.

> ***Over-widening*** of the stream channels results in a decrease in velocity causing deposition of sediment, reduction in riffle/pool style complexes, loss of habitat, and can lead to increased bank erosion and lateral extension of the channel in the immediate area and downstream.
>
> ***Slope increases*** due to straightening, or changes made to the stream profile, result in an increase in stream velocity and power, resulting in the instability of channelized sections as well as areas upstream and downstream.
>
> ***Decrease in water depths*** associated with the wider channel, will result in water temperature increases during base flow conditions. Increased temperatures are strongly detrimental to fisheries habitat, and in addition channelized streams exhibit a flattened channel bottom (loss of riffle/pool complexes), resulting in the loss of biotic health and diversity.
>
> ***Stream side berms*** or levees are typically constructed to prevent infrastructure damage and flooding. These embankments typically increase peak flood elevation, as well as stream velocities which results in increased erosive forces. Stream systems entrenched within berms typically experience degradation.

3. Check Dams

In the past, a common practice for controlling erosion of stream bottoms was the installation of cross channel check dams, constructed initially of wood and later of concrete, steel sheet piling, gabion baskets or other materials. Check dams are frequently used to address stream channel incision, to raise base stream flow elevation for easier water withdrawal, or to reduce stream slope by creating a barrier across the stream channel. In many areas of the Catskill Mountains, check dams were constructed to create seasonal impoundments for use by tourists for swimming and fishing.

Figure III-20: Old concrete check dam on the Batavia Kill.

Typically, check dam structures result in aggradation above the structure due to the localized reduction in stream slope. The aggraded section of a stream pushes erosive forces against the streambanks, and often the stream will migrate around the structure, requiring bank armoring to prevent the loss of the check dam. Depending on the height and form of the check dam, downstream impacts may include degradation due to the force of larger flood flows spilling over the check dam resulting in downstream scour problems. These structures also impede migration by fish and biotic life to upstream reaches during varying flow events.

4. Gravel Management

Gravel management is the removal of sediment (typically gravel) from stream reaches where deposition is perceived to be a problem. Stream reaches with point bars as well as deposition near bridges are generally the target of these activities. Removal is done to increase channel capacity for flood conveyance, to provide construction aggregate (road base, fill, etc), and to prevent erosion resulting from gravel deposition. A stream's response to gravel removal may include over-widening of the channel which in turn promotes further deposition. Gravel removal can also reduce the stream bottom elevation, resulting in an entrenched or confined condition. Entrenchment channels result in increased stream power, streambank erosion and downcutting of the channel. Gravel management typically results in local

Figure III-21: Hardened streambanks can transfer erosional problems downstream.

incision upstream and downstream of the harvest area, and it results in an increased width/depth ratio through the area.

5. Streambank Protection

Streambank management activities that provide structural protection of stream banks using rip-rap, gabion baskets, concrete or steel walls, can have a very significant destabilizing effect on stream form. Traditional approaches to streambank protection typically do not address the source or cause of the instability eroding the streambanks, and often redirect these problems either upstream or downstream from the original problem. While rip-rap may provide immediate benefit to an actively eroding streambank, if the erosion was occurring as a result of an evolution in the stream's morphological form, the bank hardening will simply relocate the impact of the erosive forces further downstream. Additionally, traditional streambank protection methods can also increase stream velocity by reducing stream channel roughness. These projects are typically detrimental to fisheries habitat and are not aesthetically pleasing.

H. STREAM RESTORATION METHODS

As discussed briefly in the previous section, there has been a growing recognition that traditional stream "restoration" practices typically have a single objective, and often may result in an overall negative impact on stream system stability. While rip-rap, gabions and other hard armoring techniques typically achieve the goal of localized streambank stability, the application of these methods is generally done without consideration of the impacts of the stream work outside the immediate project area. Traditional restoration methods have not addressed multiple issues such as fisheries habitat, flooding and water quality; as such, these efforts are not as effective as they could be if managers had a better understanding of the stream's geomorphic form and function. In many cases, on-going evolutionary changes in stream form are only interrupted by local stabilization techniques that cause stream instability to shift upstream or downstream. In many cases, work undertaken to address one form of instability may create a domino effect of instability elsewhere.

While there are many definitions of stream restoration, the primary goal is to "restore" the natural dynamic equilibrium of the ecosystem as close as possible to pre-disturbance conditions. Restoration may be achieved by mimicking the features that are associated with a stable stream form and are appropriate for the valley setting and the stream's flow and sediment regime. The factors that are causing the damage to the ecosystem must be identified and addressed by the final restoration strategy. In reality is not possible to exactly recreate a natural system that remains in dynamic equilibrium. Effective restoration projects are possible if the management strategy re-establishes the general structure, function and dynamics of the self sustaining stream system, leaving final adjustments to the stream itself. While there are many opinions on stream management, restoration activities can be organized by three basic approaches, natural, assisted and managed recovry.

Natural Recovery:

The first approach to stream restoration involves nonintervention or allowing the destabilized stream system to recover through a natural process. If the cause of the instability is localized, and minor in scope, stream systems may often recover quickly. Recovery through natural processes in the Catskill Mountains is often impacted by the frequency of flood flows, which can quickly set back any gains in stability that have occurred. Natural recovery is also interrupted by other activities, such as rip-rapping and gravel removal, which may occur as the result of flood response or maintenance activities.

Assisted Recovery:

The second approach to stream restoration involves partial intervention, or "assisted recovery". This approach can work well when the target stream reach is attempting to regain a stable state, and there are no larger watershed level issues, such as a change in the sediment supply, affecting the stream's stability. Assisted recovery must be done carefully and with a good understanding of the stream's characteristics in order to avoid further instability. Assisted recovery may be as simple as planting riparian vegetation to maintain bank stability, or as complicated as designing comprehensive stormwater management retrofits. Riparian landowners effectively promote assisted recovery in a number of mays including planting trees and shrubs, limiting mowing or brush removal and can careful selection of disposal areas for their yard waste.

Managed Recovery:

Finally, the most intensive approach to stream restoration involves "managed recovery", where extensive reconstruction of a stable stream form must be undertaken. This approach involves extensive grading to reconstruct a stable stream morphology. Managed recovery is generally required when the target stream reach is extremely unstable, and conditions have deteriorated to the point where natural or assisted recovery are no longer feasible. To date, all of the projects completed by the GCSWCD in the Catskill Mountains have been completed using managed recovery techniques.

I. NATURAL CHANNEL DESIGN (NCD) CONCEPTS

As the understanding of fluvial process has improved, a number of stream restoration practitioners have developed new methodologies to both assess the underlaying cause of stream instability, and to use these assessments to address stream form and function in restoration strategies. In addition to the stream classification system presented earlier in this section, Dave Rosgen, of Wildland Hydrology, has developed a number of protocols for assessing stream system instability and for developing restoration designs. During the course of the Batavia Kill Project, GCSWCD and NYCDEP staff members studied these methodologies with Rosgen at his facility in Colorado and returned to the Catskill Mountains to test their application in the watershed.

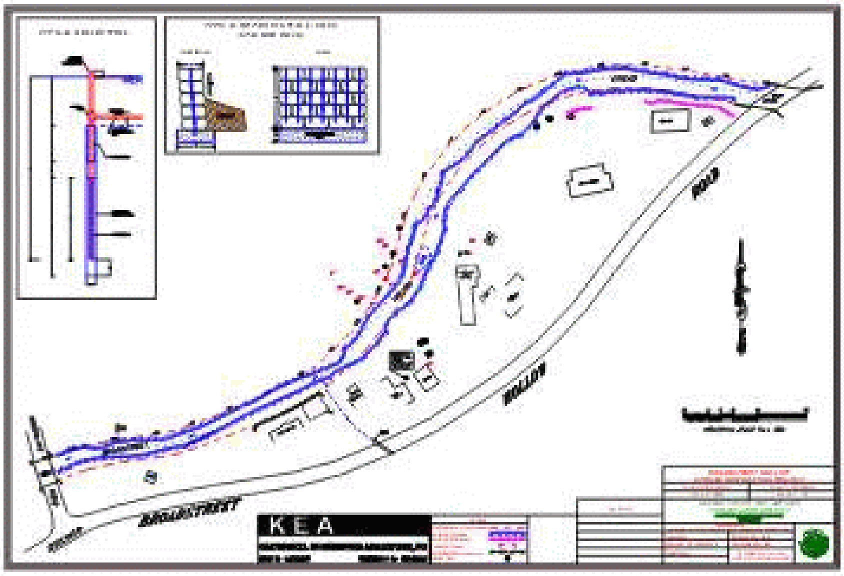


Figure III-22: Typical design sheet for a stream restoration project using NCD concepts. Broadstreet Hollow Stream Project 2000.

In its simplest definition, Natural Channel Design (NCD) can be described as a restoration strategy which focuses on restoring "natural" form and function to a stream reach, while minimizing the use of traditional, hardened stabilization practices. Using NCD, stream managers can design a restoration project which will provide an appropriate stream morphology and address the stream's ability to handle both the wide range of flows it experiences, as well as the transport of the stream's sediment supply.

One of the primary features of NCD methods is the use of stable stream reaches as a "blue print" for restoration of unstable stream reaches. After the cause of the stream instability has been identified, and the influence of the surrounding landform and watershed characteristics have been considered, the stream restoration practitioner must correctly identify the appropriate stream type for restoration. Once this has been determined, stable reference reaches are located and detailed measurements are taken. The process for the use of NCD concepts can be summarized in 7 major steps. As the design is developed, each step involves detailed measurements, analysis and calculations.

1. Determine cause of instability
2. Determine appropriate stream type to be constructed
3. Identify, and obtain measurements of stream form from reference reach
4. Design the stream channel dimension, pattern & profile
5. Test design channel to insure effective flow and sediment transport function
6. Address streambank protection - rock structures & vegetation
7. Address construction requirements

Addressing Streambank Stability

While the development of a stable stream form is critical to providing effective restoration, the protection of the streambanks from erosive forces is essential. While traditional restoration practices often focus on the use of rip-rap to protect the streambanks from erosion, NCD projects use a combination of in-stream rock structures and vegetative plantings to provide effective streambank stability. Used in combination, in-stream structures such as rock vanes, cross vanes and vegetative plantings, can provide very effective stabilization of the streambanks.

1. Rock Structures

In the Batavia Kill, the GCSWCD and NYCDEP have been utilizing a series of in-stream rock structures developed by Dave Rosgen to assist in providing stability to the stream channel. Known as rock vanes and cross vanes, these structures function by decreasing (or flattening) the slope of the water column along the streambanks which in turn greatly reduces shear stress on the banks. The rock vanes also work to redirect velocities away from the streambanks to the center of the stream channel.

Figure III-23: View, looking upstream, of 3 rock vanes. Note that water is deflected away from the streambank.

Rock vanes are constructed of large boulders that are interlocked and placed pointing upstream. Therefore, these structures are able to resist the stream flows. The rock structures are sloped from the stream channel bottom at a flat slope between 4% and 7% and are tied into the streambank at, or just below, the bankfull elevation. The area above the rock structures (upstream) are depositional areas, and the small wedge of deposition materials effectively reduces water surface slope against the streambank.

Figure III-24: View of a cross vane from upstream. Note that velocities are placed in the center of the stream channel and still, flat water is located along the banks upstream of the structure.

Rock vanes are a single armed structure, extending from only one streambank. On the other hand, cross vanes are constructed as two rock vanes, on opposite sides of the stream, with a rock sill connecting the two vane's arms across the channel bottom. The sill on the Cross Vanes provides grade control in the stream profile, and this structure is often used when stream systems are experiencing problems with degradation (down-cutting).

Rock structure are effective in reducing boundary shear stress against the streambanks and deflecting stream velocities. In addition, the rock structures also have good habitat value, as they create and maintain a pool just down stream of the structure and fish find the submerged sections of the structures to be good refuge during higher flows. Other structural methods used to provide streambank stability include W-weirs, which are essentially two cross vanes siide by side across wider stream channels, and rootwads. Rootwads involve placing the root fan of large trees into the streambank facing upstream similiar to a rock structure. The root fan deflects velocities away from the streambanks, and local scour provides excellent fisheries habitat.

2. Vegetation

Arguably the single most important factor in long term stream stability is the establishment of effective riparian vegetation. In natural stream systems, the presence of deep rooted vegetation, whether it be trees, shrubs or herbaceous plants, is usually the controlling factor in maintaining the stream's stable form.

On the restoration project, the GCSWCD and NYCDEP have been using a number of different techniques to re-establish stream side vegetation. Right after construction, the District uses a deep rooted conservation grass mixture to provide immediate stability to the project site. While the conservation grass is adequate for those flatter parts of the floodplain, the streambanks themselves require deeper rooted trees and shrubs to establish stability. In these locations, the most cost effective method to establish vegetation involves the use of dormant plant materials, as well as rooted plants.

Figure III-26: Excavation of streambank benches and the placement of alternating lifts of soil and willow shoots is the basis of brush layering.

In general, the methods which use dormant plant materials is referred to as bio-engineering. This technique involves the use of select plant species which have a very strong capability to generate a new root system and shoots from cuttings of dormant plants. Various forms of willows, as well as other plants such as red osier dogwood, have this ability.

When a healthy, dormant cutting is planted under good conditions of soil contact and moisture, the buried sections of the willows will establish new root growth, while adventitious buds, in the stems above ground, will break dormancy and create a new shoot. There are a number of different methods which can be used to establishing plantings from dormant materials, but the District has been focusing on the use of live fascines, brush layering and live posts/stakes.

In addition to the dormant materials, the District also uses transplants of live materials and bare-root plant stock on the stream projects. Clumps of willows or small trees can be excavated and replanted on stream projects to provide some larger, more mature plant materials. The District uses the “mother tree” theory, spacing out trees, that are characterized as being good seed bearers,t along the streambanks. These larger plants may experience a short-term decline as they acclimate to their new home, but generally they rapidly start producing seed crops, quickly filling the area with small seedlings.

Figure III-25: Installing Brush Layering.