U.S. Environmental Protection Agency

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Distance Learning Modules on Watershed Management
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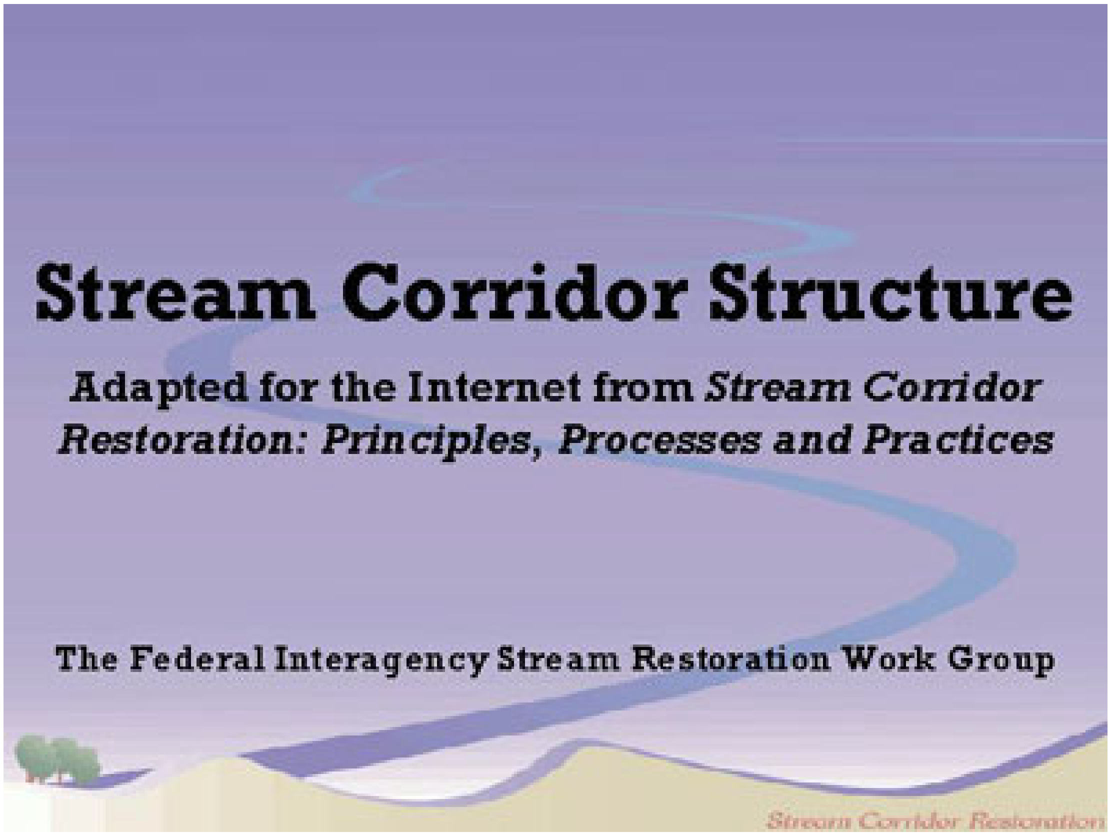

Stream Corridor Structure

Adapted for the Internet from *Stream Corridor Restoration: Principles, Processes and Practices*

The Federal Interagency Stream Restoration Work Group

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Introduction

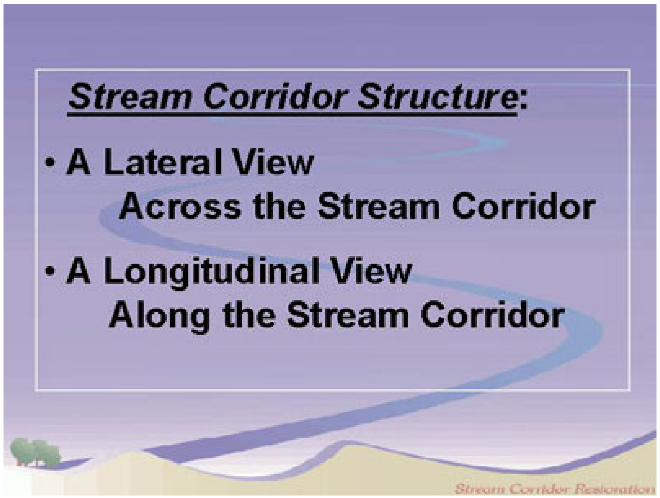
This module is about the physical structure of one of the most ecologically and hydrologically important parts of the watershed and the environment in general -- the stream corridor (defined as the stream, its floodplains, and a transitional upland fringe). The module's text, photos and graphics have been adapted with minor modifications from Stream Corridor Restoration: Principles, Processes, and Practices (www.nrcs.usda.gov/technical/stream_restoration), a 1998 publication developed by the Federal Interagency Stream Restoration Work Group (FISRWG). As an alternative to completing this module interactively, some readers with copies of this document may choose to read Chapters 1B and 1C and then return to this site to take the module's self-test.

The Watershed Academy Web module on Watershed Ecology (www.epa.gov/watertrain/ecology) introduces the importance of observing how a whole watershed is physically structured as part of the essential knowledge for analyzing and managing watershed problems. Although major processes and events such as ice ages, earthquakes and volcanic eruptions have sculpted much of our landscape structure over time, the flowing water of streams has played a major role especially on more recent time scales. Not only does studying stream corridor structure reveal how many watershed features were formed, it also gives us further insights into how they function. The goal of this training module is to introduce readers to the typical features of stream structure as a basis for further insights into how streams and stream corridors function as ecosystems.

There are two main sections in this module (Figure 1):

A Lateral View Across the Stream Corridor
The focus here is on structural features or zones that one encounters moving across the stream. Lateral structure of the corridor affects the movement of water, materials, energy, and organisms from upland areas into the stream channel.

A Longitudinal View Along the Stream Corridor
This section takes a view of structure along the stream corridor's whole length from its headwaters to mouth. It includes discussions of channel form, sediment transport and deposition, and how biological communities have adapted to different stages of the river continuum.



***Stream Corridor Structure*:**

- **A Lateral View Across the Stream Corridor**
- **A Longitudinal View Along the Stream Corridor**

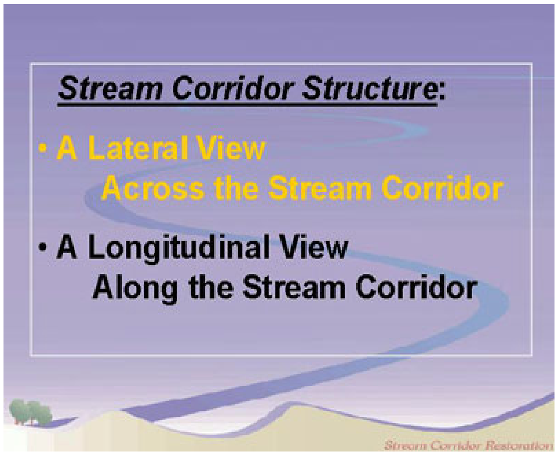
Stream Corridor Restoration

Figure 1

Stream Corridor Structure: A Lateral View (Figure 2)

In spite of the fact that streams vary widely, most stream corridors have three major components in cross section (Figure 3):

- ***Stream channel***, a channel with flowing water at least part of the year.
- ***Floodplain,*** a highly variable area on one or both sides of the stream channel that is inundated by floodwaters at some interval, from frequent to rare.
- ***Transitional upland fringe***, a portion of the upland on the landward side of the floodplain that serves as a transitional zone or edge between the floodplain and the surrounding landscape.



***Stream Corridor Structure*:**

- A Lateral View
  Across the Stream Corridor
- A Longitudinal View
  Along the Stream Corridor

Stream Corridor Restoration

Figure 2

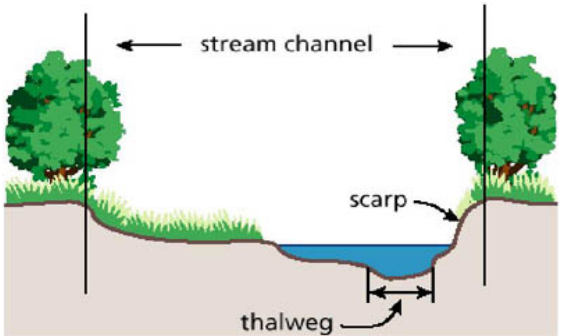
The three main components of a stream corridor

Figure 3

In many river corridors, a more complex assortment of features can be seen. In this example, the floodplain is seasonally inundated and includes features such as floodplain forest, emergent marshes and wet meadows. This river's transitional upland fringe includes an upland forest and a hill prairie. Landforms such as natural levees are created by processes of erosion and sedimentation, primarily during floods. The various plant communities possess unique moisture tolerances and requirements, and consequently occupy distinct positions relative to the stream.

The Stream Channel

Nearly all channels are formed, maintained, and altered by the water and sediment they carry. Usually they are gently rounded in shape and roughly parabolic, but channel form can vary greatly.



Cross section of a stream channel

Figure 4

Figure 4 presents a cross section of a typical stream channel. The sloped bank is called a **scarp**. The deepest part of the channel is called the **thalweg**. The dimensions of a **channel cross section** define the amount of water that can pass through without spilling over the banks.

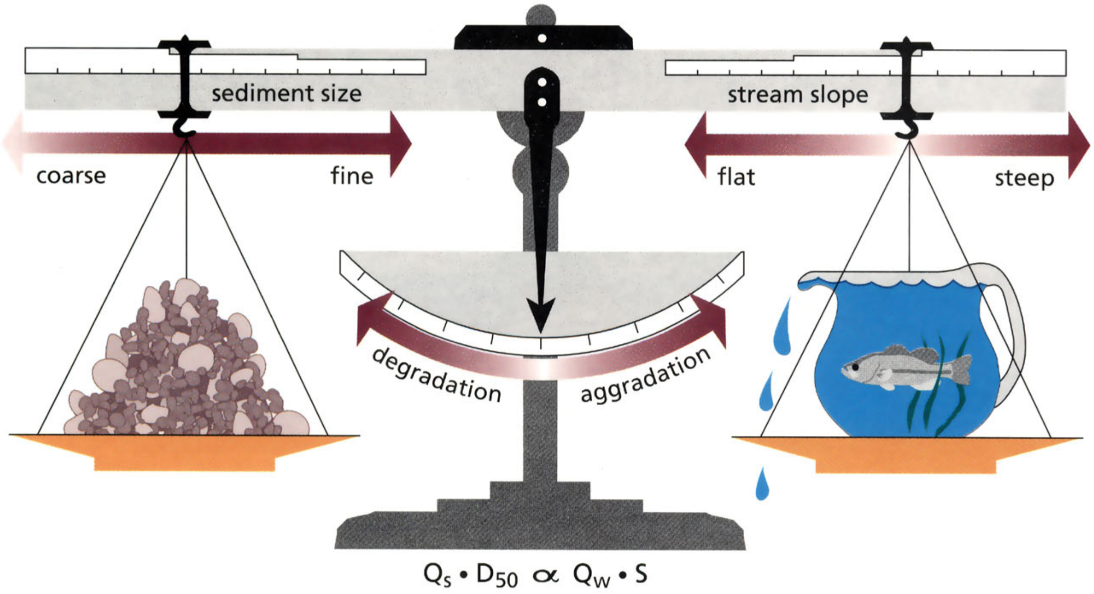
Two attributes of the channel -- **channel equilibrium** and **streamflow** -- are of particular interest to stream managers because they influence most physical characteristics of the channel.

Lane's Relationship: Alluvial Channel Equilibrium

Channel equilibrium (Figure 5) involves the interplay of four basic factors:

- Sediment discharge (**Q_s**)
- Sediment particle size (**D_{50}**)
- Streamflow (**Q_w**)
- Stream slope (**S**)

Lane (1955) showed this relationship qualitatively as: $Q_s \bullet D_{50} \propto Q_w \bullet S$



Factors affecting channel equilibrium. At equilibrium, slope and flow balance the size and quantity of sediment particles the stream moves.

(Rosgen 1996, from Lane, 1955. The importance of fluvial morphology in hydraulic engineering. <u>Procedings ASCE</u>, 81(745):1-17. used with the permission of American Society of Civil Engineers)

Figure 5: The American Society of Civil Engineers publications can be found at http://www.pubs.asce.org.

This equation is shown here as a balance with sediment load on one weighing pan and streamflow on the other. The hook holding the sediment pan can slide along the horizontal arm to adjust according to sediment size. The hook holding the streamflow side can adjust according to stream slope.

Channel equilibrium occurs when all four variables are in balance. If a change occurs, the balance will temporarily be tipped and equilibrium lost. If one variable changes, one or more of the other variables must increase or decrease proportionally if equilibrium is to be maintained. For example, if channel slope is increased (e.g., by channel straightening) and streamflow remains the same, either the sediment load or the size of the particles must also increase. Likewise, if flow is increased (e.g., by an inter-basin transfer) and the slope stays the same, sediment load or sediment particle size has to increase to maintain channel equilibrium. Under these examples' conditions, a stream seeking a new equilibrium will tend to erode more of its banks and bed, transporting larger particle sizes and a greater sediment load.

Alluvial streams that are free to adjust to changes in these four variables generally do so and reestablish new equilibrium conditions. Non-alluvial streams such as bedrock or artificial, concrete channels are unable to follow Lane's relationship because of their inability to adjust the sediment size and quantity variables.

The stream balance equation is useful for making qualitative predictions concerning channel impacts due to changes in runoff or sediment loads from the watershed. Quantitative predictions, however, require the use of more complex equations. Sediment transport equations, for example, are used to compare sediment load and energy in the stream. If excess energy is left over after the load is moved, channel adjustment occurs as the stream picks up more load by eroding its banks or scouring its bed. No matter how much complexity is built into these and other equations of this type, however, they all relate back to the basic balance relationships described by Lane.

Streamflow

A second distinguishing feature of the channel is streamflow. As part of the water cycle, the ultimate source of all flow is precipitation. The pathways precipitation takes after it falls to earth, however, affect many aspects of streamflow including its quantity, quality, and timing. It is useful to recognize flow components based on these pathways (Figure 6).

Stormflow in this Colorado river has filled the channel and is about to inundate the floodplain where alders are growing.

Figure 6

The two basic components are:

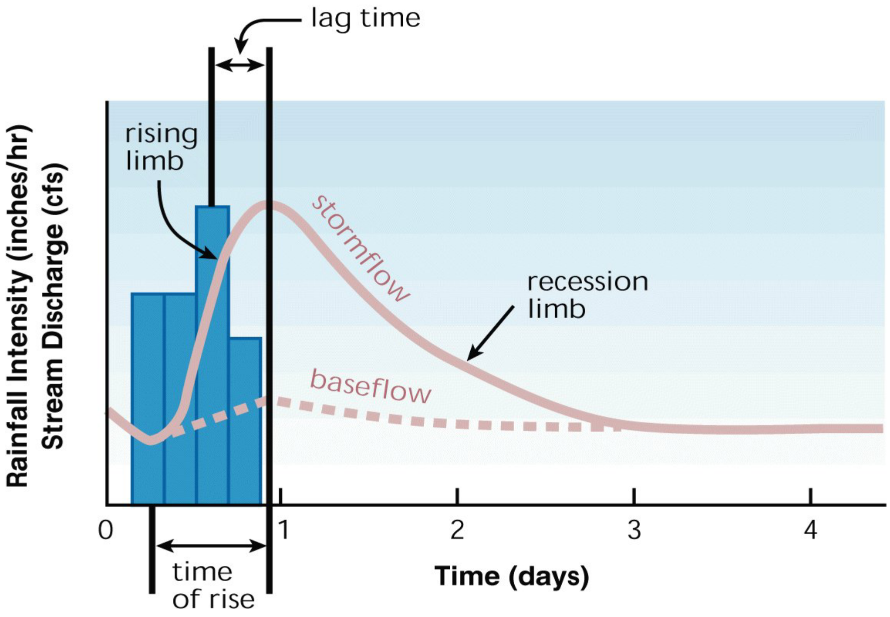
- ***Stormflow***, from precipitation that reaches the channel over a short time frame through overland or underground routes.
- ***Baseflow*** (Figure 7), from precipitation that percolates to the ground water and moves slowly through substrate before reaching the channel. It sustains streamflow during periods of little or no precipitation.

Base flow in a Virginia mountain stream. Water levels at base flow in small streams are typically low and clear.

Figure 7

Streamflow at any one time might consist of water from one or both sources. If neither source provides water to the channel, the stream goes dry.

A **storm hydrograph** (Figure 8) is a tool used to show how streamflow changes with time. The portion of the hydrograph that lies to the left of the peak is called the **rising limb**, which shows how long it takes the stream to peak following a precipitation event. The portion of the curve to the right of the peak is called the **recession limb**.



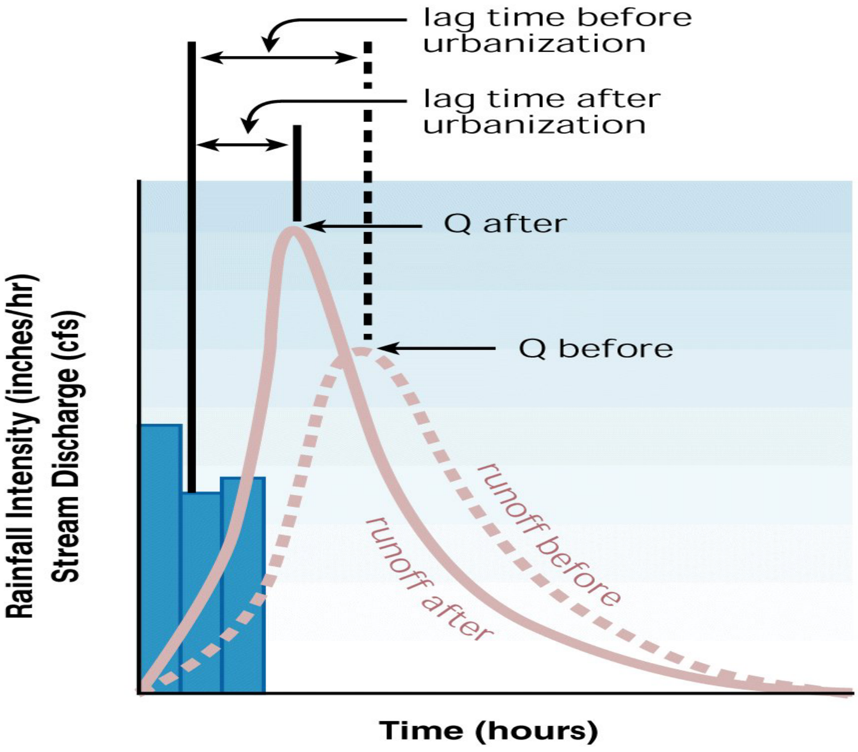
A hydrograph shows how long a stream takes to rise from baseflow to maximum discharge and then return. Blue bars indicate rainfall amount and timing relative to flow changes.

Figure 8

Changes in Hydrology After Urbanization

The hydrology of urban streams changes (Figure 9) as sites are cleared and natural vegetation is replaced by impervious cover such as rooftops, roadways, parking lots, sidewalks, and driveways. One of the consequences is that more of a stream's annual flow is delivered as storm water runoff rather than baseflow. Depending on the degree of watershed impervious cover, the annual volume of storm water runoff can increase by up to 16 times that for natural areas (Schueler 1995). In addition, since impervious cover prevents rainfall from infiltrating into the soil, less flow is available to recharge ground water. Therefore, during extended periods without rainfall, baseflow levels are often reduced in urban streams (Simmons and Reynolds 1982).

Storm runoff moves more rapidly over smooth, hard pavement than over surfaces with natural vegetation cover. As a result, streamflow (or discharge, **Q**) undergoes changes in timing and magnitude. The rising limbs of storm hydrographs become steeper and higher in urbanizing areas. Recession limbs also decline more steeply in urban streams. The increased runoff and decreased infiltration recharge less ground water, which also results in lower baseflow after the storm runoff is over.



A comparison of hydrographs before and after urbanization (blue bars indicate rainfall rate and timing). The discharge curve is higher and steeper for urban streams than for non-urbanized streams due to faster and greater runoff.

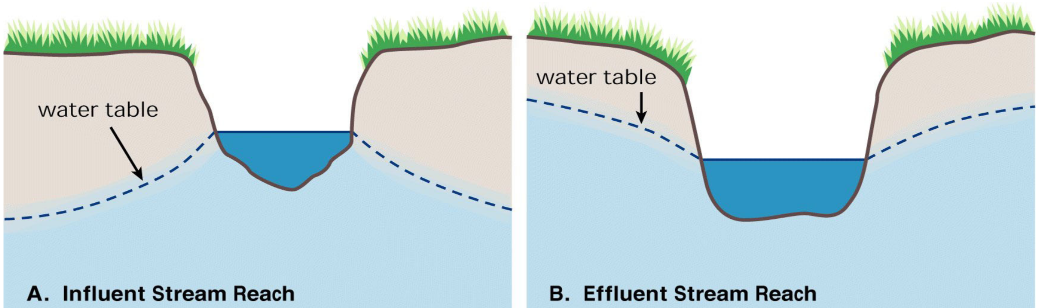
Figure 9

Channel and Ground Water Relationships

Interactions between ground water and the channel vary throughout the watershed (Figure10). In general, the connection is strongest in streams with gravel riverbeds in well-developed alluvial floodplains.

There are two types of water movement between streams and ground water:

- ***Influent or "losing" reaches*** lose stream water to the aquifer.
- ***Effluent or "gaining" reaches*** receive discharges from the aquifer.



Cross sections of (a) influent and (b) effluent stream reaches. Influent or "losing" reaches loose stream water to the aquifer. Effluent or "gaining" reaches receive discharges from the aquifer.

Figure 10

Stream managers categorize streams based on the balance and timing of the stormflow and baseflow components.

There are three main categories:

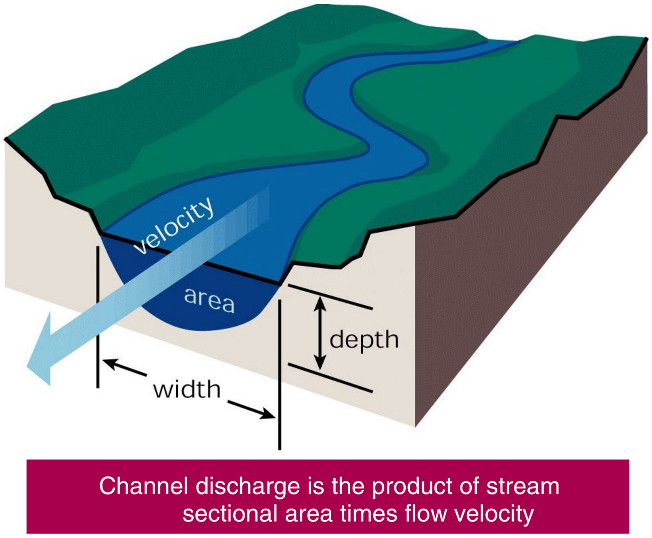
- ***Ephemeral streams*** (Figure 11) flow only during or immediately after periods of precipitation. They generally flow less than 30 days per year.
- ***Intermittent streams*** flow only during certain times of the year. Seasonal flow in an intermittent stream usually lasts longer than 30 days per year.
- ***Perennial streams*** flow continuously during both wet and dry times. Baseflow is dependably generated from the movement of ground water into the channel.

Ephemeral streams flow only during or immediately after periods of precipitation, generally less than 30 days a year.

Figure 11

Discharge Regime (Figure 12)

Discharge is the term used to describe the volume of water moving down the channel per unit time. The basic unit of measurement used in the United States to describe discharge is cubic feet per second (cfs).



Channel discharge is the product of stream sectional area times flow velocity

Figure 12

Discharge is calculated as:

$$Q=AV$$

where:

Q = Discharge (cfs)

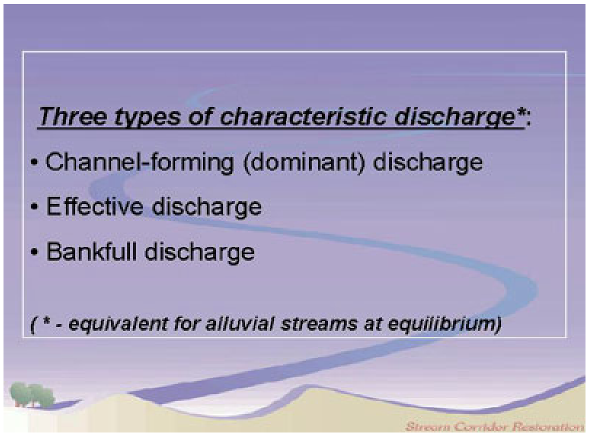
A = Area through which the water is flowing in square feet

V = Average velocity in the downstream direction in feet per second

As discussed earlier in this section, streamflow is one of the variables that determine the size and shape of the channel. There are three types of characteristic discharge (Figure 13):

- ***Channel-forming (or dominant) discharge***. To envision the concept of channel-forming discharge, imagine placing a water hose discharging at constant rate in a freshly tilled garden. Eventually, a small channel will form and reach an equilibrium geometry. At a larger scale, consider a newly constructed floodwater-retarding reservoir that slowly releases stored floodwater at a constant flow rate. This flow becomes the new channel-forming discharge and will alter channel morphology until the channel reaches equilibrium.

  An estimate of channel-forming discharge for a particular stream reach can, with some qualifications, be related to depth, width, and shape of channel. Although channel-forming discharges are strictly applicable only to channels in equilibrium, the concept can be used to select appropriate channel geometry for restoring a disturbed reach. However, there is no method for directly calculating channel-forming discharge.



Three types of characteristic discharge*:

- Channel-forming (dominant) discharge
- Effective discharge
- Bankfull discharge

*(* - equivalent for alluvial streams at equilibrium)*

Figure 13

- ***Effective discharge***. The effective discharge is the calculated measure of channel-forming discharge.

  Computation of effective discharge requires long-term water and sediment measurements, either for the stream in question or for one very similar. Since this type of data is often not available for stream restoration sites, modeled or computed data are sometimes substituted. Effective discharge can be computed for either stable or evolving channels.

- ***Bankfull discharge*** (Figure 14). This discharge occurs when water just begins to leave the channel and spread onto the floodplain.

Bankfull discharge is the flow at which water just begins to leave the channel and move onto the floodplain. This flood is beginning to exceed bankfull discharge.

Figure 14

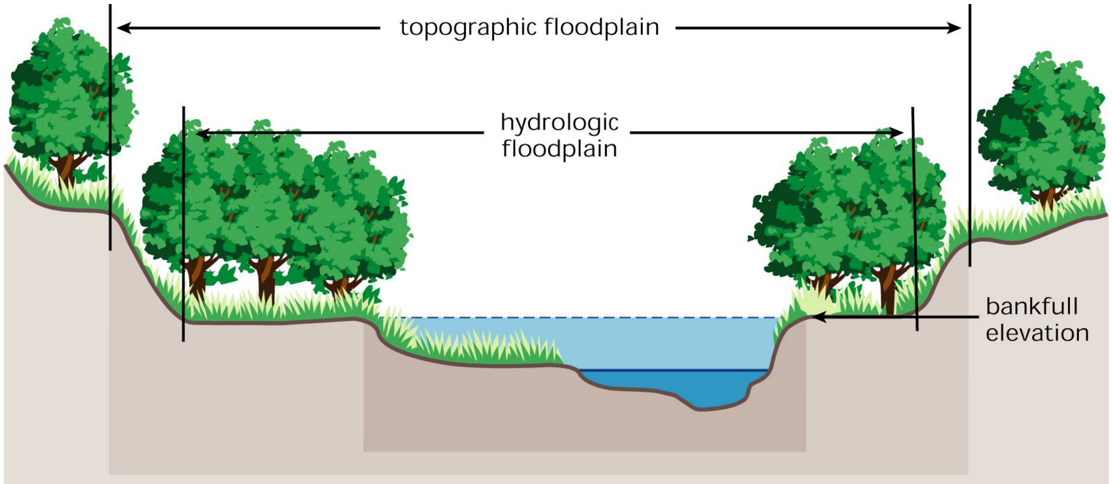
Bankfull discharge is equivalent to channel-forming (conceptual) and effective (calculated) discharge for alluvial streams at equilibrium.

The Floodplain

The floor of most stream valleys is relatively flat. This is because over time the stream moves back and forth across the valley floor in a process called lateral migration. In addition, periodic flooding causes sediments to move longitudinally and to be deposited on the valley floor near the channel. These two processes continually modify the floodplain.
Through time, the channel reworks the entire valley floor. As the channel migrates, it maintains the same average size and shape if conditions upstream remain constant and the channel stays in equilibrium.

Two very general types of floodplains may be defined:

- ***Hydrologic floodplain*** *(Figure 15)*, the land adjacent to the baseflow channel residing below bankfull elevation. It is inundated about two years out of three. Not every stream corridor has a hydrologic floodplain.
- ***Topographic floodplain***, the land adjacent to the channel including the hydrologic floodplain and other lands up to an elevation based on the elevation reached by a flood peak of a given frequency (for example, the 100-year floodplain).
  Professionals involved with flooding issues define the boundaries of a floodplain in terms of flood frequencies (probability of recurrence, in years). Thus, 100-year and 500-year floodplains are commonly used in the development of planning and regulation standards.



The hydrologic floodplain is defined by bankfull elevation. The topographic floodplain includes the hydrologic floodplain and higher floodplains up to a defined elevation that corresponds to a specific flood frequency.

Figure 15

Flood Storage

The floodplain provides temporary storage space for floodwaters and sediment produced by the watershed. This attribute serves to add to the **lag time** of a flood--the time between the middle of the rainfall event and the runoff peak.

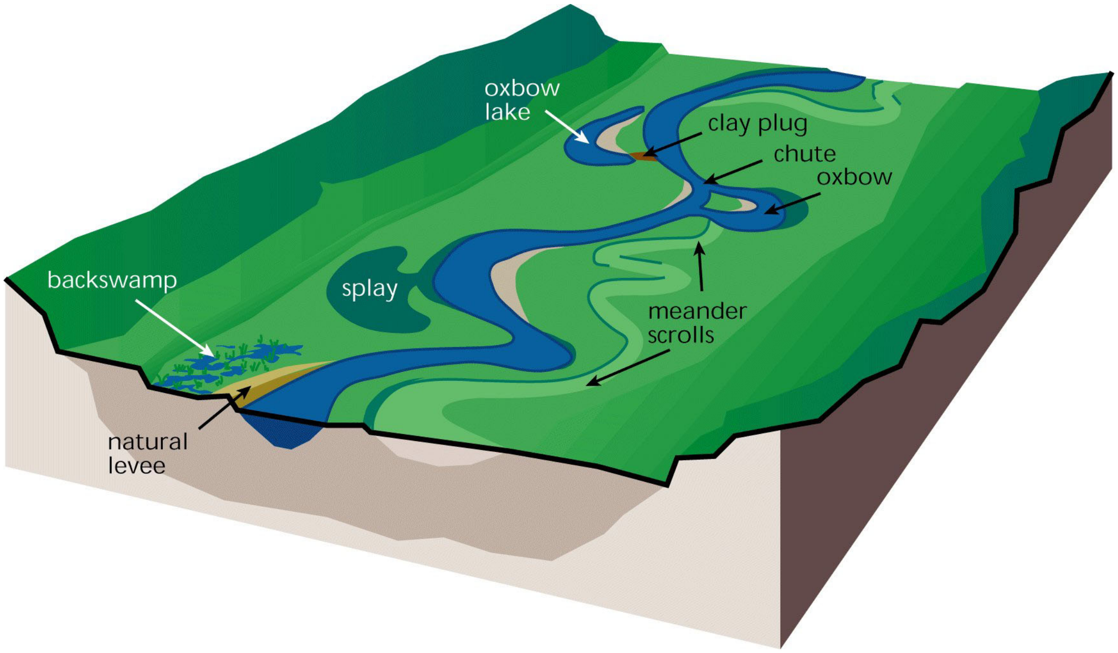
If a stream's capacity for moving water and sediment is diminished, or if the sediment loads produced from the watershed become too great for the stream to transport, flooding will occur more frequently and the valley floor will begin to fill. Valley filling results in the temporary storage of sediment produced by the watershed.

Landforms and Deposit

Many topographic features (Figure 16) are formed on the floodplain by the lateral migration of the channel. These features result in varying soil and moisture conditions and provide a variety of habitat niches that support plant and animal diversity.

Floodplain landforms and deposits include:

- ***Meander scroll***, a sediment formation marking former channel locations.
- ***Chute**,* a new channel formed across the base of a meander. As it grows in size, it carries more of the flow.
- ***Oxbow***, a term used to describe the severed meander after a chute is formed.
- ***Clay plug***, a soil deposit developed at the intersection of the oxbow and the new main channel.
- ***Oxbow lake***, a body of water created after clay plugs the oxbow from the main channel.
- ***Natural levees***, formations built up along the bank of some, generally low-gradient streams that flood. As sediment-laden water spills over the bank, the sudden loss of depth and velocity causes coarser-sized sediment to drop out of suspension and collect along the edge of the stream.
- ***Splays***, delta-shaped deposits of coarser sediments that occur when a natural levee is breached. Natural levees and splays can prevent floodwaters from returning to the channel when floodwaters recede.
- ***Backswamps***, a term used to describe floodplain wetlands formed by natural levees.



Floodplain landforms and other features caused in part by meandering streams

Figure 16

The Transitional Upland Fringe

The transitional upland fringe (Figure 17) serves as a transitional zone between the floodplain and surrounding landscape. Thus, its outside boundary is also the outside boundary of the stream corridor itself.

Whereas stream-related hydrologic and geomorphic processes might have formed a portion of the transitional upland fringe in geologic times, they are not responsible for maintaining or altering its present form. Consequently, land use activities have the greatest potential to impact this component of the stream corridor.

Transitional upland fringe is a transition zone between the floodplain and the surrounding upland landscape.

Figure 17

There is no typical cross-sectional structure for this component. Transitional upland fringes can be flat, sloping, or in cases such as ravine walls, nearly vertical. Their width may vary substantially, and their outer boundaries are often indistinct. They can incorporate features such as hillslopes, bluffs, forests, and prairies, often modified by land use. All transitional upland fringes have one common attribute, however -- they are distinguishable from the surrounding landscape by some kind of greater connection to the floodplain and stream, such as the continuation of floodplain forests or other natural vegetation part-way up the hillslopes or on the edges of upland terraces.

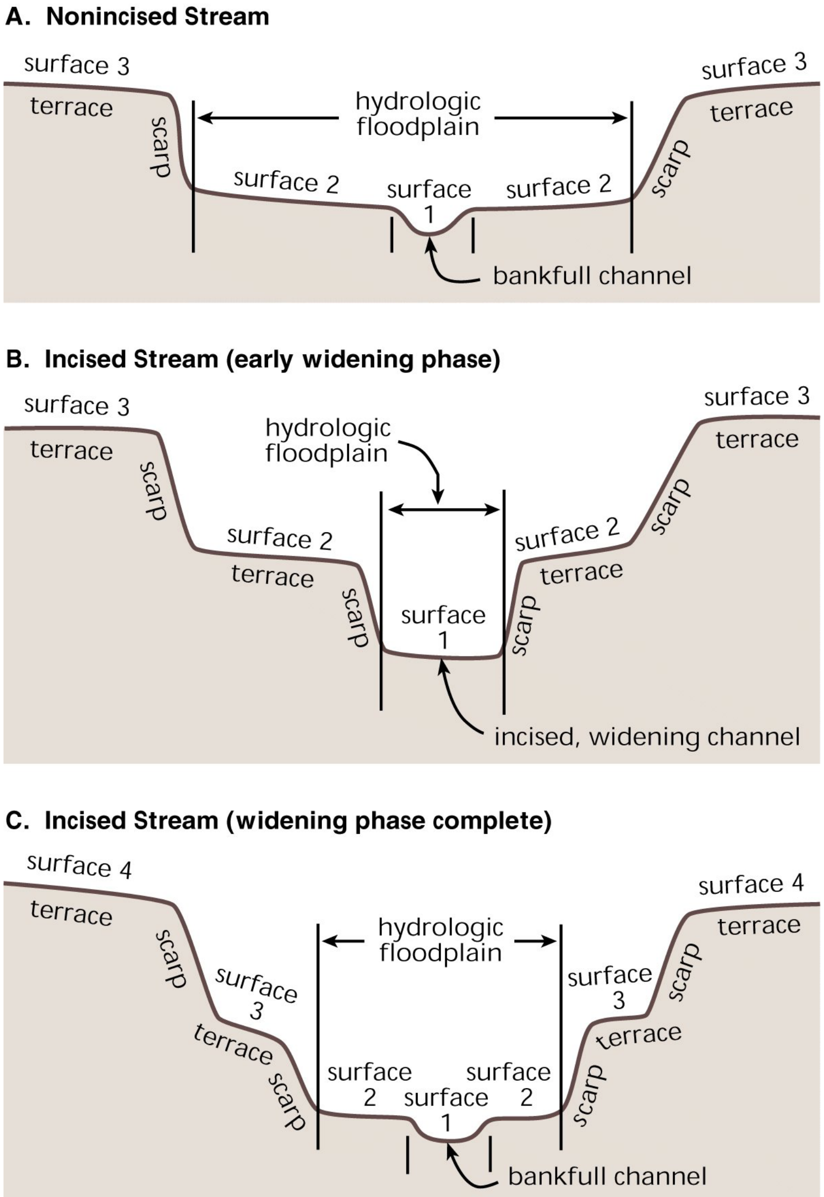
Terraces formed by an incising stream in response to new patterns of streamflow or sediment load in the watershed.

Figure 18

An examination of the floodplain side of the transitional upland fringe often reveals one or more flat-topped benches. These landforms are called terraces (Figure 18). They are formed in response to new patterns of streamflow, changes in sediment size or load, or changes in watershed base level--the elevation at the watershed outlet. Although many terraces were formerly active floodplains, most have become isolated from periodic flooding by the stream in recent years. In some regions of the country, some of the higher, older terraces were formed by glaciation.
Terrace formation can be

explained using the aforementioned stream balance equation. When one or more variables change, equilibrium is lost, and either degradation or aggradation occurs.

Figure 19 presents an example of terrace formation by channel incision. Cross section A represents a nonincised channel. Due to changes in streamflow or sediment delivery, equilibrium is lost and the channel degrades and widens. The original floodplain is abandoned and becomes a terrace (cross section B). The widening phase is completed when a floodplain evolves within the widened channel (cross section C)



Terrace formation by incising or widening floodplains

Figure 19

Vegetation Across the Stream Corridor

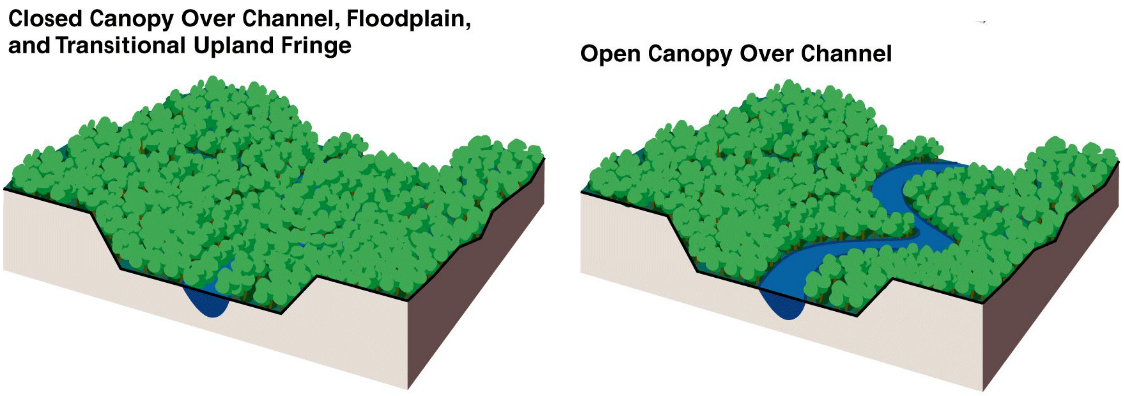
Vegetation is an important and highly variable element in the stream corridor (Figure 20). In some minimally disturbed stream corridors, a series of plant communities might extend uninterrupted across the entire corridor. The distribution of these communities would be based on different hydrologic and soil conditions. In smaller streams the riparian vegetation might even form a closed canopy above the channel.

Plant communities play a significant role in determining stream corridor condition, vulnerability, and potential for (or lack of) restoration. Thus, the type, extent and distribution, soil moisture preferences, elevation, species composition, age, vigor, and rooting depth are all important characteristics that must be considered when planning and designing stream corridor restoration.

Although vegetation patterns vary widely among different stream and river types, sizes, and regions of the country, the following are some of the more common vegetative patterns:

Submerged aquatic plants will grow in many types of channels if the substrate and stream velocity allow for rooting (Figure 21, a). Obligate hydrophytes (plants requiring submerged or saturated conditions) including floating rooted, free floating, and emergent herbaceous and shrub species can become established in the edges of slow-flowing waters of shallow- gradient rivers and deeper streams. Examples may include coontail, duckweed, pond lily, and cattail.

Gravel bars, shores and active floodplains within the bankfull channel (Figure 21, b) may support stands of herbaceous plants and small shrubs or tree seedlings temporarily, but these communities are displaced by moderate flooding almost yearly. These plants are often somewhat water-tolerant but are not necessarily obligate hydrophytes; examples include stargrass, smartweed, and seedlings of cottonwood, alder and willow.



Examples of different forested vegetation structure in stream corridors

Figure 20

In forested regions of the US, plant communities dominated by shrubs and trees are found on the floodplains just above the bankfull channel (Figure 21, c). These communities can vary with distance from the water. For example, alders and willows may dominate the edge while mature trees begin to dominate farther from the stream.

In the absence of land use disturbances, the transitional upland fringe will often consist of forested terraces and hillslopes in most regions. In desert and grassland regions, however (Figure 21, d), the fringe may mark the end of riparian woodlands or shrubs and the beginning of dry grasslands or desertscrub.

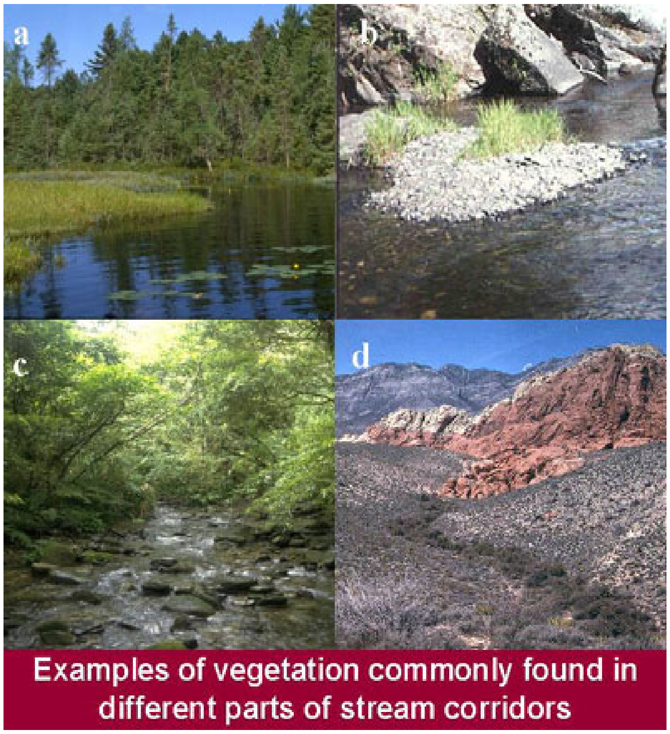
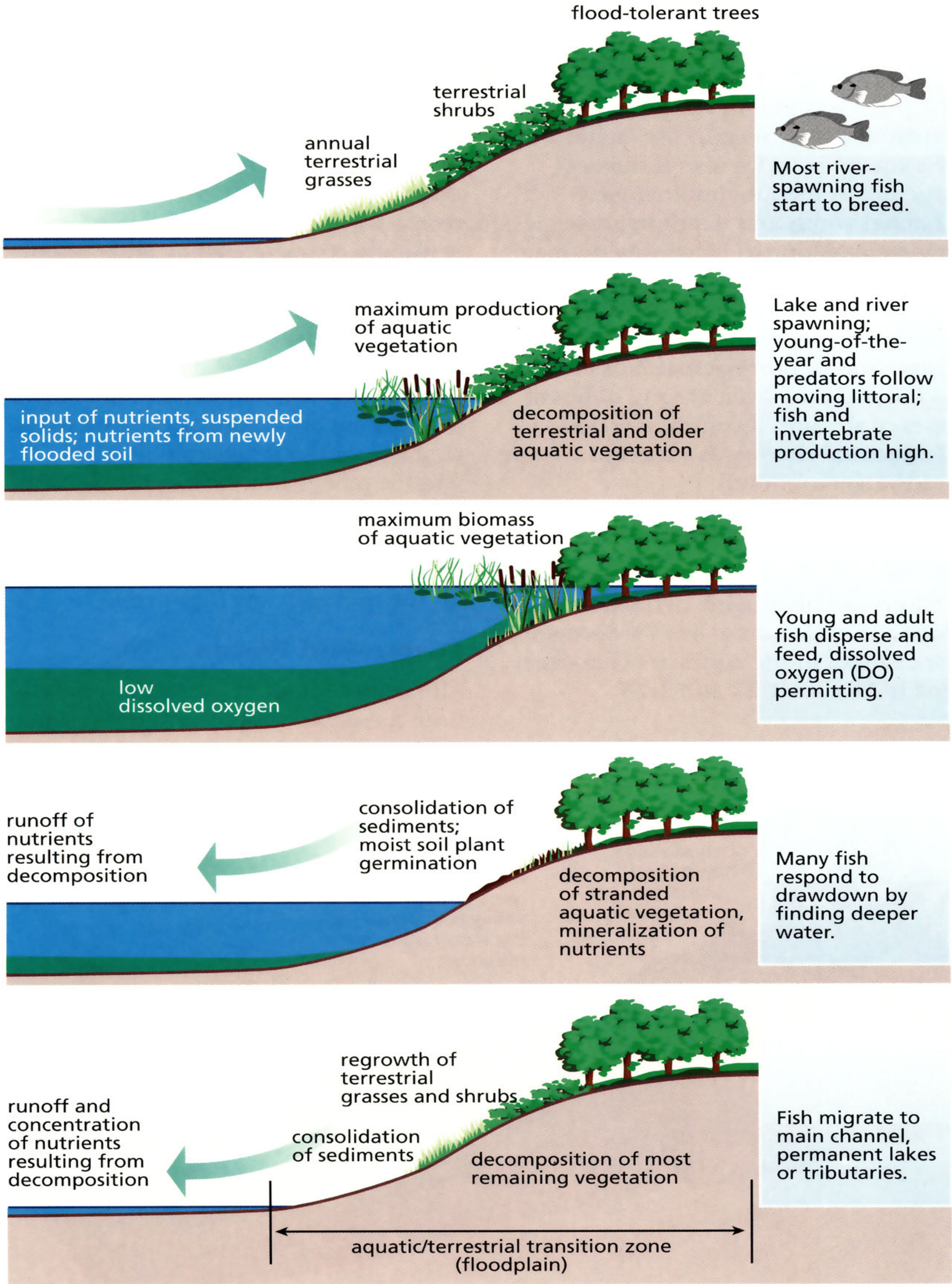


Figure 21

Flood-Pulse Concept

This concept (Figure 22 on the next page) demonstrates how flooding processes, plants and wildlife in all parts of the stream corridor interact. Floodplains serve as essential focal points for the growth of many riparian plant communities and the wildlife they support. Some riparian plant species such as willows and cottonwoods depend on flooding for regeneration. Flooding also nourishes floodplains with sediments and nutrients and provides habitat for invertebrate communities, amphibians, reptiles, and fish spawning.

The flood-pulse concept was developed to summarize how the dynamic interaction between water and land is exploited by the aquatic and terrestrial river corridor biota. Applicable primarily on larger rivers, the concept demonstrates that the predictable advance and retraction of water on the floodplain in a natural setting enhances biological productivity and maintains diversity (Bayley 1995).



The flood-pulse concept diagrammed in five stages of an annual hydrologic cycle. The left column describes nutrient movement, the right describes typical life history traits of fish.

From Bayley, BioScience vol 45 no 3, p.154, March 1995. ©1995 American Institute of Biological Science.

Figure 22

The processes that develop the characteristic structure seen in the lateral view of a stream corridor also influence structure in the longitudinal view (Figure 23). Channel width and depth increase downstream due to increasing drainage area and discharge. Related structural changes also occur in the channel, floodplain, and transitional upland fringe, and in processes such as erosion and deposition. Even among different types of streams, a common sequence of structural changes is observable from headwaters to mouth.

Stream Corridor Structure:

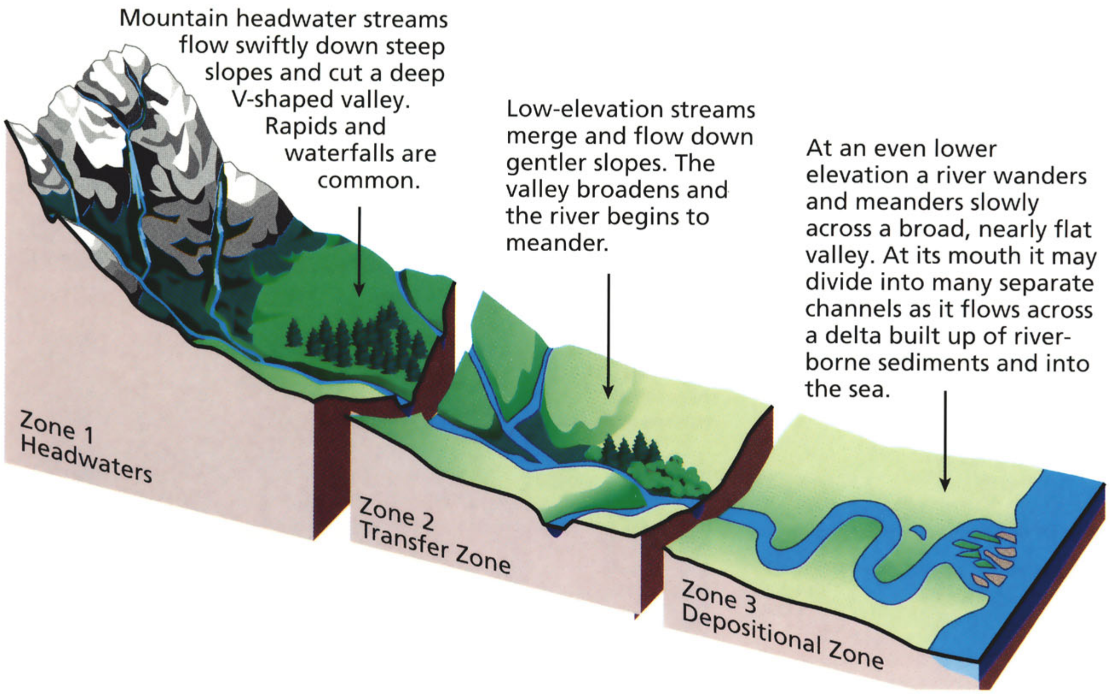
- A Lateral View
  Across the Stream Corridor
- A Longitudinal View
  Along the Stream Corridor

Stream Corridor Restoration

Figure 23

Longitudinal Zones

The overall longitudinal profile of most streams can be roughly divided into three zones (Schumm 1977). Zone 1, or **headwaters**, often has the steepest gradient (Figure 24). Sediment erodes from slopes of the watershed and moves downstream. Zone 2, the **transfer zone**, receives some of the eroded material. It is usually characterized by wide floodplains and meandering



Three longitudinal profile zones, from headwaters to mouth.

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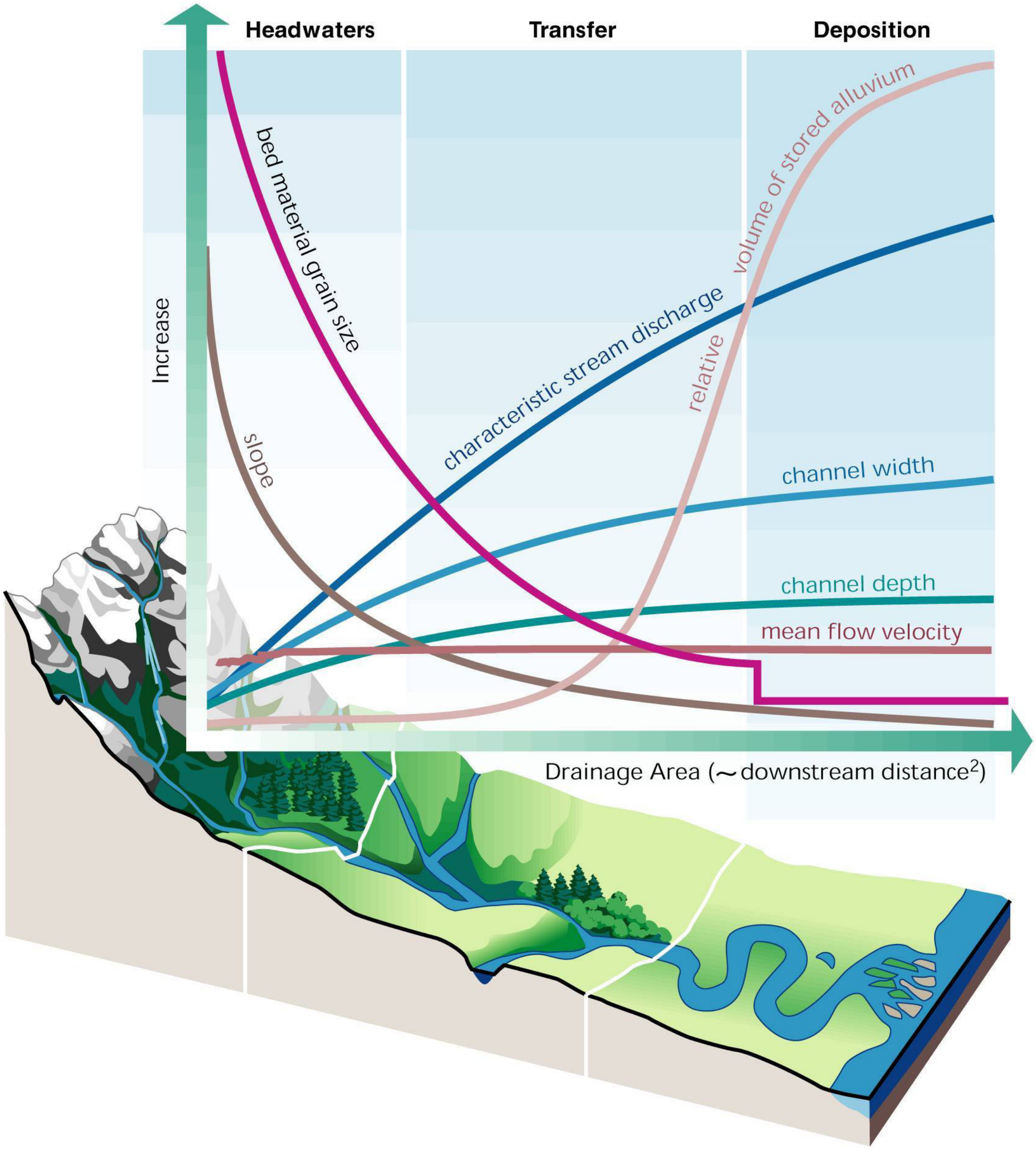
Figure 24

channel patterns. The gradient flattens in Zone 3, the primary **depositional zone**. Though the figure displays headwaters as mountain streams, these general patterns and changes are also often applicable to watersheds with relatively small topographic relief from the headwaters to mouth. It is important to note that erosion, transfer, and deposition occur in all zones, but the zone concept focuses on the most dominant process.

Figure 25 depicts how several flow, channel size, and sediment characteristics change throughout the three longitudinal zones**.**

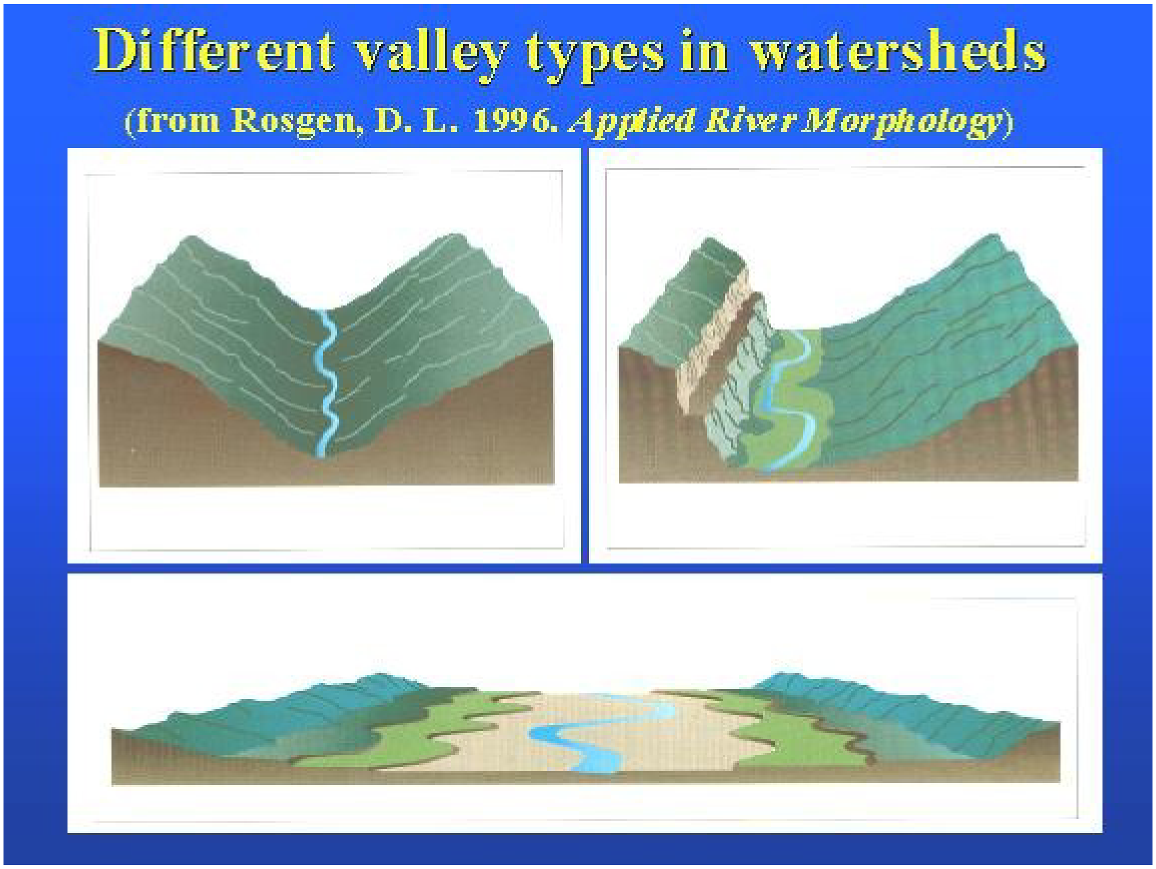


Changes in flow, sediment, and channel size characteristics throughout the longitudinal profile's three zones.

Figure 25

Watershed Form

All watersheds share a common definition: a **watershed** is an "area of land that drains water, sediment, and dissolved materials to a common outlet at some point along a stream channel" (Dunne and Leopold 1978). Watershed form (Figure 26) varies greatly, however, and is tied to many factors including climatic regime, underlying geology, fluvial geomorphology, soils, and vegetation. Subsequently, watershed form affects the form of the stream corridor as seen in longitudinal profile.



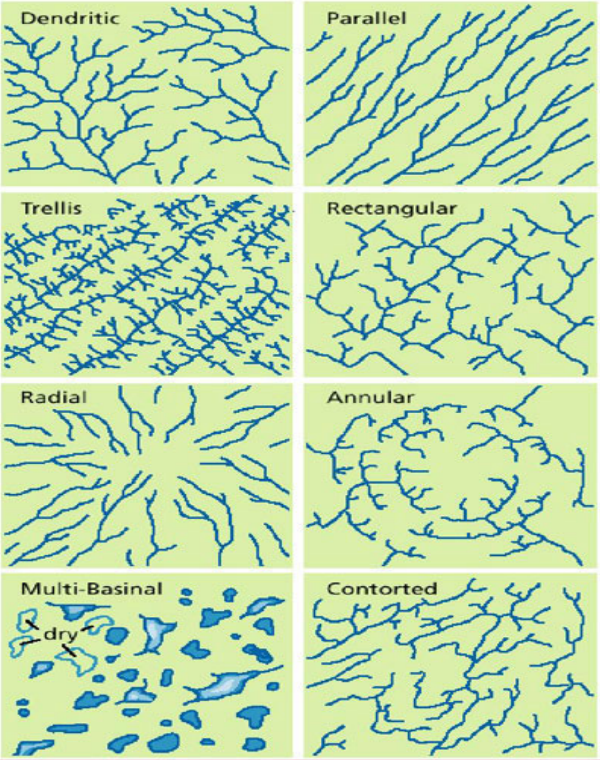
Different valley types in watersheds

(from Rosgen, D. L. 1996. *Applied River Morphology*)

Figure 26

Drainage Patterns

One distinctive aspect of a watershed when observed in planform (map view) is its drainage pattern (Figure 27). Drainage patterns are primarily controlled by the overall topography and underlying geologic structure of the watershed.



Watershed drainage patterns

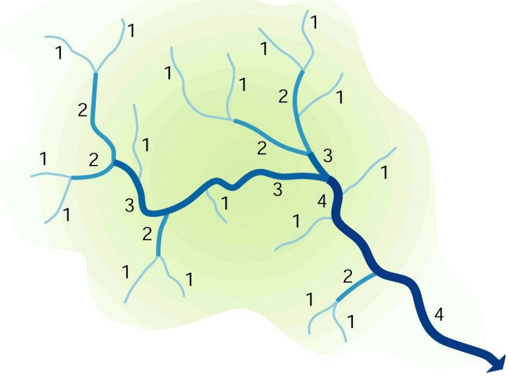
from A.D. Howard, AAPG Bulletin v.51 p 2246-59. © 1967, reprinted by permission of the American Association of Petroleum Geologists and Datapages, Inc.

Figure 27

Stream Ordering

A method of classifying, or ordering, the hierarchy of natural channels within a watershed was developed by Horton (1945) (Figure 28). Several modifications of the original stream ordering scheme have been proposed, but the modified system of Strahler (1957) is probably the most popular today.

Strahler's stream ordering system is a well-known classification based on stream/tributary relationships. The uppermost channels in a drainage network (i.e., headwater channels with no upstream tributaries) are designated as first-order streams down to their first confluence. A second-order stream is formed below the confluence of two first-order channels. Third-order streams are created when two second-order channels join, and so on. Note in the figure that the intersection of a channel with another channel of lower order does not raise the order of the stream below the intersection (e.g., a fourth-order stream intersecting with a second-order stream is still a fourth- order stream below the intersection).



Stream ordering in a drainage network classifies the hierarchy of channels in a watershed.

Figure 28

Within a given drainage basin, stream order correlates well with other basin parameters, such as drainage area or channel length. Consequently, knowing what order a stream is can provide clues concerning other characteristics such as which longitudinal zone it resides in and relative channel size and depth.

Channel Form Along the Corridor

The form of the channel can change as it moves through the three longitudinal zones. Channel form is typically described by two main characteristics--thread (single or multiple) and sinuosity.

Single- and Multiple-Thread Streams

Single-thread (one-channel) streams are most common, but multiple-thread streams occur in some landscapes (Figure 29). Multiple-thread streams are further categorized as either braided or anastomosed streams.

Three conditions tend to promote the formation of braided streams:

- Erodible banks.
- An abundance of coarse sediment.
- Rapid and frequent variations in discharge.

Single-thread (left) and braided (right) channel forms. Single-thread are most common. Braided usually form in unstable conditions with high sediment supply, erosion and flow.

Figure 29

Braided streams typically get their start when a central sediment bar begins to form in a channel due to reduced streamflow or an increase in sediment load. The central bar causes water to flow into the two smaller cross sections on either side. The smaller cross section results in a higher velocity flow. Given erodible banks, this causes the channels to widen. As they do this, flow velocity decreases, which allows another central bar to form. The process is then repeated and more channels are created.

In landscapes where braided streams occur naturally, the plant and animal communities have adapted to frequent and rapid changes in the channel and riparian area. In cases where disturbances trigger the braiding process, however, physical conditions might be too dynamic for many species.

The second, less common category of multiple-thread channels is called **anastomosed streams**. They occur on much flatter gradients than braided streams and have channels that are narrow and deep (as opposed to the wide, shallow channels found in braided streams). Their banks are typically made up of fine, cohesive sediments, making them relatively erosion-resistant. Anastomosed streams form when the downstream base level rises, causing a rapid buildup of sediment. Since bank materials are not easily erodible, the original single-thread stream breaks up into multiple channels. Streams entering deltas in a lake or bay are often anastomosed. Streams on alluvial fans, in contrast, can be braided or anastomosed.

Sinuosity

Natural channels are rarely straight. Sinuosity is a term indicating the amount of curvature in the channel (Figure 30). The **sinuosity** of a reach is computed by dividing the channel centerline length by the length of the valley centerline. If the channel length/valley length ratio is more than about 1.3, the stream can be considered meandering in form.

Sinuosity is generally related to the product of discharge and gradient. Low to moderate levels of sinuosity are typically found in Zones 1 and 2 of the longitudinal profile. Extremely sinuous streams often occur in the broad, flat valleys of Zone 3.

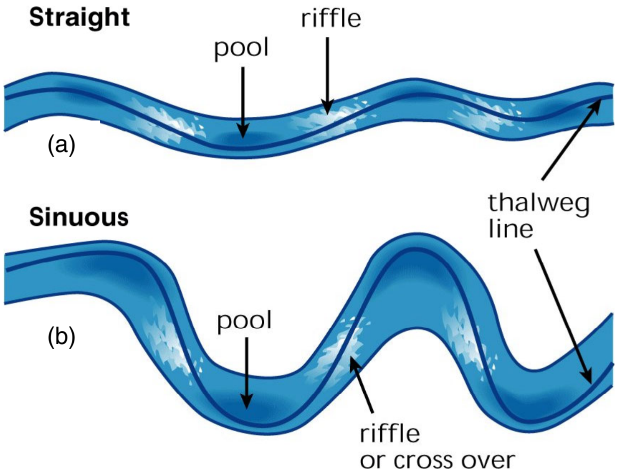
Sinuosity: low (left) and high (right). As sinuosity is closely linked to low gradient, very sinuous channels are more typical of longitudinal zone 3.

Figure 30

Pools and Riffles

No matter the channel form, most streams share a similar attribute of alternating, regularly spaced, deep and shallow areas called **pools** and **riffles.** The pools and riffles are associated with the thalweg, which meanders within the channel (Figure 31). Pools typically form in the thalweg near the outside bank of bends. Riffle areas usually form between two bends at the point where the thalweg crosses over from one side of the channel to the other.

The makeup of the streambed plays a role in determining pool and riffle characteristics. Gravel and cobble-bed streams typically have regularly spaced pools and riffles that help maintain channel stability in a high-energy environment. Coarser sediment particles are found in riffle areas while smaller particles occur in pools. The pool-to-pool or riffle-to-riffle spacing is normally about 5 to 7 times the channel width at bankfull discharge (Leopold et al. 1964).



Sequence of pools and riffles in straight (a) and sinuous (b) stream channels.

Figure 31

Sand-bed streams, on the other hand, do not form true riffles since the grain size distribution in the riffle area is similar to that in the pools. However, sand-bed streams do have evenly spaced pools. High-gradient streams also usually have pools but not riffles, but for a different reason. In this case, water moves from pool to pool in a stairstep fashion.

Vegetation Along the Stream Corridor

Vegetation is an important and highly variable element in the longitudinal as well as the lateral view (Figure 32). Floodplains are narrow or nonexistent in Zone 1 of the longitudinal profile; thus flood-dependent or tolerant plant communities tend to be limited in distribution, except where wetland plants may dominate at or near the stream's source. Upland plant communities, such as forests on moderate to steep slopes in the eastern or northwestern United States, might come close to bordering the stream and create a canopy that leaves little open sky visible from the channel. In other parts of the country, headwaters in flatter terrain may support plant communities dominated by grasses and broad-leaved herbs, shrubs, or planted vegetation.

Headwaters vegetation patterns vary greatly. Above are (left) alpine wetland and stream in Glacier National Park, Montana, and (right) a steep, forested headwaters stream in Virginia.

Figure 32

Despite the variation in plant community type, many headwaters areas provide organic matter from vegetation along with the sediment they export to Zones 2 and 3 downstream. For example, logs and woody debris from headwaters forests are among the most ecologically important features supporting food chains and instream habitat structure in Pacific Northwest rivers from the mountains to the sea (Maser and Sedell 1994).

Zone 2 has a wider and more complex floodplain and larger channel than Zone 1 (Figure 33). Plant communities associated with floodplains at different elevations might vary due to differences in soil type, flooding frequency, and soil moisture. Localized differences in erosion and deposition of sediment add complexity and diversity to the types of plant communities that become established.

The Grande Ronde River in Northeastern Oregon exemplifies the broad floodplains and complex vegetation of zone 2.

Figure 33

The lower gradient, larger stream size, and less steep terrain commonly found in Zone 2 often attract more agricultural or residential development than in the headwaters zone. This phenomenon frequently counteracts the natural tendency to form broad and diverse stream

corridor plant communities in the middle and lower reaches. This is especially true when land uses involve clearing the native vegetation and narrowing the vegetated corridor.
Often, a native plant community is replaced by a planted vegetation community such as agricultural crops or residential lawns. In such cases, stream processes involving flooding, erosion/deposition, import or export of organic matter and sediment, stream corridor habitat diversity, and water quality characteristics are usually significantly altered.

The lower gradient, increased sediment deposition, broader floodplains, and greater water volume in Zone 3 all set the stage for plant communities different from those found in either upstream zone (Figure 34). Large floodplain wetlands become prevalent because of the generally flatter terrain. Highly productive and diverse biological communities, such as bottomland hardwoods, establish themselves in the deep, rich alluvial soils of the floodplain. The slower flow in the channel also allows emergent marsh vegetation, rooted floating or free-floating plants, and submerged aquatic beds to thrive.

The lower Mohawk River near Scotia, New York provides a good example of the channel, floodplain, and river corridor vegetation characteristics of zone 3.

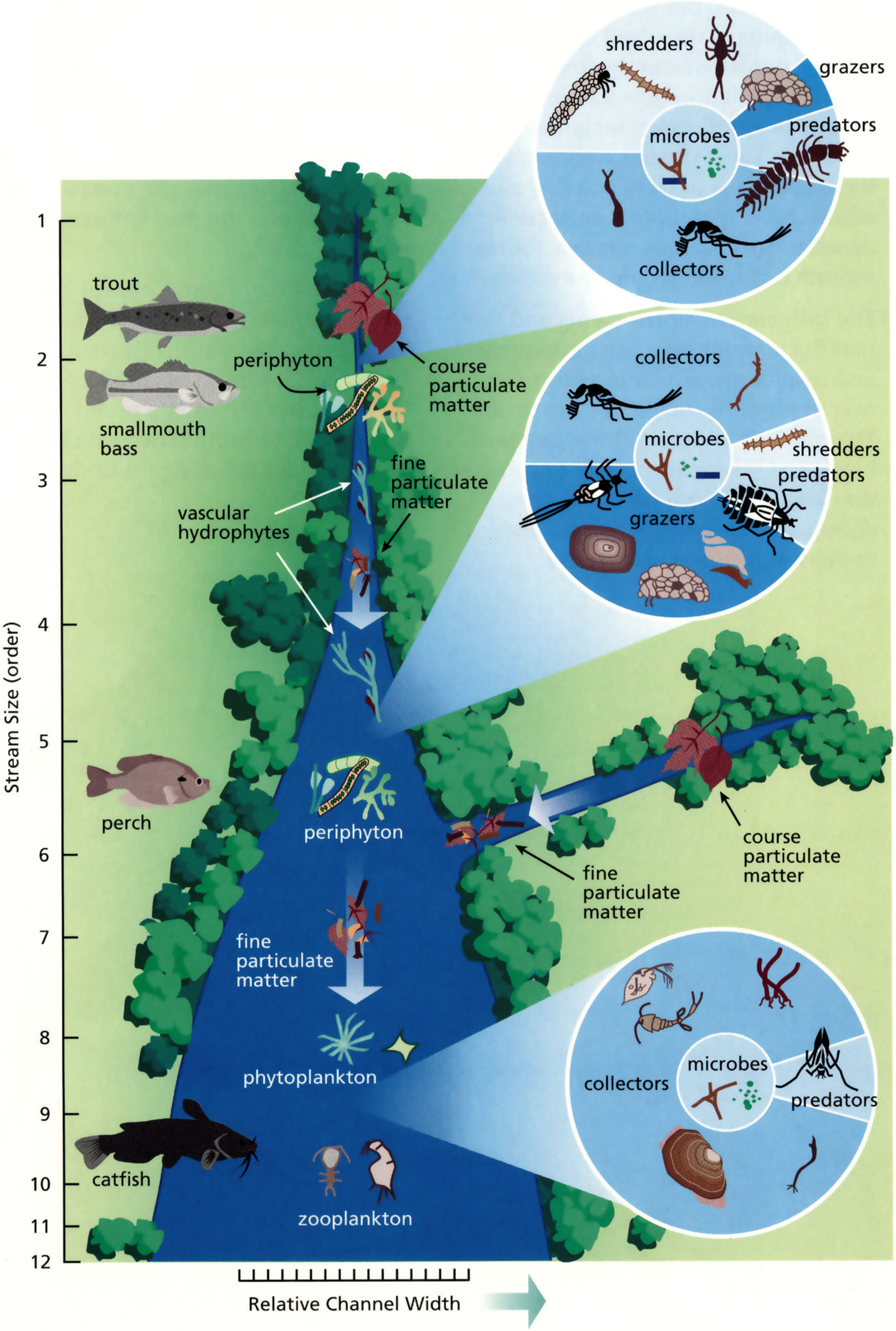
Figure 34

The changing sequence of plant communities along streams from source to mouth is an important source of biodiversity and resiliency to change. Although many, or perhaps most, of a stream corridor’s plant communities might be fragmented, a continuous corridor of native plant communities is desirable. Restoring vegetative connectivity in even a portion of a stream will usually improve conditions and increase its beneficial functions.

The River Continuum Concept

The River Continuum Concept is an attempt to generalize and explain longitudinal changes in stream ecosystems (Vannote et al. 1980). This conceptual model shown in Figure 35 (on the next page) not only helps to identify connections between the watershed, floodplain, and stream systems, but it also describes how biological communities develop and change from the headwaters to the mouth. The River Continuum Concept can place a site or reach in context within a larger watershed or landscape and thus help practitioners define and focus restoration goals.

The River Continuum Concept hypothesizes that many first- to third-order headwater streams are shaded by the riparian forest canopy. This shading, in turn, limits the growth of algae, periphyton, and other aquatic plants.



The River Continuum Concept
(Source: Vannote et al. 1980. Used with permission of NRC Research Press)

Figure 35

Since energy cannot be created through photosynthesis (autotrophic production), the aquatic biota in these small streams is dependent on **allochthonous** materials (i.e., materials coming from outside the channel such as leaves and twigs).

Biological communities are uniquely adapted to use externally derived organic inputs. Consequently, these headwater streams are considered **heterotrophic** (i.e., dependent on the energy produced in the surrounding watershed). Temperature regimes are also relatively stable due to the influence of ground water recharge, which tends to reduce biological diversity to those species with relatively narrow thermal niches.

Predictable changes occur as one proceeds downstream to fourth-, fifth-, and sixth-order streams. The channel widens, which increases the amount of incident sunlight and average temperatures. Levels of primary production increase in response to increases in light, which shifts many streams to a dependence on **autochthonous** materials (i.e., materials coming from inside the channel), or internal autotrophic production (Minshall 1978).

In addition, smaller, preprocessed organic particles are received from upstream sections, which serves to balance autotrophy and heterotrophy within the stream. Species richness of the invertebrate community increases as a variety of new habitat and food resources appear. Invertebrate functional groups, such as the grazers and collectors, increase in abundance as they adapt to using both autochthonous and allochthonous food resources. Midsized streams also decrease in thermal stability as temperature fluctuations increase, which further tends to increase biotic diversity by increasing the number of thermal niches.

Larger streams and rivers of seventh to twelfth order tend to increase in physical stability, but undergo significant changes in structure and biological function. Larger streams develop increased reliance on primary productivity by phytoplankton, but continue to receive heavy inputs of dissolved and ultra-fine organic particles from upstream. Invertebrate populations are dominated by fine-particle collectors (i.e. zooplankton). Large streams frequently carry increased loads of clays and fine silts, which increase turbidity, decrease light penetration, and thus increase the significance of heterotrophic processes.

The influence of storm events and thermal fluctuations decrease in frequency and magnitude, which increases the overall physical stability of the stream. This stability increases the strength of biological interactions, such as competition and predation, which tends to eliminate less competitive taxa and thereby reduce species richness.

The fact that the River Continuum Concept applies only to perennial streams is a limitation. Another limitation is that disturbances and their impacts on the river continuum are not addressed by the model. Disturbances can disrupt the connections between the watershed and its streams and the river continuum as well.

The River Continuum Concept has not received universal acceptance due to these and other reasons (Statzner and Higler 1985, Junk et al. 1989). Nevertheless, it has served as a useful conceptual model and stimulated much research since it was first introduced in 1980.

Summary

This concludes the Stream Corridor Structure module. In this module, we reviewed what a stream corridor is and examined its structure, which reveals much about how the corridor was formed as well as how it now functions as a critical part of the watershed. We examined structure by looking at a cross-section of the corridor, including the stream channel, floodplains, and the transitional upland fringe. Also we looked at structure along the full length of the stream corridor, including the differences among the headwaters, the transfer zone, and the depositional zone. Two popular conceptual views of rivers - the flood-pulse concept and the river continuum concept - were used to relate structure to function in summing up the sections on lateral and longitudinal structure, respectively.

A self-test to assess your comprehension is included on page 30 of this module.

Acknowledgments

This module was adapted with minor changes from the published document *Stream Corridor Restoration: Principles, Processes and Practices* written by the Federal Interagency Stream Restoration Work Group. Appreciation is extended to all of the authors of this document, plus donors of photographs and graphics for use in the document and in this module, and to several publishers who granted permission to use copyrighted graphics. Thanks are also offered to the technical reviewers who helped improve and finalize this training module: Jerry Bernard, Derek Booth, Donald Garofalo, Robert Goo, Douglas Shields, and Ron Tuttle.

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Self Test for Stream Corridor Structure Module

After you've completed the quiz, check your answers with the ones provided on page 34 of the document. A passing grade is 14 of 20 correct, or 70 percent.

1. Bankfull flow is reached when streamflow just begins to spill over the channel's banks onto the terrace.

☐ A. True

☐ B. False

2. An influent stream reach loses stream water to groundwater.

☐ A. True

☐ B. False

3. If a change is made in any of the variables of Lane's equation, the stream will adjust to reestablish equilibrium.

☐ A. True

☐ B. False

4. The widest part of the channel is called the thalweg.

☐ A. True

☐ B. False

5. The transfer zone has the steepest gradient of the three longitudinal stream zones.

☐ A. True

☐ B. False

6. Although not flooded frequently, most terraces are flooded regularly.

☐ A. True

☐ B. False

7. Braided channels are often, but not always, a sign of unstable, high-disturbance conditions

☐ A. True

☐ B. False

8. Intermittent streams flow generally less than 30 days per year.

☐ A. True

☐ B. False

9. Pool-to-pool spacing along a stream is usually about 5 to 7 times the width of the bankfull channel.

☐ A. True

☐ B. False

10. The river continuum concept explains changes seen as one goes across a river corridor.

☐ A. True

☐ B. False

11. According to the river continuum concept, greater shading of headwaters streams makes their biota more dependent on food sources from outside the channel.

☐ A. True

☐ B. False

12. Lane's equation is useful for making qualitative predictions about channel impacts from changes in runoff or sediment load from the watershed.

☐ A. True

☐ B. False

13. Going from headwaters to mouth along a stream, the general pattern is for which of the following parameters to decrease?

☐ A. stream slope
☐ B. bed sediment particle size
☐ C. channel width
☐ D. flow velocity
☐ E. A, B and D
☐ F. A and B
☐ G. none of the above

14. Stream discharge is calculated in terms of:

☐ A. channel cross-sectional area
☐ B. velocity of streamflow
☐ C. baseflow
☐ D. stormflow
☐ E. A and B
☐ F. C and D

15. Stream channel size is determined by the combined interactions of sediment discharge, streamflow, and what else?

☐ A. stream channel slope
☐ B. floodplain width
☐ C. sediment particle size
☐ D. A and C
☐ E. B and C
☐ F. A and B

16. The hydrographs in urbanized areas often show increases in which of the following, as compared to the same stream's hydrograph before development?

☐ A. peak stormflow, lag time it takes to reach peak stormflow
☐ B. ground water recharge, peak stormflow
☐ C. peak stormflow, base flow after stormflow is over
☐ D. speed of runoff, volume of runoff, peak stormflow

17. The water in a stream flowing at bankfull discharge level is usually coming from:

☐ A. ground water
☐ B. direct precipitation on the stream surface
☐ C. overland runoff of precipitation
☐ D. All of the above
☐ E. A and C
☐ F. B and C

18. The thalweg is:

☐ A. flooded only two of every three years
☐ B. an ancient mythological beast
☐ C. the deepest part of the channel
☐ D. the highest type of terrace

19. Streams are braided rather than single-channelled due to which of the following?

☐ A. highly erodible banks
☐ B. rapid and frequent discharge variations
☐ C. an abundance of sediment
☐ D. A and B
☐ E. A and C
☐ F. B and C
☐ G. A, B and C

20. Going from headwaters to mouth along a stream, the general pattern is for which of the following parameters to increase?

☐ A. stream slope
☐ B. bed sediment particle size
☐ C. channel width
☐ D. volume of stored alluvium
☐ E. B and C
☐ F. C and D
☐ G. A through D

Answers for Stream Corridor Module Self Test

Q1: B Q2: A Q3: A Q4: B Q5: B Q6: B Q7: A Q8: B
Q9: A Q10: B Q11: A Q12: A Q13: E Q14: E Q15: D Q16: D
Q17: D Q18: C Q19: G Q20: F