A SunCam online continuing education course

Floodplain Engineering:

An Introduction to Stream Classification & Restoration

by

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Introduction:
This course presents an introduction to the process of stream restoration. This topic may seem somewhat simple at first glance. However, there is an extensive amount of analysis and design that goes into the process. The technical literature (and, consequently, this course) deal significantly with stream classifications, channel bed and bank characteristics, watershed parameters, and similar data.

Stream restoration can take many forms and can be used to address a variety of conditions. These include streams that are eroding due to increased flow velocities caused by upstream development, streams that are being silted in because of erosion from upstream, streams that have become degraded by pollution, loss of streamside vegetation, or agricultural activities, and a myriad of other situations.

When you complete this course, you should have a working knowledge of the different methods of stream classification and analysis and should be able to understand some of the common the processes employed for designing a stream restoration project. It is important to state at the outset of the course that this is only an introduction and that, due to the complexities and various situations that can be involved, each stream restoration project is unique. Some of these complexities include the following:

1. Determining what the goal of the stream restoration will be. This can be as varied as armoring a stream bank to prevent catastrophic erosion to re-establishing a wooded stream to enhance the biotic community.
2. Determining what the restored stream channel will look like. Some examples of how to determine this are:
    - Picking a healthy stream reach from another section of the water course (or elsewhere in the watershed) and attempting to replicate that channel.
    - Providing a stream channel that will provide specific benefits, such as fishing, prevention of flooding, or others.
3. Determining the time frame for the restoration. Obviously, if the goal is to prevent a catastrophic erosion that may endanger buildings or infrastructure, the project should be planned, approved by the applicable governmental agencies, and constructed as quickly as possible. On the other hand, if an eroded stream that passes through a cow pasture is slated for restoration to a more natural, healthy, wooded stream, then several years of monitoring and maintenance will

be required after the initial phase of the project is completed before the stream can be considered "restored".

4. Determining which governmental agency or agencies have regulatory jurisdiction over the project. This will obviously depend on where the project is located as well as a host of other factors (for instance, whether or not wetlands will be disturbed by the restoration).

It would also be well to point out at this point that nearly any well-planned and well-executed stream restoration plan will require the assistance of other professionals to work alongside the engineer in the design. These may include fishery experts, terrestrial and aquatic vegetation experts, and others.

Stream processes (both natural and man-made) are dynamic and can cause significant changes in channel geometry and location. This old stone bridge over a lawn in a municipal park in New Jersey bears testimony to these processes. The stream channel that was once crossed by this bridge is now located many feet away from the structure.

Nature of the Problem:
All shown in the photograph above, streams are dynamic features that are constantly changing. Many of these changes are relatively benign and do not adversely affect people or the environment. However, stream systems can become degraded through a variety of both mand-made and natural processes and when the degradation reaches some critical junction there is often the need to rectify the situation. The New York State Department of Economic Conservation (NYDEC) has prepared a "Stream Corridor Management" reference manual and much of the following information is taken from this manual. According to the NYDEC, the following factors contribute to degradation of the stream corridor:

1. Construction and development activities. The ground disturbance associated with construction activities can dramatically increase erosion and subsequent sediment reaching a stream bank. The table below shows the amount of sediment generated by various land uses. (Note that the sediment value for "active construction areas" is significantly higher than it is for the other land uses listed in the table).

Land Use	**Sediment Volume (Tons per acre per year)**
Woods	0.2
Developed urban areas, grassed areas, pasture, hay, abandoned fields with good cover	1.0
Clean, tiled cropland (corn, soybeans, etc.)	10
Active construction areas	50

The photograph below shows a large construction yard in eastern Pennsylvania. It is easy to see why such a scalped area has a large potential for erosion and subsequent sediment volume downstream. In many cases, most of all of this sediment will end up in a nearby stream.

2. Urbanization, which has the following detrimental effects.
    - Increased stormwater runoff and increased potential for stream bank and channel erosion.
    - Increased load of nutrients, sediment and toxic materials (e.g. heavy metals) into the stream.
    - Alteration of the natural water temperature regime. (A recent study in Virginia indicated that urbanization affected steam temperatures in a variety of ways which were dependent on the season of the year and other factors).
    - Litter.
3. Agricultural activities. These can significantly increase the potential for erosion into the stream channel. In addition, pesticides and fertilizers can wash into the stream. Finally, these activities generally involve the removal of the streamside vegetation, which in turn, can lead to less efficient filtration of the runoff entering the stream and also to an increase in the summer temperatures within

the stream itself. Forestry can have a similar effect on a stream. In fact, according to the NYDEC manual: "Erosion from logging roads and skid trails located too close to streams contributes to sedimentation. The deposition of waste materials such as limbs and branches in a stream can cause a shifting of the stream channel and increased sediment loading."

4. Transportation. The removal of vegetation, the increase in impervious surfaces, and the treatment of roads for snow removal can all contribute to nearby stream degradation.
5. Mining activities. These generally include all of the detrimental effects associated with forestry and can also include other negative impacts. The effects of mining on a stream can often be minimized by proper placement and filtering of mine tailings, spoil banks, and soil stockpiles.

As noted above, all of these activities can cause a variety of stream problems. However, it might be worthwhile to enumerate the most common problems associated with degraded stream channels once again, below:

1. Impaired Fisheries Habitat: These can be due to sedimentation, an increase in water temperature (trout and several other species of fish are temperature-sensitive), or other factors.
2. Impaired Water Supplies: Both the quality and amount of water available can be diminished.
3. Impacts to Recreation: Obviously, streams that are in a more "natural" state are better for fishing, canoeing, picnicking, etc. than are badly degraded watercourses.

Stream Classification Schemes:
One of the very first steps in a stream restoration project is to classify the stream reach in question. There are a significant number of stream classification schemes which are used by various governmental agencies. In order to introduce the complexity and variety of these, several will be described in detail below.

The US Forest Service has several criteria for classifying steams. One of these is the Rosgen Classification Method, which is described in the table below:

Stream	Description	Channel	Width	Sinuosity**	Slope	Landform & Soils

Class		E*	to Depth Ratio			Features
Aa+	Very steep, deeply entrenched, debris transport, torrent streams	<1.4	>12	1.0 to 1.1	>10%	Very high relief. Erosional, bedrock, or depositional features, debris flow potential. Deeply entrenched streams, vertical steps with deep scour pools, waterfalls.
A	Steep, entrenched, cascading, step-pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock or boulder-dominated channel.	<1.4	>12	<1.2	4% to 10%	High relief. Erosional or depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step-pool bed morphology.
B	Moderately entrenched, moderate gradient, riffle dominated channel with infrequently spaced pools. Very stable plan and profile with stable banks.	1.4 to 2.2	>12	>1.2	2% to 4%	Moderate relief, colluvial deposition and/ or structural. Moderate entrenchment and width to depth ratio. Narrow gently-sloping valleys. Rapids predominate with scour pools.
C	Low gradient, meandering point bar, riffle/pool, alluvial channels with broad, well-defined flood plains.	>2.2	>40	>1.4	2%	Broad valleys with terraces in association with flood plains and alluvial soils. Slightly entrenched with well-defined, meandering channels. Riffle/pool bed morphology.

D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.	n/a	40	N/A	<4%	Broad valleys with alluvium, steeper fans. Glacial debris and depositional features. Active lateral adjustment with abundance of sediment supply. Convergence/divergence bed features, aggradation processes, high bed load and bank erosion.
DA	Anastomosing (i.e. multiple channels) narrow and deep with extensive, well-vegetated floodplains and associated wetlands. Very gentle relief with highly variable sinuosities and width to depth ratios. Very stable streambanks.	>4.0	<40	Variable	<0.5%	Broad, low-gradient valleys with fine, alluvium and/or lacustrine soils. Anastomized geologic control creating fine deposition will well-vegetated bars that are laterally stable with broad wetland floodplains. Very low bed-load, high wash load sediment.
E	Low gradient, meandering riffle/pool stream with low width to depth ratio and little deposition. Very efficient and stable. High meander width ratio.	>2.2	<12	>1.5	<2%	Broad valleys and meadows. Alluvial materials with floodplains. Highly sinuous with stable, well-vegetated banks. Riffle/pool morphology with very low width to depth ratios.
F	Entrenched, meandering riffle/pool channel on low gradient with	<1.4	>12	>1.4	<2%	Entrenched in highly weathered material. Gentle gradients with high width to depth

	high width to depth ratio.					ratio. Meandering, laterally unstable with high bank erosion rates. Riffle/pool morphology.
G	Entrenched gully step-pool and low width to depth ratio on moderate gradients.	<1.4	<12	>1.2	2% to 4%	Gullies, step-pool morphology with moderate slopes and low width to depth ratio. Narrow valleys or colluvial materials (fans and/or deltas). Unstable, with grade control problems and high bank erosion rates.

*E signifies channel entrenchment, which is the degree to which the stream is incised into the landscape. It is defined as the width of the flood-prone area divided by the width of the stream channel, itself.
**Sinuosity is measure of the curvature of the stream channel.

The stream classes described in the table above can be further subdivided by the following lists of modifiers relative to the channel bed material, channel slope, and bed structure:

Materials:

Modifier	**Channel Material**
1	Bedrock
2	Boulder (over 10”)
3	Cobble (2.5 to 10”)
4	Gravel (0.08 to 2.5”)
5	Sand
6	Silt/Clay

Slope:

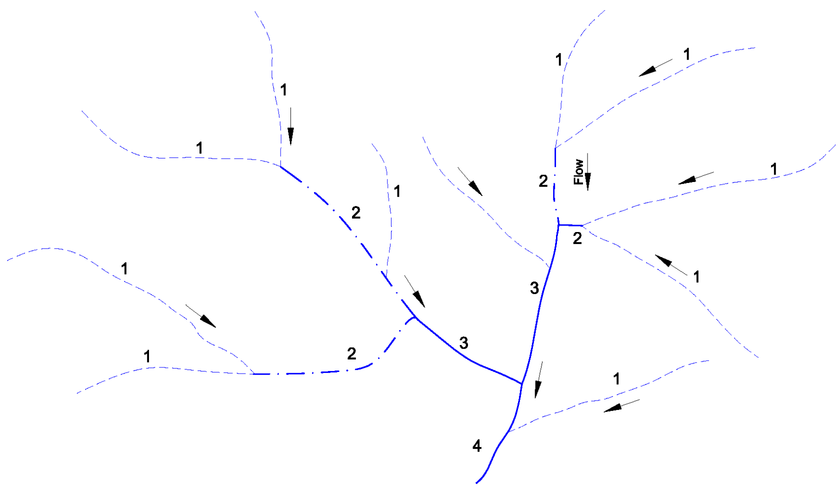
Modifier	**Slope**
h	Hydraulic (>10%)
a	Aggressive (4 to 10%)
b	Balanced (1.5 to 4%)
c	Cumulative (0.5 to 1.5%)

f	Flat (<0.5%)

Bed structure:

Modifier	**Structure**
PR	Pool-riffle (alternating pools and riffles)
PB	Plane-bed (Lacking distinct bedforms)
SP	Step-pool (Alternating pools and vertical steps)
C	Cascade (tumbling flow over disorganized large rocks)

Another simple stream classification system has to do with the stream order. This is a very simple classification system and shows how many tributaries a particular stream reach has. A reach with no tributaries is classified as a first order stream. If a reach has one tributary it is classified as a second order stream. In order for stream reach to be classified as a third order stream it must be at the intersection of 2 second order streams, and so on for 4th order and higher order streams. This is illustrated below. Note that in some cases first order streams flow into second order streams but in other cases they actually flow directly into higher order streams.

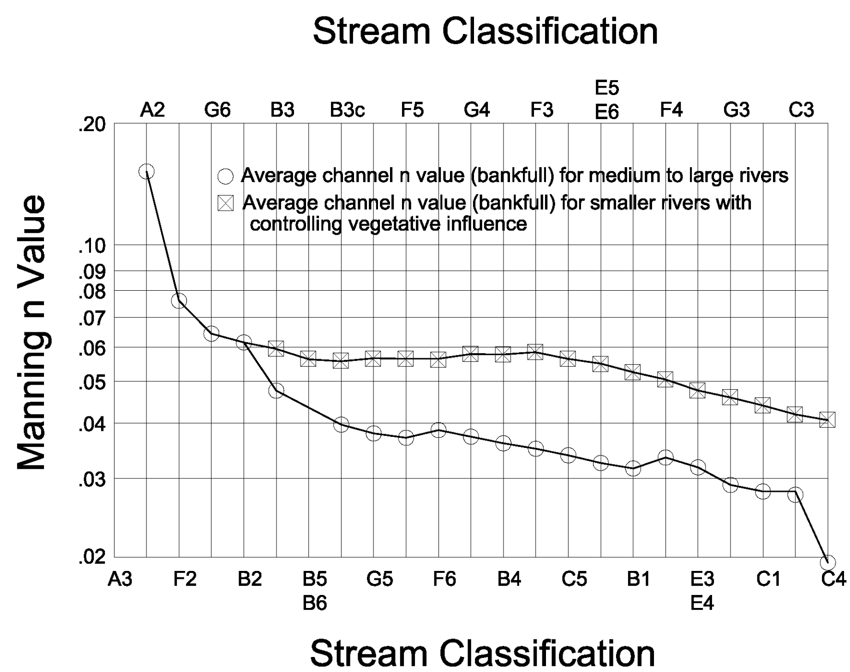


Schematic Stream Order Diagram

The Rosgen Classification Scheme can also be used to approximate the "roughness" of the stream channel.

The flow through a stream channel can often be approximated by using the Manning's equation:
$Q=(1.486/n)A(R)^{2/3}S^{1/2}$
Where:
Q is the discharge in CFS
A is the cross sectional area of the channel
R is the hydraulic radius (defined as the area divided by the wetted perimeter)
n is the Manning's roughness coefficient
Assigning the proper n value in this equation requires a considerable amount of engineering judgment. Generally, the n value has been assigned based on a qualitative description of the stream channel and overbank areas. However, there are other ways to assign roughness

coefficients. One of these is to relate the n value to stream classification using the Rosgen classification system discussed above. The following graph shows the relationship.



Manning's Roughness Coefficient
vs. Stream Classification

Manning's Roughness Coefficient Example #1:
Using the Manning's Roughness Coefficient chart above, determine the n value for the stream pictured below. (The drainage area for the stream to this point is approximately 1.4 square miles).

Solution:
In order to determine the n value, first we will try to determine the correct stream classification. The stream appears to have the following characteristics:

- moderate gradient
- Many riffles
- Stable bed and banks
- The channel is lined with cobbles (rocks between 2.5” and 10” in size).

Looking at the Rosgen classifications above, it would appear that this stream could be classified as B type stream. We should also apply the modifier “3” to account for the cobbles. Looking at the chart, it can be seen that there are two potential n values for a B3 stream, depending on whether it is a medium-to-large or smaller river. This is somewhat subjective. However, the chart also specifies that smaller streams have controlling vegetation influencing the flow. The photograph was taken during the winter, but it is obvious that there is significant streamside

vegetation that could affect flood flows during the growing season. Therefore, it probably more accurate to use the value for smaller streams.
Based on this logic, the overall n value for this stream channel can be assigned as approximately 0.057.

Manning's Roughness Coefficient Example #2:
Determine Manning's n roughness coefficient is based on the stream shown in the photograph below. The drainage area of this stream to this point is approximately 5.7 square miles and the bottom is sand.

Solution:
Once again, in order to determine the n value, first we will try to determine the correct stream classification. The stream appears to have the following characteristics:

- Minimal gradient and a fairly high width to depth ratio (i.e. the stream is relatively wide but not very deep).
- Very stable bed and banks.

The Rosgen classification for this stream would probably be an "E5". (Remember that the modifier "5" is because the bed is sand). Once again, we are required to make a decision as to whether this is a large or a small stream. However, the drainage area of this stream is significantly larger than in the previous example. Therefore, we will use the "large stream" value in the chart and assign this stream an n value of 0.033.

The Rosgen Method also includes a design methodology for channel design/restoration. This is a somewhat cumbersome procedure but it has the advantages of being scientifically-based and of being repeatable. A complete discussion of this methodology is well beyond the scope of this course. However, it consists of a number of steps and perusal of these steps proves that the Rosgen Method is both (i) extremely thorough and (ii) very labor-intensive and time consuming to conduct.

Site Investigations & Assessment:

After classifying the stream, it is then necessary to determine the stream condition (i.e. stable, unstable, etc.).
The following basic information must be included in any stream investigation:

1. Description of the watershed and existing land use.
2. Assessment of historical stream conditions.
3. Measurements of the stream channel (including both low-flow and bank-full conditions). Also, there should be a description of any channel debris, woody material, and bed & bank vegetation.
4. Characterization of the channel bed. (Also include any observations of responses to channel alterations and any evidence of resulting stream degradation and recovery.)
5. Description of the river bank profiled and any evidence of bank instability.
6. Descriptions and locations of pools, riffles, etc.
7. A preliminary listing of alternatives for stream restoration should be made at this time.

Checklist for Assessment of Channel Reach Conditions:

Condition	Channel Bed Characteristics	Channel Bank Characteristics
Stable	The channel bed is in as close to a stable condition as can be expected in a natural stream. The reach exhibits few signs of local bed scour or deposition.	The channel banks are as close to a stable condition as can be expected in a natural stream and appear to have low erosion potential. Banks are predominately covered are either covered by extensive vegetation or boulders or are in a bedrock formation. Local bank erosion is within an allowable rate of change.
Moderately Stable	The channel bed in the reach is in a somewhat stable condition. However, the reach may be transition. Bed aggradation or degradation is occurring at a low rate of change. Moderate to high rates of bed scour or deposition are occurring at local points throughout the reach. (e.g. rapid aggradation can occur immediately above a minor debris blockage such as a single tree and scour can immediately below such points).	The channel banks are in a somewhat stable condition and exhibit medium erodibility. Banks are partially vegetated with moderately erodible soils. Typically, parallel flows do not result in bank erosion. The reach may be in transition. Banks exhibit moderate local bank erosion that does not appear to be spreading. (e.g. in an otherwise stable reach, a single section of the bank has fallen in and resulted in local, moderate bank erosion).
Unstable	The channel bed is predominantly unstable. The bed is undergoing widespread aggradation and/or degradation at a moderate rate. Moderate scour is occurring and many of the pools are filled with loose sediment.	The channel banks are predominantly unstable. Banks are experiencing widespread erosion at a moderate rate. Channel banks are undergoing local bank erosion at a high rate of change and the erosion does not appear to be self-healing.
Very Unstable	The channel bed is in a very unstable condition. Typically, the channel shows no sign of approaching equilibrium with its current geometry and composition. The bed is undergoing widespread aggradation and/or degradation at a high rate. Reaches are severely scoured and all of	The channel banks exhibit high erodibility and do not have any controls that restrict extensive changes in composition or geometry. Riparian root masses are not present to slow rapid bank retreat. Any parallel or impinging flows will cause continuing extensive bank erosion. Reaches have near

	the pools are filled with loose sediment.	vertical to overhanging banks.

Based on the table above, it would appear that the channel in the photograph below (which shows a reach of the Raritan River in Somerset County, New Jersey) can be considered unstable. The bank is nearly vertical and is obviously undergoing continuing erosion. This problem would be expected to worsen over time. Note that there are trees present along the bank and, at one time, they may have provided stability. The velocity in the channel bank is obviously erosive and it is only a matter of time before the bank collapses into the river, taking the trees with it.

The photograph below shows another stream. This one is a slow-moving, low-gradient stream through a meadow. The banks are covered with vegetation and there is no indication of erosion in the channel. Therefore, this stream reach can be described as stable.

Pfankuch Stream Assessment Method:
The Pfankuch Stream Assessment form provides yet another way to classify streams. This system uses descriptions of the stream channel and banks to determine the overall quality of a stream reach. The table below shows the scoring used in this classification scheme.

Location	Excellent Condition	Good Condition	Fair Condition	Poor Condition
(1) Landform	Bank slope <30%. Score=2.	Bank slope 30-40%. Score =4.	Bank slope 40-60%. Score =6.	Bank slope >60%. Score =8.
(2)Mass wasting or	No evidence of	Infrequent and/	Moderate	Frequent or

failure	past or any potential for future mass wasting into channel. Score=3.	or very small. Score =6.	frequency and size, with some raw spots eroded by water during high flows. Score=9.	large, causing sediment nearly yearlong or imminent danger of same. Score=12.
(3)Debris jam potential.	Essentially absent from immediate channel area. Score=2.	Present, but mostly small twigs and limbs. Score=4.	Present; volume & size are both increasing. Score=6.	Moderate to heavy amounts; predominantly larger sizes. Score=8.
(4)Vegetative bank protection.	>90% plant density. Vigor & variety suggests a deep, dense, soil-binding root mass. Score=3.	70-90% density. Fewer plant specimens or lower vigor suggests less dense root mass. Score=6.	50-70% density. Lower vigor & still fewer specimens form a somewhat shallow and discontinuous root mass. Score=9.	<50% density plus fewer species & less vigor indicate poor, discontinuous, and shallow root mass. Score=12.
(5)Channel capacity.	Ample for present pls some increase. Width/Depth ratio (W/D) <7. Score=1.	Adequate. Overbank flows are rare. W/D ration of 8 to 15. Score=2.	Barely contains present peaks. Occasional overbank floods. W/D ratio of 15 to 25. Score=3.	Inadequate. Overbank flows common. W/D ratio>25. Score=4.
(6)Bank rock content.	>65%, with numerous large, angular boulders (12+"). Score=2.	40-65%, mostly small boulders to cobbles (6-12"). Score=4.	20-40% with most 3-6" diameter. Score=6.	<20% rock fragments of gravel size (1-3" or less). Score=8.
(7)Obstructions/flow deflectors/sediment traps.	Rocks and old logs firmly embedded. Flow pattern without cutting	Some present, causing erosive cross currents and minor pool filling.	Moderately frequent, moderately unstable obstructions &	Frequent obstructions & deflectors cause bank erosion yearlong.

	or deposition. Pools & riffle stable. Score=2.	Obstructions & deflectors newer & less firm. Score=4.	deflectors move with high water causing bank flooding & filling of pools. Score=6.	Sediment traps full, channel migrations occurring. Score=8.
(8)Cutting.	Little or none evident. Infrequent raw banks generally <6" high. Score=4.	Some, intermittently at outcurves and constrictions. Raw banks up to 12". Score=8.	Significant. Cuts 12-24" high. Roots matt overhangs and sloughing evident. Score=12.	Almost continuous cuts, some over 24" high. Failure at overhangs frequent. Score=16.
(9)Deposition.	Little or no enlargement of channel or point bar. Score=4.	Some new increase in bar formation, mostly from coarse gravels. Score=8.	Moderate deposition of coarse gravel & coarse sand on old and some new bars. Score=12.	Extensive deposits of predominantly fine particles. Accelerated bar development. Score=16.
(10)Rock angularity.	Sharp edges & corners; plane surfaces roughened. Score=1.	Rounded corners & edges. Surfaces smooth & flat. Score=2.	Corners & edges well rounded in 2 dimensions. Score=3.	Well rounded in all dimensions. Surfaces smooth. Score=4.
(11)Brightness.	Surface dull, darkened, or stained, not "bright". Score=1.	Mostly dull, but may have up to 35% bright surfaces. Score=2.	Between 35% & 65% bright surfaces. Score=3.	Predominantly bright. >65% exposed or scoured surfaces. Score=4.
(12)Consolidation or particle packing.	Assorted sizes tightly packed and/or overlapping. Score=2.	Moderately packed with some overlapping. Score=4.	Mostly a loose assortment with no apparent overlap. Score=6.	No packing evident. Loose assortment; easily moved. Score=8.
(13)Bottom size distribution & percent stable	No change in sizes evident. Stable	Slight shift in either direction. Stable	Moderate change in sizes. Stable materials:	Marked distribution change. Stable

materials.	materials: 80-100%. Score=4.	materials: 50-80%. Score=8.	20-50%. Score=12.	materials: 0-20%. Score=16.
(14)Scouring & depositing.	<5% of the bottom affected by scouring & deposition. Score=6.	5-30% affected. Scour at constrictions & where grades steepen. Some deposition in pools. Score=12.	30-50% affected. Deposits & scour at obstructions, constrictions, & bends. Some filling of pools. Score=18.	>50% of the bottom in flux or change nearly yearlong. Score=24.
(15)Clinging aquatic vegetation (measuring algae).	Abundant. Growth largely moss-like, dark green, perennial (even in swift water). Score=1.	Common. Algae forms in low velocity & pool areas. Moss here & in swifter waters. Score=2.	Present, but spotty, mostly in backwater areas. Seasonal bloom makes rocks slick. Score=3.	Perennial types scarce or absent. Yellow-green. Short term bloom may be present. Score=4.

In the table above, the first 4 parameters deal with the upper banks, the next 5 address the lower banks and the final 6 describe the channel bottom. In a particular stream assessment, each of these parameters is analyzed and assigned a score according to the table. The final results are interpreted as follows:

Excellent condition: Score <39.
Good condition: Score between 39 and 76.
Fair condition: Score between 77 and 114.
Poor condition: Score > 114.

The rocky stream in the photograph below can be classified according to the Pfankuch system.

Using the Pfankuch Method we will attempt to classify the relative stability of this stream. The table below summarizes the results:

Parameter Number	Description	Score
1	The slope down to the bank is between 30 & 40%	4
2	There is no evidence of mass wasting (i.e. landslides)	3
3	There is no evidence of potential jams in the channel.	2
4	The banks appear to be about 75% vegetated.	6
5	The channel capacity seems to be adequate with a W/D ratio of approximately 10.	2
6	Nearly the entire bank is comprised of large rocks.	2
7	Rocks appear to be firmly embedded.	2
8	There is some cutting evident but the depth does not exceed 12".	8
9	There does not seem to be any recent enlargement of the channel	4
10	The rocks have sharp edges.	1
11	Hard to see in the photo, but the rocks are mainly dull with maybe 20-25% bright surfaces.	2
12	The particles are well packed.	2
13	The bed is stable.	4

14	There is some scour evident in the foreground. Approximately 10-20% of the bed is affected.	12
15	Algae is present (but hard to see in the photo) in the low velocity and pool areas.	2

Adding up all of these scores yields a result of 56. Therefore, according to the Pfankuch method, the stability of this stream would be classified as "good".

Procedures Used for Stream Restoration:
There are several techniques for restoring degraded stream channels. These naturally depend upon the degree and type of degradation and also on the type of stream. The Rosgen Method, described earlier, has been adopted by the United States Resource Conservation Service (NRCS), which has a useful publication entitled "Stream Restoration Design National Engineering Handbook". Much of the following discussion is based on information taken from the NRCS.

When restoring a degraded stream channel the engineer has to decide what the baseline condition was that needs to be re-established. Often this is the condition of a stream prior to a massive storm that created significant erosion. In other cases, a stream channel has been allowed to degrade over a period of decades (due to increased urbanization, etc.) and it may be difficult to determine a suitable baseline condition.

The NRCS recommends a five phase process in the design of stream restoration projects. These are discussed briefly below:

1. Phase I: Determine the objectives and goals of the restoration. This is vitally important and cannot be overstressed. Some typical goals of a stream restoration project include:
    - Flood level reduction.
    - Streambank stability.
    - Reduce sediment supply, loss of streamside land, and attached nutrients.
    - Provide a stable riverbank for existing and/or proposed buildings, parking areas, and other improvements.
    - Be self-maintaining and cost-effective.
    - Improve water quality, fish habitat, and wetlands. (Note that this a very generic goal. In an actual stream restoration design, the goal will have to be much more specific to be realistic. Also, note that water quality and fish habitat are generally affected significantly by upstream stream reaches and by surrounding land uses).

2. Phase II: Developing local and regional relations in geomorphic characterization, hydrology, and hydraulics: This includes collecting a significant amount of data on the region's streams and overall landforms.
3. Phase III: Assessment of the watershed and river: This phase includes an analysis of the existing and historic land uses in the watershed. The goal of this phase is an assessment of overall river stability. The classification schemes described previously are helpful in this regard.
4. Phase IV: Passive recommendations for restoration: Sometimes, less is more, and a stream can be "restored" without structural changes to the channel. This can be accomplished by making watershed modifications that reduce sedimentation or contaminants reaching the stream.
5. Design the stream restoration using the "Rosgen Geomorphic Channel Design" methodology previously discussed.

The following table lists some common stream channel problems and desired restoration outcomes.

Identified Need or Client Objectives	**Channel/Riparian/Watershed Characteristics**	**Desired Outcome/Effects**
I. Erosion & sediment control (streambank erosion, channel aggradation, channel degradation, concentrated flow and scour erosion, sheet and rill erosion).	• Excessive bank recession rates. • Instream bar formation. • Incised channels that are deepening, then widening. • Lack of vegetative cover on banks, flood-prone zones and riparian areas, allowing concentrated flows and consequent sheet, rill, and scour erosion. • Concentrated flow gullies from adjacent areas and land uses. • Overall water has less native perennial cover, more impervious surfaces	• Return to normal reference bank recession rates and point bar dynamics. • Incised channels are stabilized and flood-prone areas are reestablished. • Aggressive herbaceous plants substantially reduce surface erosion and hinder the invasion of weeds. (Note: Unfortunately, these same plants can impede the successional progression to a desirable plant community).

	and/or more direct flow paths which are not buffered or filtered.	• Woody plants bind steambank soils and in adjacent flood-prone areas increase surface roughness, thereby reducing the potential for scour erosion. • Buffers and associated practices in adjacent upland areas can slow runoff, reducing stress on the streambanks and slowing the channel degradation process.
II. Production and use of stream and streamside vegetation (game fish, livestock forage, forest products).	• Channel banks and bed are modified and maintained to favor specific game fish. • Streamside herbaceous plants, woody plants or a combination consistent with the client's operation are grown to satisfy particular economic requirements.	• Production and utilization goals are achieved when fish and vegetation products reach desired biomass, size, or quality. • Aquatic and plant community succession is retarded and/or managed (or completely replaced by a production community) to maintain the desired operational condition.
III. Restoration of ecological functions (creation of a successional stage which can be maintained or allowed to succeed to a desired plant	• Herbaceous plants, woody plants or a combination consistent with desired successional stage or progression to the reference reach plant community.	• Functions such as soil stability, vertical and horizontal habitat, and nutrient cycling are achieved when vegetation reaches the desired successional

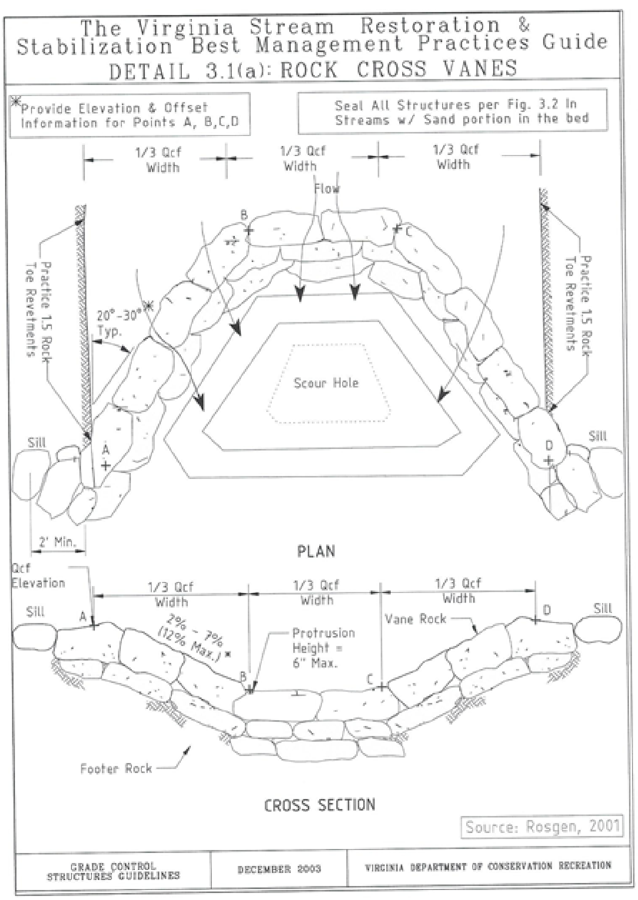
community).		condition. • Domestic use for recreation, grazing, timber harvesting, or other exploitation is excluded or sufficiently restricted so that the desired successional stage is reached and maintained.

Structures to be used in Stream Restorations:

Because stream restorations can take such a wide variety of shapes, a thorough discussion of all of the available structures and processes that can be used is well beyond the scope of this course. However, there are several types of restoration facilities that are generally employed. These include the following:

1. Vegetation. Providing stream bank and upland vegetation can provide protection against scour and erosion. It is imperative that native plantings be used and that the vegetation be checked periodically to ensure that it is thriving.
2. Bank armoring. This can be accomplished by boulders, concrete wall, gabions, erosion control matting, or other structures. Obviously, the particular structure used will depend on the nature of the flows and other considerations.
3. In-channel structures. These structures can take many forms and are generally designed to reduce erosive velocities and/or to armor a vulnerable section of the channel. Structures can be made of rock or wood and are used to provide grade control, reduce channel grade (and, consequently, flow velocity and erosive potential), reduce flow energy, and other similar functions. Rock vanes are linear structures that extend out from the stream bank into the channel in an upstream direction. They can extend from one or both banks and can extend either partway or completely across the stream channel. Their main function is to reduce erosion along a vulnerable stream bank by re-directing the flow toward the center of the stream. As a side benefit, they can enhance the in-stream habitat by providing a scour hole on the downstream side and be enhancing riffle

habitat on the upstream side of the vane. The detail below is taken from the Virginia Department of Conservation Recreation website and shows a rock vane that spans the entire channel. Note that the vane extends out from the banks in an upstream direction and includes a scour hole on the downstream end.



Maintenance & Monitoring of the Restored Stream:

Once a stream restoration project has been implemented, it is essential that the restored stream be monitored and maintained on a regular basis. If this is not done, the same factors that degraded the stream in the first place are liable to undo any good that the restoration accomplished. Naturally, the monitoring and maintenance should be tailored to the actual restoration that took place. When monitoring a restored stream the following checklists can be useful:

Checklist of Physical and Chemical Stream Parameters:

Physical Attribute	**Parameter to be monitored**
Plan view	Sinuosity, channel width, bars, riffles, pools, boulders, logs
Cross-sectional profile	• Bank repose angle • Depth at bankfull • Width • Width to depth ratio
Longitudinal profile	• Water surface slope • Bed slope • Pool size, shape, and profile • Riffle size, shape and profile • Bar features
Assessment of hydrologic flow regimes	Determination of various storm hydrographs (such as the 2 year and 10 year storms) and determination of base flow.
Channel evolutionary track determination	• Decreased or increased runoff • Incisement/degradation • Overwidening/aggradation • Increasing or decreasing sinuosity • Bank erosion patterns
Riparian corridor conditions corresponding to the above	• Saturated and/or ponded terraces within the riparian area • Alluvium terraces & fluvial levees • Upland/well-drained/sloped or terraced geomorphology • Riparian vegetation composition, community patterns and successional stage
Watershed trends: previous 20 years and future 20 years	• Land use • Land management practices • Soil types, topography, & regional climate & weather patterns
Water clarity	Turbidity
Constituents of the channel	• Dissolved and suspended solids

water	• Nutrients • Toxins (both natural and man-made)
Organic loading	Biological oxygen demand
Oxygen capacity	Dissolved oxygen
Water quality measures	• Temperature • pH • Hardness

Checklist of Biological Stream Parameters:

Biological Attribute	**Parameter to be Monitored**
Primary productivity	• Periphyton • Plankton • Vascular and non-vascular plants
Zooplankton/diatoms	• Species • Numbers • Diversity • Biomass • Macro and micro-organisms present
Fish community	• Anadromous and resident species • Specific populations or life stages • Number of out-migrating smolts • Number of returning adults
Riparian wildlife/terrestrial community	• Amphibians • Reptiles • Birds • Mammals • Plants (including an enumeration of any invasive species)
Riparian vegetation	• Structure • Composition • Function • Changes in time (including, but not limited to: succession, colonization, and extirpation of specific species or suites of species)
Habitat structure	• Spawning gravel • Instream cover • Shade

	• Pool/riffle ratio • Amount and size distribution of large woody debris

A review of the checklists above indicates several issues. For one thing, it is obvious that not all of the monitoring recommended can be done by engineers who are not specifically trained for the tasks. Here, once again, it is evident that a successful stream restoration project must be a collaborative effort between engineers, field biologists, and other professionals. Another thing that is evident is that not all of the monitoring included in these checklists will be applicable to all streams and stream restoration projects. Many streams do not have anadromous fish species, to name just one example. Determining exactly what needs to be monitored is an essential first step to a proper monitoring and maintenance schedule for any project.

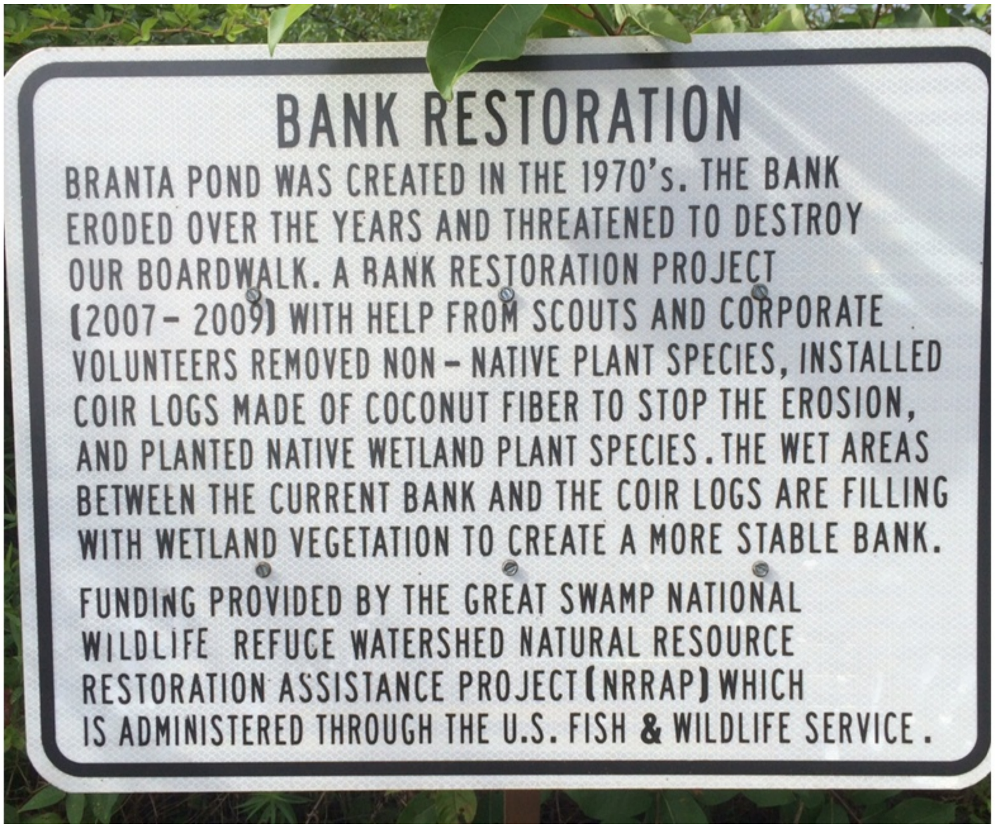
Of course, the purpose of the monitoring is to determine what maintenance (if any) needs to be taken to restore the proper functioning of the stream. The following listing outlines several of the most common maintenance issues and areas:

Project Location	**Maintenance Actions**
Stream channel	• Repair of structures including (but not limited to) grade control structures, weirs, and rock vanes) • Island and bar preservation and/or development • Bank toe stabilization with rock or vegetation, as appropriate • Rock barbs • Removal of nuisance aquatic vegetation, woody debris accumulation, or other undesirable materials
Floodplain	• Repair or re-formation of bank grading • Actions to address encroachments • Maintaining planned boundaries and conditions for rights of way. • Replacing or adding new vegetation due to poor establishment or lack of survival of original plantings
Buffer strips, setbacks, & easements	• Establishment of boundaries after encroachments by adjacent land owners.
Meander bends	• Stabilization of eroding or unstable banks • Seeding of newly stabilized areas

Looking at this another way, the following list outlines maintenance features for specific stream protection and enhancement measures:

Protection/enhancement features	**Maintenance actions**
Streambank stability	Repair bank armoring structures (stone-filled revetments, soil-covered riprap, cellular blocks, geogrid, geotextile fabrics, soil cement, bulkheads, etc.)
Stream/habitat features	• Repair, replacement, or expansion of fish cover structures • Repair and/or replacement of pools/riffles rocks and structures
Vegetation	• Removal of excess woody vegetation • Repair, maintain irrigation, water availability • Replanting, replacement of trampled, dead, and/or impaired vegetation • Maintain, repair, and/or replace fencing, signage, and barriers for vegetation protection • Repair and/or replacement of brush mattress, matting, or other soil bioengineering materials • Seeding or reseeding established vegetated areas • Mulching for soil and plant stability
Access & human use structures	• Clearing of access pathways for humans and livestock • Cleaning and repair of recreational structures, including picnic tables, boat ramps, parking areas, etc. • Cleaning and repair of restroom facilities

The photograph below shows a public education sign posted along a wildlife walkway at the Somerset County Environmental Education Center in Basking Ridge, New Jersey. Signs like this are useful in enhancing public consciousness of restoration projects.



Also, when providing maintenance on a stream restoration project it is important to have tools to evaluate the goals of the maintenance. The following list can be used in this regard:

General Maintenance Objectives	**Potential Evaluation Tools & Criteria**
Channel capacity & stability	• Channel cross sections • Flood stage surveys • Width to depth ratio • Rates of bank and bed erosion • Longitudinal profile • Aerial photography interpretation
Improve aquatic habitat	• Water depths • Water velocities • Percent overhang, shading, cover • Pool/riffle composition • Stream temperature • Bed-material composition

	• Population assessment for fish, invertebrates, and macrophytes
Improve riparian habitat	• Percent vegetative cover • Species diversity • Size distribution • Age class distribution • Planting survival • Reproductive vigor • Wildlife use • Aerial photography
Improve water quality	• Temperature • pH • Dissolved oxygen • Conductivity • Nitrogen & phosphorous • Herbicides and pesticides • Turbidity and opacity • Suspended/floating matter • Trash loading • Odor
Recreational & community involvement	• Visual resource improvement based on landscape control point surveys • Recreational use surveys • Community participation in management

Restoration of ponds can be thought of as a special case of stream restoration. The photograph below shows a pond in a municipal park undergoing restoration. The silt fence in the background is necessary to keep sediment from travelling downstream and degrading the lower reaches of the stream.

The following photographs show the same pond shortly after the restoration has been completed. Notice how the vegetation along the pond is thriving and helping to maintain a stable environment.

Concluding Remarks:
It can be seen that a well-designed stream restoration project can be beneficial to the environment and to the general public in a variety of ways. It can restore wildlife habitat, improve water quality, provide areas for passive recreation, enhance the aesthetic value of a neighborhood and reduce downstream erosion and siltation. Many high-profile stream restoration projects have taken place in recent years. Some of these include:

- The Meadow Creek Restoration project, in Charlottesville, Virginia.
- The Chilogatee Stream Restoration Project in Blount County, Tennessee.
- The Iron Mountain Stream Restoration Project in the City of Portland, Oregon.

In all of these cases (and in many others), degraded unsightly watercourses have been restored to their natural state. These projects were, in many cases, cooperative efforts that brought together the expertise of many organizations. The Chilogatee Stream Restoration Project, for example, was a collaborative effort spearheaded by the Tennessee Stream Mitigation Program.
A simple stream restoration project in Somerset County, New Jersey, is pictured below. In this case the county bridge needed to be replaced and the area immediately upstream of the bridge was stabilized with erosion matting and bank armoring.

This course has attempted to point out the complexities of stream restoration. There are many points to remember in designing a stream restoration project:

1. There is generally not one "right" answer. The project can be designed to function properly using a variety of techniques and methodologies.
2. Most "restoration" is actually rehabilitation or reclamation. Restoring a stream to its pre-development status is generally an unachievable goal, especially when

the upstream reaches are affected by urbanization, agriculture, erosion, or other factors.

3. It is essential that the design engineer determine what governmental agencies have jurisdiction over the stream restoration project. The governing regulations will affect the overall stream restoration project as profoundly as any other single factor.
4. It is essential to have specific, measurable goals for the project. Nebulous goals, such as improving water quality for fish, are almost impossible to quantify and, consequently, are not realistic. More focused goals, such as lowering the summertime water temperature in a stream reach by 4 degrees Fahrenheit, are much more likely to succeed.
5. Some stream reaches cannot be restored due to overall watershed characteristics. For instance, if the upstream reaches of a stream are continuing to be subject to excessive sedimentation, then no amount of stream restoration work in a downstream reach will significantly reduce turbidity.
6. It is imperative that the engineer engage experts in other fields (e.g. streamside vegetation, fish biology, etc.) in planning a stream restoration project.
7. Streams differ not only from reach to reach but especially between areas of the country. The "natural" condition of a stream in New England is vastly different than the same condition of a stream in the arid southwest. Likewise, tidal streams behave differently from streams that are unaffected by tidal action. Engineers working on stream restoration projects must always keep in mind the particular characteristics of the stream reach under considerations and must realize that this reach does not exist in isolation but is part of a much-wider ecosystem that is affected by climate, geographical region, and suite of other parameters.
8. No stream restoration project is permanent. Streams are constantly changing and environmental and human-induced changes will constantly work against the restoration. Long-term maintenance of the restoration project is essential in keeping the restored stream reach functioning properly. Invasive species growing within the stream channel or along the stream bank can present a particularly difficult on-going problem.

One final stream restoration project is shown below. This is a restored mill race (and mill pond visible in the background) which was reconstructed to match its 19th century condition as part of an historical reclamation project after years of neglect had allowed it to deteriorate to the point of being recognizable.

This restored "stream" illustrates the almost endless types of watercourses that can be restored.

