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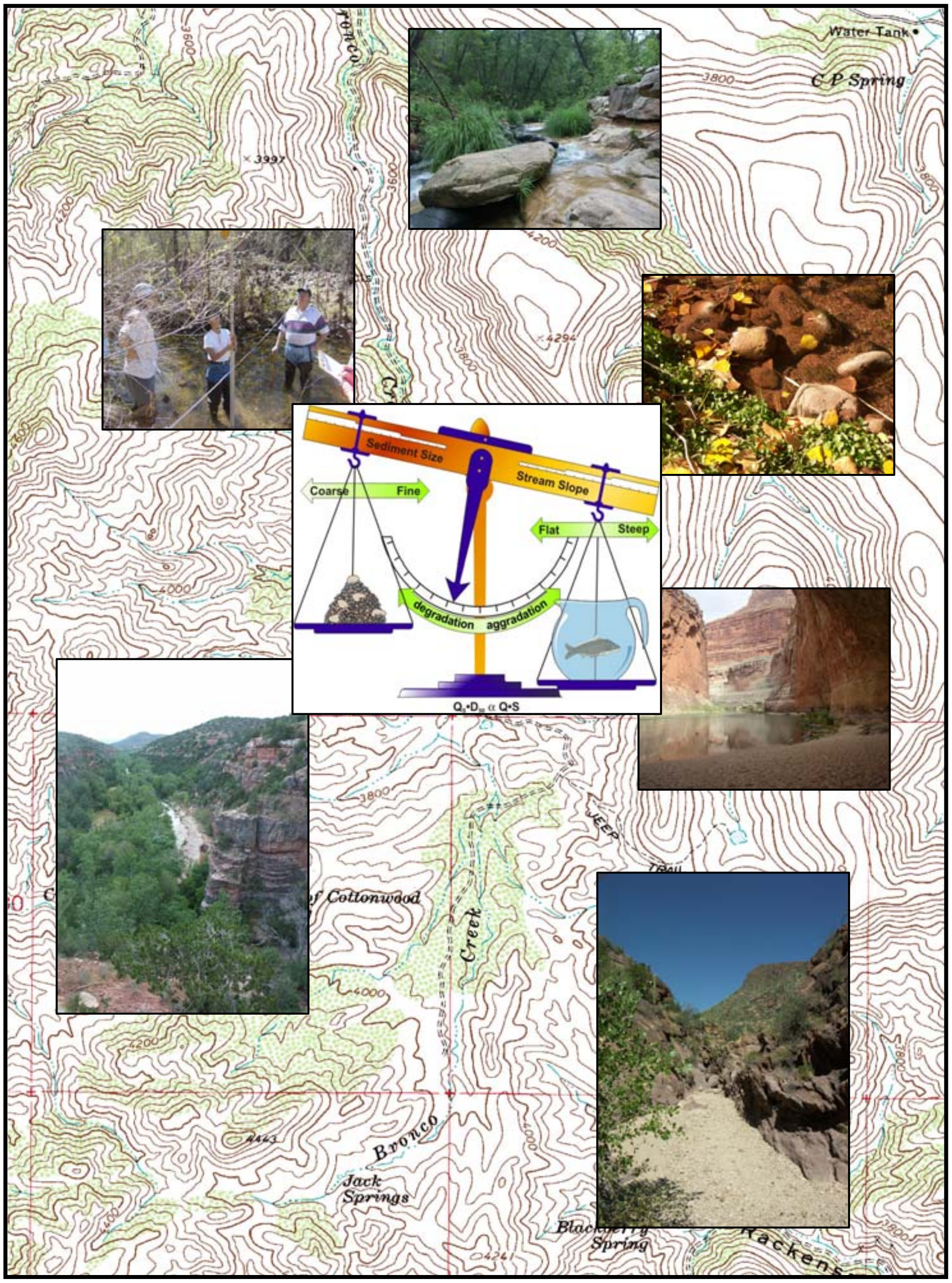
STREAM PROCESSES FOR WATERSHED STEWARDS



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Streams Processes for Watersheds Stewards

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PART I: STREAM PROCESSES

George Zaimes & Robert Emanuel

"Water is the eye of a landscape." –Vincent Lean, Collectanea, 1902

INTRODUCTION

Streams are natural linear configurations in the land surface that transport water and sediment. They are characterized by water moving under the influence of gravity that flows through defined channels to progressively lower elevations. Streams are one of the most readily identifiable features of the landscape. Looking down from an airplane you may be able to pick them out of the landscape as winding, twisting or straight lines that tend to branch off and eventually become smaller and smaller toward the higher elevations of a watershed. From an aerial view you may also be able to identify their end points in lakes, reservoirs, larger rivers or oceans.

Before explaining more about streams it is essential to understand the broader sciences of geomorphology and fluvial geomorphology.

In this part you will learn about:

- Basic terms related to streams.
- Basic terms of fluvial geomorphology.
- The process of stream formation & evolution.
- Stream impacts on aquatic life.

These fields explain stream processes and how and where water moves before it reaches the stream.

THE HYDROLOGIC CYCLE

The hydrologic processes that redistribute water through the oceans, atmosphere and land can be described by the hydrologic cycle (Figure 1). Water in stream channels originates from precipitation, overland flow, subsurface flow, and groundwater flow.

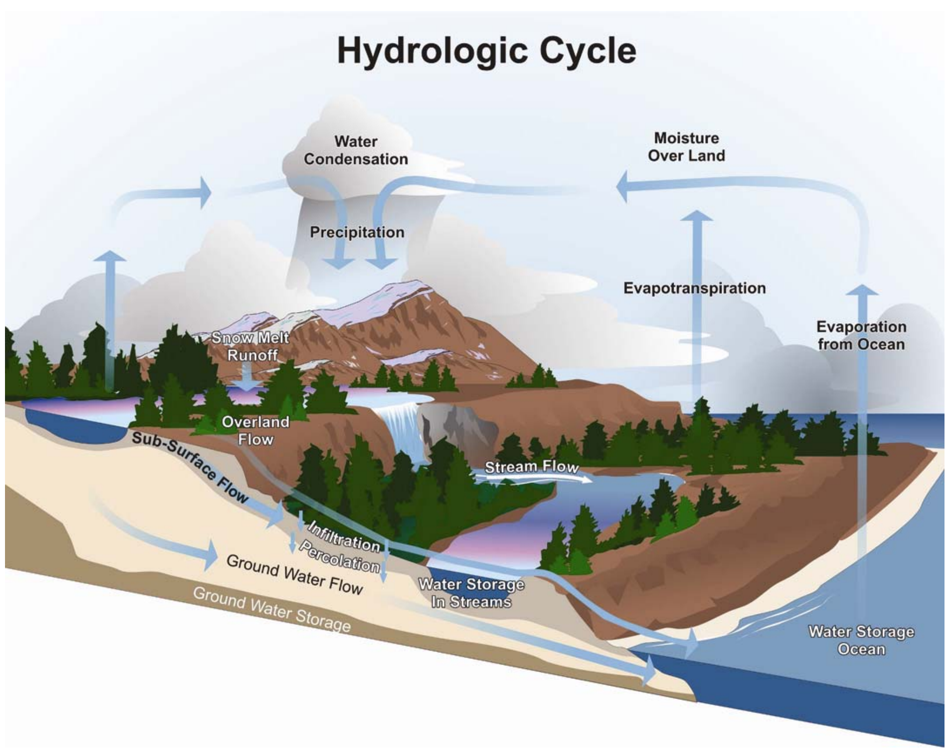

Figure 1. The hydrologic cycle is the movement of water between land, streams, oceans and the atmosphere. This cycle involves many numerous pathways and major storage units such as soils, aquifers, oceans, atmosphere and plants. Water is not created or destroyed (Illustration by D. Cantrell).

Precipitation includes the water that condenses into droplets or ice crystals and falls to the ground. Various forms include: rain, snow, hail, freezing rain, and fog drip. **Evaporation** is the loss of water as vapor from surfaces such as streams, lakes, puddles, ponds and soil pores. **Transpiration** is the loss of water as vapor from plant pores. Often evaporation and transpiration are combined into the term **evapotranspiration**. **Sublimination** of snow is another way water returns to its vapor phase. Finally, the **storage of water** in the watershed includes various locations where the water is retained temporarily before it is evaporated, transpired, or moved to the outlet of the watershed. Water flow in the watershed is delayed by being stored in the soil's unsaturated and saturated zones.

In addition, surface soil depressions, vegetation, other living organisms, as well as puddles, lakes, constructed reservoirs, wetlands or the stream channel itself can act as significant sources of stored water. The amount of precipitation that a watershed receives depends on a number of factors, including local climate, longitude and latitude, altitude, as well as proximity to the ocean. Evaporation is heavily dependent on temperature and is influenced by the same factors as precipitation. Transpiration depends on the amount and kind of vegetation and the growing season. Lastly, evapotranspiration depends upon the combination of temperature, precipitation and vegetation characteristics or season.

If precipitation exceeds evapotranspiration then water will be stored (maybe temporarily) in the watershed in one of the locations mentioned previously. **Infiltration** is the process of water entering the surface of the soil. Infiltration is influenced by vegetation cover, soil surface roughness and soil subsurface conditions (soil structure, texture, moisture and organic matter content) as well as topographic characteristics. High rates of infiltration will lead to more water entering the soil profile, more subsurface flow and potential recharge. More recharge usually increases groundwater flow. In contrast, when infiltration rates are low, water will be temporarily stored in surface depressions or it will move as overland flow, eventually entering the stream. Typically, overland flow water reaches the stream much faster than subsurface and ground water flow.

IMPORTANCE OF STREAMS

Streams are often the focus of the landscape and the watershed. While the watershed captures and defines the water movement in the landscape, the stream transports water across the watershed. In addition to water, the stream also recruits and transports sediments. The transportation of water and sediment is the major function of streams.

Naturally, wildlife and humans are very attracted to, and in arid regions dependent upon streams. Many flora also prefer locations near stream courses. Land areas adjacent to streams are called **riparian areas**. These areas have distinctive vegetative, soil and hydrological characteristics compared to the watershed uplands or other drier sites because of their proximity to higher amounts of water. In Arizona, 90% of all vertebrates spend some portion of their life in riparian areas. In addition, 70% of threatened and endangered Arizona vertebrates depend on riparian habitat.
Reduction, alteration or elimination of the amount of water in streams has major impacts on the riparian vegetation and fauna. Finally, most major cities and towns in Arizona and the rest of the United States are located near a stream or some significant source of surface water.

GEOMORPHOLOGY

Geomorphology is the branch of geology dealing with the origin, evolution and configuration of the natural features of the earth's surface. It originates from the Greek words geo, which means earth, and morphology, which refers to the scientific study of form and structure. Geology is the science of rocks, mountains and valleys—the basic foundations of watersheds. Most geologic development is controlled by processes taking place deep within the earth. Geomorphology is concerned with the external forces of nature that change rocks, mountains and valleys after they are formed on the surface of the earth. These forces include **weathering**—or the impact of climate and life on the earth's crust. Weathering can be divided into two types—physical and chemical—depending upon how a particular force interacts with the parent materials in question.

Physical weathering is the mechanical separation of rocks into smaller particles that are then transported, deposited and incorporated into soils and sediments. Expansion or contraction of parent materials through heating and freezing are the main mechanisms of physical weathering. Water can play a critical role in physical weathering as it freezes and thaws within the parent material thereby expanding cracks and fissures that can break down rocks. Wind and water erosion can also play an important role in physical weathering. Finally, life itself plays an important role in weathering. Anyone who has watched a tree root destroy a sidewalk can attest to the power of life to weather rock-like materials!

Chemical weathering occurs where the minerals in rocks interact with water to form new materials at the expense of the original structure of the rocks. Water brings the minerals in rocks into contact with a variety of different elements that can break them down. Furthermore, organisms such as bacteria, fungi and plants will speed the chemical weathering through their own metabolic processes.

Physical and chemical weathering often work together to reduce parent material into smaller and smaller particles. For example, as physical weathering takes place and reduces rocks to smaller particles, the surface area exposed to chemical weathering agents and water is greatly increased.

FLUVIAL GEOMORPHOLOGY

Water is one of the most important agents for both chemical and physical weathering. Water has the ability to decompose rock, move a soil particle or alter the shape of an entire hillside. These geomorphic processes are very important to watersheds by shaping the landforms in which water will be transported.

From a watershed perspective, the three critical processes are:

1. weathering of the earth's crust to form soil particles
2. erosion by water of those soils to yield waterborne sediment
3. transportation and deposition of that sediment within and through the watershed

Geomorphology that relates to water movement in the landscape is called **fluvial geomorphology**. Two of the main fluvial processes are overland flow and stream flow. **Overland flow** (also known as **surface runoff**) consists of water from precipitation or snowmelt that does not infiltrate into the soil and moves over the surface of the landscape. **Stream flow** is the water running within a drainage feature such as a stream channel. Overland flow transports eroded particles to streams where many of the particles are transported as sediment in the water column. Stream flow can then transport the sediment load downstream. The processes of erosion, transport and deposition of sediment can lead to **Degradation** (lowering the elevation of the land surface) or **aggradation** (increasing the elevation of the land surface). These processes result in two types of fluvial landforms that are shaped by water: **Erosional fluvial landforms** are shaped by the progressive removal of rock or material (degradation). Examples include ravines, canyons, or mountain peaks. **Depositional fluvial landforms** are built from transported and deposited material. Examples include alluvial fans, deltas, or floodplains.

WHAT HAPPENS BEFORE THE STREAM FORMS?

Precipitation that delivers the water to the watershed can also have a significant impact on soil, particularly bare soil. The direct force of falling rain drops on bare soil causes soil particles to be lifted and then deposited in new positions is called **splash erosion** (Figure 2a). When precipitation exceeds soil infiltration rates, overland flow will start. At some point, the water will also start removing soil in very thin uniform layers as **sheet erosion** (Figure 2b). The process continues with **rill erosion** (Figure 2c) that results from the concentration of overland flow into deeper, faster-flowing channels that follow depressions. When flow becomes deeper, increasing flow velocities can cause scour and lead to the formation of **gullies** (Figure 2d). Rill erosion is the intermediate process between sheet and gully erosion.

Gullies are relatively deep channels that are generally formed on valley sides and floors where no well-defined channel previously existed.

They are commonly found in areas with low-density vegetative cover or with soils that are highly erodible. Gullies can also be found in environments where compacted soil and sparse vegetation have increased overland flow significantly. Two main processes that result in the formation of gullies are downcutting and headcutting. **Downcutting** is the vertical lowering of the gully floor that leads to gully deepening and widening. **Headcutting** is the upslope movement that extends the gully in the headwater areas.

As with gullies, the main erosional processes that modify streams are downcutting and headcutting. In streams, however, lateral erosion is also very important. **Downcutting** (also called **incision**) is the deepening of the stream caused by channel bed erosion. **Headcutting** is when the stream channel length increases in the headwaters. Finally, **lateral erosion** (Figure 2e and 2g) widens stream channels. It is caused by stream bank erosion and excessive downcutting.

STREAM CHANNEL FORMATION

Streams exhibit a wide range of physical characteristics at different phases of their formation and will react differently to management or restoration efforts. Stream managers or users must understand channel formation to adequately address stream problems and restoration.

ALLUVIUM VERSUS COLLUVIUM MATERIAL

Alluvium materials are sediments deposited by streams. Because alluvium is transported by water, it is sorted by size and weight by the water volume and velocity. Fast moving streams can transport larger sediments such as gravel and cobbles. When the stream velocity becomes very slow even the fine sediments such as silts and clays are deposited. In contrast, **colluvium** is the soil transported by landslides or slow surface movement (creep) due to gravitational force. Colluvium material is unsorted, unstratified, and has a heterogeneous mix of sizes.

STREAM REACHES

Streams can begin as a very small and narrow trickle of water. But streams can also be hundreds of fee wide. As a result, as one moves along a stream it can be divided into smaller sections that are called reaches. A reach is a segment of the stream that has fairly uniform features or characteristics. These can include hydraulic, which are distinctive enough from the upstream or downstream reach. It is very important to distinguish between stream reaches, particularly when implementing management plans.

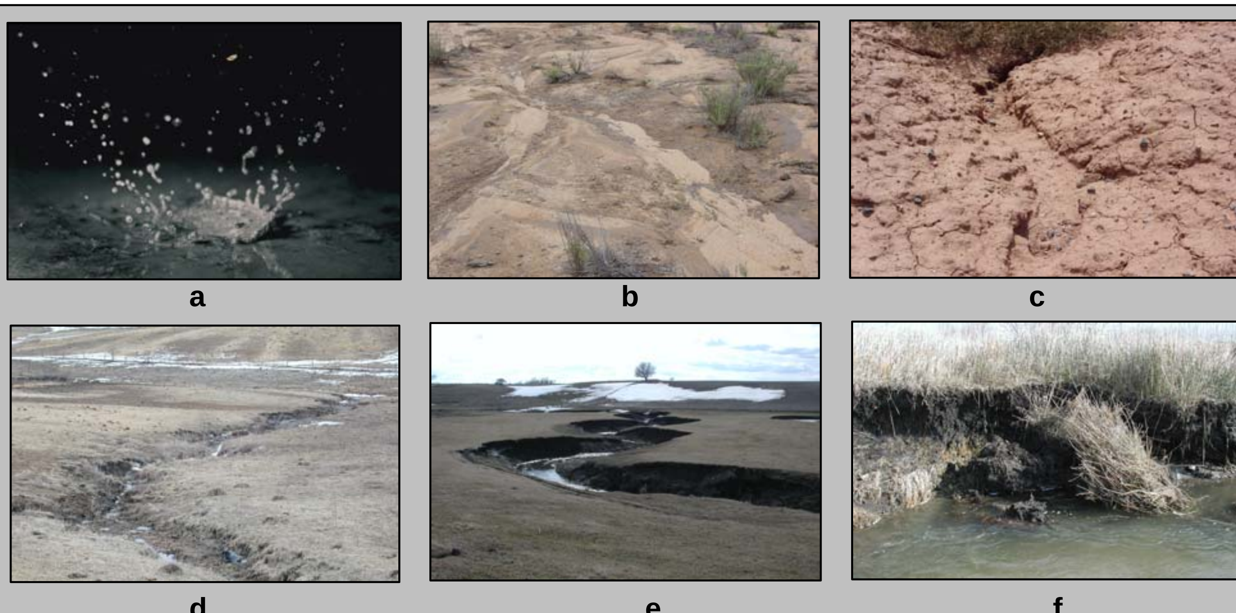

Figure 2. Different types of soil erosion (from left to right): **a**. Splash erosion (Courtesy of NRCS **b**. Sheet erosion; **c**. Rill erosion; **d**. Gully erosion; **e** and **f**. Stream bank erosion (courtesy of G. Zaimes).

Although stream reaches are interconnected and influenced by upstream and downstream reaches, their response to management might be very different.

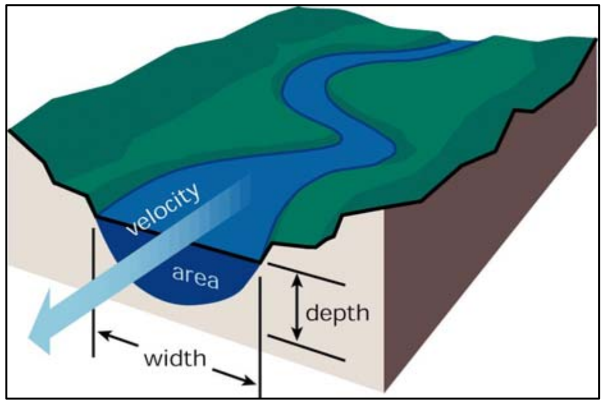

Figure 3. Stream flow discharge (cfs) is estimated by multiplying the water's mean velocity (ft sec) with the stream cross sectional area (ft^2) at a specific point [from "Stream Corridor Restoration: Principles, Processes, and Practices, 10/98, by the Federal Interagency Stream Restoration Working Group (FISRWG)].

TRANSMISSION LOSSES

In semiarid regions, where the dry channels make up a significant portion of the drainage network, stream flow water can decrease as it moves downstream. This decrease in stream flow is called **transmission loss**. As stream flow travels through a normally dry channel, water infiltrates into the channel bed and banks, reducing the runoff volume and the peak rate of flow downstream. Water lost to infiltration can contribute to groundwater recharge, and at a minimum will affect soil moisture distribution in surface sediment layers. Groundwater recharge can be seen as increases in water levels in wells, in and adjacent to channels following flood events. Stream flow losses to this type of infiltration can be large.

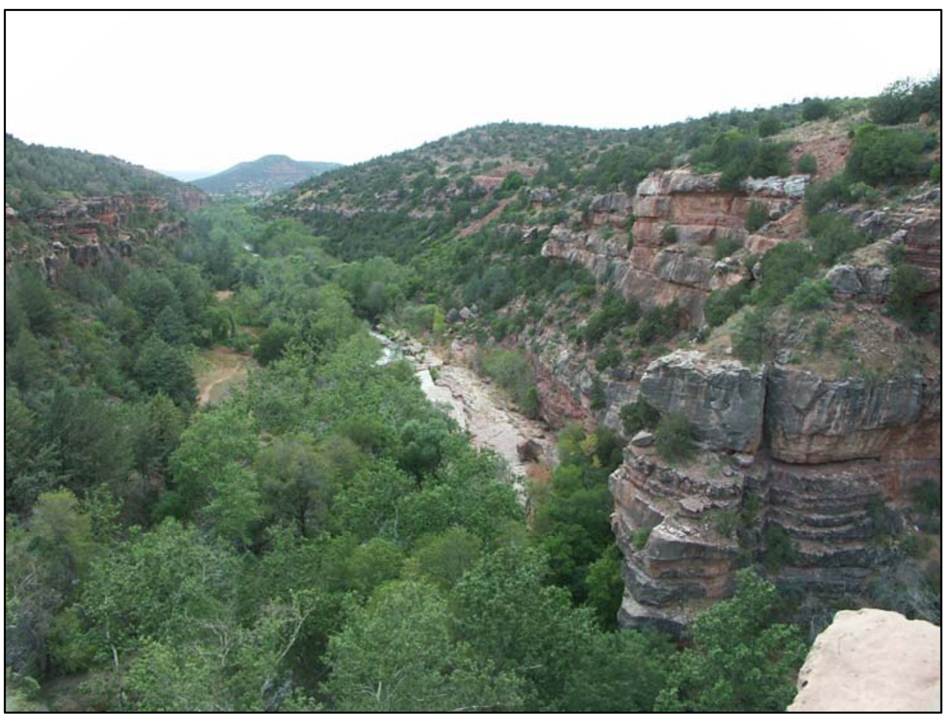

Figure 4. Stream flow discharge in Oak Creek Canyon on a summer day (courtesy of R. Emanuel).

WATER IN THE STREAM CHANNEL

The amount of water that will travel through the stream can be estimated. This is something very useful for watershed managers to know and understand. The main factors influencing water in the stream channel are the amount of precipitation the watershed receives and the pathways water will take in the watershed to reach the stream. These pathways are **overland**, **subsurface** and **ground water flow** (Figure 1) and depend on watershed characteristics. Subsurface flow (also known as **interflow**) is generated as water from rain or snowmelt infiltrates the soil and moves through the soil's **unsaturated zone** (above the water table). In contrast, ground water flow consists of water that moves through the soil's **saturated zone** (beneath the water table).

The equation in the box below is called the **water balance equation**. Q is stream flow discharge, P is precipitation**,** ET is evapotranspiration, St is surface and subsurface storage of water in the watershed and DSt is the change in storage of water.

The Water Balance Equation

$$Q = P - ET \pm DSt$$

Stream flow discharge is defined as the volume of water passing a point on the stream for a specific period of time and is typically measured in cubic feet of water per second (cfs). As you can see in the box below, it is commonly estimated by multiplying the mean stream velocity (V) (measured in feet per second) by the stream cross sectional area (A) (measured in square feet) at a specific point in the channel (see Figures 3 and 4).

Stream Flow Discharge Equation

$$Q = V \times A$$

Stream flow discharge is one of the most important and widely used variables to describe streams. It can be used to compare the magnitude of streams or to characterize flow variability. **Discharge return periods** are a measure of the probability that a certain discharge will occur. For example, every year there is a 1 in 100 chance that a 100 year return period flood will occur. This is the origin of the phrase "100 year flood." The **bankfull discharge** is the quantity of water that controls the form and distribution of materials in the channel. Bankfull literally means the point at which water is just overflowing the main channel and entering the active floodplain. Statistically, the bankfull discharge return period for natural, undisturbed streams should be anywhere between 1.5 years in normal to wet regions or 3 years in more arid regions.

DYNAMIC EQUILIBRIUM

All streams try to move towards a state of **dynamic equilibrium**. One way to describe this equilibrium is the amount of sediment delivered to the channel from the watershed is in long-term balance with the capacity of the stream to transport and discharge that sediment. Sediment **suspended** in water eventually equals sediment settling out of the water column or being deposited. **Sediment load** is the total amount of sediment, including that in the bed of the stream, being moved by flowing water. The streams dynamic equilibrium can be expressed with the "stream power proportionality" equation developed by Lane (see accompanying box and Figure 5).

Stable streams are in dynamic equilibrium and called **graded** (**poised**). The slope of a graded stream, over a period of years, has delicately adjusted to provide, with the available discharge and prevailing channel characteristics, the velocity required for the transportation of the sediment load supplied from the drainage basin.

A graded stream can have depositional and erosional events, but overall the sediment transported and supplied to the stream is balanced over long periods. Disturbance of the equilibrium leads to unstable streams that are **degrading** (**eroding**) or **aggrading** (**depositing**). Degrading streams have a deficit of sediment supply, while aggrading streams have an excess of sediment supply. In both degrading and aggrading streams, the stream is trying to adjust its slope based on the sediment supply. A stream can typically exhibit all three equilibrium states in various reaches along the same stream.

LANE'S EQUATION: $Q \times S \sim Q_S \times D_{50}$

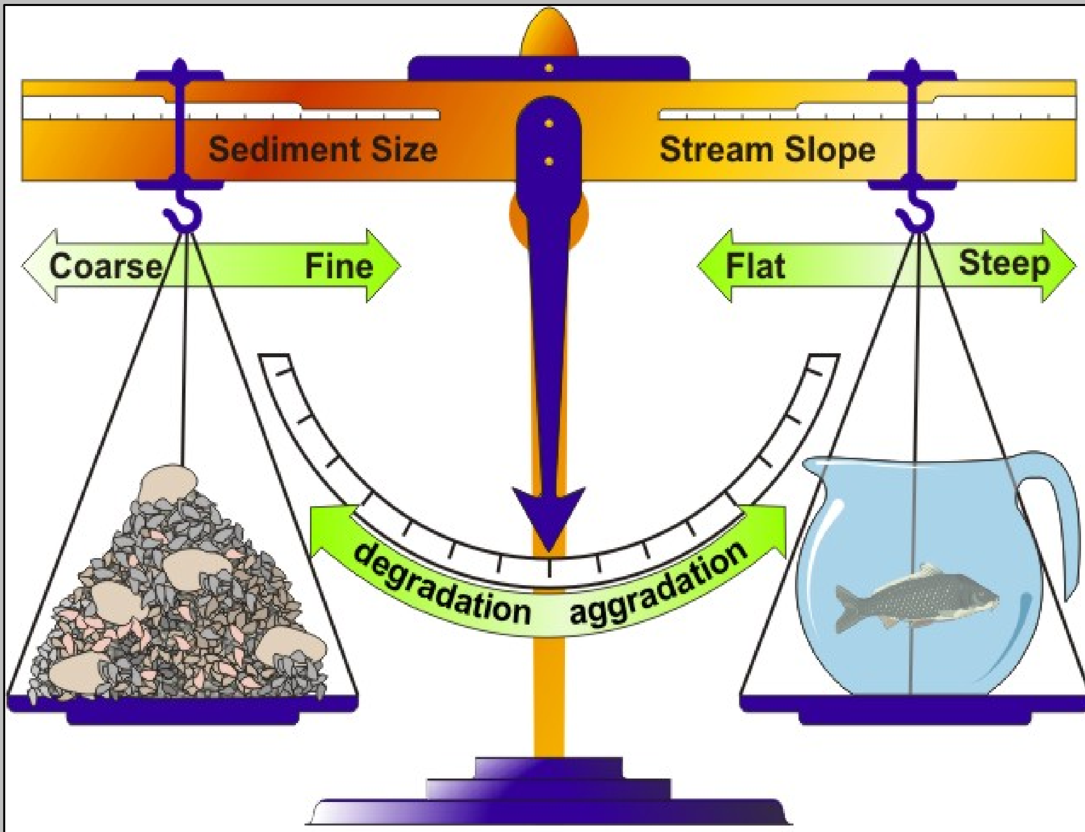

Figure 5. Lane's stream power proportionality equation expresses the stream dynamic equilibrium (Illustration by D. Cantrell, based on Rosgen 1996).

According to Lane's equation, the products of Q x S and Q_s x D_{50} are proportional to each other although not equal to each other. Channel Q is the stream flow discharge, S is the channel gradient (slope), Q_s is the sediment discharge, and D_{50} is the median grain size of the bed material.

The equilibrium occurs when all four variables are in balance. The bottom line is that a given amount of water with a certain velocity can only move so much sediment of a given size.

ILLUSTRATING STREAM FLOW: HYDROGRAPHS

Hydrographs (Figure 6 and 7) are used to describe stream flow discharges over a specific time period. Peak flows, time to peak flow (lag time), storm flow and base flow are the major components of a typical hydrograph (Figure 6). **Peak flow** is the highest stream flow discharge (cfs) measured after a precipitation or a snowmelt event. The time it takes to reach peak flow for the watershed since the highest rainfall intensity is called the **lag time**. **Storm flow** is the amount of water that reaches the channel as overland flow or subsurface flow, a short period during or after a precipitation or snowmelt event. After the event ends and the surge of water in the stream subsides, base flow conditions are re-established. **Baseflow** is the water that sustains stream flow between storm or snowmelt events and its sources of water are subsurface and ground water flows. In many Arizona streams, base flows are zero because they are dry on the surface for most of the year (Figure 7). When overland flow is the dominant pathway, lag time is typically very short, peak flows are very high and base flow conditions are much lower then when subsurface and groundwater flows are the dominant pathways (Figure 7). In other words, the water moves very quickly out of the watershed. Urbanization can cause these types of peak flows. The construction of buildings, parking lots and roads that are **impermeable** to infiltration can cause rapid overland flow and may create these types of peak flows. In contrast, in watersheds with a higher degree of infiltrating water, the time to peak flow is longer, the peak flows are much lower, flows last for longer periods of time, and higher base flow conditions are observed (Figure 7). Baseflow conditions are higher because of the greater contributions of ground water flow to the stream. The dimensions and shape of the hydrographs are also affected by the precipitation and snowmelt history, and stream and watershed characteristics.

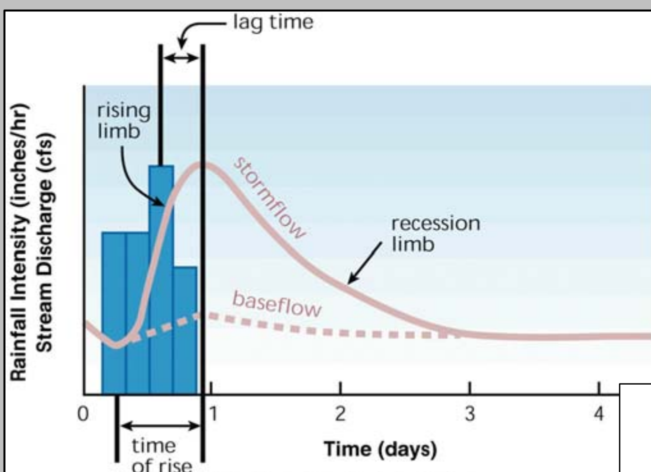

Figure 6. (left) Typical hydrograph [from "Stream Corridor Restoration: Principles, Processes, and Practices, 10/98, by the Federal Interagency Stream Restoration Working Group (FISRWG)].

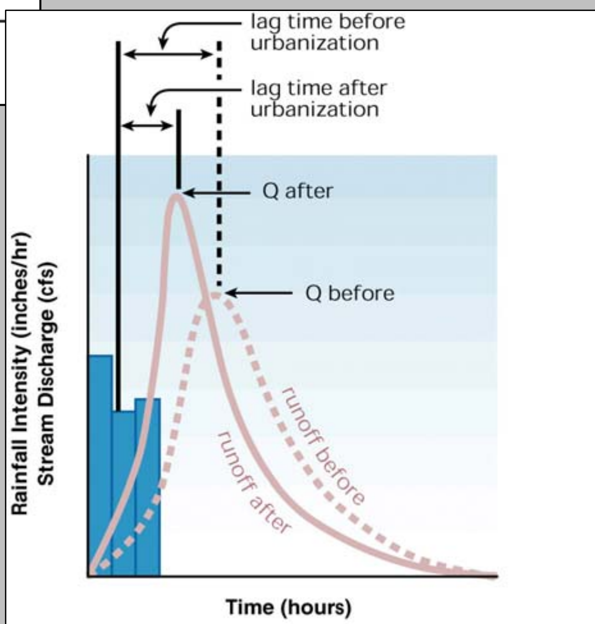

Figure 7. (right) Change in the stream flow hydrograph after urbanization. Base flow is zero in this graph [from "Stream Corridor Restoration: Principles, Processes, and Practices, 10/98, by the Federal Interagency Stream Restoration Working Group (FISRWG)].

HUMAN INFLUENCES ON CHANNEL DYNAMICS

One of the major impacts of humans to the landscape is the change in vegetation cover. Examples are timber clearcutting, land clearing for agriculture, road construction, overgrazing and urbanization. In these cases, vegetation cover decreases and bare ground increases. Often, these human activities can lead to soil compaction and increase impervious surfaces that result in decreased infiltration of water into the soil. Impervious surfaces increase when pavement or hard surfaces—especially common in urban areas--are built on the landscape. All these actions will increase overland flow and peak flows, but this does not lead to an increase of the total stream flow discharge. Just think of the amount of water running over a parking lot compared to a field of native vegetation. Higher peak flows increase the waters sediment transport capacity that can lead to stream degradation. If the slope of the stream remains the same an increase in stream flow discharge will lead to degradation because the sediment load will need to increase to maintain dynamic equilibrium. Experts often call this a stream that is 'starving' for sediment. The assumption is that median grain size of the bed material has not changed.

THE CHANNEL EVOLUTION MODEL

In addition to channel stability (dynamic equilibrium), **sediment transport** and **channel dimensions** (width and depth of the channel) are very important characteristics for describing streams. These characteristics are incorporated in a conceptual model called the incised **channel evolution model (CEM)**. This model builds upon the dynamic equilibrium theory and describes the stages a stream goes through to reach a new dynamic equilibrium following a disturbance. It also describes the stream bank erosion processes (downcutting, headcutting, or lateral erosion) that are dominant during the different stages.

WHY SHOULD WE MANAGE SEDIMENT LOADS?

Streams recruit and transport sediments and water through the watershed and serve as areas of high environmental dynamism—or change. The movement of soil is a natural process in most watersheds—particularly in places like Arizona where the soils are often actively eroding—and then becoming sediment in streams—due to a number of factors including climate and geology. However, poor land management or natural disasters can increase erosion and strongly impact the morphology of streams. Sediment can build up quickly in downstream sites where it is undesirable. In doing so, it changes the grade or **base-level** of the stream, an effect that can cause changes all the way up to the head waters of a stream (depending on local geology). Among the potential causes of increased soil erosion in watersheds are excessive cattle grazing, timber removal, roads or other types of construction and fire.

Another factor that can adversely impact the sediment load of streams is the amount of paved or **impermeable** surface in a watershed. For example, as cities build out into the floodplains of watersheds, the amount of run-off that comes from their parking lots, streets, and rooftops flows into streams much more quickly than it typically would from well-vegetated areas. In well-vegetated areas water can infiltrate into the soil and move slowly into streams through ground and surface-water connections. Much of this runoff from urban areas carries little sediment. The sediment-starved water picks up sediment through bed and bank erosion upon reaching a stream.

What can you do to help manage streams?

- Minimize excess erosion from your home or business, especially during construction of new buildings or roads.
- Keep excess storm water from running off your property—harvest, store and use it in your landscape.
- Educate your community about what streams do and why they should care for them.
- Get involved in a local stream restoration project.

There are five different stages (Figure 8):

- ❖ **Stage I** (**Stable**): The stream flow discharge of Q_2 will spill in the floodplain and deposit sediment and organic matter. Q_2 is a discharge that has a probability of occurring every two years and is associated with bankfull discharge of undisturbed streams in normal to wet environments. Smaller magnitude flows tend to occur more frequently than larger flows. Relatively low discharge flows connect the stream and the floodplain, both physically and biologically, as they inundate the floodplain. The stream bank height h is below the critical height h_c. Critical height h_c is that height above which the banks have high potential of collapsing by gravitational forces.

- ❖ **Stage II** (**Incision**): This stage starts after disequilibrium conditions occur. These conditions occur as a result of higher Q (stream flow discharge) or S (slope), which lead to an increase in Q_s (sediment discharge) capacity in order to maintain the dynamic equilibrium. The increased Q_s capacity causes downcutting of the stream bed. The height of the stream banks increases to higher than critical. As a result the banks now can hold stream flow discharge of Q_{10}. Q_{10} is the discharge that has the probability to occur every ten years. A knick point is a point in the stream profile where the slope abruptly changes, can indicate the movement of incision upstream and in the tributaries.

- ❖ **Stage III** (**Widening**): The extensive increase in bank heights (higher than the critical height) of the channel leads to excessive stream bank instability. The banks start collapsing and the stream starts widening. These streams are extremely deep and wide. Most of the sediment is still moving downstream.

- ❖ **Stage IV** (**Stabilizing**): Excessive sediment deposition from the stream banks in the channel makes it impossible for the stream flow discharge to remove all of it. The stream bank height starts decreasing (typically equals the critical height). Vegetation starts growing on the sloughing material that is not removed. A new lower capacity stream channel is formed.

- ❖ **Stage V** (**Stable with terraces**): A new channel develops and the new banks have heights shorter than the critical bank height. The new floodplain is connected with the stream. Terraces are the remnants of the original floodplain.

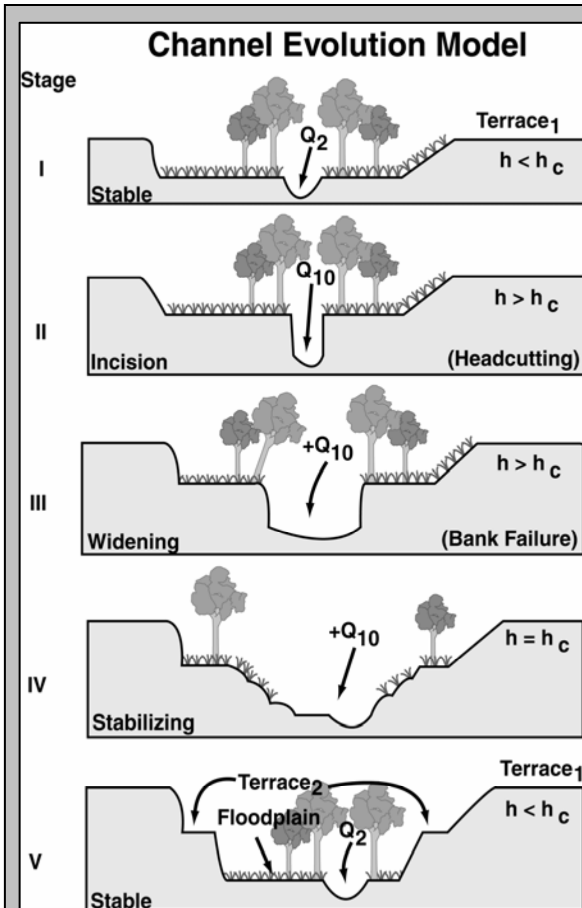

Figure 8. The five stages of the Channel Evolution Model: i) stable, ii) incision, iii) widening, iv) stabilizing v) stabilizing with terraces (from Schultz et al. 2000; based on Schumm et al. 1984). **Q_2** is the discharge that has a probability of occurring every two years and is associated with bankfull discharge in some environments. **Q_{10}** is the probability of discharge occurring every ten years. The actual bank height is **h** while **h_c** is the critical height, the height after which the banks have a high potential of collapsing by gravity alone.

WHY IS THIS MODEL IMPORTANT?

Within each of the five stages of channel development described by the Channel Evolution Model, channel adjustment is dominated by on of the several processes. For example, in **Stage II**, downcutting yields the majority of the stream sediment while in **Stage III** lateral (stream bank) erosion is the primary mechanism of channel adjustment. The difference between these types of erosion has implications for determining the type of restoration efforts. In **Stage II** success of restoration depends upon stopping stream downcutting by what is called "bed stabilization." Bed stabilization is usually done by installing grade control structures such as gabions or check dams. In **Stage III,** where lateral erosion dominates, restoration efforts should focus on the stream banks. We must note that as with all conceptual models, the conditions described in the model are idealized. In nature we do not have the idealized conditions. In addition, a stream may exhibit a range of evolutionary stages among reaches along its length. If degradation happens to a stream reach it influences upstream reaches that will also try to reach the new base level.

Figure 9. Streamside vegetation can consist of a.) trees or b.) herbaceous vegetation (Courtesy G. Zaimes).

LIFE & STREAM PROCESSES

Stream morphology is also related to the type and distribution of stream bank vegetation. For example, banks that would normally erode easily are often held in place by the roots of riparian trees, shrubs and grasses. Likewise, as streams adjust to changes in water and sediment loads, vegetation may also change. For example, as streams widen, trees may become more infrequent while grasses and low growing vegetation increase. In other cases, as streams narrow, grasses may proliferate on the shallow water table close to the stream bank while deeper-rooted trees will be found on the old floodplain or in side channels that no longer receive regular flows except during floods. In other cases, as streams narrow, grasses may proliferate on the shallow water table close to the stream bank while deeper-rooted trees will be found on the old floodplain or in side channels that no longer receive regular flows except during floods. Where plant life will establish depends upon soil type, degree of soil saturation, and depth to water table. The soil type and the frequency of inundation by water will also influence plant establishment and type. Vegetation along stream banks can provide a variety of cover, habitat and food sources for life in the stream. The stream sediment load and channel type are also important to the distribution and type of fish, macroinvertebrates (aquatic insects, crustaceans and mollusks), and other life in the aquatic ecosystem.

Figure 10. Elimination of streamside vegetation can increase stream bank erosion (Courtesy G. Zaimes).

PART II: STREAM CLASSIFICATIONS

George Zaimes & Robert Emanuel

INTRODUCTION

Streams are highly variable as well as complex. This can lead to significant differences in stream behavior and characteristics. It is important for watershed managers to differentiate among stream types to determine appropriate restoration activities. The main objectives of stream classification are:

- predict stream behavior from its appearance
- develop hydrologic and sediment relationships for a given stream type or condition
- compare streams with similar geomorphic characteristics
- extrapolate data to streams with similar characteristics
- develop a framework for communication between stream managers, researchers and the public

Classification can vary along the stream and classification of a particular channel reach can vary through time. The most well-known classifications are based on stream pattern.

In this part you will learn about:

- Classification of streams
- Sediment in streams
- Stream and floodplain landforms

CLASSIFICATION BASED ON STREAM PATTERN

Stream patterns describe the planform of a channel (planimetric view). The main characteristics used to separate patterns are the number of threads (single or multiple), sinuosity, and the island stability in a stream with multiple threads. **Sinuosity** is an important variable for describing stream meanders. It is the ratio of channel length to the straight length between the beginning and end of the same channel. Streams are considered meandering if sinuosity is higher than the ratio of 1.5.

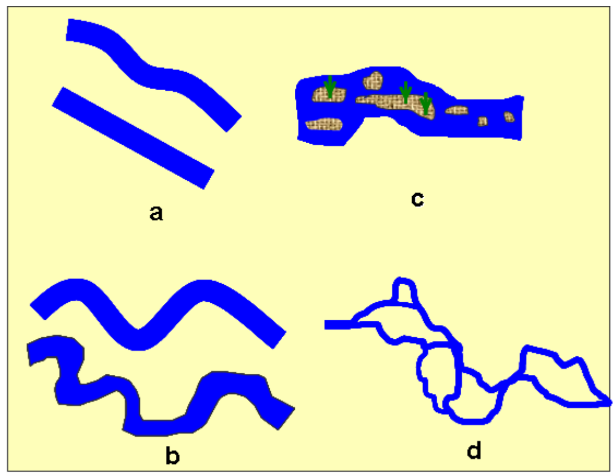

Figure 11. The different stream patterns: a) straight, b) meandering, c) braided and d) anastomosed.

The four main stream patterns (Figure 11) are:

- **straight**: streams with a single thread that is straight.
- **meandering**: streams with a single thread but having many curves.
- **braided**: streams have multiple threads with many sand bars that migrate frequently.
- **anastomosed**: streams that have multiple threads but do not migrate laterally.

CLASSIFICATION BASED ON STREAM FLOW CONDITIONS

Classification based on stream flow conditions are the result of the connectivity between stream and ground water (Figure 12). **Perennial** streams have water flowing in the channel year around and the stream is in direct contact with water table. **Intermittent** streams have water flowing only part of the year however, the stream is still in direct contact with water table. **Interrupted** streams have perennial water in their upper reaches and intermittent flow in their reaches at lower elevations. Finally, **ephemeral** streams flow with water only after precipitation events and the stream are well above the water table. Some large, permanent gullies may be considered ephemeral streams.

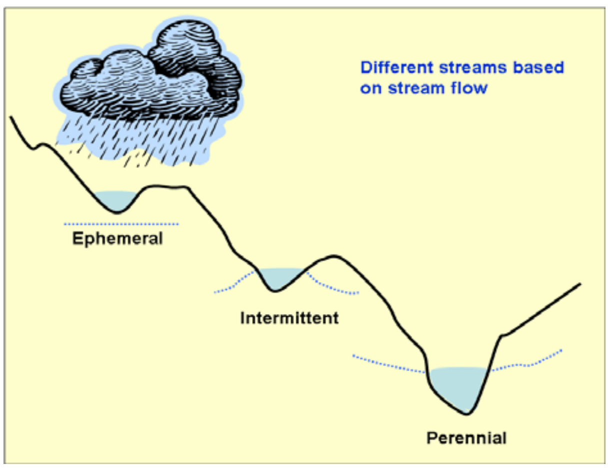

Figure 12. Ephemeral, intermittent and perennial streams.

CLASSIFICATION BASED ON STREAM ORDER

This classification is based on the type and number of tributaries that make up a channel network. Stream orders provide a way to rank and identify relative sizes of channels in a drainage basin. Smaller order numbers are given to smaller, headwater streams that are typically found in the upper reaches of a watershed. Higher order streams are given a larger number as the upper reaches join the main channel and are commonly found in the lowlands. The two major methods of ordering were developed by and named after researchers Strahler and Shreve. Both methods apply only to intermittent and perennial streams. The Strahler method is the most commonly used (Figure 13a). First-order streams are the furthest upstream channels that have no tributaries.

A **tributary** is a stream that joins another stream reach or body of water. When two first-order streams unite, they form a second order stream. In the same way, when two second-order streams unite a third-order stream is created, and so on. Where two streams of different order join, for example a first and third-order, the combined stream retains the order of the higher order stream contributing to it. The main assumption behind this ordering system is that when two similar order streams join to create the next higher order stream, mean discharge capacity is doubled.

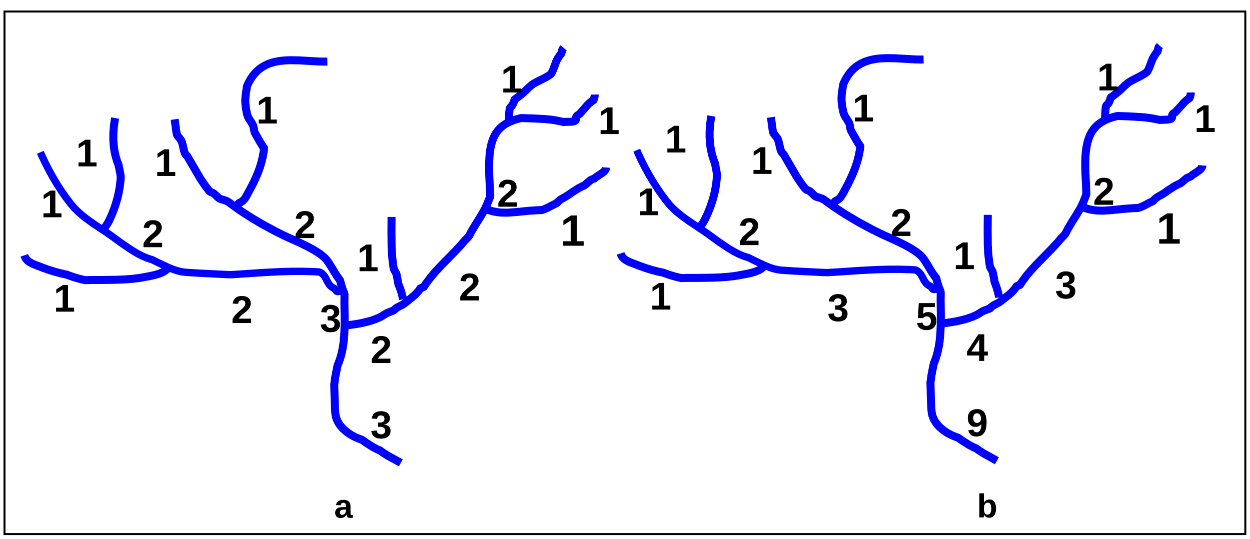

Figure 13. The two main stream order classification systems a.) Strahler and b.) Shreve.

In the Shreve method, (Figure 13b) the stream order of the two streams contributing to a junction are added and provide the rank number of the stream below the junction. The rank of a particular stream represents the total number of first-order streams that have contributed to it. If we assume that the contributing area of each first order stream is approximately the same and that discharge is neither lost nor gained from any source other than the tributaries (which is not always true), then the Shreve number is roughly proportional to the magnitude of discharge in the stream to which it refers. For example, a first order stream has a lower magnitude discharge than a ninth order stream. The bigger the stream order, the more water flows through it. One of the shortcomings of stream orders is that streams of the same stream order might be very different if they are located in different ecosystems or climates.

CLASSIFICATION BY ROSGEN

Hydrologist Dave Rosgen developed a taxonomic classification of streams commonly used by land managers. It incorporates some of the previously described channel characteristics such as channel type, vegetation, and topography.
His classification includes four levels. In this publication only **Level I** is described (Figure 15, on next page). The Level I classification integrates the following general geomorphic characteristics: basin relief, land-form and valley morphology. The specific characteristics are:

1. Entrenchment, which describes the relationship of a stream and its valley
2. Slope, which includes valley slope and sinuosity
3. Shape, which describes how narrow or deep, and how wide or shallow the channel is
4. Channel pattern (described in previous section).

Figure 14. Examples of different Arizona stream types that can be classified by channel type, vegetation and topography (courtesy of R. Emanuel).

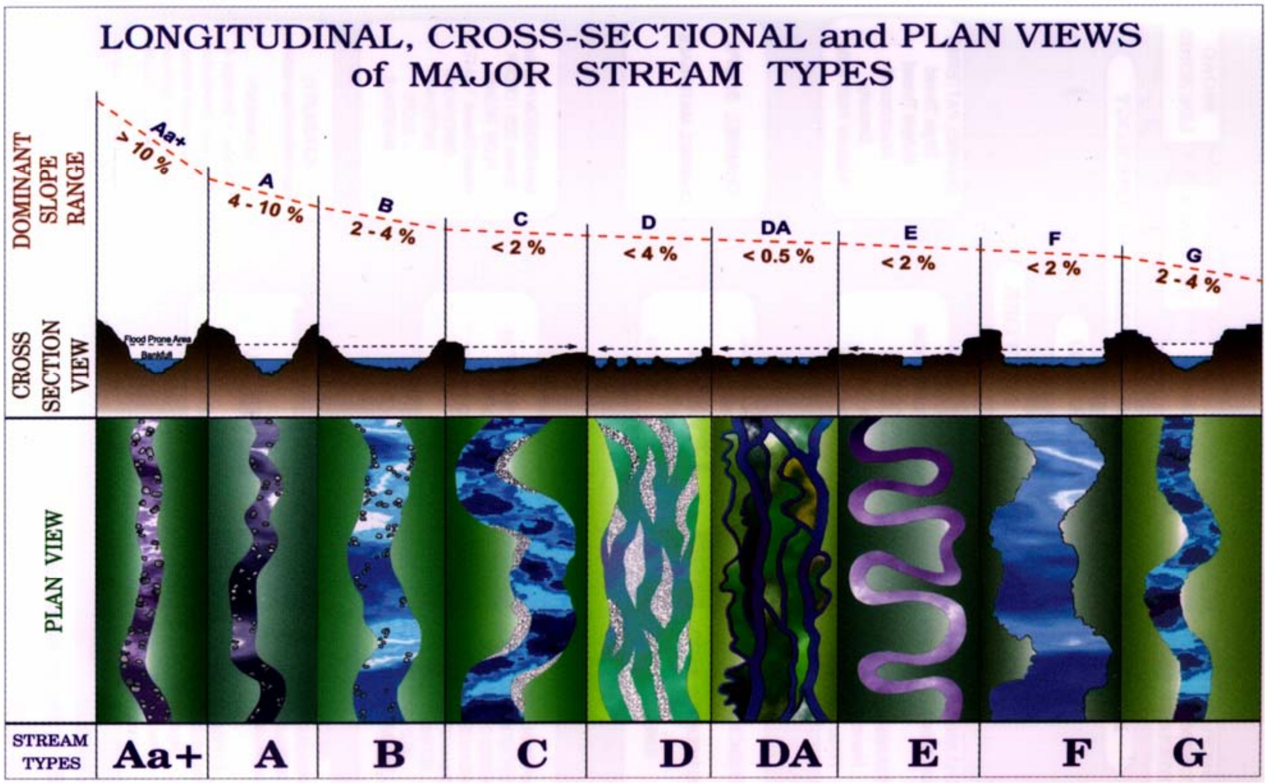

Figure 15. The nine types of streams based on Level I Rosgen classification (Rosgen, 1996).

Following Rosgen's Level I classification scheme there are nine stream types (Figure 15):

Aa+: Streams are very steep (slope > 10%), very entrenched, with low width/depth ratio (< 12) and totally confined laterally.
A: Similar to Aa+ but not as steep (slope 4-10%).
B: Streams are developed in moderately steep to gently sloped terrain (slope < 2%) with constricted valleys that do not allow a wide floodplain. Streams are entrenched, with moderate stream width/depth ratio (> 12), and low sinuosity (> 1.2).
C: Streams are constructed in alluvial deposits in narrow to wide valleys. These streams are sinuous (> 1.2), have low slopes (< 2%), slight entrenchment, and moderate width/depth ratio (>12) with a well-developed floodplain.
D: The main characteristic of a D type stream is the braided pattern with multiple threads.
DA: Streams of this type also have multiple threads, but in an anastomosed stream pattern.
E: Represents the end-point of channel stability for alluvial streams undergoing the channel evolution model sequence. Streams are slightly entrenched, highly sinuous (> 1.5) with a very low width/depth ratio (< 12).
F: Streams of this type are very deeply entrenched, in valleys of low relief with highly weathered or erodible material. Typically, these streams are working towards the re-establishment of a functional floodplain.
G: These streams are entrenched, narrow, and deep with low to moderate sinuosity (< 1.2).

It is worthwhile to note that Rosgen's stream classification is not universally accepted. However, it does provide a framework for communication among stream managers, researchers, hydrologists, agency personnel and others interested in riparian issues. One of the primary criticisms of this classification method is that it does not incorporate the processes that created and will continue to modify the stream. In addition, the classification method has not been validated across all environments, and there is uncertainty of determining bankfull elevation and equilibrium conditions. Regardless of these shortcomings, the Rosgen classification is gaining popularity therefore stream and watershed stewards should be aware of this scheme.

OTHER IMPORTANT CLASSIFICATIONS

Gaining/losing streams/reaches: This classification refers to the direction of water movement between the stream and the water table (ground water). **Gaining** (**effluent**) streams receive groundwater and **losing** (**influent**) streams drain to groundwater (Figure 16).

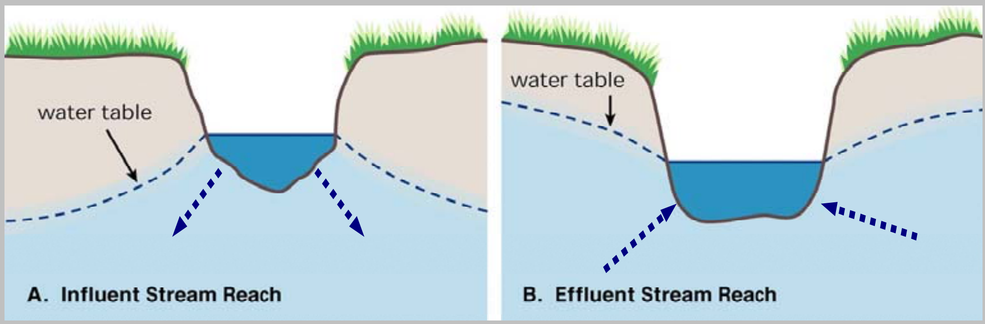

Figure 16. Gaining (effluent) and losing (influent streams) [from "Stream Corridor Restoration: Principles, Processes, and Practices, 10/98, by the Federal Interagency Stream Restoration Working Group (FISRWG)].

Regulated and non-regulated streams: Dams or other in-stream structures like dikes and levees control regulated streams. In contrast, non-regulated streams are not controlled by any human-made structures. Most streams in the United States are regulated. One of the last non-regulated streams is the upper reaches of the San Pedro River in southeast Arizona.

Channelized and non-channelized: Channelized streams or reaches have been artificially straightened while non-channelized reaches retain their natural sinuosity.

Channel material: Channel material may be classified as either alluvial or non-alluvial. Alluvial channels consist of material the stream has transported and can freely adjust its dimensions (such as size, shape and slope). Non-alluvial channels can not adjust freely. An example of non-alluvial stream is one controlled by the geologic structure of bedrock.

Sediment load transport: The sediment load of a stream can be transported as suspended or bed load material. **Suspended load** consists of the sediments that are transported in suspension by turbulent flowing water. **Bed load** consists of the sediments that move along or near the streambed by sliding, rolling, or saltating (Figure 17). Saltating sediments are those that jump for a short time above the stream bed but return to the stream bed. Depending on which transport sediment method dominates, streams can be categorized as having suspended, bedload and mixed (where both suspended and bed load are equally important) sediment transport.

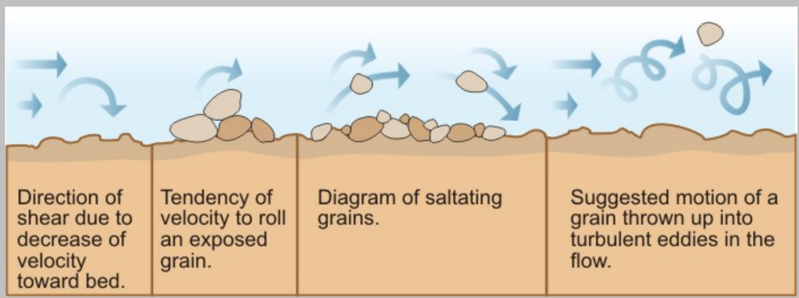

Figure 17. Sliding, rolling and saltating sediments on the stream bed (Illustration By D. Cantrell based on Dunne and Leopold, 1978).

SPECIAL STREAM TYPES OF THE SOUTHWESTERN U.S.

Washes and **arroyos** are commonly found in the Southwestern United States. Washes (Figure 18a) indicate intermittent or ephemeral streams (dry wash). Arroyos (Figure 18b) are deeply entrenched stream channels with flat beds and nearly vertical stream banks. Typically, arroyos are ephemeral but they can also be intermittent or even perennial. Arroyos are generally large, and persist in the landscape longer than gullies.

STREAM FUNCTIONAL ZONES

From the head waters to their confluences, streams perform a variety of functions in regard to sediment. Typically as you move downstream, the slope and sediment size that makes up the stream bed decreases while stream flow increases. This is not true in streams that have transmission losses (which is quite common in Arizona). The stream **longitudinal profile** can be divided in three zones each with a different dominant function (Figure 19).

In the production zone (Zone 1), sediment and water are produced, although some sediment storage also occurs. Included are headwater streams that are closely influenced by activities on the uplands (typically 1-3 order streams based on the Strahler classification). A good example of an Arizona stream in zone 1 is Upper Oak Creek as it flows through Oak Creek Canyon.

Zone 2 is the zone of transport and includes mid-order streams (typically 4-6 order streams) that primarily carry sediment and water from Zone 1 to Zone 3. Upland land use has much less direct influence on transport processes in these streams. A good example of a stream flowing through Zone 2 is the reach of the middle San Pedro River.

Typically, sixth or greater order streams run through Zone 3, the zone of deposition. In this zone, rivers are slow moving and deposition results in sediment storage within the channel, along the banks and in deltas or floodplains. A good example for Arizona is the Lower Colorado River.

This is a generalized model and in many cases stream order classification described in this section will not always match these zones. Although one process dominates in each zone, erosion, transport, and deposition processes occur within each zone. Major hydrologic and morphologic changes take place in each of these three zones.

THE RIVER CONTINUUM CONCEPT

Just as the physical characteristics of a stream vary longitudinally along its profile, flora and fauna also vary. The River Continuum Concept provides a framework for understanding variations in physical and biological processes within and along a stream from its headwaters to the watershed outlet. The River Continuum Concept presents the relationship among functional zones of a fluvial system, the impact of riparian vegetation on in-stream processes and macroinvertebrates in the stream.

a

b

Figure 18. a.) A wash and b.) an arroyo in southwestern Arizona (Courtesy of G. Zaimes).

Macroinvertebrates are an important component of the aquatic food chain that provide important information for understanding streams. These are spineless animals that are still visible to the naked eye. These important members of stream life include insects, crustaceans, and mollusks. Many other aquatic and terrestrial animals feed on macroinvertebrates, so they constitute a critical component to the life of the stream and act as indicators of stream health and normal functioning.

Macroinvertebrates can be divided into four major "functional feeding groups" based on the primary food gathering method used by each group. **Shredders** for example, take organic matter and shred it into tiny bits before consuming it. They depend upon falling leaf litter and other organic matter for their food. **Collectors** filter feed on materials passing through the water column. For this reason, they need streams with sediment and other materials that move quickly through the current. **Scrapers** or **Grazers** remove algae from rocks and underwater debris. Because of this, they thrive in steams that receive direct sunlight which fosters the growth of the algae they depend upon. Finally, **predators** feed on the other three functional groups. Variations in these biological processes are the basis for distinguishing the three zones based on the River Continuum Concept, similar to the way in which stream functional zones describe variations in physical processes.

The River Continuum Concept is based on changes in the amount of organic matter (food), vegetative cover and sunlight that penetrate the stream as a function of its'sediment load, channel bottom type and quantity or type of vegetation that grows along its banks. This change influences the type and proportion of organisms and functional groups as you move from a one end of the stream to the other (Figure 19). For example, in the headwaters vegetation is generally denser. As a result, less sunlight penetrates and more organic matter falls into the stream. These conditions favor shredders and collectors over scrapers. The middle reach of a stream generally has more sunlight and greater amounts of nutrients flowing through it, promoting algae production on substrates. These conditions favor scrapers which replace shredders. Downstream from this point, collectors are the primary feeding group that can survive in the turbid, nutrient-rich waters. Predators are found in all three zones in roughly the same proportions.

The River Continuum Concept can be applied to interpret the health of the stream channel in response to stream morphological adjustments. Stream reaches in watersheds that generate excess erosion upstream will show lower percentages of shredders and scrapers as compared to those expected based on the river continuum concept (Figure 19). Stream reaches where nutrient levels are low, in response to dams or other structures that impede sediment flow, will also have an altered balance of organisms. The River Continuum Concept does not take into consideration the impacts of disturbances that can disrupt stream-watershed connectivity. This is one of the reasons that it is not universally accepted. Another reason is that it can be applied only to perennial streams.

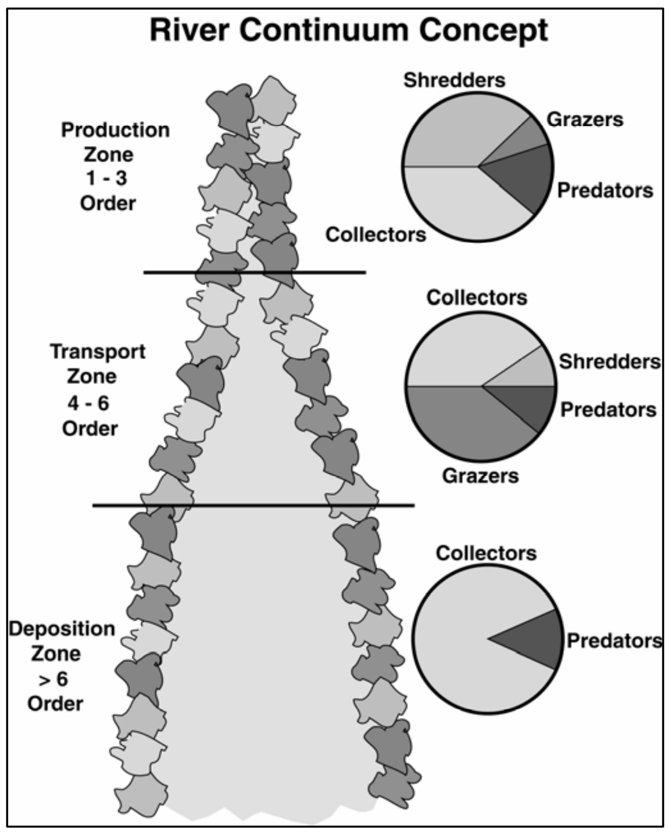

Figure 19. The three zones of the river continuum concept: a.) zone of production, b.) zone of transfer/ transportation, and c.) zone of deposition (Schultz et al., 2000).

SOME FINAL THOUGHTS

Streams can change quickly during our human lifespan, in sharp contrast to the geology of many parts of Arizona. Strong physical forces are at play in a stream with regards to energy, sediment and life. While the appearance and height of mountain ranges, for example, generally don't change in a season, a stream can be altered suddenly and sometimes with seemingly irreversible results. While streams are extremely dynamic—even with little human or natural interference—they also maintain their basic characteristics. The location of a stream might change as its bank erodes on the outside of the meander bend and gravel bars are deposited on the inside of the bends. If a gradient becomes too flat, a meander cutoff might occur, leaving the meander bend behind as a side channel or oxbow lake. These adjustments are part of a "graded" stream system. Graded or poised streams maintain their average width, depth, gradient, meander geometry, and size and amount of sediment moving through the system, as well as the timing and duration of stream flows. Understanding the proper management options to maintain or move toward a graded stream is essential to have functional streams and watersheds.

Streams are complex systems formed and influenced by many variables. What happens upstream can impact downstream areas and vice versa. Many changes to the land and streams in a watershed cause streams to become "unstable" for periods of time. Examples of such changes include vegetation removal, landslides, urbanization, roads and groundwater extraction. In these cases, streams may transform from perennial to intermittent, and from intermittent to ephemeral, depending upon the local conditions and the connectivity that a stream has with the water table. Sediment loads may also shift and adjust, depending on upstream activities such as urbanization, timber harvest, mining, livestock grazing, road building and fire.

Understanding stream characteristics and how they change within a watershed is important to successfully restore or maintain healthy streams. For this reason, professionals and others involved in stream and watershed monitoring, management, and restoration must have a basic understanding of stream processes and their classification to effectively manage them.

Figure 20. Examples of management impacts on streams in Arizona (top and bottom photos courtesy of the Central Arizona Project, others R. Emanuel).

INSTREAM & FLOODPLAIN LANDFORM TERMS

Wetted perimeter is the cross-sectional length of the channel perpendicular to the stream flow that is in contact with the flowing water.

Chute is a new channel formed across the base of a meander.

Headcut is a point in a stream where active downcutting is taking place.
Downcutting will eventually start moving upstream.

Historic floodplain or **terrace** is the area of land adjacent to the active floodplain of a stream that once received floodwaters but is inundated only rarely if at all.

Hydrologic or **active floodplain** is the land adjacent to the active channel. It is inundated after the stream exceeds bankfull discharge.

Oxbow describes the severed meander after a chute is formed.

Channel plug a point in the stream where the waters entry and exit point become blocked with sediments.

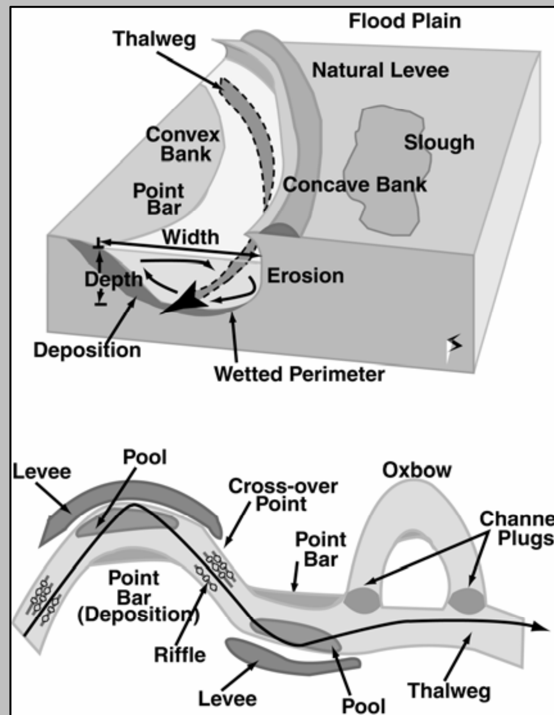

Figure 21. Instream and floodplain landforms (Schultz et al., 2000).

Natural levees form along the edge of the outside bend and are typically are higher than the rest of the floodplain. They result from sediment deposition of floodwaters.

Alluvial fans are typical in arid climates; they are the low cone of alluvial material consisting of sand and gravel at the mouth of the canyon or ravine and built on the adjacent plain.

Sloughs are wet spots in the floodplain typically behind a levee or old filled oxbows.

A stream's **inside bends** are convex with depositional material while the **outside bends** are concave and actively eroding.

A **Point bar** is an area where sediment deposition takes place, forming the turning point of a new meander.

Pools are areas where the stream erodes deeply into its channel (as in a scour pool) or an area where natural features force water to slow and pool behind them. Water usually moves slowly through pools.

Riffles are areas of shallower, faster-moving water with enough velocity to move coarser material. These often appear as "mini-rapids" in areas above pools.

Run is the term for an area of smooth but swift water between pools and riffles.
In certain types of streams that are healthy, riffle, pools and runs should re-occur 5 to 7 times the width of the channel.

Thalweg is the deepest part of the stream channel and where stream flow is the fastest.

WORDS TO KNOW

Aggradation - The raising of stream beds, floodplains or banks by deposition of sediment eroded and transported from upstream.

Aggrading stream - A stream that is accumulating sediment along its bed and banks in response to excessive sediment supply.

Alluvium - The deposits of clay, silt, sand, gravel, or other particulate material that has been deposited by a stream or other body of running water into a streambed, on a floodplain, delta or at the base of a mountain.

Anastomosed stream - A stream with multiple threads that branch and rejoin, but overall do not migrate laterally.

Arroyo - Deeply entrenched streams found in arid and semiarid regions characterized by a flat bed and nearly vertical stream banks. Typically, runoff in arroyos is ephemeral. An arroyo differs from a gully because it persists much longer.

Bankfull discharge - The quantity of water that controls channel form and distribution of materials. Bankfull literally means the point at which water is just overflowing the main channel and entering the active floodplain.

Base level - The lowest level to which a stream will erode.

Base flow - Sustained flow of streams not attributed to direct runoff from precipitation or snowmelt.

Bed load - Sediments that move along, on or near the streambed by sliding, rolling or saltating.

Braided stream - A stream with multiple threads that forms sand bars that migrate frequently.

Channel - The natural stream that conveys water; a ditch or channel excavated for the flow of water.

Channel control points - Stream features that are not easily eroded and can control the depth of the channel upstream.

Channel evolution model - A conceptual model describing the stages a stream goes through in a effort to reach a new dynamic equilibrium following degradation.

Channelization - The straightening, deepening and widening of meandering streams.

Collectors - Marcroinvertebrates which filter feed on materials passing through the water column. They constitute one of the four macroinvertebrate functional feeding groups.

Colluvium - Loose deposits of rock moved downslope by gravity in slides or soil creep; distinguished from alluvium by being moved mechanically and not necessarily by water.

Degradation - The lowering of stream beds, floodplains, or banks by steam erosion with the sediment being transported downstream.

Degrading stream - A stream that is deepening and/or widening as sediment is removed to satisfy a deficit in sediment supply.

Deposition - The act of depositing materials; in geology this refers to materials that have been moved by some mechanical, biological, or other physical process.

Depositing stream - See aggrading stream.

Depositional fluvial landforms - Landforms built from transported and deposited material. Examples include alluvial fans, deltas, and floodplains.

Discharge return periods - A measure of the probability that a particular discharge will occur. For example, every year there is a 1 in 100 chance that a 100 year flood will occur.

Downcutting (also see incision) - The deepening of a stream caused by stream bed erosion.

Dynamic equilibrium - A condition where the amount of sediment delivered to a stream from the watershed is in long-term balance with the capacity of the stream to transport and discharge the sediment.

Effluent stream - 1) See gaining stream. 2) A stream receiving treated discharge from water treatment plants or other industrial users.

Ephemeral stream - A stream that only flows in response to rainfall or snowmelt events.

Erodibility - A measure of the soil's susceptibility to the erosive force of water running over bare ground.

Eroding stream - See degrading stream.

Erosion - The wearing away and removal of materials of the Earth's crust by natural means; includes weathering, solution, corrosion, and transportation.

Erosional fluvial landforms - Landforms shaped by the progressive removal of rock or material (degradation). Examples include ravines, canyons and mountain peaks.

Evaporation - The loss of water as vapor from surfaces such as streams, lakes, puddles, ponds and soil pores.

Evapotranspiration - The sum of evaporation and plant transpiration (the loss of water to the watershed as vapor through plant pores).

Fluvial geomorphology - The scientific study of the process by which water flowing through a drainage network acts to erode, transport, and deposit sediment, and the resulting landforms.

Functional zones of a stream system - A zonal classification of stream reaches based on whether it produces, transports or deposits sediments.

Gaining stream - A stream that receives water from ground water

Geomorphology - The branch of geology dealing with the origin, evolution, and configuration of the natural features of the earth's surface.

Graded stream - See poised stream.

Grazers - See scrapers.

Greenline - The first perennial vegetation that forms a lineal grouping of community types on or near the water's edge. Most often occurs at or slightly below the bankfull stage.

Ground water flow - Water that moves through the soil's saturated zone (beneath the water table).

Gully - Recently formed, relatively deep, channels on valley sides and floors where no well-defined channel previously existed.

Headcutting - A process of erosion that occurs when the stream channel length grows in the headwaters or when the channel is adjusting its slope. Generally it is caused by sheet, rill and gully forming erosion.

Hydrograph - A graphical description of stream flow discharge through time. Generally used to describe stream response to runoff events.

Hydrology - The study of occurrence, distribution and chemistry of all waters of the earth.

Impervious surface - A surface that water cannot easily infiltrate, causing overland runoff sometimes referred to as impermeable surface.

Incision (incising) - The erosion of stream channel bottom material.

Infiltration - The process whereby water travels downward into the soil.

Influent stream - See losing stream.

Intermittent stream - A stream where water flows only part of the year. The stream is in contact with the water table.

Interflow - See subsurface flow.

Interrupted stream - A stream with perennial water in its upper reaches and intermittent flow in its lower reaches.

Lag time - The time it takes a stream to reach peak flow after the rainfall storm event reaches its peak (also see peak flow).

Lateral erosion - The widening of a stream channel caused by stream bank erosion.

Longitudinal profile - The change in slope of the stream from the headwaters to the lowlands or a specific stream reach.

Losing stream - A stream that drains water to the ground water.

Macroinvertebrates - Organisms without backbones, but that are large enough to be visible to the naked eye. Examples include amphipods, shrimp, snails, spiders, and insects.

Meander - The sinuous lateral path of a stream.

Meander belt - The outermost region of a stream's sinuous lateral path.

Meandering stream - Stream with a single thread that has many curves. A stream is considered meandering if sinuosity is higher than the ratio of 1.5 (also see sinuosity).

Overland flow - Water from precipitation or snowmelt that does not infiltrate into the soil and as a result moves over the surface of the landscape.

Peak flow - The highest stream flow discharge measured during or after a runoff event.

Perennial stream - A stream within which water flows year round in direct contact with water table.

Poised stream - A stream that has adjusted its longitudinal profile to a local base level, sediment load and flow, and is not currently degrading (downcutting) or aggrading (rising due to sediment deposition). A stream in equilibrium.

Precipitation - Water that condenses into droplets or ice crystals and falls to the ground in various forms such as rain, snow, hail, freezing rain, and fog drip.

Predators - Macroinvertebrates that feed on the other three macroinvertebrate functional groups.

Reach - A segment of the stream that contains fairly uniform features or characteristics. The length of the reach can be highly variable.

Rill erosion - Erosion caused by the concentration of overland flow into deeper, faster-flowing channels that follow depressions or low points.

Riparian areas - Land areas adjacent to streams that have distinctive hydrologic, soil and vegetative characteristics compared to the uplands of the watershed due to higher amounts of water in their soils.

River Continuum Concept (RCC) - A conceptual model and framework for understanding variations among physical and biological processes both within and along a stream from its headwaters to the watershed outlet.

Rosgen classification - Taxonomic classification of streams based on stream geomorphic characteristics.

Saturated zone - The zone in which voids in the rock or soil are filled with water.

Scrapers - Macroinvertebrates that remove algae from rocks and underwater debris. These constitute one of the four macroinvertebrate functional feeding groups.

Sediment - Geologic deposits from water; mineral particles derived from soil, alluvial or rock materials moved by water; also refers to material suspended in water or recently deposited from suspension.

Sediment load - Sediment transported as suspended or bed load in streams.

Sedimentation - The process of depositing sediment by water.

Sheet erosion - Erosion caused by overland flow and the removal of soil, in somewhat uniform and very shallow thin layers.

Shredders - Macroinvertebrates that take organic matter and shred it into tiny bits before consuming it. These constitute one of the four macroinvertebrate functional feeding groups.

Sinuosity - The ratio of channel length to valley length. It is calculated by dividing the channel's length to the straight length between the beginning and end of the same channel.

Splash erosion - Erosion created by the direct force of falling rain drops on bare soil causing soil particles to be lifted and then re-deposited in new positions.

Straight stream - A stream with a single thread that is straight.

Storage areas of water - Locations within a watershed where water is temporarily retained. Examples include unsaturated soil (above the water table), the saturated zone (beneath the water table), surface soil depressions, vegetation, living organisms, puddles, lakes, constructed reservoirs, wetlands, or the stream channel itself.

Stormflow - Flow generated in response to a precipitation event. Stormflow may reach the channel as overland flow, surface or subsurface flow.

Stream - A natural linear configuration in the land surface that recruits and transports water and sediment.

Stream classification - A framework for differentiating streams based on physical and/or biological characteristics.

Stream flow - The water running within a drainage feature such as a stream channel.

Stream flow discharge - The volume of water passing a given point for a specific period of time. Typically measured in cubic feet per second (cfs).

Stream order - A classification based on the type and number of tributaries contributing to a particular stream network. Stream orders provide a way to rank relative sizes of channels in a drainage basin.

Stream pattern - The planform of a channel (planimetric view). The main characteristics used to distinguish the patterns are the number of threads (single or multiple), sinuosity and the island stability in a stream with multiple threads

Sublimination - The transformation of water from the solid phase to the gaseous phase without passing through the liquid phase. An example is ice transforming to water vapor.

Subsurface flow - Consists of water from rain or snowmelt that infiltrates soil and moves through the soil's unsaturated zone (above the water table).

Transpiration - The loss of water as vapor from plant pores.

Tributary - A stream that joins another stream or body of water. In Arizona, a tributary may contribute very small or intermittent amounts of water to the main waterbody.

Turbidity - A measure of the reduced transparency of water due to suspended material, colloidial material or dissolved color.

Unsaturated zone - The zone between the land surface and the water table.

Vadose zone - See unsaturated zone.

Washes - Intermittent or ephemeral streams.

Water balance equation - An equation for calculating the difference between the amount of precipitation entering a watershed and the amount leaving, minus the amount stored.

$$Q = P - ET \pm DSt$$

Where Q is stream flow discharge, P is precipitation, ET is evapotranspiration, St is surface and subsurface storage of water in the watershed while DSt is the change in storage of water.

Water table - The top of the saturated zone.

Weathering - The process of removing particles of a material—usually rock—through mechanical, biological, other physical (such as through the action of wind and water), as well as chemical processes.

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