Going with the Flow

Understanding Effects of Land Management on Rivers, Floods, and Floodplains

Barbara Ellis-Sugai and Derek C. Godwin

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Introduction

Many people are seeking to actively improve fish habitat and water quality for salmon and trout in the Pacific Northwest. The most common approaches are to conduct stream and riparian enhancement projects to improve these functions. Understanding river processes, floods, and floodplains is invaluable in planning successful projects. This publication attempts to provide basic information to help landowners, watershed groups, and resource professionals implement successful enhancement projects and management plans that ultimately improve fish habitat and water quality.

A Stream Network Defines a Watershed

A watershed is an area of land that collects rain and snow and discharges much of it to a stream, river, or other water body. A watershed has a stream network made up of a main stream with tributaries that flow into it. Not all streams within a watershed have the same characteristics. Several stream classification systems have been developed to describe these differences and compare one stream to another.

Montgomery and Buffington (1998) devised a stream classification system that is useful in describing a watershed's stream network. They separate streams into three categories—*source, transport*, and *depositional streams* (figures 1 and 2). They use measurable characteristics to identify these stream types. One characteristic is the stream's slope or gradient. The second is the ratio of stream width to the width of the valley floor. Following are general descriptions of these stream types. See Montgomery and Buffington (1997, 1998) for more detailed decriptions.

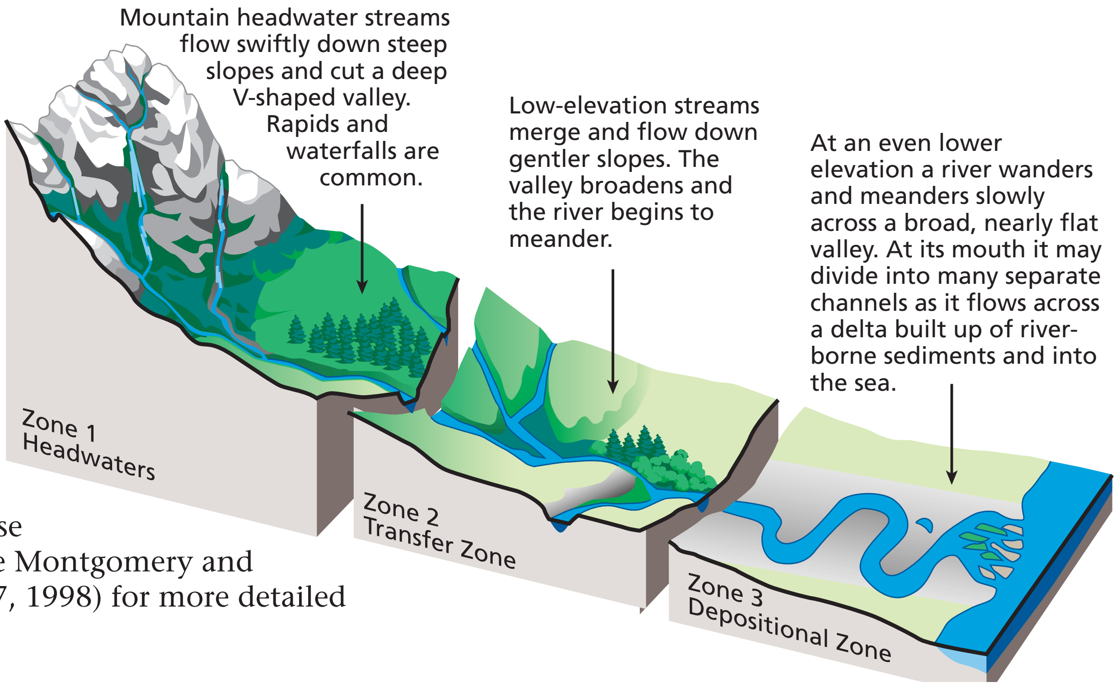


Figure 1. Example of three different stream types in a watershed. Source: Miller (1990).

Source streams: These are headwater streams that are steep (greater than 20 percent), straight, and have no floodplain. These streams are source areas for sediment and wood. In

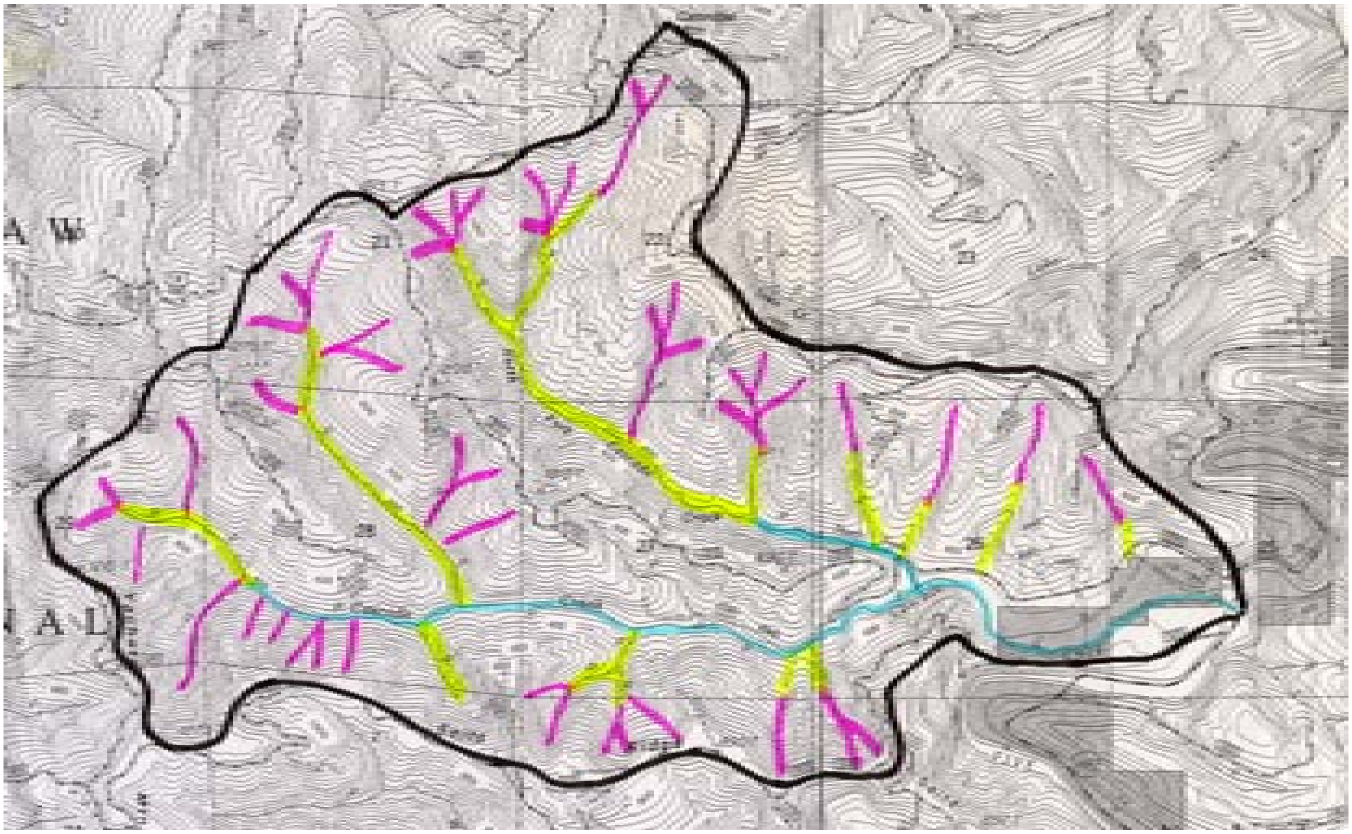


Figure 2. Topographic map showing the Cascade Creek watershed and stream network in the Coast Range, Oregon. Pink = source stream; yellow = transport stream; blue = deposition stream. (USFS)

mountainous areas, they can be prone to landslides in the stream channel that carry wood, sediment, and water downstream (debris torrents).

Transport streams: These streams typically have a moderate gradient
(3–20 percent). They develop small meanders in moderately narrow valleys with small floodplains. Sediment and wood are temporarily stored here as they move from source to depositional areas.

What happens in one part of the stream network can affect the other parts.

Deposition streams: These streams are low gradient (less than 3 percent). They are meandering streams in wide valleys with large floodplains (relative to stream size). Sediment and wood are deposited here for long periods of time. These streams are the most sensitive to changes in the watershed, such as a change in sediment supply.

The *Oregon Watershed Assessment Manual* uses a similar stream classification system. The stream types (or channel types) are separated by stream gradient, confinement class (based on ratio of stream width to valley width), and size of stream (based on Oregon Department of Forestry designations for stream size). Figure 3 illustrates some of the stream types described by this classification system.

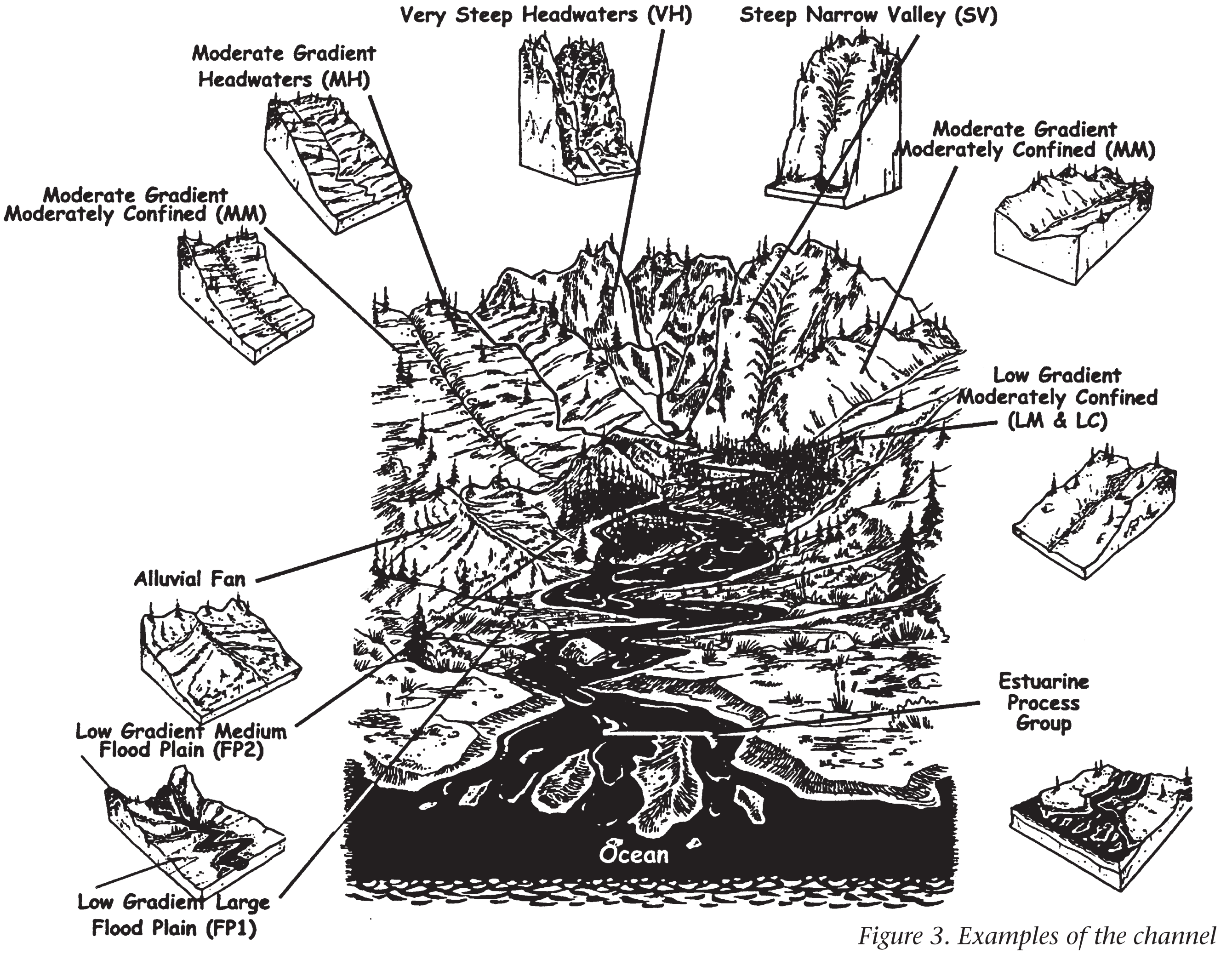


Figure 3. Examples of the channel habitat types and their relative position in the watershed as determined by the classification method in the Oregon Watershed Assessment Manual. (Oregon Watershed Assessment Manual, *June 1999*)

For comparison, Dave Rosgen (1996) developed a more site-specific stream classification system that has been adopted by several resource agencies and groups. His system is more complex and categorizes streams by differences in their channel gradients, bed materials, ratios of stream width to depth, degree of meandering (sinuosity), and the extent the channels have downcut into their floodplain.

Streams Are Always Changing

Streams constantly adjust their shape to changing conditions. The following stream characteristics influence a stream's shape.

- *Channel slope or gradient* (drop in elevation over a given distance)
- *Stream flow or discharge* (the volume of water moving through the channel at a given time, usually expressed as cubic feet per second)
- *Material found in the streambed and banks* such as silt, clay, sand, gravel, cobble, boulders, bedrock, large wood, and tree roots

- *Amount of sediment moving through the stream network* (silt, clay, sand, gravel, cobble, and boulders)
- *The ratio of the stream's width to its depth* (streams range from wide and shallow to narrow and deep) (figure 4)
- *Sinuosity* (the distance a river travels divided by the straight-line distance.) A perfectly straight channel would have a sinuosity equal to one. The more meandering the channel, the higher the number (figure 5).
- *Amount and type of riparian vegetation* (vegetation growing next to the stream, such as trees, shrubs, and grasses)

All of these factors are linked together. If one variable changes, the others will change in response. For example, if erosion increases in the watershed and the supply of sediment increases, several results are possible. If the stream's capacity to transport the sediment is overwhelmed, the sediment may be deposited, which will raise the elevation of the streambed. Gravel bars may get bigger, causing erosion of the opposite banks in order to maintain the same channel size. Pools may fill in, reducing the quality of fish habitat. The stream may change from having a single channel to multiple channels.

Montgomery and Buffington (1993) give several examples of the effect an increased sediment supply can have on streams. The Williams River in Saskatchewan, Canada, passes through sand dunes. As the river passes through the sand dunes, it picks up extra sediment and becomes a braided channel five times wider and half as deep as the river upstream of the dune field. Another well-studied example depicts the effects of hydraulic mining in the Sierra Nevada Mountains of California. Large amounts of sediment were added to rivers in the foothills of the Sierras between 1850 and 1880 as miners used high-pressure water hoses to wash rock and soil into streams where it could be sluiced for gold. As a result, channels filled in and widened. This effect progressed downstream, and after the "wave," or "wedge," of sediment passed through the stream, the stream downcut into the material that had been left behind.

In a different example, stream bank erosion is likely to increase if riparian vegetation is removed along depositional streams with banks that are sensitive to erosion. This would cause more sediment to be deposited downstream and may lead to channel widening and further bank erosion downstream (figures 6a and 6b).

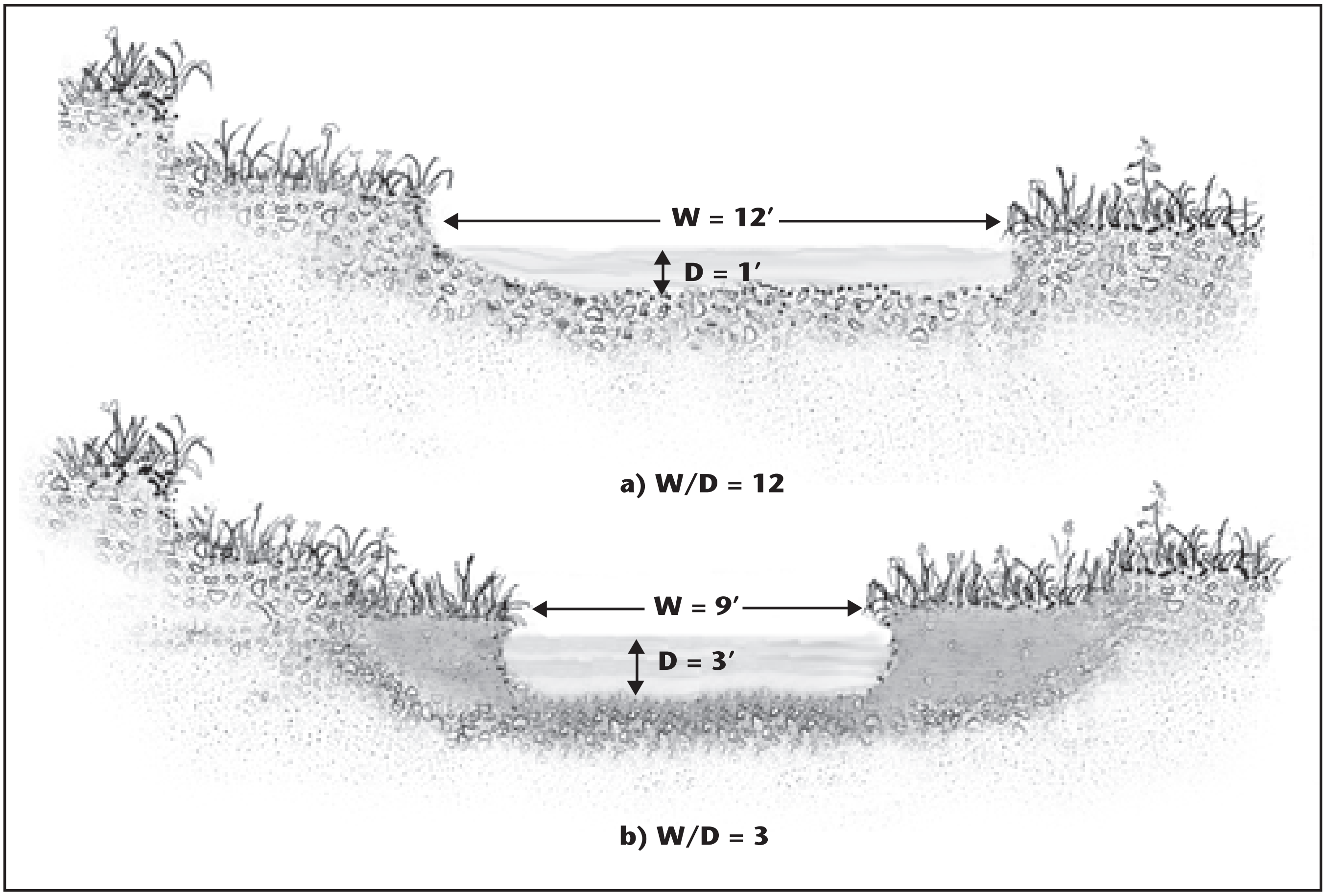


Figure 4. Width to depth diagram. (Illustration by Ralph Penunuri)

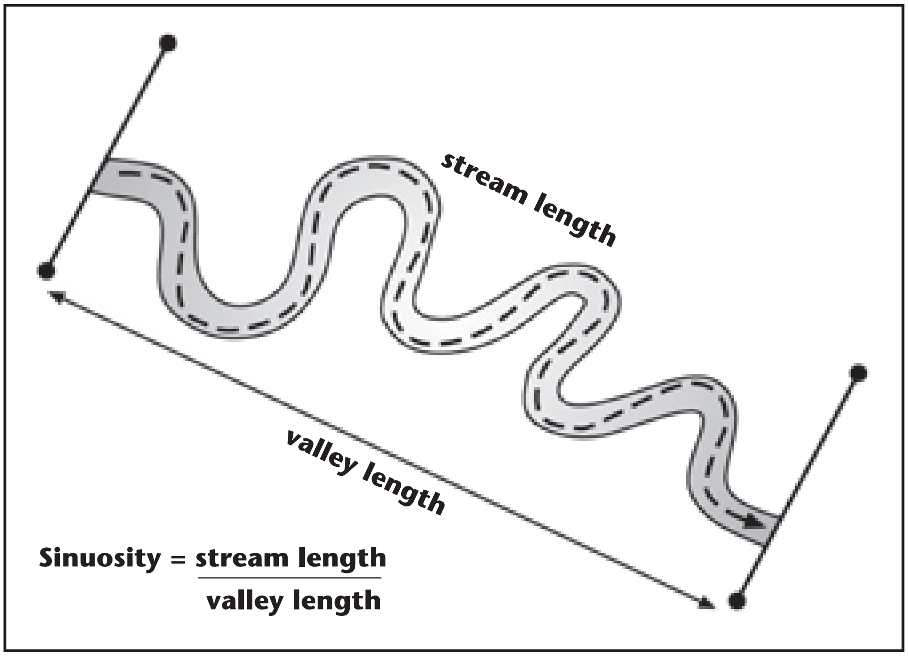
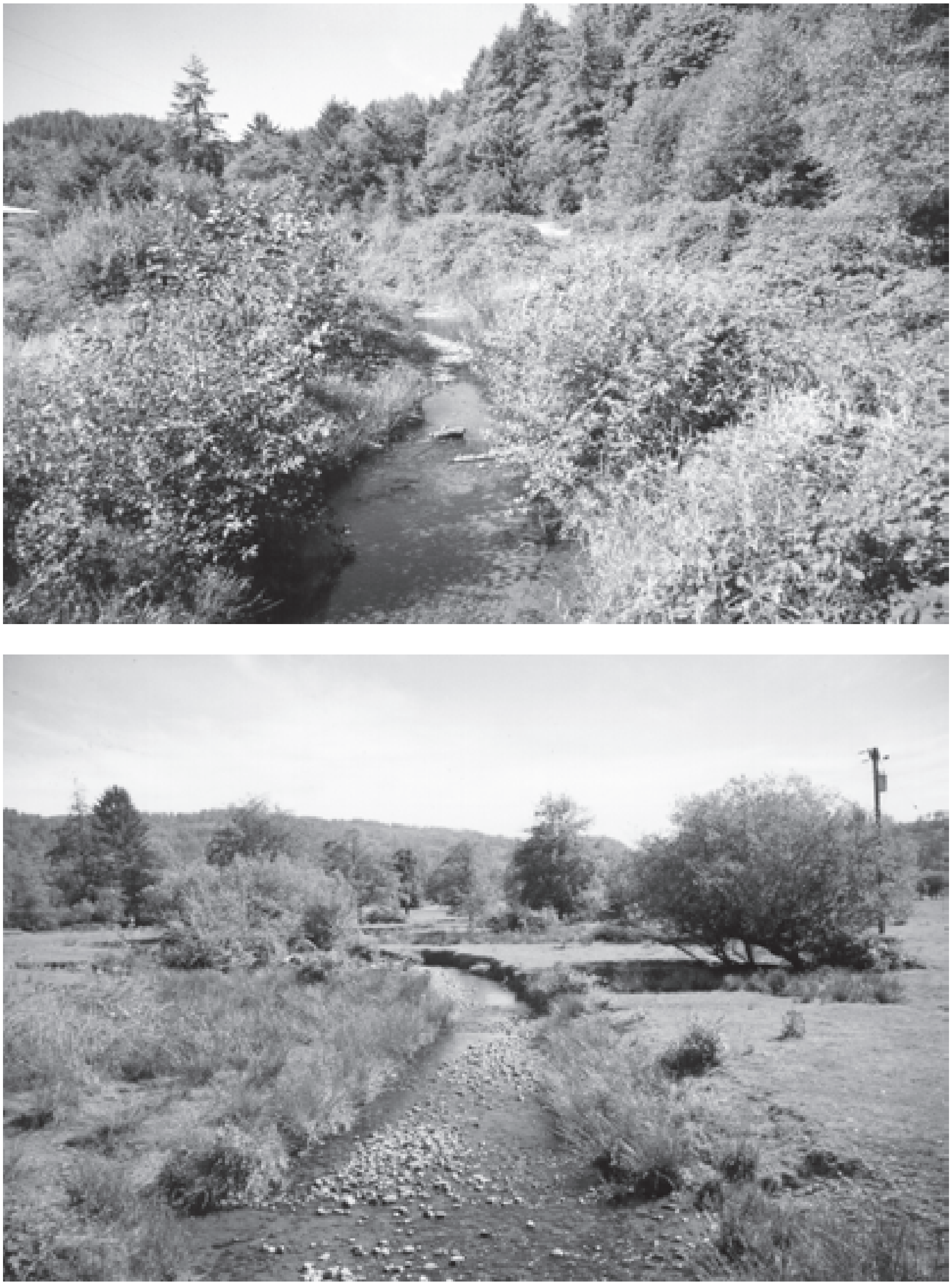


Figure 5. Example of how to measure and calculate sinuosity. (Illustration by Ralph Penunuri, modified from Rosgen, 1996, Applied River Morphology*)*



Figures 6a and 6b. West Creek photos illustrating two riparian conditions. 6a (top) depicts riparian conditions with low amount of stream erosion. 6b (bottom) depicts an overgrazed riparian area with an increase in erosion. (USFS)

Why Do Streams Meander?

Ninety percent of the world's low-gradient rivers are single-channel, meandering streams (Leopold, 1994).

The word "meander" is derived from a Greek word that means "to wander."

A stream's pattern develops naturally to dissipate its energy and carry sediment. Streams with steep gradients (source and transport streams) dissipate their energy by creating pools through a series of steps, falls, and plunges (figure 7). Such streams look almost straight on a map. This "step pool" pattern can be thought of as meanders turned on their side. As the stream's slope (gradient) flattens, the depositional segments of a stream dissipate energy by creating a meandering flow pattern. Meanders cause the river to dissipate energy along the winding path as the water is forced around the bends (figure 8). Meanders in a river are analogous to switchbacks in a mountain road. They reduce the river's slope and therefore the velocity of the water. Energy is also used up through friction of the water against the bed and banks of the stream.

Figure 7. Photo of step pool transport stream. (USFS)

A regular meander pattern can often be seen from a distance. For instance, you might recognize meanders from a map or an airplane by looking at the shape of many rivers. Each meander might look different, but the elements of the basic pattern often are repeated over longer distances. Research has shown that meanders have a predictable size and shape (Leopold, 1994) (figure 9). No matter how big the river is, there is a fairly constant relationship between the wavelength of the meanders, the channel width, and the radius of curvature. For example, a low-gradient meandering stream (depositional stream) tends to have a meander wavelength that is 10–14 times the channel width, and a meander radius of curvature 2–3 times the channel width. Figure 10 graphically illustrates stream channel geometry and terminology.

Figure 8. General landscape view of a meandering stream (aerial photo of Calapooia River, Oregon). River flows in direction of arrows. (Farm Services Agency, Marion County)

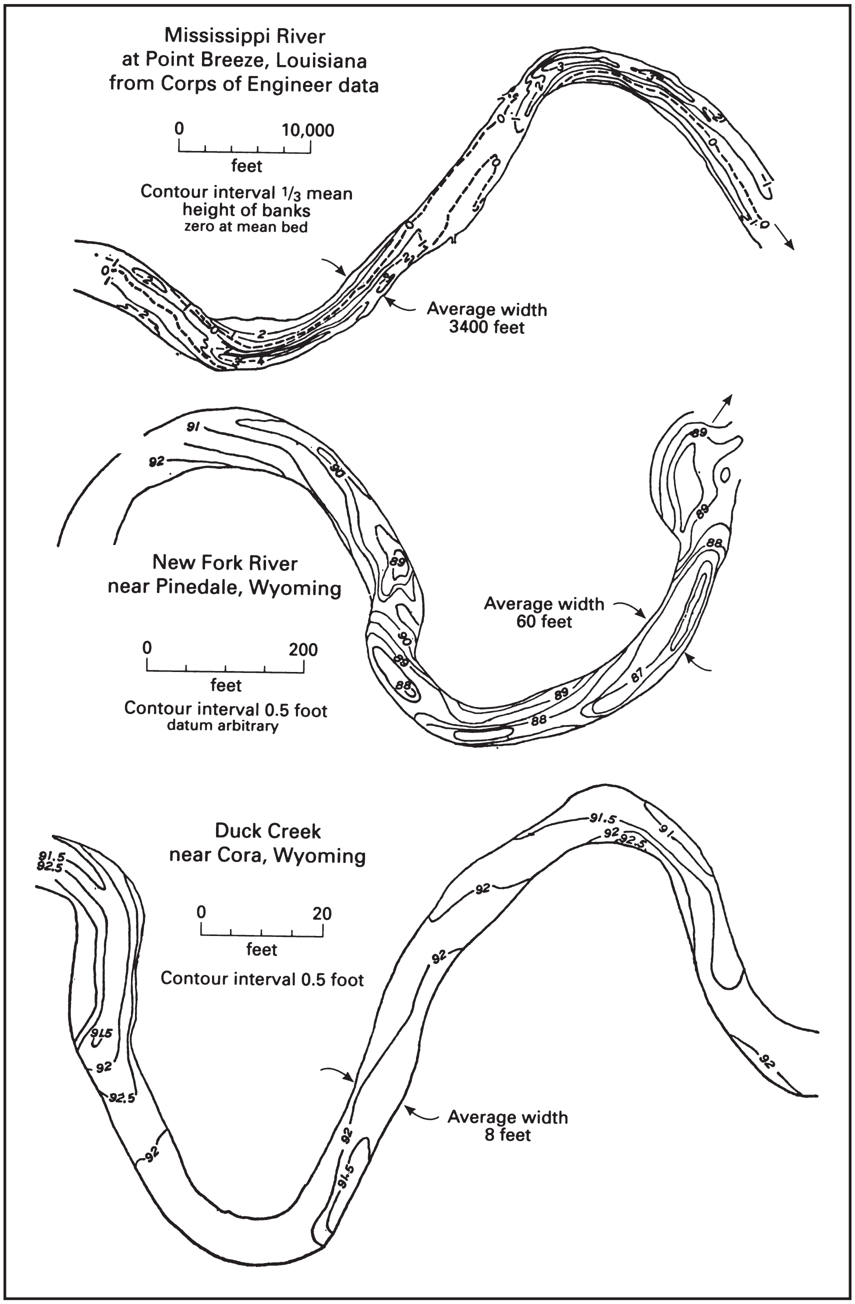


Figure 9. Leopold's diagram of meanders of different-size rivers (Leopold, 1994).

The Walla Walla River had been channelized and diked around Milton-Freewater, Oregon, to provide flood control. During the 1964 flood that affected much of the Pacific Northwest, the river broke through the dikes in several places when the flow exceeded the capacity of the artificial channel. Once the river overtopped the channel, the river developed a regular meander pattern that is superimposed over the straight channel. The river is flowing from the bottom of the photo to the top (figure 11).

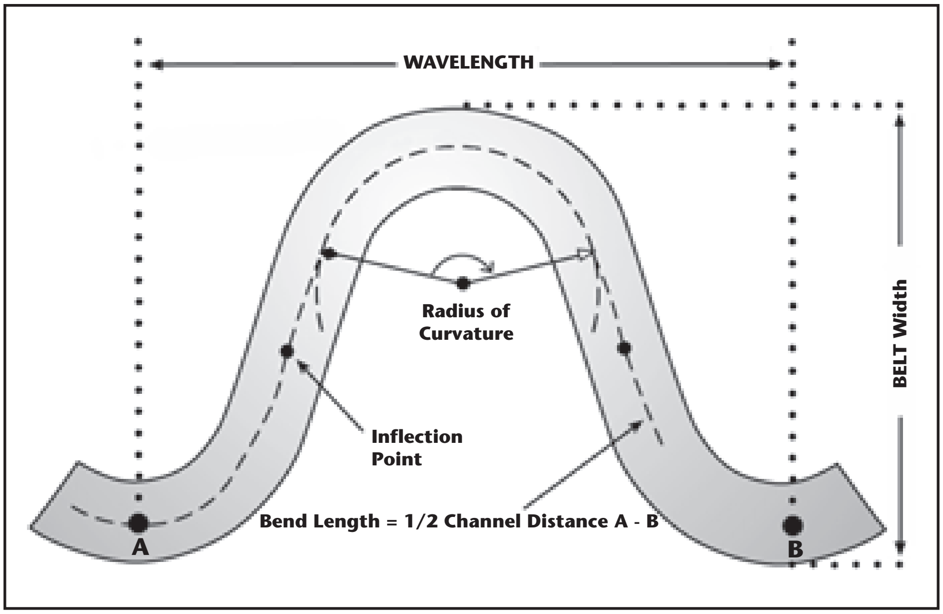


Figure 10. Graphic of stream channel geometry. (Illustration by Ralph Penunuri, modified from Rosgen, 1996, Applied River Morphology*)*

Figure 11. Walla Walla River (1964 flood showing meanders in a channelized section near Milton-Freewater). (OSU Archives)

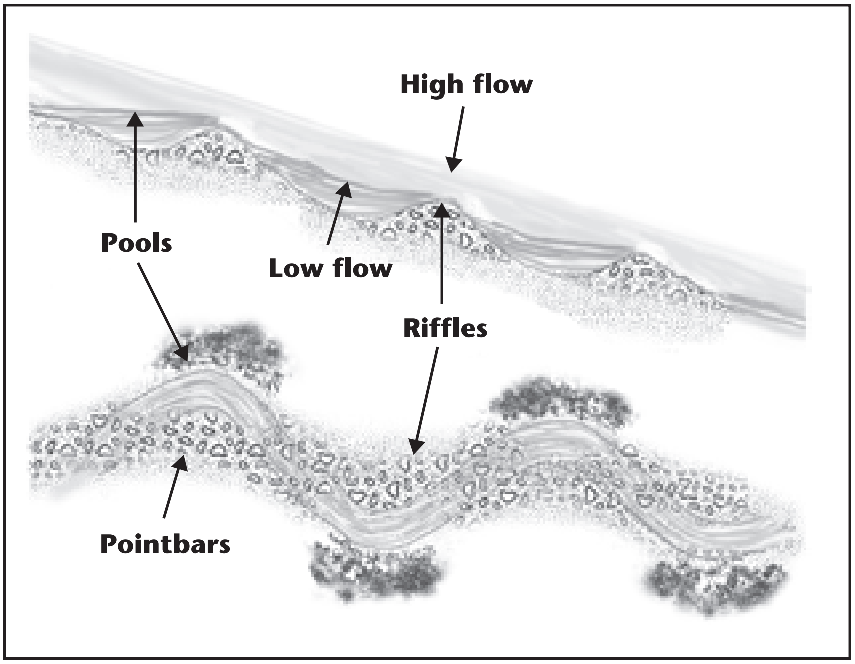


Figure 12. Profile and plan view of pools, riffles, and point bars. (Illustration by Ralph Penunuri, modified from Leopold, 1994)

Pools, Riffles, and Gravel Bars

During high winter flows, the velocity of the water is greatest on the outside of the bend and slowest on the inside. This causes a pool to be scoured on the outside and sediment to be deposited on the inside of the bend. The inside of the bend becomes a sand or gravel bar, also known as a point bar. Water flowing through the straight parts of the channel between bends tends to have lower velocity and to form riffles. Riffles are another form of gravel bars that extend across the width of the channel (figure 12).

A gravel bar is an accumulation of sediment ranging in size from sand and gravel to cobbles. Some of the sediment may move downstream during high flows. However, the location and general size of gravel bars tend to remain the same, relative to the meander bends. An everyday example is a group of cars stopped at a red light. There are always a few cars stopped at the intersection, but individual cars keep moving down the street from one intersection to the next.

The shape of the stream channel is formed during annual high flows. Although dramatic channel changes might occur during less frequent flood events, the more frequent annual high flows establish the channel dimensions. The annual flows occur more often and move more sediment over time as compared to the less frequent floods. Gravel bars are deposited during high flows, then remain in place and define the path of the channel during low flows. Pools are flat and deeper than riffles during low flows and maintain a slower velocity than riffles. Riffles are steep and shallow during low flows.

The Effects of Changing Sinuosity

Sinuosity is reduced when meandering streams are “straightened” or “channelized.” This practice can have several effects on the stream. Streams were usually channelized in order to make them more efficient at transporting water, to reduce flooding, or to drain wetlands. As a result, the length of the stream channel is reduced, the gradient is increased, and the water velocity is increased. These changes lead to higher erosive forces, and the straightened channel is likely to start eroding its banks or downcutting into the floodplain. As the stream becomes more incised, the banks become higher and steeper and

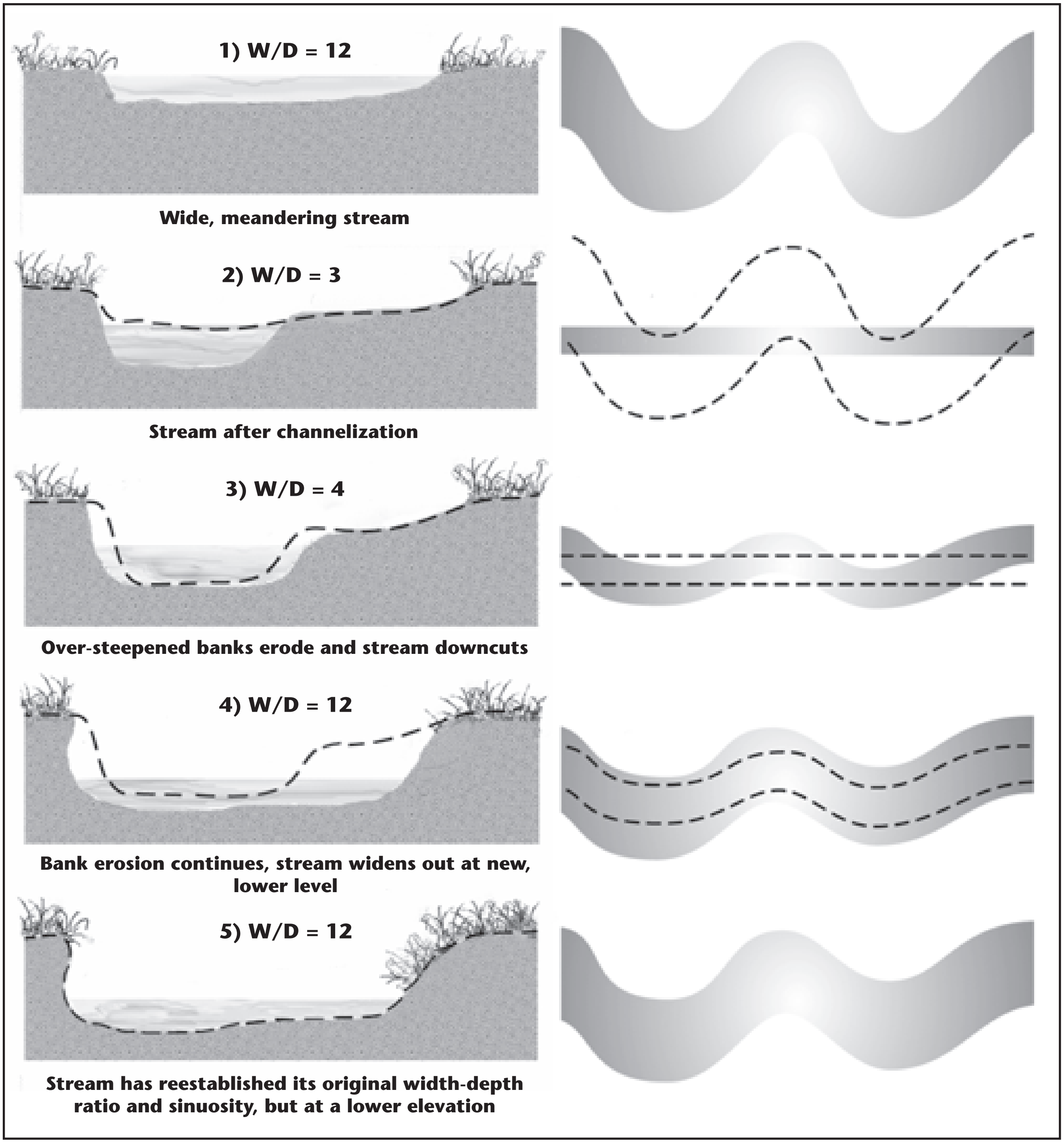


Figure 13a. Example of stream evolution and adjustment. 13a is initially a wide, shallow stream. 13b (next page) is initially a narrow, deep stream. (Illustration by Ralph Penunuri, modified from Rosgen, 1996, Applied River Morphology*)*

more prone to erosion. The number and depth of pools decrease. Increases in channel erosion can increase sediment deposited downstream of the channelized stretch of stream. The straightened stream will often try to reestablish a meandering pattern through bank erosion; the result is a stream that is trying to rebuild its floodplain and meander pattern, but at a lower elevation due to downcutting into the floodplain (figures 13a and 13b).

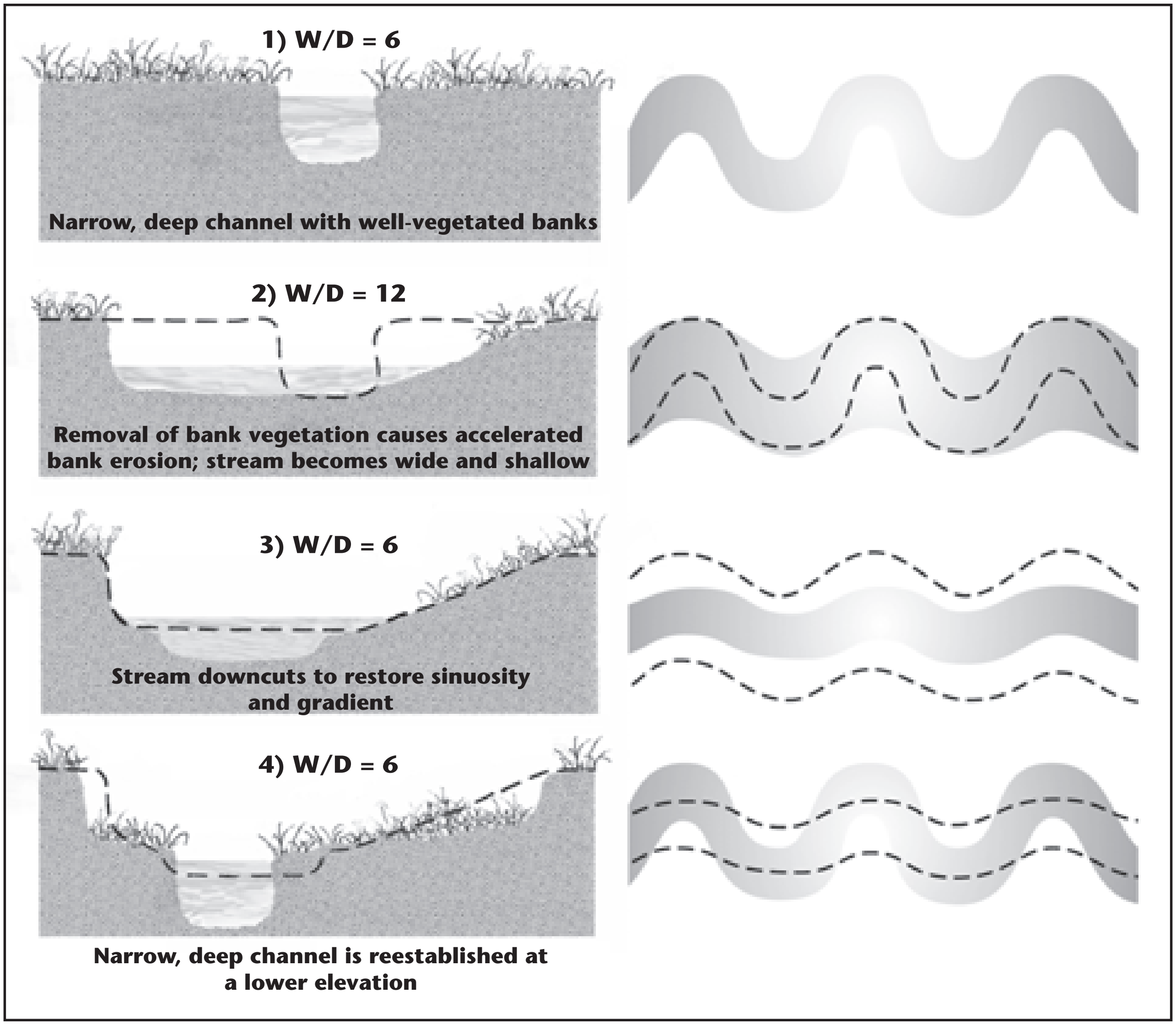


Figure 13b. Example of stream evolution and adjustment. 13b is initially a narrow, deep stream. (Illustration by Ralph Penunuri, modified from Rosgen, 1996, Applied River Morphology*)*

What Is a "Stable" Stream?

A "stable" stream is not a static stream. A stream is considered "stable" if its channel characteristics (width, depth, gradient, sinuosity, sediment type and amount) remain relatively constant over time and the stream neither deposits excessive sediment (aggrades) nor scours and downcuts (degrades) (Rosgen, 1996). The stream's ability to transport sediment is in balance with the sediment supply.

Stable Streams Migrate

A stream channel can maintain an average meander pattern and characteristics over a long distance. However, *the location of the channel doesn't necessarily remain in the same place in the valley floor.* Meander bends migrate in a downstream direction, and river channels can move laterally across the valley floor over time. This migration occurs as the outsides of the bends erode and gravel bars are deposited on the inside of the bend. The channel migrates in the direction of the strongest energy located on meander bends. This tends to make meander bends migrate in a downstream direction (figure 14).

Sometimes the stream will form an oxbow lake during high flows by cutting off a meander and leaving the old meander bend isolated from the stream. These cutoffs are formed because the stream's sinuosity has become too large and the slope has become too flat. The stream adjusts its gradient by straightening out a bend.

Stream channels tend to migrate laterally as the banks erode. Changes in the stream's characteristics can cause the stream to migrate excessively as it adjusts. Typical examples of accelerated changes include vegetation loss and increased sediment load.

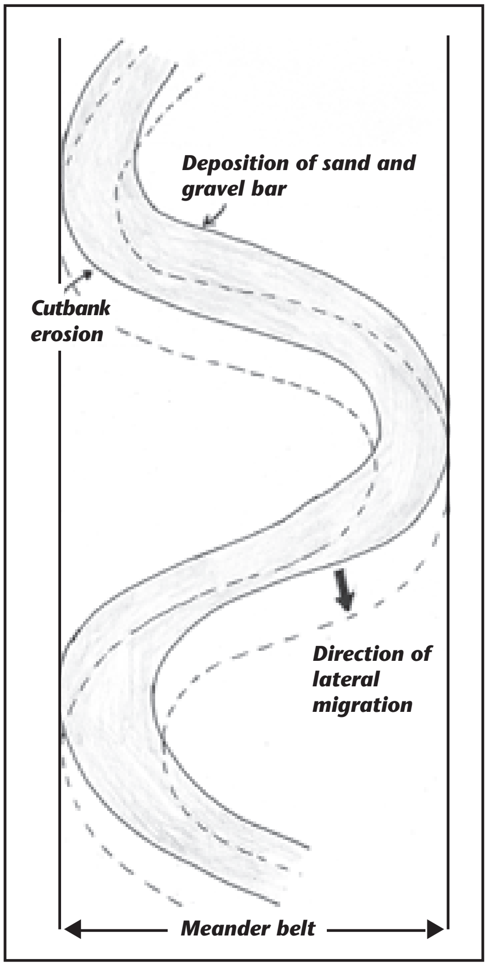


Figure 14. Lateral channel migration of a meandering stream. (USFS)

Predicting the Extent of Channel Migration

Even rivers that are actively migrating and meandering tend to stay within a predictable area of the valley floor known as a meander belt. A meander belt is delineated by drawing two parallel lines, one on each side of the river, which connects the outside of meander bends (see figure 10). Just like meander length and radius of curvature, meander belt width is related to channel width. A stream's belt width tends to vary from narrow for steep-source streams to very wide for very low-gradient depositional streams.

The area occupied by the meander belt, sometimes called the "channel migration zone," can be mapped and used to show where future bank erosion and lateral channel migration is likely to occur. In narrow valleys, the meander belt may occupy the entire width of the valley floor. Understanding and mapping the channel migration zone can help with planning transportation systems, rural and urban infrastructure (zoning and location of houses, buildings, roads, etc.), and areas where restoring or maintaining riparian vegetation would be beneficial to the stream. Figures 15 and 16 illustrate the channel migration of the Marys River over time (Ellis-Sugai, 1998).

Why Is the Streambank Eroding?

Streams are constantly changing by meandering, migrating, and rearranging pools, riffles, and gravel bars. Streambank erosion is an inherent part of the changes that occur with these processes.

A streambank is a complex network of vegetation, roots, wood, and sediment (clay, gravel, bedrock, etc.). This complex network provides a resistance (roughness) to the stream as it flows by.

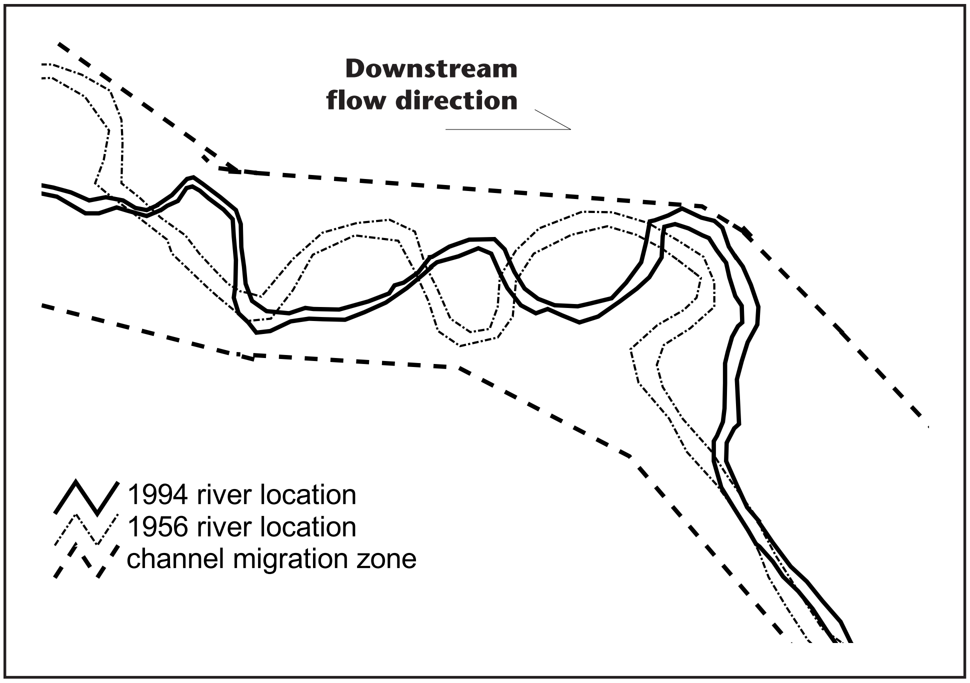


Figure 15. Downstream meander migration of the Marys River between 1956 and 1994. (USFS)

The stream dissipates energy as it flows past this resistance. Erosion occurs when the stream has more energy applied to the bank than the bank can withstand.

Bank erosion may be a symptom of changes in riparian vegetation. Decreased amounts of vegetation and associated root strength weaken the resistance of the streambank, making it more susceptible to erosion. In addition, the bank becomes more prone to erosion if the stream downcuts below the rooting depth of the streamside vegetation.

A narrow strip of riparian vegetation is often kept next to the stream to benefit fish, wildlife, and water quality benefits. As conditions change, a meandering stream might erode through the narrow buffer, leaving an unstable bank prone to excessive erosion. A wider riparian buffer would allow for change and help maintain bank stability.

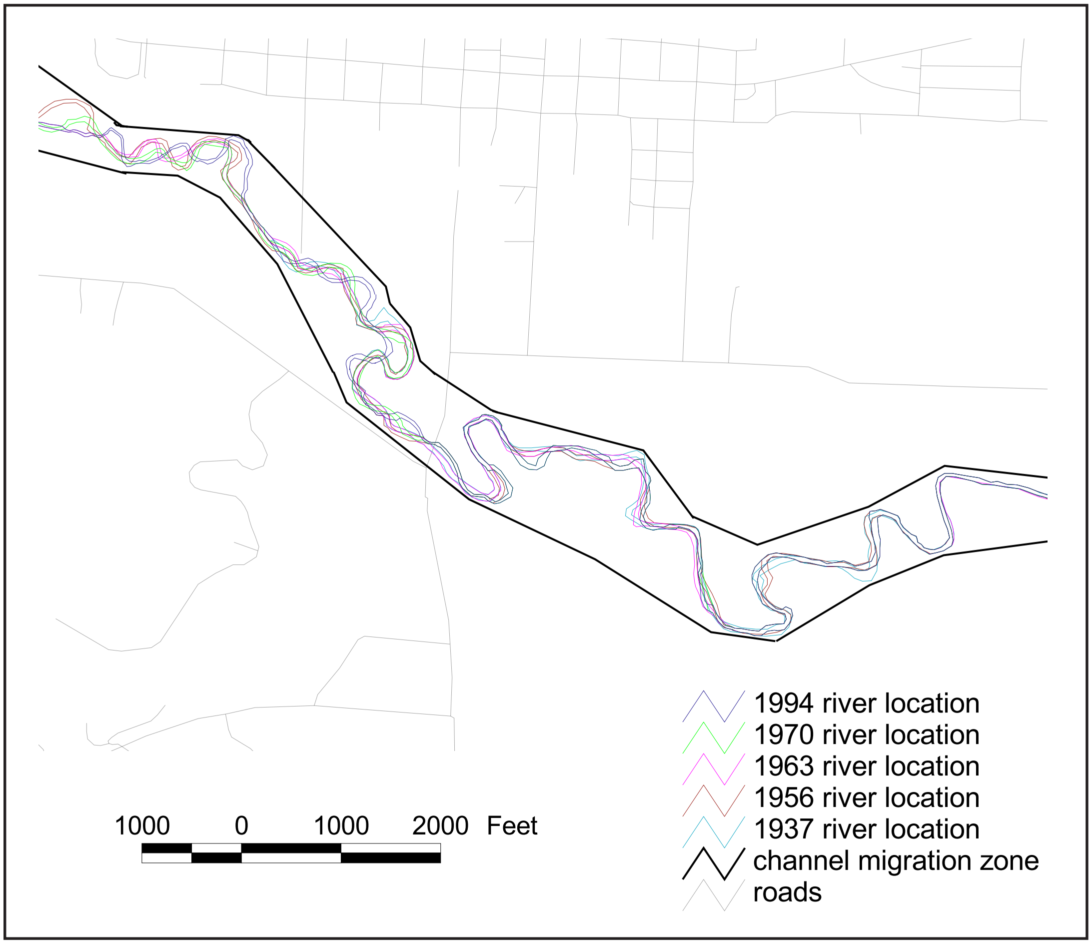


Figure 16. Location of Marys River channel between 1937 and 1994. The channel migration zone delineates the area where channel migration and bank erosion are most likely to occur. (USFS)

Figure 17 illustrates an example of the Marys River eroding through the riparian buffer (Ellis-Sugai, 1998).

Bank erosion also can be a symptom of larger changes in the watershed. Watershed-wide changes, such as increases in flow, water velocity, or sediment deposition on gravel bars, can force more energy into the stream bank.

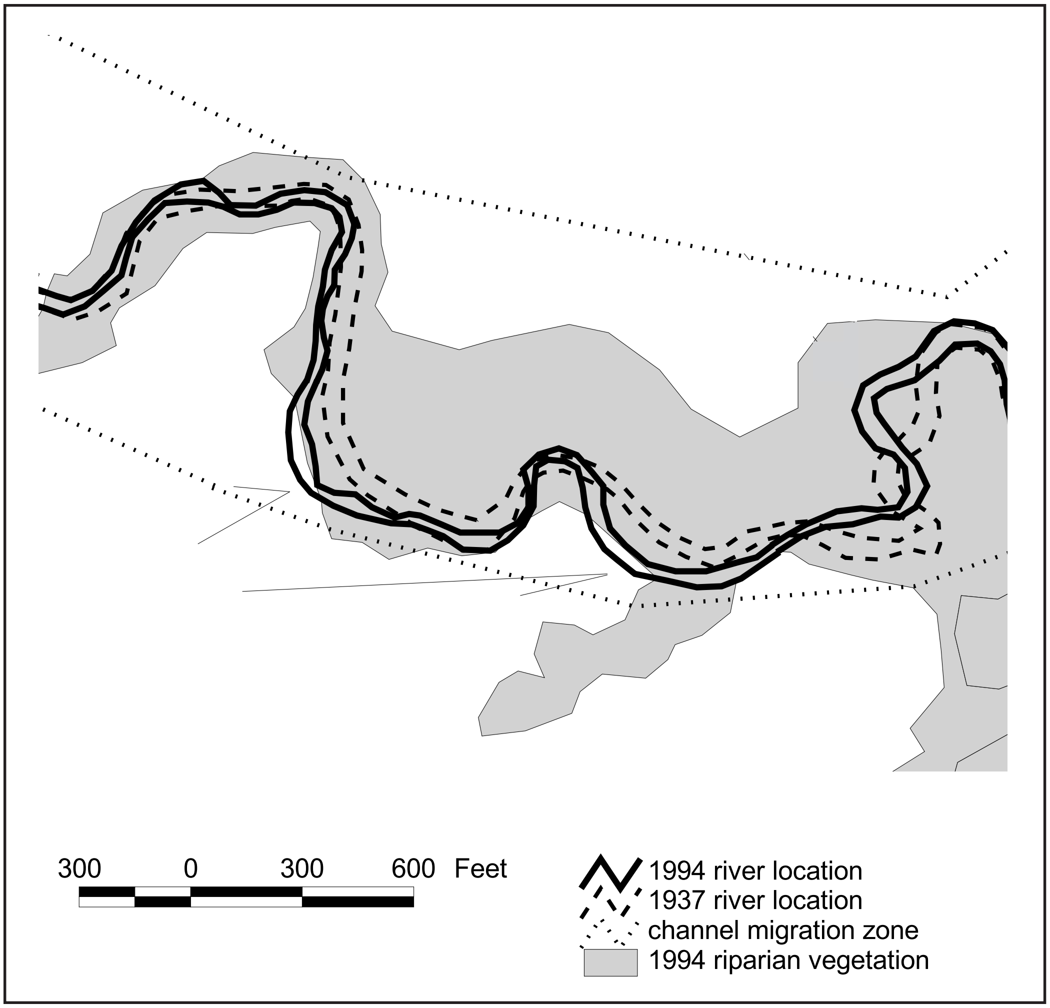


Figure 17. Map of channel migration between 1937 and 1994 on the Marys River. Grey area is the extent of the well-vegetated riparian zone in 1994. Notice that the natural channel migration has pushed the location of the channel beyond the woody vegetation in the riparian zone in several places. The dotted line is the channel migration zone. (USFS)

Stabilizing Streambanks

A stable stream meanders and migrates but maintains its dimension, pattern, and profile over time without aggrading or degrading (Rosgen, 1996). A stable stream may make minor adjustments in its characteristics to maintain its stability, for example, by cutting off a meander and leaving an oxbow lake. A stable stream has a streambank with a complex network of vegetation, roots, and wood to allow some erosion while maintaining its characteristics (for example, width-to-depth ratio, sinuosity, slope).

Many projects aim to permanently prevent a stream from eroding and migrating. These projects typically place rock on the bank (riprap) or build rock deflectors (barbs, groins, jetties, etc.) to deflect flow away from the bank. Various amounts and sizes of rock are used. However, if the stream is not allowed to erode and migrate to adjust to changing conditions, the stream will adjust downstream or upstream of the project area. These adjustments often result in more bank erosion and sediment deposits than would have occurred before stabilization.

Bank stabilization methods should be chosen for their ability to temporarily withstand bank erosion until riparian vegetation is established. These methods should always be designed for minimum impacts upstream and downstream. Many methods are available that use native plants (for example, willows), natural materials that decompose (for example, fiber mats), logs, and some rocks. The amount and size of rock and longevity of materials can be engineered to allow the bank to reestablish vegetation and allow the stream to adjust over time. Analyzing the channel migration zone (belt width) can help to plan the location and width of riparian vegetation.

Remember, streambank erosion is caused by many factors and is a symptom of a river that is adjusting its characteristics to handle upstream and downstream changes. All bank stabilization projects should account for these off-site effects. Establishing and managing the proper type and quantity of riparian vegetation is critical to supporting stable stream conditions. See the resources section for technical assistance and more information.

Large Wood in Streams and Floodplains

Random events such as debris torrents, landslides, and windstorms deliver sediment and organic materials to streams. In many areas west of the Cascades, these events have introduced trees and large wood to streams and floodplains. Streams adjust their characteristics over time to the new wood by depositing sediment (all sizes) behind the wood, scouring pools, changing sinuosity, eroding streambanks, etc.

Much of this wood was removed in the past to improve river navigation, transport logs downstream, and improve salmon migration. Relatively recent research has proven that large wood is a critical part of salmon habitat in many streams. Large wood provides fish habitat (refuge) during high flows, nurse logs for reestablishing some vegetation, wildlife habitat, and future habitat when the stream migrates.

Figure 18. Example of large wood being placed in the stream channel and floodplain of Beaver Creek in Curry County, Oregon. (Derek Godwin)

As part of the effort to restore stream habitat, large wood is being placed in many western Oregon streams and floodplains to replenish the amount historically present (figure 18). The large wood that is placed in streams is typically greater than $1^1/_2$ times the stream channel width and over two feet in diameter. The wood often moves during high flows but stays in the general area if sized and placed properly. The size, amount, and placement of large wood can have major effects on stream conditions and fish habitat. Therefore, it is important to evaluate the short-term and long-term effects on stream conditions and habitat when designing these projects. In addition, these projects should always consider the upstream and downstream effects.

Establishing and managing the proper type and quantity of riparian vegetation should complement the addition of large woody material in the stream and floodplain. There should be enough riparian vegetation to allow the stream to migrate without losing its vegetation from erosion. Such changes occur within the overall meander belt. Also, riparian vegetation should be managed to provide the long-term source of large wood and shade in these streams and floodplains.

Understanding Floods and Floodplains

In spite of our efforts to control floods, flood damage in the United States has steadily increased and costs now average over $2 billion per year (1992 Federal Interagency Floodplain Management Task Force). Many of these costs are repetitive (requiring replacement of structures on multiple occasions). Rather than relying on flood control measures to help decrease the costs, we might do better to understand the function of floodplains and rivers and to use better floodplain management.

What is a Floodplain?

There are several definitions of a floodplain, such as

- “A floodplain is a level area near a river channel, constructed by the river in the present climate and overflowed during moderate flow events. Note the phrase ‘in the present climate,’ because a floodplain can be abandoned and at least partly destroyed when the climate becomes drier. An abandoned floodplain is called a terrace.” (Leopold, 1994, p. 8)
- “all the alluvial surfaces that can still be reached by the occasional great flood” (Schmudde 1963, in Reckendorf, 1996). This definition implies that there may be more than one floodplain level adjacent to the river.

Perhaps the most basic and insightful definition has been given by the Army Corps of Engineers (1964):

- “(A floodplain is) the relatively flat land bordering a river; *it is actually a part of the river channel* and as such, carries water during times of flood.” (Italics added.)

All definitions agree on one point: the floodplain and the river are part of the same system (figure 19).

Function of a Floodplain

The floodplain serves as a “safety valve” for a river. During a flood, a river spreads out of its banks and over the floodplain. The water that covers the floodplain moves more slowly, and sediment carried by the floodwaters is deposited on the floodplain. These events often develop fertile land along rivers. Vegetation on floodplains filters sediment and other materials from the water before it reaches the river channel, and can help maintain higher water quality.

The floodplain acts as a sponge to absorb the floodwaters and slowly release the water as the flood recedes. A floodplain also can act as a natural reservoir, which helps to reduce the height of the flood downstream.

Figure 19. Example of a creek that is flowing outside of its banks and onto the floodplain (Spring Creek, Pennsylvania). (Barbara Ellis-Sugai, USFS)

The Flood Frequency Concept

The February 1996 flood in Oregon was rated as a 100-year flood event on the Yamhill River, a 143-year flood event on the Santiam River, and a 42-year flood event on the Willamette River near Salem. What do these numbers really mean?

Flood frequency is based on historic streamflow records from stream gaging stations. It is a measure of probability. In other words, every year there is a 1-in-100 chance that a 100-year flood event will occur. Thus, it is entirely possible to have more than one “100-year flood” in a century. For example, floods that occurred in the Willamette Valley in 1861, 1890, and 1964 are classified as greater than or equal to the theoretical 100-year flood level in Salem (Coulton, 1997).

The height of the 100-year flood is not an exact number, and there are several sources of error that can influence the accuracy of the calculation. One source of error is the length of record at a gaging station. The shorter the record, the greater the error in calculating the height of the 100-year flood. Many stream gage records in Oregon are only 30 years long; therefore, the 100-year flood height has to be projected from a set of data that might not have recorded a 100-year event. For a gage record that is 25 years long, the confidence level might be 85 percent. In other words, the height of the 100-year flood could be off by 15 percent. Also, climate cycles of relatively wet and dry years have been well documented by climatologists. If the years of record are predominantly in dry years, flood heights can be underestimated.

Another possible source of error is changing conditions in a watershed over time. For instance, if urbanized areas have increased in size, the amount of land covered by impermeable surfaces has also increased. Urbanization leads to faster, higher, and more frequent water runoff during rain events. So rainstorms that might not have caused a flood before an area was urbanized might overflow the stream's banks after the area is urbanized.

How Humans Interact with Rivers to Change Flood Events

Floods are natural *processes* and only become *disasters* when people and property are affected. If we build houses and businesses in floodprone areas, we put ourselves at risk. Over the years, we have changed rivers in a variety of ways to provide flood control and drain land for development or agriculture, or to prevent bank erosion. These projects sometimes have had unintended consequences. We have implemented many policies and practices that have changed the way rivers handle flooding, for better or worse. Some of these practices are listed below.

Dams

Dams and reservoirs can hold back floodwaters and reduce the height of peak flows. For instance, the Corps of Engineers estimates that the height of the February 1996 flood was reduced by 9 feet in Eugene and 7.5 feet in Salem because of the dams in the Willamette River basin (Branch, 1997).

The presence of dams also can give people a sense of false security. For instance, within the Willamette River basin, dams and reservoirs control only 27 percent of the basin's area. Flood control effectiveness diminishes downstream from the reservoirs as tributary streams without dams add to the flow of the river (Coulton, 1997)

Levees, Dikes, and Roads

Levees and dikes are built to prevent flooding on land adjacent to rivers. Flooding might decrease in the area adjacent to the levees but increase downstream. Because levees and dikes block a river's access to its floodplain, the water that would have spread across the floodplain is instead funneled downstream and thus can increase peak flows downstream. The river's water velocity is also greater because of the funnel effect, which can worsen bank erosion downstream. When the upper Mississippi River flooded in 1993, the flood crests at St. Louis were as much as nine feet higher than for an earlier flood of the same size, because levees had been built upstream of the city (Williams, 1994). Also, when a levee does fail, the effects can be sudden and catastrophic, rather than a gradual rise of water (Williams, 1994). Farmers in the Willamette Valley found that scour due to levee breaks caused more damage to their fields than inundation by floodwaters (American Institute of Hydrology, Pacific Northwest Water Issues Conference, October 1997). Roads are often built on levees in floodplains and produce the same consequences.

Undersized Bridges and Culverts

Bridges and culverts that are too small to carry the stream's flow during flood events can back up water and cause flooding upstream of the bridge or culvert. Flooding problems in Salem during the February 1996 flood were compounded by undersized bridges (Reckendorf, 1997). Undersized bridges can also cause sediment deposition upstream of their locations because they slow the water down, causing sediment to drop out. Undersized bridges and culverts are also more prone to plugging up with debris, which can compound upstream flooding problems.

Channelization

Channelization was a common practice in low-gradient streams and floodplains between the 1930s and 1960s. Meandering stream channels were straightened to make the stream more efficient at moving water, to reduce the amount of land used by the stream, and to drain the land next to the stream. More land was then perceived to be available for agriculture, housing, roads, and other development.

Straightening stream channels might make the stream more efficient at moving water through that part of the stream, but the consequence can be increased flooding downstream of the channelized section (see figure 11). Streams naturally follow a sinuous, meandering course. When the meanders are eliminated, the stream length is shortened. As a result, the gradient of the stream becomes steeper, which leads to higher water velocities, higher instantaneous flows, and possibly greater flooding downstream. Figure 13a graphically illustrates a stream's evolution due to channelization.

Many stream restoration projects around the United States are working to rebuild meandering stream channels where streams have been straightened and water quality and fish habitat have been degraded as a result. (See "Bailey Creek Case Study," page 32.)

Urbanization

Developing land for towns, cities, and suburbs turns more of the surface area in the watershed into impermeable surfaces. Rainfall no longer is captured and stored in the soil, and water runs off the land and into streams more quickly. As a result, high flows become higher, arrive sooner after a storm starts, last for shorter periods of time, and occur more frequently (figure 20). Stream channels have to become larger to

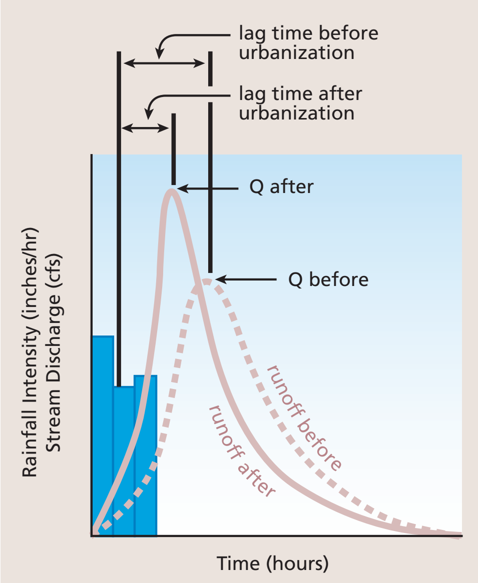


Figure 20. Hypothetical hydrograph from Leopold's "A View of the River," showing the faster and higher peak flow after urbanization.

carry the increased instantaneous runoff, and this adjustment is often done through bank erosion (which widens the stream channel) or stream downcutting (which deepens the stream channel). The streams also carry less water during nonrainfall periods, providing less fish habitat. Many streams in urban areas have often been filled to increase the land area for buildings. This magnifies the problems because the water is routed to another stream nearby.

Streams in urban settings have often been straightened (channelized), had the riparian vegetation cleared away, had levees built next to the stream, or had bank-hardening measures (rock, concrete, and other materials) applied to them. These channels are more efficient at transporting water quickly, but this often results in greater flooding and erosion downstream.

For example, the number of houses within the 3.7 square-mile Watts Branch watershed near Washington D.C. increased noticeably over a 50-year period. In 1950, there were 140 houses; in 1965, there were 780; and in 1984, the number had increased to 2,060. The increased urbanized area had a significant effect on the flow regime of Watts Branch. As the number of houses present in the watershed increased, the number of times the streamflow exceeded 220 cubic feet per second also increased. The number of times the stream overflowed its bank increased from twice per year to seven times per year over the three decades that stream gage records were kept (Leopold, 1994) (table 1).

Table 1: Comparing the number of houses present in the Watts Branch watershed with streamflow information.

Year	Number of houses	Period of discharge records	Number of times discharge exceeded 220 cfs*	Number of times discharge exceeded 350 cfs
1965	780	1958–1967	21	10
1984	2,060	1978–-1987	73	32

*220 cubic feet per second is considered the bankfull discharge for Watts Branch. The bankfull discharge was determined to be a 1.5-year flow event.

Many urban restoration projects focus on building storm water detention ponds and reestablishing riparian areas and wetlands. These projects aim to mimic historic conditions by improving the watershed’s ability to capture and store water, then release it over a longer period of time.

Floodplain Encroachment

Filling in floodplains with soil to build houses, businesses, and roads reduces the floodplain’s ability to disperse energy by spreading out the water, to filter and absorb water, and to lessen the impact of flood events. Also, buildings placed in the floodplain are at higher risk of flood damage. For example, in the cities of Tualatin and Salem, Oregon, housing and business developments have been established in floodplains. In both cities, these areas were flooded in 1996 (Reckendorf, 1997).

> "With flood damages, you either pay less up front in good floodplain management and implementation or pay more later in rescue relief and damages." (Reckendorf, 1997)

The Economics of Floodplain Management

There are, and have always been, competing interests between the desire to develop the attractive, flat land adjacent to the river, and to protect it so that it can function as a natural floodplain. The costs associated with flood damage have been increasing steadily throughout the 20th century in the United States (Coulton, 1997). It is less expensive to refrain from building in high-risk areas in the first place than it is to pay for repairs or rebuilding after a flood. And it is likely that these areas will flood again.

Reducing the Impacts of Floods

What we can do as a community

- Zoning—protect the floodplain; use it for parks, greenbelts, and open spaces.
- Provide economic incentives for landowners to leave lands adjacent to streams and rivers undeveloped through conservation easements or trusts.

What We Can Do as Individuals

- When buying property, be aware of the location. Note the proximity and relative elevation to streams and other bodies of water. Check to see whether it is in a floodprone area. Ask local residents whether the area has ever flooded. Historic information might be available at county historical museums, local libraries, and the local USDA Natural Resource Conservation Service office.
- Become involved in land-use and community development issues.
- Encourage planning departments and elected officials to develop a better understanding of how rivers function and to adjust zoning boundaries.
- If you own stream-front property, allow trees and brush to grow along the river's edge. Don't plant a lawn to the water's edge.

Stream Rehabilitation, Restoration, and Enhancement

Improving stream conditions for aquatic life is an important part of the salmon recovery effort in the Pacific Northwest.

Streams are complex systems that are influenced by many variables. For that reason, it is absolutely necessary to have a good understanding of the stream that is under consideration for an improvement project.

Because people have different values and goals for streams, it is important that people involved with the project define commonly used terms to ensure a common vision. For the purpose of this paper, the terms *rehabilitation*, *restoration*, and *enhancement* are used interchangeably and imply the restoration of stream functions and processes to support the stated goals. The term *condition* implies how well the functions and processes have been restored to meet the goals. Stream functions include carrying and storing water, sediment, large wood, organic matter, and other particles in the stream, riparian area, and floodplain. Functions also include providing habitat, food, and water for people, fish, and wildlife. Stream processes are how the stream carries and stores these materials and how the stream affects habitat, food, and water quality.

Common stream-restoration goals include improving salmon and trout habitat and establishing a stable stream that carries its sediment load without aggrading or degrading. Following are the steps generally accepted among scientists for planning and conducting a restoration project.

1. What are the goals and functions to restore? For example, improve habitat for salmon and trout.
2. What are the present conditions? Stream classification systems can be used to describe present functions and processes. These systems also might help determine potential conditions. For example, the stream is providing minimal deep pools for fish habitat because of a high width-to-depth ratio, excessive erosion, and steep slope.
3. What are the factors limiting the ability to reach stated goals? For example, the management of a road close to a stream might limit the amount and types of riparian vegetation, the extent of erosion and channel migration, and the use of the floodplain. This step requires a clear, detailed description of the factors affecting the stream (e.g., bank erosion, downcutting, wide and shallow channel, riparian conditions, up-slope problems). If possible, compare the degraded stream to a stable stream in the same area with similar features (similar gradient, valley width, channel size, etc). At a minimum, find out the drainage area, stream flow characteristics (timing, response to rainfall events, etc.), bankfull discharge, and the sediment type and transport characteristics.
4. What stream characteristics and processes need to be altered to reach the restoration goals? Consider short- and long-term changes. A stream's condition is directly related to upstream

For technical assistance or information, contact your local USDA NRCS, watershed council, swcd, Extension Service, USFS, BLM, ODFW.

and downstream alterations and land-use changes in the watershed. Most stream improvement projects involve changing the factors causing the present stream conditions, and letting the stream adjust over time. Assessing historic and current land-use practices will help in understanding how the stream developed its current condition (e.g., landslides, urbanization, change in riparian vegetation). Knowing the history of the watershed also might help identify changes that need to be made that support a more stable stream condition.

In some cases, intervening to improve stream characteristics in a shorter time period is necessary. Many options must be reviewed for their capacity to improve conditions relative to cost and potential impacts to the area. Before landowners make decisions regarding modification of a stream, they must identify the potential array of stream conditions and corresponding characteristics. All of the present variables have to fit together, such as amount of water, amount of sediment, size of the channel, and size of the meanders. Stream characteristics also must be related to the watershed and valley features. For example, modifying a low-gradient, meandering stream with a wide floodplain into a narrow, confined, steep-gradient stream is not feasible. Another example that is not recommended is to modify a stream to characteristics that do not account for the urbanization or change in flood flows for the watershed. A restored stream's designed characteristics must account for increased urbanization and corresponding runoff. It might not be possible to recreate the stream's historic characteristics if the conditions within the watershed have changed.

Because of the complexity of stream processes and potential impact on aquatic life and water quality, it is recommended that a team of specialists design and evaluate the possible projects (hydrologists, stream ecologists, fish biologists, riparian specialists, engineers, geologists, etc.).

In the area of stream restoration, there are many past examples of inappropriate "fixes" that have done more harm than good and created unintended consequences. For example, streams were straightened to provide flood control, and check dams were installed in meandering streams with erodable banks. In order to "first, do no harm," stream improvements should be approached with respect for the complexity of the stream system. Each site and situation will be different. There is no "cookbook," nor are there any "one-solution-fits-all-situations" remedies. Each project must be compatible with the stream type, the valley setting, and the stream's natural tendencies.

All stream restoration projects must improve, by definition, riparian and floodplain conditions. The river, the riparian zone, and the floodplain are all part of the same system, and the river's characteristics are determined by the watershed's characteristics and conditions. In addition, stream improvement projects must consider upstream and downstream causes of present stream conditions. For example, high rates of erosion-caused sediment might be transported downstream to the project site, or a headcut (downcutting or erosion of the stream bed) might be progressing upstream to the project site.

Conclusions

Streams change over time, but they can maintain some basic characteristics. The location of the stream can change over time as the outer bank of meander bends erode and gravel bars are deposited on the inside of bends. If the gradient becomes too flat, a meander cutoff can occur, leaving the meander bend behind as a side channel or oxbow lake. These adjustments are part of a stable stream system. Stable streams maintain their average width, depth, gradient, meander geometry, size and amount of sediment moving through the system, and timing and duration of flows.

Streams are complex systems that are formed and influenced by many variables. What happens upstream can affect the downstream areas, and vice-versa. Many changes (both natural and human-caused) to the land and streams in the watershed (e.g., removing vegetation, landslides, urbanization, roads) cause streams to become unstable for periods of time. Stream conditions during these unstable periods can negatively affect fish habitat and water quality.

Improving stream conditions for fish and water quality is a major effort in the Pacific Northwest. Understanding the stream's characteristics and how those characteristics change with different watershed conditions is crucial to successful improvement projects. These improvement projects will include fixing the cause of the problem upstream, downstream, or in adjacent riparian areas and allowing the stream to adjust over time. The improvements also might include designing and implementing in-stream projects that directly manipulate stream characteristics (width, depth, gradient, sinuosity, etc.). Many lessons are learned from past restoration projects. Improvement projects should support a stream's stable characteristics while allowing the stream to adjust over time within the channel migration zone. These projects should also protect or improve the stream, floodplain, and riparian zone functions and processes based on the goals. Floodplain protection and restoration is crucial to stream restoration projects. Economically, it is often less expensive over time to protect and restore a floodplain than it is to pay for flood damages later.

Bailey Creek Case Study

Bailey Creek flows through Enchanted Valley into Mercer Lake near Florence, Oregon. Based on historic aerial photos and ground surveys, Bailey Creek was once a meandering, low-gradient stream in the middle of the valley. During most of the 20th century, Enchanted Valley was privately owned and the land was used for a dairy farm. Prior to 1952, Bailey Creek was diverted into a straight ditch along the southern edge of the valley, probably to create more pasture. Figure 21 is a 1952 air photo that shows remnants of the old channel in the middle of the valley. Bailey Creek flows north to south and into Mercer Lake. A straight diversion ditch was built along the east side of the valley.

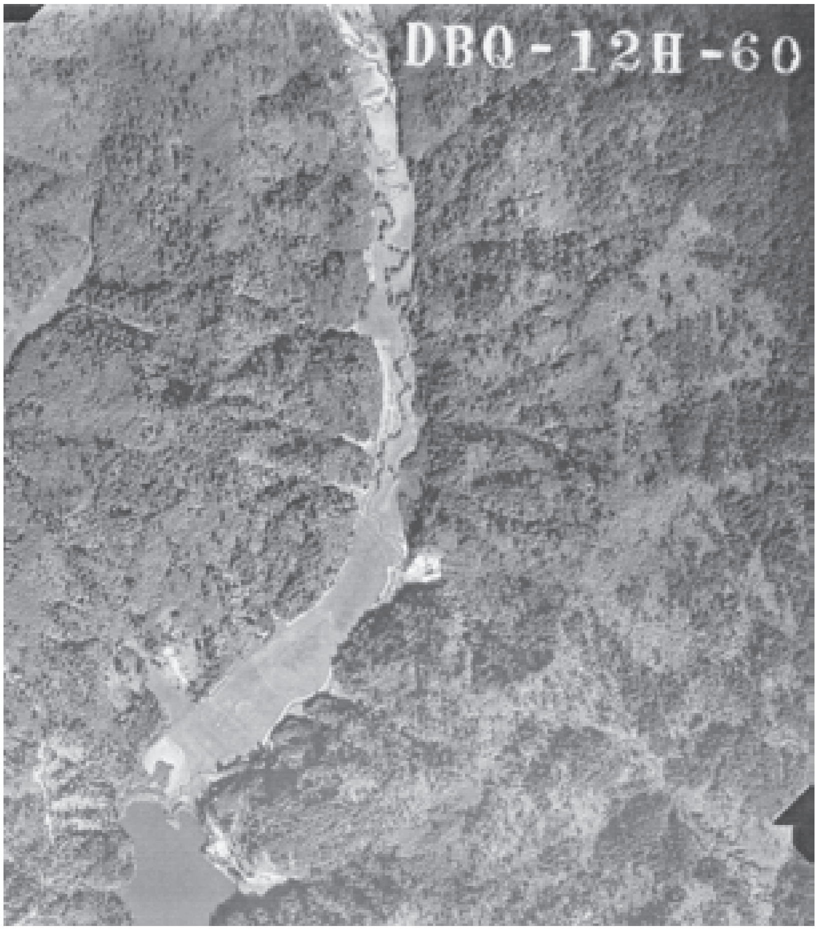


Figure 21. 1952 aerial photo of Bailey Creek in Enchanted Valley, Oregon. Bailey Creek flows north to south into Mercer Lake. (USFS)

Effects of the channelization of Bailey Creek include increased sediment deposition at the mouth of the creek in Mercer Lake, increased bank erosion as the stream tries to rebuild its meandering pattern, and downcutting of the stream channel. Historic aerial photos and site surveys were used to construct a map that compares channel changes between 1952 and 1995 (figure 22). The upper part of Bailey Creek was probably ditched just before the 1952 photos were taken because much of the historic channel was still present. The lower part of Bailey Creek was constructed prior to 1939, based on aerial photos.

Figure 23 compares the cross sections of the stream above and below channelization and illustrates the change in channel geometry due to downcutting. Figures 24a and 24b show the increased bank erosion in the upper part of the valley. As the banks erode to recreate a meander pattern, sand and gravel are deposited on the opposite sides to create new point bars.

The bank erosion and downcutting within the straightened channel have increased sediment production and caused a

Continued

Bailey Creek Case Study continued

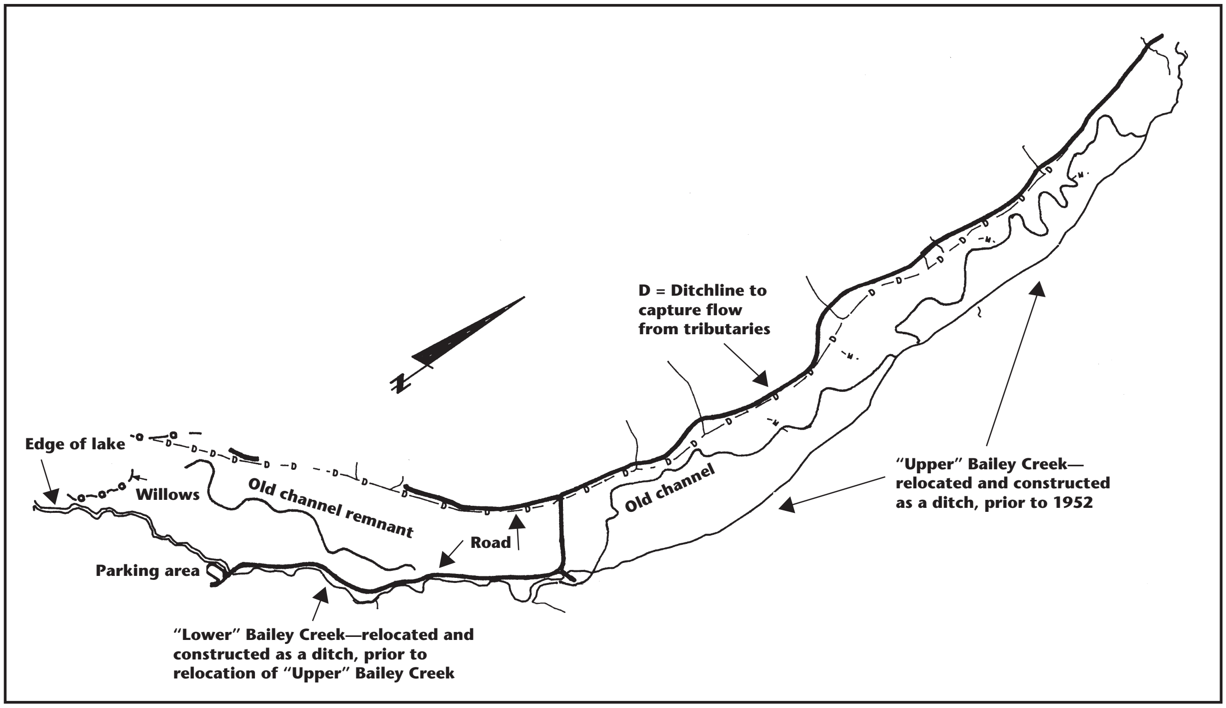


Figure 22. Map of Bailey Creek. Illustrates remnant old channel (mapped from aerial photos and ground surveys). Illustrates Bailey Creek as a ditch along west edge of flood plain. Illustrates ditch line along each edge of flood plain, probably constructed to capture flow from tributaries and route to Mercer Lake. (USFS)

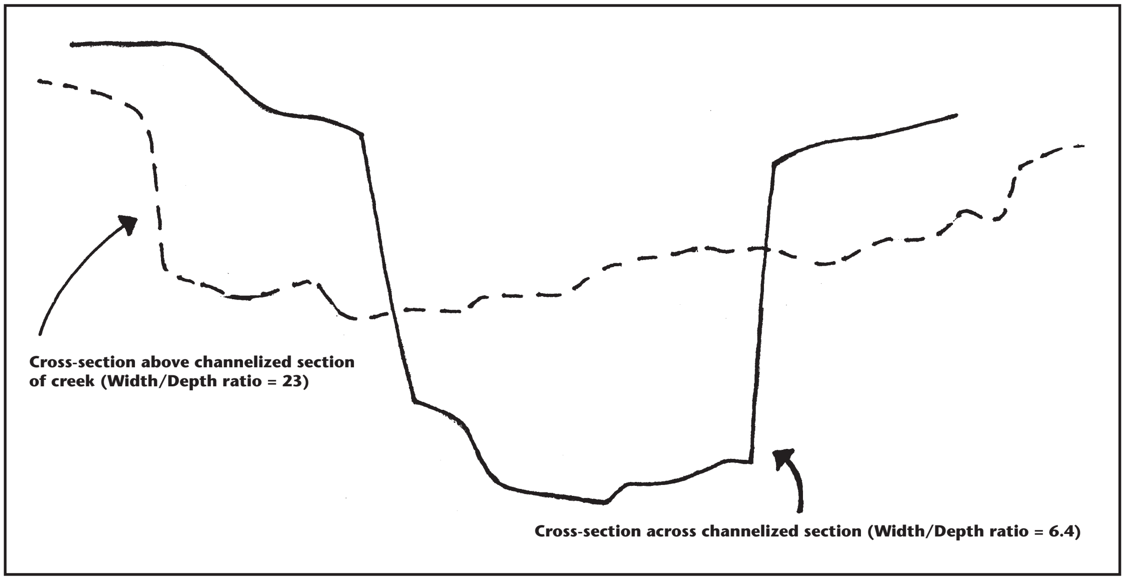


Figure 23. Comparisons of cross-sections across Bailey Creek. The dashed line is a cross-section measured above the channel and is relatively undisturbed. The solid line is a cross-section measured midway down the channelized and straightened section of Bailey Creek. Note the difference in the width/depth ratios and the amount of downcutting that has taken place in the channelized section of the creek. (USFS)

Continued

Bailey Creek Case Study continued

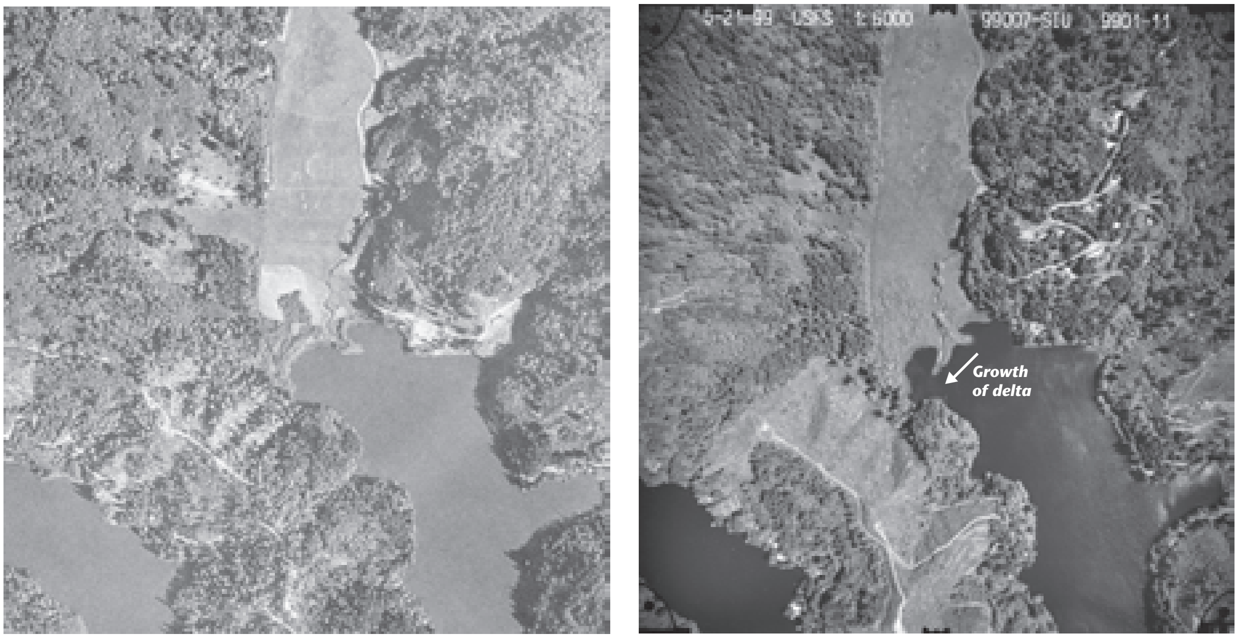
Figures 24a and 24b. Stream evolution and adjustment in the "upper" Bailey Creek. Bailey Creek is increasing its sinuosity by eroding outside banks and depositing sediment on the inside point bars. Vegetation is beginning to be established on the point bars. (USFS)

delta to grow at the mouth of Bailey Creek. A series of air photos from 1952 to 1999 shows the growth of the delta (figures 25a and 25b). Based on topographic field surveys of the delta, the edge of the delta progressed out into the lake by 12 feet in one year (September 1998–99).

The Siuslaw National Forest acquired Enchanted Valley in the early 1990s. In 1995, planning was begun to restore a meandering stream channel in the valley. In 1999, a new meandering channel was built in the lower part of the valley. Figure 26 is a map of the new channel. The constructed channel was built to flow in the vicinity of the historic channel and to function similarly. The new channel is designed to carry the annual high flow within its banks, but to allow higher flows to inundate the floodplain more frequently. It is also designed to have a gradient, sinuosity, and average stream flow similar to the historic meandering channel. All of these changes, in addition to establishing native riparian vegetation, are expected to support the normal changes in stream pattern without excessive erosion and downcutting.

Continued

Bailey Creek Case Study continued



Figures 25a and 25b. Air photos showing the growth of the delta at the mouth of Bailey Creek from 1952 (left) to 1999 (right). 1952 air photo has been enlarged to show scale similar to 1999 photo. (USFS)

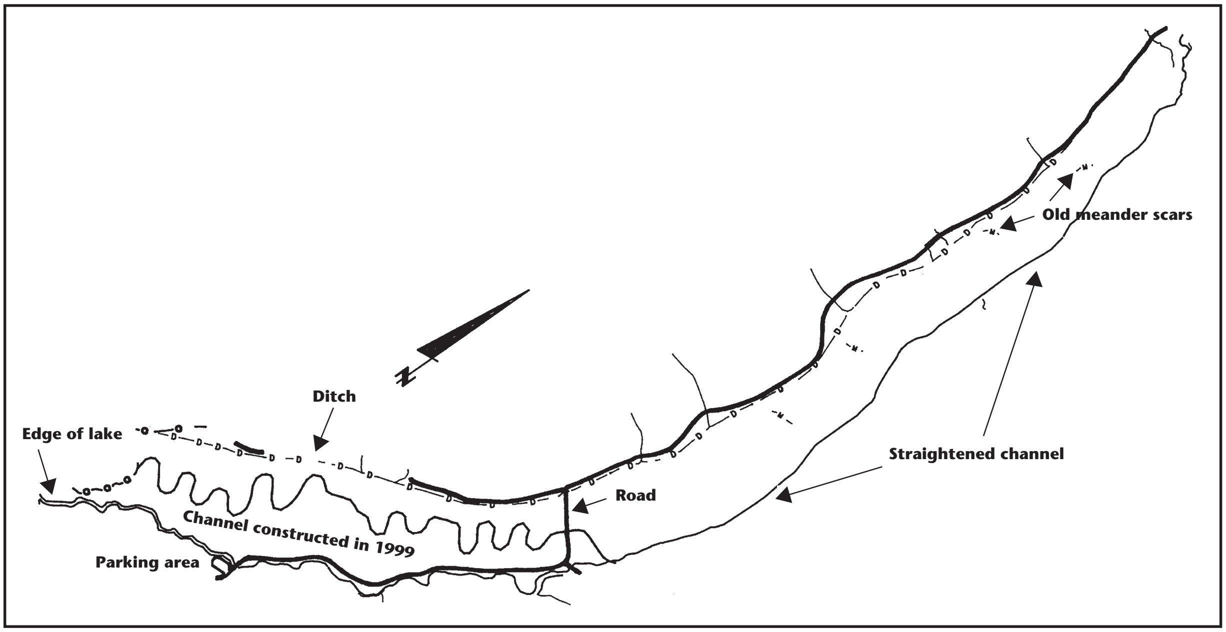


Figure 26. Map of newly constructed channel of Bailey Creek. (USFS)

Glossary

Bankfull discharge—the amount of stream flow that is equal to a peak flow event that occurs on average every 1.2 to 2 years. This flow might not be literally to the top of the stream banks.

Barb—in-stream structure consisting of boulders and riprap-sized rock that diverts the streamflow where highest velocities occur during bankfull discharge. The Natural Resources Conservation Service designed these structures to provide erosion control until vegetation can be established on stream banks.

Braided channel—segment of a stream that has more than two main channels carrying streamflow during a bankfull discharge flow event.

Channelize—to mechanically alter a stream's bed and banks to cause the stream to flow straight.

Check dam—structure usually made of boulders and smaller rocks used for grade control in a stream.

Cobble—size class for rocks that have a diameter ranging from 64 to 256 millimeters (2.5 to 10 inches).

Confinement—a measure of how much the stream channel is laterally constrained within the valley floor. A stream channel is defined as confined when the valley width is less than two times the channel width, moderately confined when the valley width is between two and four times the channel width, and unconfined when the valley width is greater than four times the channel width (*OWEB Watershed Assessment Manual*, 1999.)

Debris torrent—landslide that has entered the stream channel and flows as a mixture of water, sediment, and debris.

Depositional segment of stream—a segment with a gradient or slope of less than three percent. Sediment and wood are deposited here for long periods of time.

Dike—mound of rock and earth that borders a stream to keep the stream from flooding into the adjacent area. Typically these have been built to prevent the stream from flooding into its floodplain.

Downcut—the erosion of the stream bed causing a decrease in elevation across the stream channel.

Entrenchment—a measure of how much the streamflow is vertically contained in a stream channel during flood events. This is a ratio of the floodprone area width divided by the bankfull width (width of channel at normal high flow). The floodprone area is determined from the width at an elevation associated with two times the maximum bankfull depth. Typical ratios for entrenched streams are less than 1.4; for moderately entrenched streams, between 1.4 and 2.2; and for slightly entrenched streams, greater than 2.2 (Rosgen, 1994, Catena paper).

Floodplain—land next to stream where water overflows during floods.

Flow event ("1.5-year flow event")—the statistical representation of an amount of streamflow. A 1.5-year flow event is a peak stream flow that occurs every 1.5 years on average.

Gradient—slope of the stream channel measured as vertical distance divided by horizontal distance.

Groin—similar to a barb, an in-stream deflector made of boulders and rock designed to divert streamflow and prevent erosion of streambanks.

Headwater stream—the segment of stream located where it is formed in a channel by the accumulation of surface and subsurface flow.

Nurse log—term used for logs on which tree seeds sprout and grow.

Point bar—sediment deposit formed on the inside bend of a stream

Sinuosity—amount of curvature in the stream channel.

Slope—same as gradient, the vertical distance divided by the horizontal distance.

Step pool—pools in a stream formed by the scour of water plunging over a step created by a log or boulders.

Stream gaging station—permanent location along a stream where the stream's elevation is continuously measured with gaging instruments. A hydrologist measures the stream's velocity and flow at different elevations at the station. The hydrologist combines the elevation and streamflow information to create a continuous record of streamflow.

Stream network—term used to describe the stream and its tributaries upstream of a given point.

Wedge of sediment—the accumulation of excessive amounts of sediment deposited in an area.

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Resources for Further Information

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Environmental Protection Agency Documents

Ecological Restoration: a tool to manage stream quality. Document EPA 841-F-95-007.
Has chapters on restoration, restoration and the Clean Water Act, linking restoration practices to water quality parameters, evaluating cost-effectiveness of restoration, and case studies.

Watershed Tools Directory. Document EPA 841-B-95-005.
Has several hundred one-page descriptions of methods and techniques for evaluation and correction of watershed problems.

To order hard copies of the above documents, fax (513-5669-7168) or mail request (with document title and number, your address, organization, and phone number) to NCEPI, 11029 Kenwood Rd., Bldg 5, Cincinnati, OH 45242. Also available on the Web at **http://www.epa.gov/OWOW/watershed.html**

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