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Walla Walla River, Mill Creek, and Coppei Creek Geomorphic Assessment

Walla Walla County Conservation District and
U.S. Forest Service, TEAMS Enterprise Unit

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Summary of Findings

A geomorphic assessment was conducted on the Walla Walla River downstream from the Frog Hollow Road Bridge, Mill Creek downstream of the Wickersham Bridge, and Coppei Creek downstream of McCown Road. The focus of the assessment was channel, vegetation, and floodplain conditions. Surveys were completed for channel and floodplain conditions, large woody debris, riparian conditions, bank stability, and streambed sediment. Recommendations have been provided on channel restoration for the assessment reaches to address unstable areas.

The assessment reach streams all have high sediment loads at higher flows. As a result, efforts to channelize these waters away from development will only be a temporary solution, because the stream will eventually fill channelized channels and migrate across active floodplains. Effective solutions for long-term channel health include recognizing areas where the channel will flood, and steering development away from these areas. Other findings from this study verify that there is considerable risk of flooding along the assessment reaches and areas upstream and downstream; corresponding floodplain maps are provided.

Rivers, over time, if not heavily manipulated by human disturbance, naturally tend to create relatively stable meander patterns, channel bankfull width-to-depths, channel features such as pools and riffles, and functional floodplains. Sediment supplied to the channel is transported downstream without adverse accumulations that can cause channel instability, except in areas where natural accumulations are expected (alluvial fans, deltas, and tributary junctions). Elements of this natural stability are often incorporated into river restoration designs. Analysis of aerial photos shows that the Walla Walla River, Mill Creek, and Coppei Creek along the assessment reach are adjusting to channel impacts, such as channel straightening, by increasing the amount of erosion at several meander bends, as evidenced by the observed highly unstable banks in some areas. Because the highly unstable banks along the river are indicative of river channel instability, restoration designs need to evaluate and consider what impacts have led to the instability, and come up with designs that can protect the banks, and allow for more stable channel conditions. Restoration designs must consider that most of the valley is developed, and that flood protection is extremely important to consider in restoration design and river management.

Channel and floodplain conditions along the Walla Walla reach are generally good, with the exception of unstable banks and channel conditions observed on private property at Johnson's Ranch below the Frog Hollow Road Bridge. Bankfull width-to-depth ratios, flood-prone widths, entrenchment ratios, stream sinuosity, and other stream variables indicate that the stream overall is relatively unconfined during flood events and in healthy condition. Historical conditions indicate that the stream was more open and had less sinuosity than at present. Compared to older photos, there has been a remarkable re-growth of cottonwood trees along the channel, and an increase in stream sinuosity. Overall, considering a full range of channel and floodplain indicators, the stream is in good conditions and recovering from past impacts. Sediment analysis indicates that the stream transports a large volume of sediment through the reach at higher flows. Because it has a slightly higher slope, more sediment is transported at higher flows at the downstream end of the reach. Restoration recommendations include bank stabilization in the vicinity of the Johnson's property, delineating floodways through the pasture and farm areas downstream, and creating vegetated grade controls to prevent channel migrations in this area. Following through with these recommendations would not only reduce the likelihood that the Walla Walla River channel would avulse into the Johnson property during a major flood event but would also continue to move the channel towards equilibrium. These recommendations would improve overall channel stability, increase entrenchment and bankfull width-to-depth ratios throughout the reach, and improve riparian conditions.

These improvements would positively impact aquatic habitat by reducing sediment caused by unstable stream banks, increasing large woody debris recruitment through improved riparian conditions, and reduce water temperatures by increasing cover in the canopy.

Channel and floodplain conditions on Mill Creek along the assessment reach indicate that conditions are generally good, with the exception of the area upstream of the Wickersham Bridge. Sediment analysis indicates that at higher flows a large amount of sediment is moved by Mill Creek. The Wickersham Bridge is a trap for bedload, with considerable sediment being stored upstream of the bridge. As a result, the channel is unstable in this location, and is at risk of creating a new channel through lateral migration. Other stream variables indicate that bankfull width-to-depth ratios are in the high range for what might be expected for the channel. Except for a few locations, the channel is relatively unconfined during floods, allowing flood waters to spread out onto the valley. By allowing the channel to occupy its floodplain during floods, the destructive force of large floods is lessened. Restoration recommendations include re-constructing the Wickersham Bridge slightly upstream along a new alignment of the channel, with a wider bridge span. Recommendations would also include a levee setback along the channel downstream in multiple locations. Vegetation along Mill Creek is abundant, with many large cottonwoods providing shade and large wood to the channel. Because it is an essential component of a healthy stream, efforts need to be enforced to maintain large wood in the channel.

Elimination of the bedload trap caused by the Wickersham Bridge would initiate the process of improving stream stability and function throughout the Mill Creek reach. The channel below the Wickersham Bridge has been sediment starved because of the trap and has become steeper and less stable over time because of it. Reducing the steepness of the channel and providing for improved floodplain access through the use of levee setbacks in multiple locations would increase sinuosity, increase entrenchment and bankfull width-to-depth ratios, stabilize the channel, and improve riparian conditions. These actions would directly benefit aquatic habitat by reducing sediment inputs, improving large woody debris recruitment, and increasing shade over time.

Channel and floodplain conditions at Coppei Creek indicate that the channel is highly confined by tall, mostly silt-erodible banks over much of its length, with low entrenchment ratios. The channel has a wide range of bankfull width-to-depths. This channel is in adjustment and will over time erode high banks along the channel and create more of a floodplain surface within the entrenched area. Recommendations for Coppei Creek include expansion of floodplains and revegetation with riparian species along the channel. This action would move the Coppei Creek reach closer to a functioning system. The expanded floodplain would allow riparian vegetation to re-establish along the stream, thus providing roughness and channel diversity. This diversity creates the refuge necessary for healthy aquatic systems. The improvement of the floodplain and subsequent riparian areas would trap sediment, build banks, hold water in the system longer into the base flow season, and improve the stream cover necessary for cooler summer temperatures.

1. Introduction and Purpose

This assessment is being completed for the Walla Walla County Conservation District in Walla Walla County, Washington. The purpose of this assessment is to describe fluvial geomorphic conditions along a section of the Walla Walla River below College Place, Washington; a section of Mill Creek upstream of the City of Walla Walla; and a section of Coppei Creek upstream of Waitsburg, Washington. Fluvial geomorphology is the study of streams and rivers and their form, processes, and function. It is important to understand the fluvial geomorphology of streams in order to anticipate the effects of stream flows on stream channels and adjacent riparian areas, floodplains, and valleys, and to find ways to maintain the health and integrity, and proper function and form of stream channels. It is also vitally important to balance, consider, and accommodate human uses of areas adjacent to stream channels, floodplains, and riparian areas. By improved understanding of fluvial geomorphic processes we can learn to avoid costly mistakes in managing streams and floodplains that can lead to property damage or loss of life, and improve the overall condition of the stream and the surrounding environment. This assessment will:

- Describe fluvial and relevant watershed processes;
- Identify how the stream has changed as a result of human activities;
- Identify potential problems within a stream corridor;
- Help refine restoration project goals and objectives;
- Relate the potential impact of proposed projects on the stream system and how it functions; and
- Provide information needed for project development, design, and monitoring.

Much of the flood-prone areas along channels covered in this report are developed, and impacts include roads, clearing of riparian areas and floodplains for agriculture, including pastures and wheat farms, and housing development. The direct and indirect impacts of development within floodplains have decreased water quality, along with valuable fish and wildlife habitat. Much of this development was done before fully understanding fluvial processes, and as a result conditions along some of the streams covered in this report are unstable or potentially unstable and in need of rehabilitation. This report will provide recommendations for environmental restoration along the stream sections that are designed to accommodate the full range of flows of the river. Restoration will be designed to provide a more stable river pattern and river dimension and profile while maintaining the health and integrity of the stream systems and at the same time accommodate appropriate human uses.

Project Area

The streams assessed in this report are all located in the Walla Walla River Basin (WWRB) (figure 1). The WWRB is located in southeast Washington and northeast Oregon, and is 1,758 square miles in area. The eastern one-fifth of the WWRB lies in the steep, volcanically-derived, lightly timbered western slopes of the Blue Mountains within the Umatilla National Forest. The remainder of the WWRB consists of moderate slopes and level terrain.

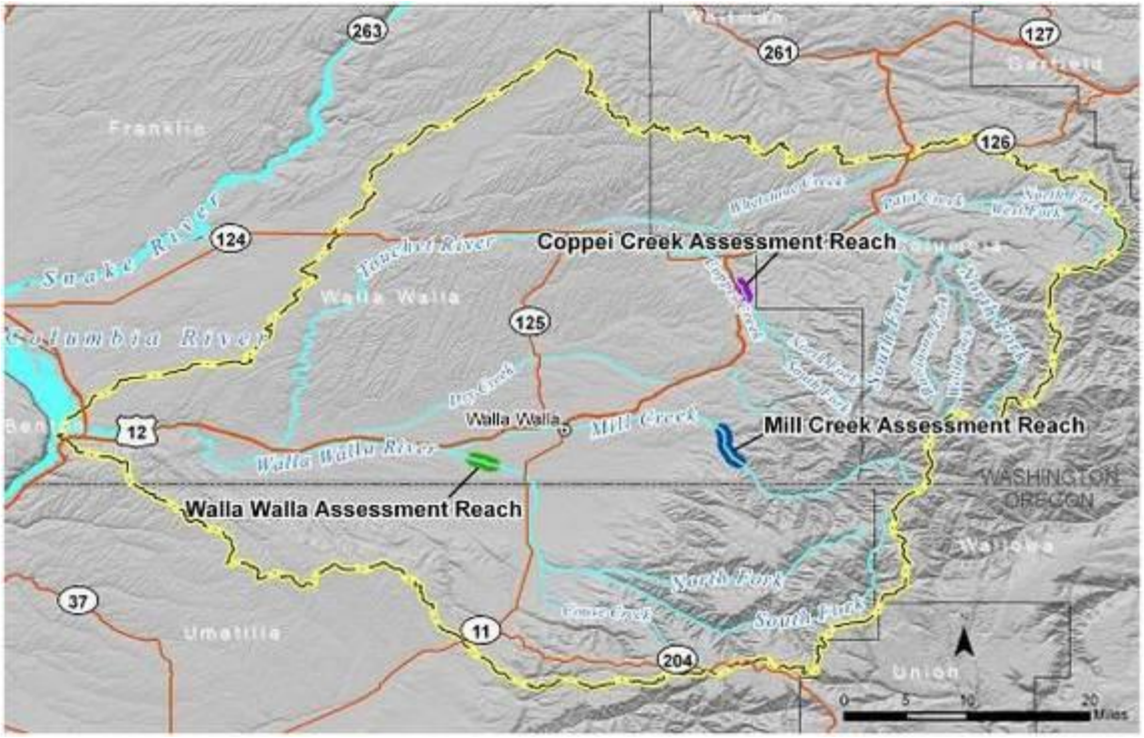


Figure 1. Location map of the Walla Walla River Basin (WWRB) and the assessment reaches associated with the Walla Walla River, Mill Creek, and Coppei Creek Geomorphic Assessment

The WWRB is part of the historical territory of the Walla Walla, Cayuse, and Umatilla Indian Tribes. The land was ceded to the Federal Government under the Treaty of 1855. However, the Tribes still have reserved rights for these lands that include the harvesting of salmon in streams in the WWRB.

2. Methods

Channel Surveys and Sediment

Stream surveys were completed on the assessment reaches for wetted and bankfull and floodplain widths; unstable stream banks; pool dimensions such as depth and length; riffle spacing and length; and amounts, orientations, and sizes of large wood. Streambed sediment was characterized throughout the study reach; sediment Wolman Pebble Counts were completed at several locations. Detailed cross-sections of the channel were surveyed with survey equipment at selected locations along each reach.

Bank stability was assessed along each study reach, which included an ocular estimate of the length of unstable banks on both sides of the river. Bank stability assessments were completed to estimate bank stability, including:

- Bank height and length,
- Percent surface protection (an estimate of bank protection from vegetation and other factors), and
- Root depth and density (an estimate of how much roots are protecting the bank).

The data were tabulated and a summary of stability was determined for each site evaluated. Not all unstable bank areas were evaluated; priority was given to those reaches where future projects are most likely.

Cross-section Survey and LiDAR

Survey equipment was used to survey sites for detailed cross-sections at two sites along the Walla Walla River and Coppei Creek, and three along Mill Creek. Light detection and ranging (LiDAR) has been used to generate detailed topography along the entire study reach, and has provided details on flooding extent, channel conditions, and features such as meander characteristics, gravel bars, vegetation extent, and river widths. This data has been used to generate cross-sections, bankfull channel dimensions, and meander features.

Riparian Vegetation Surveys

Plots to determine riparian vegetation extent and abundance were completed. The focus of vegetation surveys was to determine the condition, composition, and extent of riparian vegetation along the study reach. Efforts were made to determine the age classes of vegetation to see if there was any new recruitment of riparian vegetation, especially cottonwoods. Survey information was to be used to determine if the types and abundance of riparian vegetation was near reference conditions, and whether the species were suitable for stabilizing stream banks, providing large wood to the channel, and reducing the erosive energy of floods.

Assessments of the three stream reaches were done to compare existing conditions with reference conditions, and identify native plant species suitable for use in restoration. Information gathered will be used to recommend projects to restore stream functioning where it has been altered.

The reference area was surveyed in September and October 2009 by walking the assessment reaches and collecting information to characterize the vegetation of each reach. Plots were taken in areas subjectively determined to have representative vegetation. Dominant species were identified when necessary plant structures were present. Species, disturbances, and conditions other than those mentioned in this report may be present. Four plots were surveyed on the Walla Walla River and Coppei Creek, and five were surveyed on Mill Creek. Plots measured 100 square meters in size (5 × 20 meters or 10 × 10 meters). In all plots, trees were counted and estimates of cover were taken by species and height class. A reference site for botany was needed for comparison of conditions on the assessment reaches. The closest stream reach in the Walla Walla Basin that can be used to describe historic reference conditions for the assessment reaches is at Lewis and Clark State Park on the Touchet River northeast of Waitsburg, Washington. Riparian vegetation in this location has been relatively undisturbed since settlement of the Walla Walla Basin began.

3. Watershed Conditions

Streams and Riparian Areas

Stream channel conditions in the Walla Walla River and its tributaries have been dramatically impacted by land management practices that were gradually adopted as the region was settled by European Americans. Because no historic physical quantitative stream data exists for the assessment streams, the impacts to stream channels cannot be quantified; however, these streams have been dramatically altered as a result of destruction of riparian zones and alteration of channels and floodplains. Many areas along the assessment reaches are in agricultural production and timber harvest is common in the upland areas of assessment watersheds. See figure 2 for a land use map of the Walla Walla Basin. In general, stream channels reflect a broad range of impacts, including (USACOE 1997):

- Removal of floodplain and stream-side riparian vegetation;
- Interruption of natural river geomorphologic processes by construction of dikes and levees, installing rip-rap, and stream channelization and straightening;
- Alteration of stream flows;
- Construction of obstructions in the channel; and
- Increased fine sediment input.

Channels within the assessment reaches, as well as most other river channels in the country, have been "controlled" to some extent to accommodate land uses introduced by European settlers. Channels also have been affected by disturbances in watersheds upstream such as fire, forestry, roads, and other land uses. Along the channels, measures have commonly been taken to keep stream channels from meandering and migrating laterally across their floodplains, and to prevent overbank flooding. These measures can include construction of dikes and levees, channelization, and rip-rapping, which are all common along the assessment reaches. These channel manipulations interfere with natural channel geomorphic processes, and disrupt relatively stable channel patterns that are developed and maintained by the channel, and negatively affect channel stability.

Stream channel flow patterns, morphology, and other features are determined by physical variables including channel width, depth, velocity, flows, slope, channel roughness, sediment load, and sediment size (Leopold et al. 1964). A change in any one of these variables results in adjustments in the other variables. Examples of changes include lateral channel migration and higher than normal rates of bank erosion, abnormal channel erosion or sediment accumulation, increased flooding with lower magnitude base flows; increased sedimentation; and substrate material size changes.

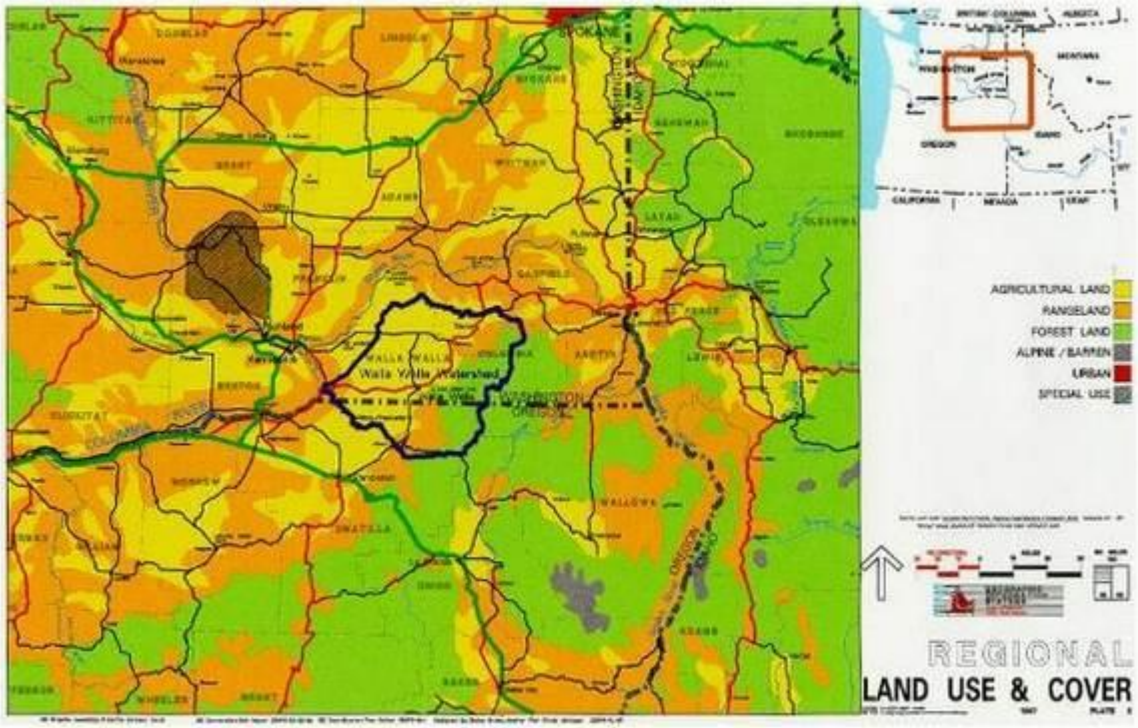


Figure 2. Land use map of the Walla Walla Basin

Stream systems that are geomorphically healthy have a sinuosity, gradient, and channel geometry that allows transport of water and sediment received from upstream. For a geomorphically healthy channel, the sediment is the result of natural rates of erosion of the watershed and stream channel under a natural flow pattern. If for any reason the sediment transport capability of the channel is diminished, or sediment is increased from upstream sources, sediment may accumulate in the channel. The most evident effects of sedimentation on channels from watersheds upstream of the assessment reaches are: (1) increased bank erosion and encroachment on riparian vegetation due to forced lateral channel adjustment; (2) higher degree of fine sediment and cobble embeddedness resulting in lower stream productivity and lower salmonid reproductive success; and (3) a reduced amount of pool habitat.

Although no past historic stream physical habitat data exists for the Walla Walla River Basin or assessment reaches, channel changes listed above have had the following effects on channel conditions throughout the basin and along the assessment reaches:

1) Stream channels are less sinuous and the gradients are steeper;
2) Stream channel width/depth ratios are higher from sediment accumulation and bank erosion, or the streams have degraded or “down-cut;”
3) There is less pool habitat, and more shallow riffles or runs;
4) Streambed sediment sizes are smaller with a substantially higher proportion of sand, silt, and embedded gravels.

Expansive riparian zones once existed along streams covered in this assessment, but agricultural and other land use changes have had an impact on streams and riparian areas. For instance, along the Oregon portion of the Walla Walla River upstream from the assessment location, an estimated 70 percent of the existing riparian zone is in poor condition (Water Resources Commission 1988) as a result of impacts to channel floodplains. Similar impacts have occurred along Mill and Coppei creeks.

Riparian areas are important because streams and terrestrial ecosystems are linked, being separated only by a riparian zone. Streams reflect impacts that occur throughout their drainage basins, and land uses and management practices such as agriculture, grazing, timber harvest, or road and bridge construction can have a significant effect on the aquatic ecosystem. Healthy riparian areas maintain fish and wildlife habitat and protect adjacent lands by buffering and very effectively moderating the negative effects of land use practices on the aquatic ecosystem. Riparian vegetation provides logs and branches that shape channel morphology, retain sediment and organic matter, and provide essential cover for fish species. As trees mature and fall into or across streams, their large mass helps to control the slope and stability of the channel, and also help create high-quality pools and riffles. Natural recruitment of large, woody material from the riparian zone is reduced by the reductions in riparian zone widths through land management impacts such as clearing riparian forests. These reductions are aggravated by intentional removal of logs and root wads that are seen by landowners and local residents as impediments to flow and making flood events worse. However, in many cases, trees in streams are important and often essential for maintaining stream stability (Platts 1991). Riparian vegetation root systems are important for stabilizing stream banks and maintaining good channel characteristics and aquatic habitat.

Large woody debris, undercut banks, and overhanging riparian vegetation provide critical cover for fish, especially salmonids. Abundance of fish in streams has been correlated with the abundance and quality of in-stream cover. When large woody debris is removed from a stream, the surface area, number, and size of pools decrease and the mean water velocity increases.

The characteristics of riparian conditions are important for streams and floodplains. Streamside vegetation needs to be vigorous and dense and to have enough species diversity that it can form layers over the ground. Each vegetative form type plays an important role in forming and protecting the aquatic habitat. In some situations, the root systems of grasses and other plants trap sediment to help rebuild damaged banks. During flood events, water moving at high velocity transports large amounts of sediment within the channel. As the flood water rises up and then over the banks, it flattens flexible stream bank vegetation (e.g., willows and grasses) into mats that hug and thus protect the stream bank from erosion. Roots of riparian vegetation also play a critical role in stabilizing stream banks.

Riparian vegetation forms a protective canopy that helps maintain lower stream temperatures in summer. At present, only a fraction remains of the riparian trees providing shade to the Walla Walla River drainage (USACOE 1997). The effect of the lack of shading is elevated temperatures throughout the WWRB, which appears to be a critical limiting factor to quality aquatic habitat.

Although no historic quantitative stream physical habitat data exists for the assessment streams, it is highly likely that these streams have been dramatically altered as a result of destruction of riparian zones. Resultant stream instability and fish habitat degradation is generally characterized by the following: (1) less in-stream cover associated with large organic debris, cutting of undercut banks, overhanging vegetation, and surface turbulence; (2) fewer slack-water pockets/pools associated with large organic debris; (3) reduced in-stream depth/velocity/substrate diversity; (4) reduced stream productivity resulting from reduced energy input from detritus; (5) reduced intergravel flow as a result of increased sedimentation (i.e., reduced stream productivity and fish reproductive success); and (6) higher water temperature resulting from reduced shading.

Streams, Communities, and Land Uses

Almost all of the lands along the assessment reaches are privately owned. Several communities are located near these reaches, and houses, ranches, and farms border the river along the assessment reaches.

General threats to stream geomorphology, as well as to healthy ecosystems for aquatic organisms and the human environment, resulting from land uses along the assessment reaches include:

- Potential catastrophic flooding exacerbated by channel changes and improper flood zoning;
- An unstable river system without functional floodplains and restriction of river's natural flowpaths needed to dissipate stream energy;
- Eroding stream banks and hillslopes;
- Threats to water quality from potential nutrient sources, such as septic systems immediately adjacent to waterways and runoff from livestock and horse pastures causing manure to reach streams and wetlands;
- Wind drift from agricultural chemical sprays, burning of crops, pesticide and herbicide applications to fields, sources of direct and indirect deposition from air pollution and windblown dust from tilled fields;
- Soil erosion from tilled fields;
- Storm water runoff originating from urban areas (especially for the Walla Walla River);
- Noxious weed invasion; and
- Poor aquatic habitat.

Walla Walla River

The assessment reach on the Walla Walla River is located near College Place and Walla Walla, Washington, both with a combined population of about 38,000; and downstream of Milton-Freewater, Oregon, population 6,500 (figure 2). The upper part of the Walla Walla River above the assessment reach drains forested uplands in the Blue Mountains, and agricultural lands in lower elevation areas. Along the assessment reach there are numerous small ranches and farms with both irrigated and non-irrigated agriculture. Agricultural activities tend to encroach upon the stream, limiting the width of the riparian vegetation. In some areas farmed land extends to the river, but in most areas there is a buffer of riparian forest and shrub vegetation. Although the width of this riparian zone is limited, there is enough stream bank storage of water to support a reduced riparian habitat. Where riparian vegetation has been cleared for farming or pasture on one bank next to the channel, stream banks are highly vulnerable to erosion, and there is increased potential for channel migration into cleared areas. Landowners in the lower section of the assessment reach realize this fact, and have constructed rock barbs or placed rip-rap to protect vulnerable, sparsely vegetated banks. Levees, rip-rapped banks, and rock barbs were observed in sections of the river, and were probably constructed by landowners to protect roads or irrigation withdrawal points.

Along the assessment reach there are no houses immediately along the channel. Houses tended to be located on terraces outside the area flooded by infrequent, large floods, probably due to awareness of the extent of flooding from past large, infrequent flood events. However, farms, pastures, fences, and other infrastructure are located in the areas that would flood during large, infrequent floods. Often, channels are re-located or straightened to accommodate farms, roads, or bridges. There is evidence of channel straightening where the river goes under the Frog Hollow Bridge. Often, flood flows that go over bank are restricted in bridge locations, and as a result, local stream velocities and channel and bank erosion are accelerated at and downstream of the bridge. Also, the old railroad grade and abutments below Frog Hollow Road Bridge constricts flood flows that go over bank, and may accelerate stream flow velocities at high flows, leading to channel changes. Constricted flows at the bridge may locally increase bed load sediment transport, and then deposit the sediment downstream after flow velocities decrease. Sediment depositing downstream may be playing a role in actively eroding bank instability observed downstream along the north bank of the river.

Land management over time has influenced conditions along the river. The river conditions today reflect a combination of impacts including riparian forest harvest and clearing, channel straightening and realignment, large woody debris removal, diversion excavation, construction and maintenance, channel confinement by bridges and railroad grades, grazing, and other impacts. The present day channel reflects all these past impacts, and is in a period of adjustment. As a result, the channel is changing and dynamic, adjusting to the new conditions, but towards a rough equilibrium condition where the inputs of water flow and sediment supplied to the channel are balanced by transport of this material from the stream system. Channel adjustment often gives rise to channel instability, as evidenced by approximately 1,450 feet of unstable banks observed along the Walla Walla assessment reach (figure 17). Some of this instability may have occurred as a result of natural channel conditions. However, some of this instability may be the result of human-use related channel changes. Evidence that will be explored further suggests that over recent history, the river has changed course numerous times, and will continue to adjust into the future. For this report, the goal is not to report on channel problems and how to return back to a pristine state, but to recommend management options that will improve conditions overall.

In summary, conditions along the Walla Walla River assessment reach that have been affected by land use and management include changes in channel shape including bankfull width-to-depth ratios, reductions in floodplain widths, and areas where the river is able to flood and reduce erosive energy; increased rate of channel migration due to vegetation clearing; increased sedimentation (which also leads to increased channel migration tendencies); and other changes related to the quality and quantity of fish habitat.

Mill Creek

The Mill Creek reach is located upstream of Walla Walla, Washington (figure 3). In this area Mill Creek flows through a narrow valley with numerous small ranches and housing subdivisions located on both sides of Mill Creek Road. In contrast to the Walla Walla River, in some areas houses are at risk and are located immediately adjacent to the channel; but in most cases, houses are located out of the more frequently flooded areas adjacent to the channel. In the Wickersham Bridge area, several houses are located in areas that are at high risk of flooding due to a combination of factors. Construction of the bridge required a channel re-alignment that has led to accumulation or aggradation of sediment upstream of the bridge. Because of sediment deposition, the capacity of the bridge has been reduced.

Figure 3. Aerial photo of Walla Walla River assessment reach (approximately 1.7 miles long; flow is from east to west)

Along the Mill Creek assessment reach, farming is the dominant land use in the uplands. The mostly forested headwaters of Mill Creek provide the water supply for the city of Walla Walla. Like the Walla Walla River, in many areas riparian forests and shrubs are located along the stream. However, in some areas these forests have been cleared for pastures, farms, or lawns. Often, it was observed that several areas with unstable eroding banks resulted from clearing native riparian vegetation. Mostly, roads are located out of areas likely to be flooded; however, a bridge located mid-way through the study reach accesses homes on the opposite side of the valley from the highway. In a few places along the assessment reach, Farm Service Agency (FSA) Conservation Reserve Enhancement Program (CREP) projects, including weed barriers and plantings of native species, have been completed.

Figure 4. Mill Creek assessment reach (approximately 3.2 miles long; flow is from south to north)

Mill Creek in throughout the study reach is dynamic and highly prone to changes in meander pattern and channel migration during high flows; as a result, it is difficult to predict how the channel location will change at higher flows. Similar to the Walla Walla River, the stream is in rough equilibrium with sediment supplied from upstream areas, locally depositing sediment in the form of gravel bars, and at the same time diverting flows into stream banks and causing erosion and channel migration. Several landowners report significant channel changes occurring over time. Also, older aerial photos reveal that in several areas the channel has shifted position over time. As part of the land use history of the channel and the valley, there is evidence that the stream has been channelized and diverted away from cleared farm land in the central part of the valley, and continues to be diverted away from the center of the valley by ad hoc levees, rock barbs, and channel excavations in some locations. Until a more stable channel meander pattern, floodplain width, and a wide enough zone for the channel to migrate is attained, this stream will continue to change course and migrate throughout the valley, especially where it has been straightened or altered to accommodate land uses. For Mill Creek, it is important to delineate areas where the stream has adequate floodplain needed to migrate in response to sediment inputs and higher flows.

Coppei Creek

The upper sections of Coppei Creek drain forested upland areas in the Blue Mountains. The assessment reach on Coppei Creek is located about 3 miles upstream from Waitsburg, Washington (figure 5). There are two farm houses and outbuildings in the valley along the assessment reach located on the valley floor away from the stream. Along the upper part of the assessment reach, CREP projects consisting of the installation of weed control barriers and plantings of native species have been completed. The lower one-half of the assessment reach has been channelized sometime in the past probably to increase agricultural lands, and has a narrow riparian forest along the channel, and wheat fields on either side of the valley bordering on the channelized stream. Compared to less impacted sections of the stream located upstream, the floodplain was wider and the stream was more sinuous before the channel was channelized. Cross-sections of the valley in this location indicate that the stream has been confined to a narrow strip in the center of the valley to maximize farmland. The cross-sections show that valley soils were pushed up against the channel creating continuous levees that confined the channel. As a result of this land use, the channel has down-cut an average of 6 to 10 feet vertically through much of the assessment reach, in some areas down to bedrock, and a large volume of valuable, irreplaceable topsoil has been lost. Down-cutting is a result of concentrating the stream flow into a narrow confined channel. The stream appears to have down-cut to its full extent, and is now eroding laterally into streambanks composed of highly erodible loess soils. The ensuing bank erosion will also result in significant soil loss as the channel adjusts.

Figure 5. Coppei assessment reach (approximately 1.2 miles long; flow is from south to north)

Observations of agricultural runoff along the assessment reaches indicate that during runoff events fine sediment is transported by side channels and road ditches to the assessment stream channels. For example, sheet and gully soil erosion was observed along Coppei Creek in January 2007 from nearby tilled wheat fields (figure 5). This was not a particularly big rainfall event, but it transported significant amounts of fine sediment into the stream channel. The small upland tributary channels along all of the assessment reaches often are plowed over, left void of vegetation filter strips along the channel bottoms to filter sediment from runoff. Fine sediment delivered to channels is a pollutant and has a detrimental effect on fish production and other aquatic life.

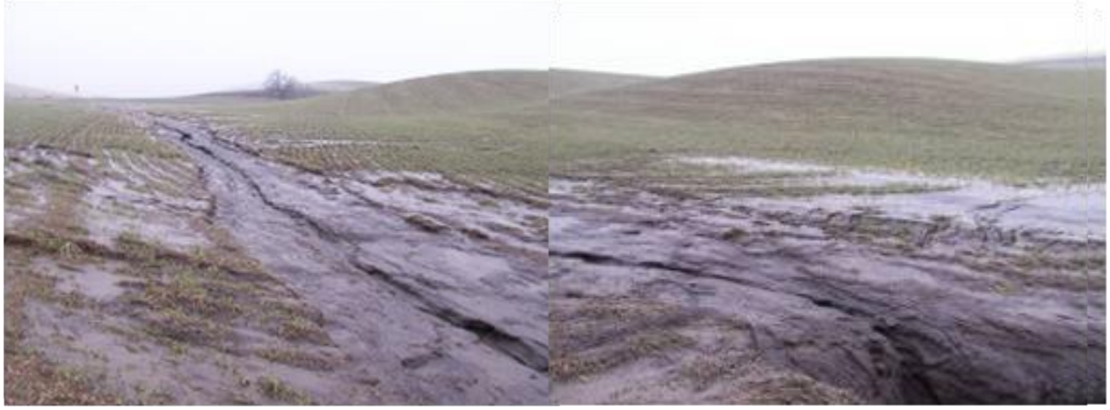


Figure 6. Soil sheet and gully erosion in loess soils in uplands above Coppei assessment reach (Alex Amonette photo, 2007)

Fisheries

Historically, the Walla Walla River and tributaries supported significant runs of spring Chinook salmon and summer steelhead. Fall Chinook, chum, and coho salmon are also believed to have been present in the Walla Walla River in smaller numbers (Chapman 1981). Anadromous fish have spawned and reared throughout the middle and upper reaches of the Walla Walla River and its tributaries. Steelhead smolts are planted in the Touchet and Walla Walla Rivers (see figure 7). Steelhead are reared at the Lyons Ferry Hatchery on the Snake River and are placed in acclimation ponds on both the Touchet and Walla Walla Rivers prior to release. The decline of the anadromous fishery can be largely attributed to the irrigation diversions that dewater stretches of river and block or impede fish passage. The river system now supports a fair run of steelhead and some resident trout and char, most of which are redband (rainbow) and bull trout.

The bull trout is a wide-ranging, typically non-anadromous species that inhabits most of the cold lakes, rivers, and streams throughout the western states and British Columbia. Within the Walla Walla River Basin, bull trout are found in the upper portion of the North and South Forks of the Walla Walla River, upper Touchet River, Mill Creek, and some of their tributaries (figure 8). Bull trout require cold water, with 7° to 8° Celsius (C) [45° to 47° Fahrenheit (F)] appearing optimal and 15°C (59°F) maximum. Spawning occurs in cool water, below 9°C (48°F). Optimal incubating temperatures seem to be 2° to 4°C (36° to 39°F). Spawning occurs from August through November with eggs hatching in late winter or early spring. Emergence occurs in early spring through May, commonly following spring peak flows. Because of extended time in the substrate, bull trout are susceptible to mortality in unstable conditions. Successful reproduction requires channel and substrate stability and adequate winter water flow to prevent the substrate from freezing. Bull trout require complex forms of in-stream cover. Adults use pools, large woody debris, large boulders, and undercut bank for resting and foraging. Juveniles also use side channels and smaller wood in the water. Channels for moving between safe wintering areas and summer foraging areas are also necessary.

One of the problems facing bull trout is the number of passage impediments and barriers in the WWRB. Bull trout may migrate many kilometers within a given basin during the winter when water temperatures drop to the point that allows them unrestricted access throughout the Walla Walla River Basin. Their population is fragmented because passage impediments and barriers prevent them from reaching many areas.

The interior redband trout is a subspecies of the rainbow trout and is found throughout the WWRB. In the portions of streams and rivers that dry up or become too warm, these fish migrate to upper reaches. Diversion dams can prevent, or at least inhibit, this migration. Genetic diversity of this fish has been impoverished by land and water use practices and the stocking of nonnative rainbow trout (Behnke 1992).

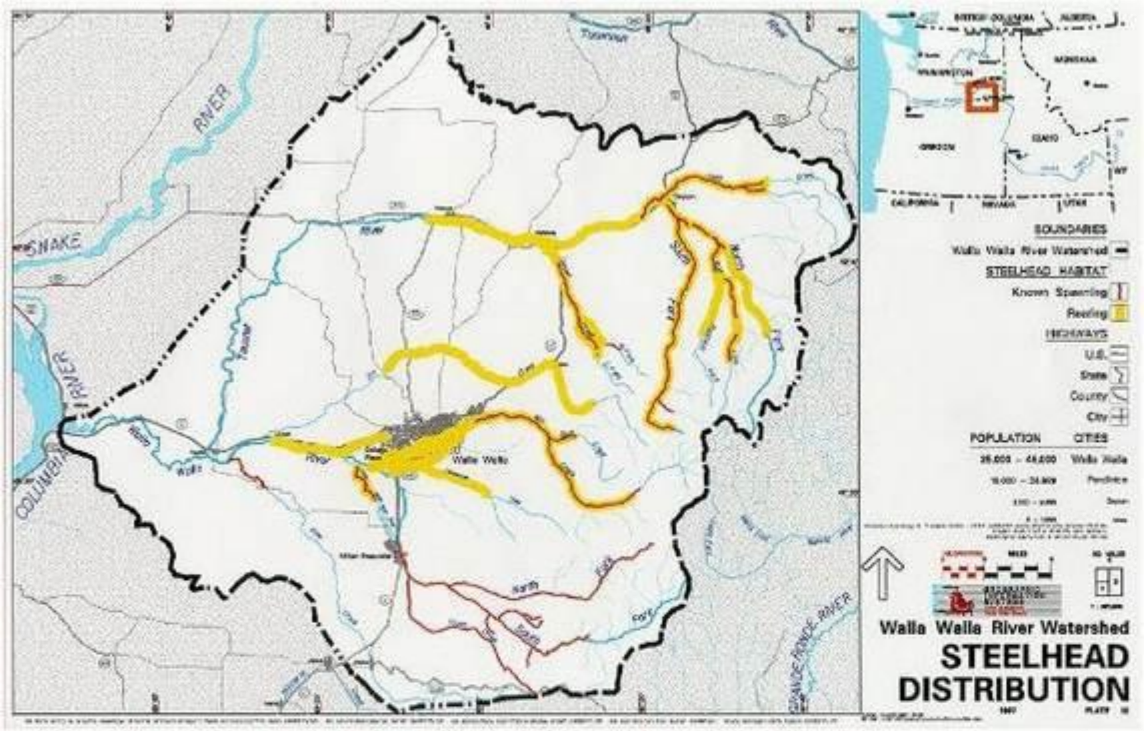


Figure 7. Steelhead distribution in the Walla Walla River Watershed

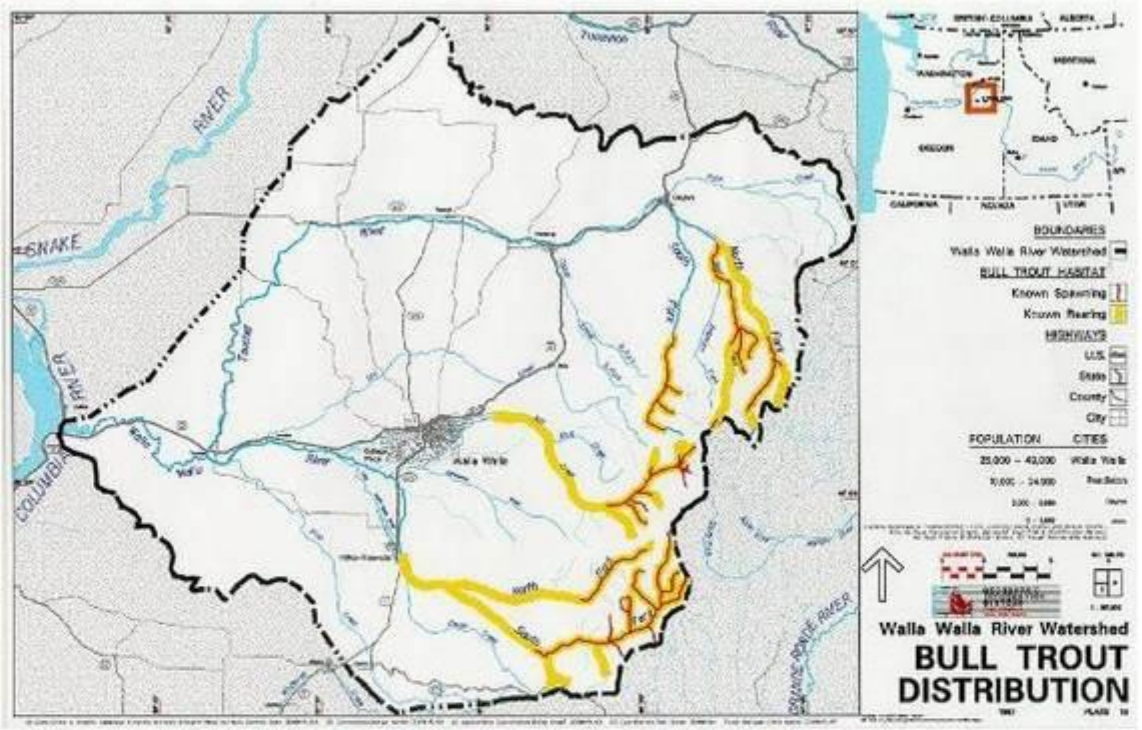


Figure 8. Bull trout distribution in the Walla Walla River Watershed

Geology and Soils

The Walla Walla assessment reach is in a mature alluvial valley with a well-developed floodplain bounded by gentle river terraces deposited by the river. There is a well-developed dendritic drainage network upstream of the study site in the tributary drainages. For Mill and Coppei creeks, the valley forms are more youthful, with some floodplain development, but bounded by low hills. Much of the surface material in upland areas adjacent to the assessment reaches is loess soil, derived from previous glacial activity, and re-deposited by wind. Underlying the loess soils is bedrock comprised of basalt.

From 17 to 6 million years ago (Mya), approximately 300 (Alt and Hyndman 1995), immense, separate Columbia River basalt lava flows erupted from large fissures (volcanic vents) located in the area where southeastern Washington and northeastern Oregon and Idaho converge. In eastern Washington alone, these basalts cover an area of tens of thousands of square miles and contain more than 200 cubic miles of lava (Alt and Hyndman 1995).

The assessment reaches are a result of extensive erosion of this layer over the past 13 million years. Basalt outcrops are visible in the hills along the upper part of Coppei Creek, along Mill Creek, and along the Walla Walla River in the Whitman Mission.

The assessment reaches are controlled laterally by the basalt overlain by loess bluffs along the margins of the valley. The main channel has gravels and the adjacent floodplain has a thin veneer of overbank alluvium and loess. These basalts are not exposed along the Walla Walla River, which has a thick covering of alluvium deposited by the river. However, in several areas basalts are exposed along the banks or on the bed of Mill and Coppei Creeks. The gravels in the river and tributary streams are made up of the Wanapum and Grande Ronde basalts that have been eroded away by the river over the past 15 million years.

Table 1 identifies the prominent features in the valley, other geological controls, and the processes that shaped them.

Table 1. Geologic events in the Walla Walla, Mill Creek, and Coppei Creek assessment areas, Walla Walla County, Washington

Age of Major Event	Shape of Landscape Feature and Valley Form	Geological Processes
2.6 Mya to present	Quaternary alluvium, non-glacial deposits of clay, silt, sand, and gravel deposited in streambeds, fans, and terraces	Deposit by rivers and streams; includes reworked loess, outburst flood deposits, and Mazama tephra (volcanic material)
3–6 Mya	Palouse hills and dunes	Glacial sediments reworked by strong southwest prevailing winds to form sand and loess (silty sediment accumulated from fallout of dust)
5–7 Mya	Rise of the Cascades	Uplifting of Modern Cascades; volcanism
6–15 Mya	Blue Mountains	Uplifting
6–15 Mya to present	Columbia Basin	Subsidence
13 Mya to present	Touchet River and its valley	Channel incision
15 Mya	Palouse Slope, flat featureless plain	Formed by Rocky Mountains, slopes westward
17–6 Mya	Columbia River Basalt Group (covers 63,200 mi^2 in WA, OR and ID)	Massive basalt lava flows spread north and west along Palouse Slope
37 Mya	Cascade Range Volcanism	Juan de Fuca Plate subducted under continent’s western edge
70 Mya	Rocky Mountains	Rise of the Rocky Mountains via subduction
100 Mya	Blue Mountains	Accreted terranes that “docked on” via plate tectonics

4. Assessment Reach Conditions

Hydrology

Climate

The climate of the Walla Walla River Watershed is characterized by relatively mild winters with some rain, snow, and frozen conditions; and long, hot, dry summers. Precipitation in the Walla Walla River Basin varies dramatically and generally correlates with elevation. Precipitation averages about 12 inches per year along the Walla Walla River, with rainfall averaging about 30 inches per year along the Mill Creek assessment reach. Coppei Creek average annual rainfall is about 20 inches per year along the assessment reach. The Blue Mountain uplands in the Walla Walla River Watershed are characterized by long, snowy winters, and mild, dry summers; higher areas can receive over 40 inches per year of total annual precipitation. Snowmelt usually begins in February in lower elevation sites, with peak snowmelt occurring in late March through April. Occasional rain-on-snow events can lead to heavy flooding, especially when deep snowpacks in the upland areas receive relatively warm, sustained rainfall. Historically, large floods in the Walla Walla River Basin streams have been heavily influenced by rain-on-snow events.

Surface Water

The Walla Walla River is part of the Walla Walla River Subbasin (hydrologic unit code [HUC] 17070102) (figure 9) located in southeast Washington and northeast Oregon. The Walla Walla River is located in the central portion of the Walla Walla River Subbasin. There are no dams or reservoirs located in the channel upstream of the study reach. Mill Creek flows from the Blue Mountains, through Walla Walla, and confluences with the Walla Walla River downstream of the study reach near Whitman Mission National Monument. Mill Creek provides water supply for the City of Walla Walla. Coppei Creek flows from the Blue Mountains and is a tributary to the Touchet River. Coppei Creek flows through the southern edge of Waitsburg and confluences with the Touchet River downstream of town.

There is currently one operational gauging station on the Walla Walla River downstream of the assessment reach, a streamflow gage on Mill Creek about 3 miles upstream of the assessment reach, and a gage on Coppei Creek just above Waitsburg, Washington, approximately 1 mile below the assessment reach. Historical flow statistics are available for the gage on the Walla Walla River and Mill Creek. The Walla Walla gage has been in operation since 1951, the Mill Creek gage since 1913, and the Coppei Creek gage since 2003. The Walla Walla River gage is located downstream of the Touchet River, which adds to the drainage area, so flow information from this gage is higher than the flows expected at the Walla Walla River assessment reach. The Mill Creek gage provides a reasonable estimate of high flows at the Mill Creek assessment site. For Coppei Creek, the gage generally represents the flows at the assessment site; however, the limited data set (2003-present) should be noted.

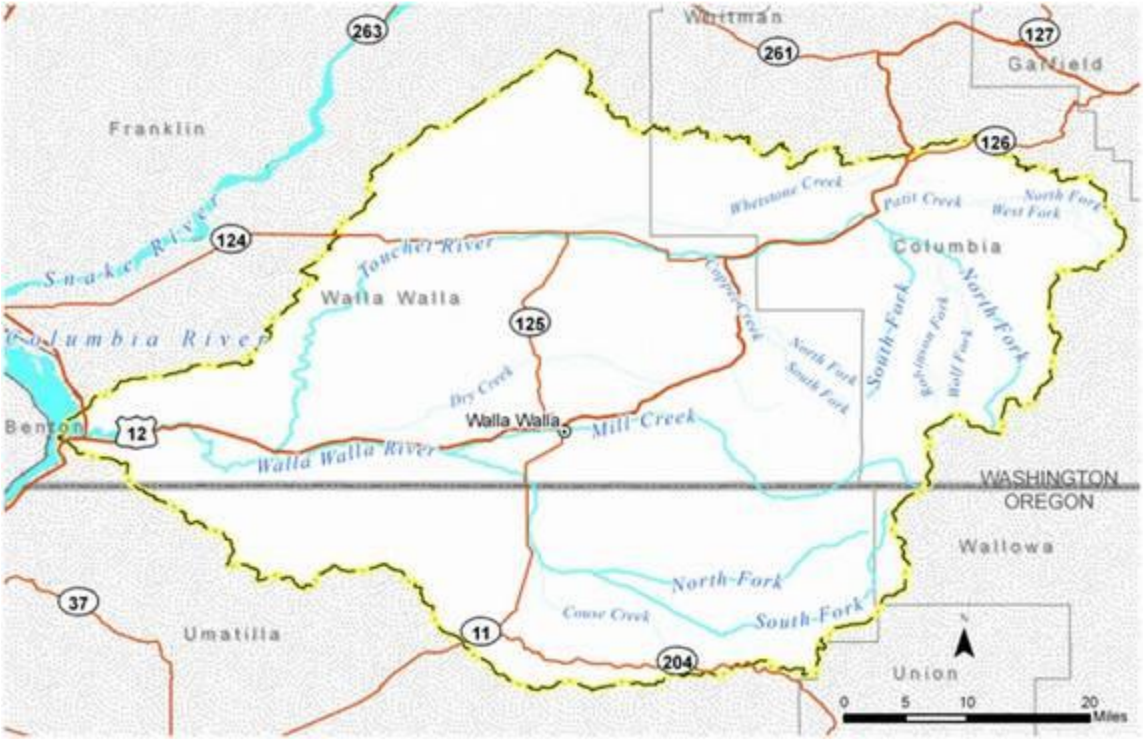


Figure 9. Major drainages within the Walla Walla River Watershed

Summer flows in the Walla Walla River are reduced by irrigation withdrawals, though there is enough water in the dewatered sections of the channels to support aquatic life during the summer months of most years. However, due to a combination of flows being too low and the temperatures of the remaining water being too high, water temperatures can negatively influence aquatic organisms, especially salmonids. This dewatering generally occurs June through October, depending upon flows within the channels. Extremely wet or dry precipitation years expand or shrink this timeframe. Only in the upper headwater sections is the water quality sufficient to support native, cold-water species such as rainbow trout, steelhead juveniles, and sculpin. Summer flows are generally low for the summer months on Mill and Coppei creeks.

Daily mean streamflows at the Walla Walla gage show that stream flows monthly average for the low flow month of August were 22 cfs (cubic feet per second), and higher flows in January had a mean of 1,080 cfs. Daily means for the Mill Creek gage were about 30 cfs, and peak flows in January were 148 cfs. Coppei Creek had August stream flows of about 1 cfs, and January high flows of about 30 to 70 cfs.

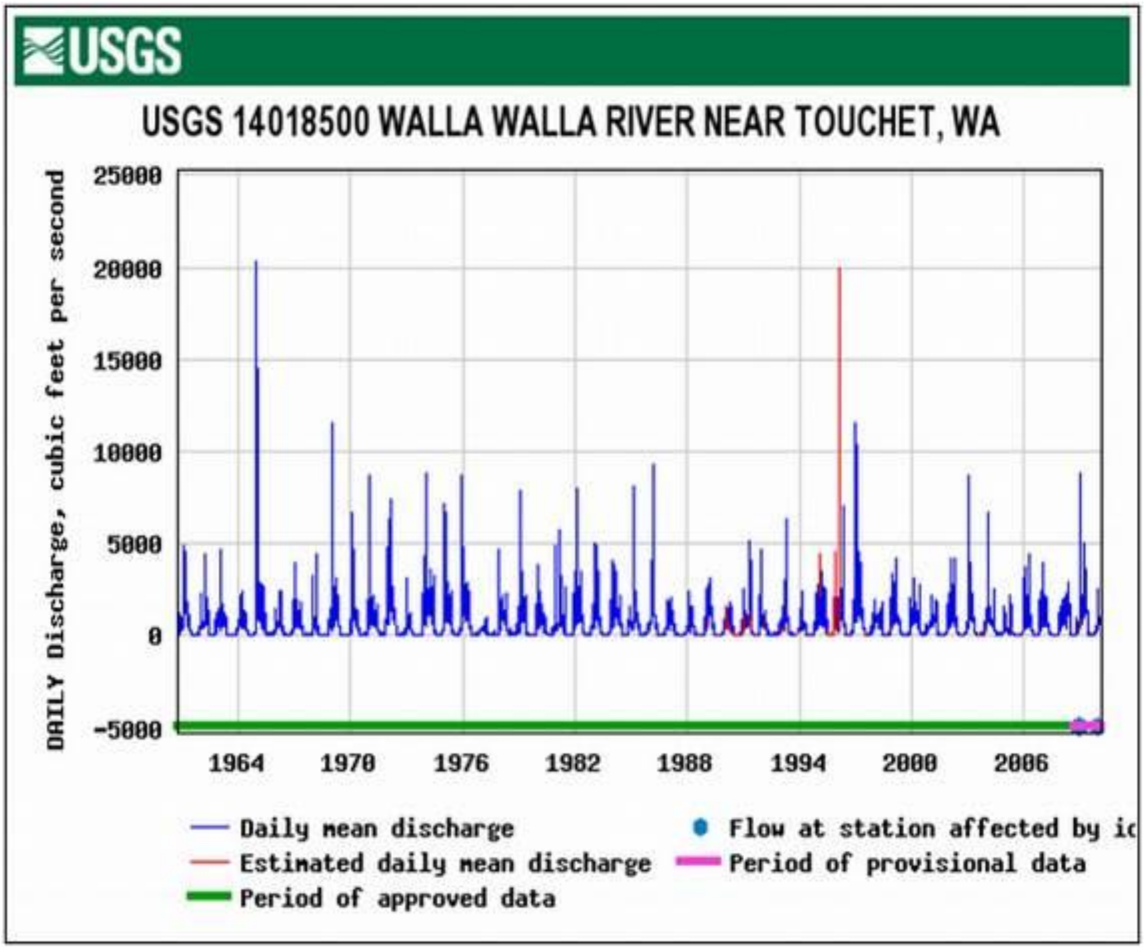


Figure 10. Daily mean discharges for the Walla Walla River from 1960 to present

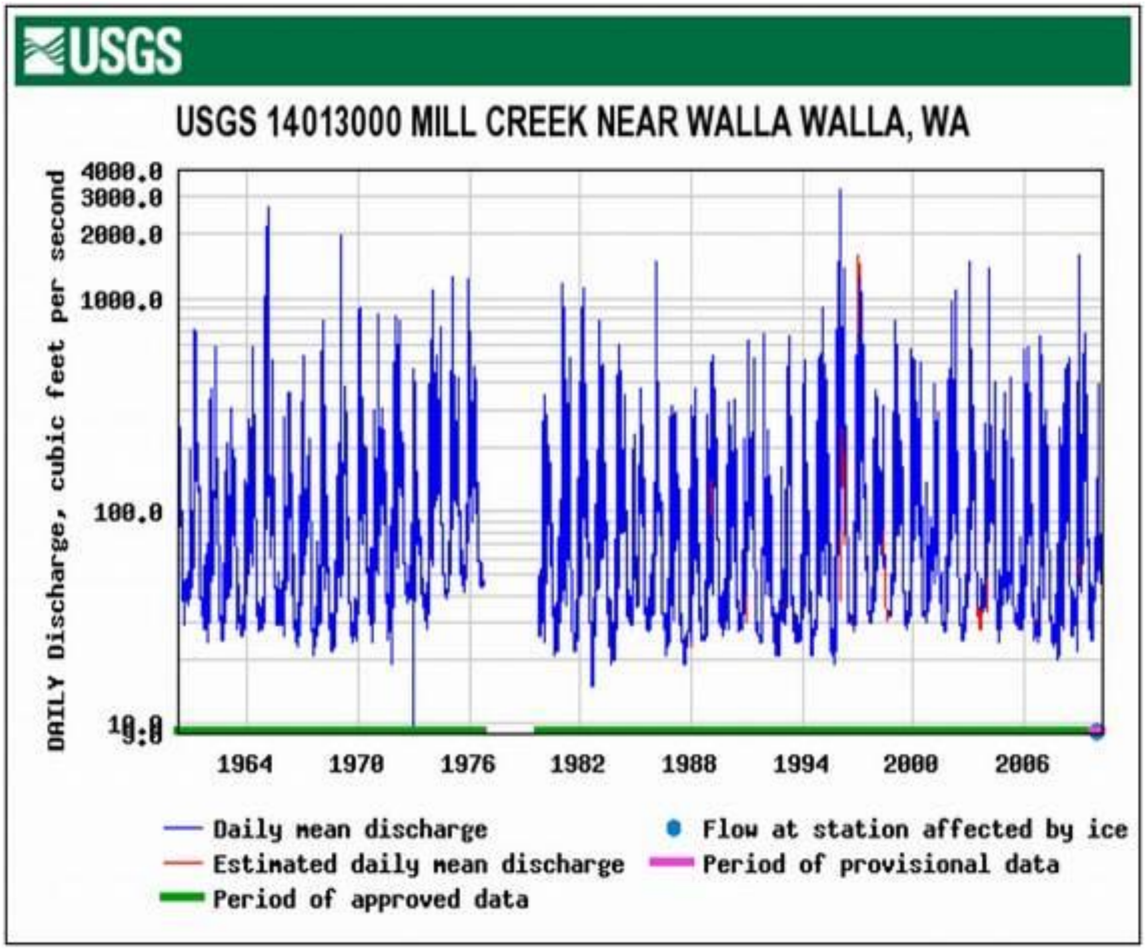


Figure 11. Daily streamflows for Mill Creek near Walla Walla, 1960 to present

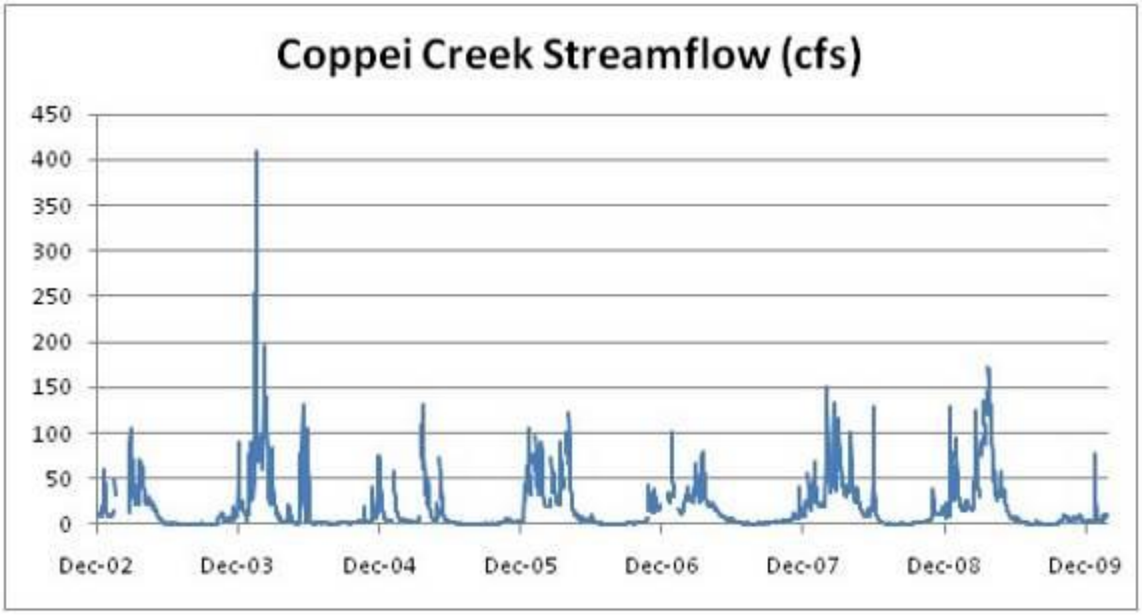


Figure 12. Daily streamflows for Coppei Creek, 2003–present

Channel Forming Flows and Floods

The largest floods of record occurred in 1964 and 1996 for all the assessment reach streams. The gage on the Walla Walla River near Touchet (HUC 14018500) shows peak events for the period of record for the Walla Walla River, 1951–present (figure 13). The peak flow of record occurred in 1964, and was 33,400 cfs. The peak flow from the 1996 flood was 32,500 cfs, comparable to the 1964 flood. Both of these floods, based on Log Pearson Type 3 flood frequency analysis, were determined to be at about the 100-year statistical flood frequency interval. Bankfull flow is approximately 4,000 cfs for this site. This gage is located several miles downstream of the Walla Walla assessment site below a major tributary, and streamflows at this site are much higher than on the assessment reach because the drainage area is much larger. The gage information provides a good indication of the frequency of large floods on the Walla Walla system in the past. The bankfull flow, 50-year, 100-year and 500-year flood estimates (table 2) were estimated using U.S. Geological Survey gage information with Stream Stats, a publicly available program located on the web (http://water.usgs.gov/osw/streamstats/).

Table 2. The bankfull, 50-, 100-, and 500-year flood frequency discharges for the Mill Creek, Coppei Creek, and Walla Walla River assessment reaches

Site	Bankfull Flow	Q50	Q100	Q500	Drainage Area
Mill Creek	642	4,040	4,840	7,020	86.7
Coppei Creek	322	1,790	2,240	3,530	25.6
Walla Walla River	732	3,930	4,880	7,550	125.2

The stream flow record for the Mill Creek gage near Walla Walla just upstream of the assessment reach shows that the 1964 and 1996 events were the biggest on record (figure 14). The 1996 flood had a peak flow of over 6,000 cfs and the 1964 flood had a peak flow of almost 4,000 cfs. Bankfull flow was estimated to be 642 cfs for the assessment site using streamflow records for the 1.5-year return interval flood.

High flows on Coppei Creek for the period of record are around 400 cfs, observed in 2003. Flood estimates for Coppei Creek are not available for the 1996 or 1964 flood. However, during the 1996 flood event, Coppei Creek overflowed its channel at the Highway 12 Bridge in Waitsburg. The channel caused extensive damage by flowing into town and down the highway. Bankfull flows on Coppei Creek are estimated to be 322 cfs, and the 100-year flood is estimated to be over 2,000 cfs.

There is a link between the size of a drainage basin and the type of storm which causes flooding. Every drainage basin has a characteristic called the "time of concentration". This is considered the time it takes for rain from the most distant part of the basin to reach the place where the flooding occurs. Generally speaking, a storm which lasts for the same length of time as the time of concentration will produce the worst flood. The size of the drainage basin is not the only factor. The time of concentration can vary from less than an hour, for a compact rocky basin (a "flash flood") such as drainages in the headwaters of Mill and Coppei Creek, or up to a day or so for the Walla Walla River.

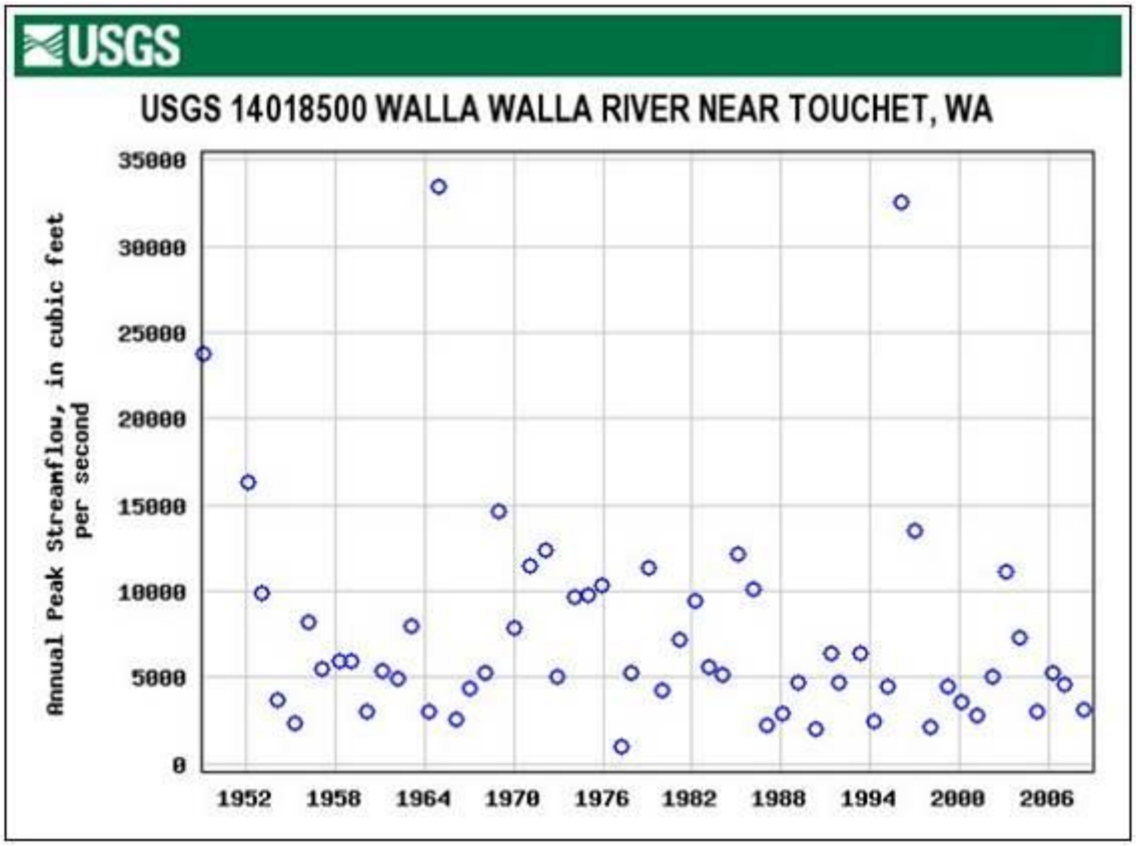


Figure 13. Peak flows for each year of streamflow record, Walla Walla River near Touchet, located several river miles below the Walla Wall River assessment reach

Flows near bankfull tend to be the primary channel forming flows (Leopold et al. 1964). These flows occur on average every 1.5 to 2.2 years. Bankfull flows are also important to use as channel restoration design flows because they represent the most important flows for channel formation and maintenance.

Bankfull flows are confined by the channel banks, and tend to concentrate erosional shear forces on the bed and banks. Hence, flows that just reach the top of the bank are often considered the flows that do the most work at moving sediment through the channel. They occur relatively frequently, compared to larger flood flows. As a result, channels often reflect erosional features created by bankfull flows. Often, bankfull flows will also deposit sediment as bars and other features that help with identifying the bankfull channel. Bankfull width-to-depths and other bankfull channel dimensions are very important for determining the conditions of channels. Once flows exceed bankfull flow, the waters tend to spread out onto the floodplains, and the erosive energy of the flows are dissipated by reduced flow velocities and roughness caused by floodplain vegetation. This is why floodplains are important for more effective stream channel corridor function.

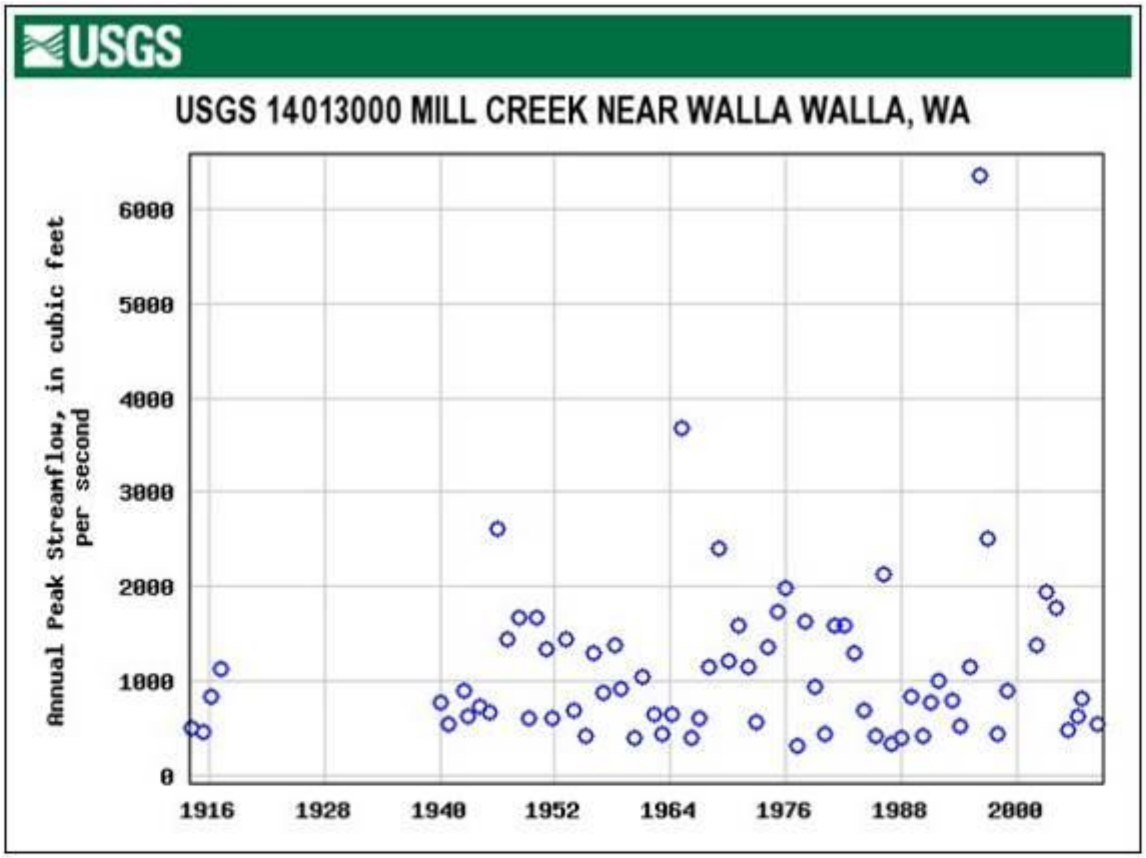


Figure 14. Peak flows for each year of streamflow record, Mill Creek near Walla Walla, located below the Mill Creek assessment reach

All stream erosional processes are driven by gravity. The gravitational force acting on water drives the flow downslope in a confined channel, where the slope of the water surface represents the balance between the energy gradient and frictional resistance from the channel bed and banks. Shear and flow are partially products of water depth, both increasing as water stage increases. However, as water levels exceed bankfull stage and water flows out on the floodplains, the volume of flow increases much faster than does channel shear; as a result it takes more and more water to even modestly increase shear stress once flows have accessed the floodplains. Shear force on the streambed moves the bedload sediment supplied to the channel; and if similar shear stresses were exerted on the floodplains, they would also erode. Typically as flows spread out onto floodplains, shear forces remain about the same for the bankfull channel, but are much less farther out on floodplains because of velocity decreases due to low water depths and channel roughness created by vegetation. In fact, in order for shear forces to be significant for erosion of wider floodplains such as those found along Mill Creek and the Walla Walla River, flows would have to be extremely high. However, for streams like Coppei Creek, where bankfull flows are confined within a gully or "canyon," flows above bankfull are confined within the canyon, and exert tremendous shear and erosional forces on the bed and banks at higher flows.

Hydrology and Climate Change

The hydrology of the Pacific Northwest (PNW) is particularly sensitive to changes in climate because seasonal runoff is dominated by snowmelt from cool season mountain snowpack, and temperature changes impact whether precipitation falls as rain or snow. Based on results from 39 global simulations performed by the Intergovernmental Panel on Climate Change, PNW temperatures are projected to increase an average of approximately 0.3°C per decade over the 21st century. Changes in annual mean precipitation are projected to be modest, with a projected increase of 1 percent by the 2020s and 2 percent by the 2040s.

For eastern Washington, April 1 snow water equivalent (SWE) is projected to decrease by an average of approximately 27 to 29 percent across the State by the 2020s, 37 to 44 percent by the 2040s, and 53 to 65 percent by the 2080s, based on the likely climate model scenarios (Elsner et al. 2009). Annual runoff across the State is projected to increase by 0 to 2 percent by the 2020s, 2 to 3 percent by the 2040s, and 4 to 6 percent by the 2080s. These changes are mainly driven by projected increases in winter precipitation.

It is uncertain what the effects might be on the study reach from climate change, but studies from nearby areas provide insight. Estimates provided by Elsner et al. (2009) indicate that for the eastern Washington Yakima Basin, studies indicate that peak flows are not expected to increase over the next century. However, with less precipitation falling as snow in the watershed, winter flows are expected to increase, and the high runoff season will be earlier in the year, becoming more noticeable by the end of this century. A similar response is expected in the study area watershed.

Hyporheic Flows

Hyporheic flow, defined as water transmitted through deposits of river substrate, was observed along the assessment reaches. The occurrences appeared to be associated with point bars and meanders. Water infiltrating into shallow groundwater along the upstream end of point bars flows downstream through subsurface river gravels, then re-surfaces at the downstream end of the gravel bars. At the downstream end of the river bend, as a result of coming into contact with cooler soil and river deposits, the water emerges from the substrate slightly cooler than ambient stream water, and can offer thermal refugia for aquatic species such as fish. Historically, hyporheic flows probably played a major role in providing thermal refugia for fish during low-flow periods. Streambed gravels were cleaner, with less fine sediment filling the spaces between the gravels, and there were likely more point bars.

As part of restoration, small channels can be strategically located to create localized areas where hyporheic flows can re-enter the river, thus providing cooler water refugia as part of project design. Vertical relief in the streambed (such as pools and riffles) also increases hyporheic exchange because water is essentially pushed into the bed through hydraulic processes. Avoidance of channel straightening and retention or creation of channel sinuosity helps maintain hyporheic flow. Studies of hyporheic flow from the nearby Umatilla River in Oregon recommend maintaining a channel sinuosity of 1.3 or greater to enhance hyporheic flow, and to maintain higher flows in channels in summer. Also, reducing channel and upland erosion and other sources of fine sediment inputs to the channel, and improving the extent of riparian cover, can increase the likelihood that hyporheic flow paths can become established in the river substrate.

Channel Conditions

Stream channel conditions throughout each of the assessment reaches vary, depending on several factors, including the level of channel confinement caused by the construction of levees and channelization, bridges, tributary confluences, agriculture, urban development, sediment transport, large wood accumulations, and the condition, species, and extent of riparian vegetation. Table 3 shows which of these factors affect the assessment reaches.

Table 3. Factors influencing stream channel conditions for the Walla Walla River, Mill Creek, and Coppei Creek assessment reaches

Impacts	Walla Walla River	Mill Creek	Coppei Creek
Levee building and past channelization	x	x	x
Channel confinement caused by bridges	x	x	
Tributary confluences	x	x	
Agriculture	x		x
Urban development		x	
Large woody debris accumulations	x	x	x
Degraded riparian condition	x	x	x

Physical factors that influence channels include channel slope, sinuosity, meander belt widths and floodplain widths, and the nature and mobility of the channel substrate.

The morphology of the river channel over time is directly influenced by runoff from the drainage basin and the amount and type of sediment load (Schumm 1977). The river channel is self-formed in that the streamflow in the channel and the sediment it carries interact to determine the channel morphology (Dunne and Leopold 1978). Channel adjustment occurs by erosion, transport, and deposition of material making up the bed and banks of the channel. The Walla Walla River, Mill Creek, and Coppei Creek morphology, over any given period, adjusts to the variability of flow and sediment in complex ways. Increased high flows tend to increase channel width and depth. Increased sediment availability and transport tends to increase width, steepen gradient by decreasing sinuosity, and decrease depth. Thus, over many years the channel has developed a cross-sectional form reflecting the inputs of flow and sediment. Geology, climate, and the resulting quantities, types, and supplies of sediment, along with the sizes of stream bed material and the geomorphic setting, influences channel form (Beschta and Platts 1986). The morphology of alluvial streams is also controlled by the interaction of flow regime with streamside vegetation and sediment inputs (Hynes 1970).

Self-formed alluvial channels adjust to the flows and sediment supplied to them by changing their pattern or planform; dimensions, such as the ratio of width to depth; and profile, which includes both the longitudinal or downstream profile, and the shape of the channel cross-section and valley floor. The resulting physical appearance and character of a river is a product of its dynamic adjustment to the current streamflow and sediment regime (Rosgen 1994). The sequence of flows that transports sediment and form channels varies in timing and quantity over time. Momentary changes in channel shape from the influx of sediments are propagated downstream as sediment is re-distributed by streamflow.

River channel patterns along the Walla Walla River, Mill Creek, and Coppei Creek vary considerably, and typically channel patterns repeat themselves in the downstream direction. Portions of the River or Creek may be described as straight, meandering, or braided; however, in most rivers, there is in fact a great range of channel patterns intermediate between these types (Chorley et al. 1984). The river pattern is described by sinuosity, channel width, and meander geometry, and the distribution of pools and riffles in a stream (see figure 15).

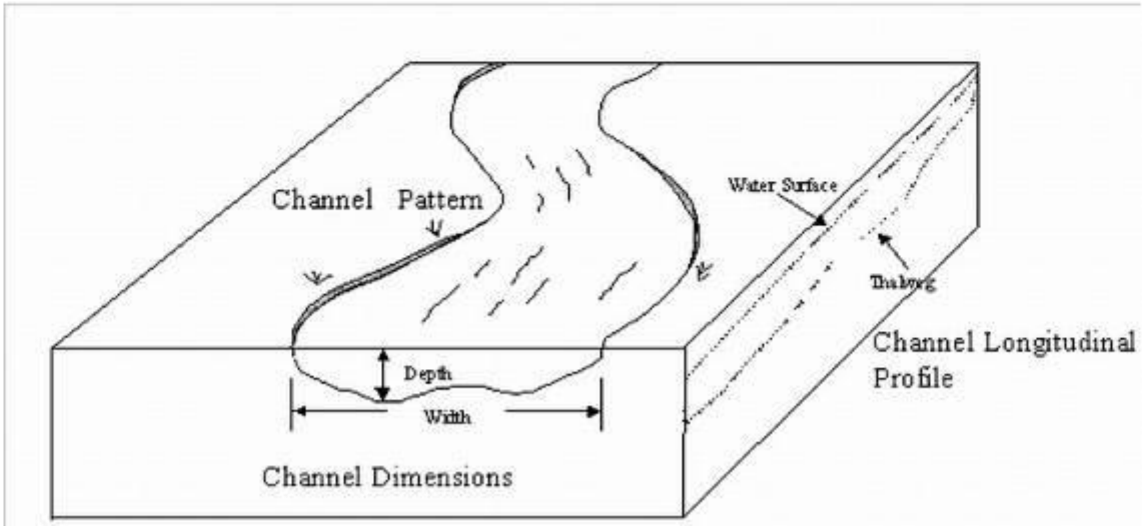


Figure 15. River channel dimensions, pattern, and profile

Note: The right side of the diagram shows how the channel would appear in longitudinal profile.

A typical cross-sectional profile across the valley floor is described in figure 16. The channel is bordered on either side by the floodplains, which is the flat area adjoining the stream channel constructed by the stream in the present climate, and is overflowed at times of relatively high discharge. Floodplains are dynamic, and expand and contract in relation to changes in environmental conditions (Rhoads 1992). The floodplains are an extension of the channel, and often support abundant streamside vegetation. The abandoned floodplains, or terraces, were constructed by the stream at some time in the past when it flowed at a higher elevation. The flat floor of a valley was constructed by the river during lateral migration and by deposition of sediment (Dunne and Leopold 1978). The river moves laterally across the valley floor by eroding one bank and simultaneously depositing sediment on the other. Over time, the channel has occupied all positions on the valley floor. Throughout the process of lateral movement, the channel maintains approximately the same width, depth, and bank height.

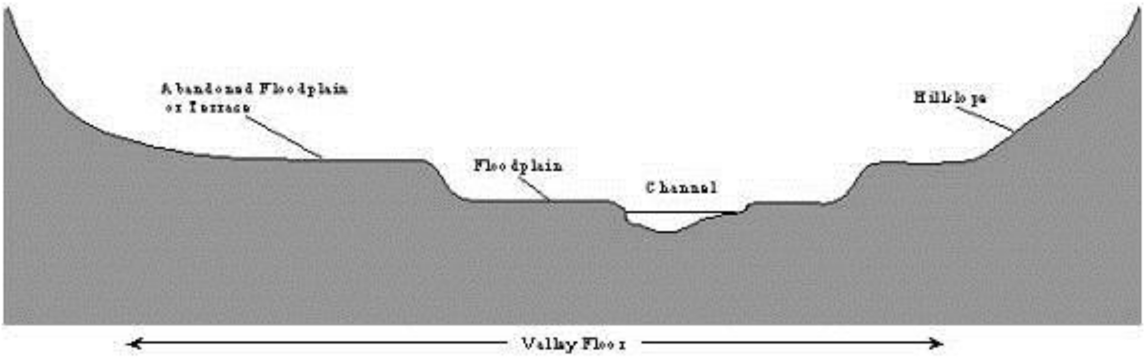


Figure 16. Schematic of a river valley floor in enlarged vertical scale showing the relation of the channel to floodplains and former floodplains or terraces

Walla Walla River

The Walla Walla River assessment reach is approximately 1.7 river-miles long and runs primarily southeast to northwest. It is bounded by a narrow band (0 to 470 feet-wide) of riparian vegetation throughout its length. Several areas of agricultural encroachment occur on the outside of meander bends at RM (river mile) 0.1, 0.4, 0.7, 1.0, 1.3, and 1.5 (figure 17). For the Walla Walla River assessment reach, river mile 0 begins at the Frog Hollow Bridge and the reach ends at river mile 1.7 at the Last Chance Bridge. All other reach features are referenced from these points. A channelized tributary named Garrison Creek enters the Walla Walla River at RM 0.1. It contributes sediment to the reach during significant runoff events.

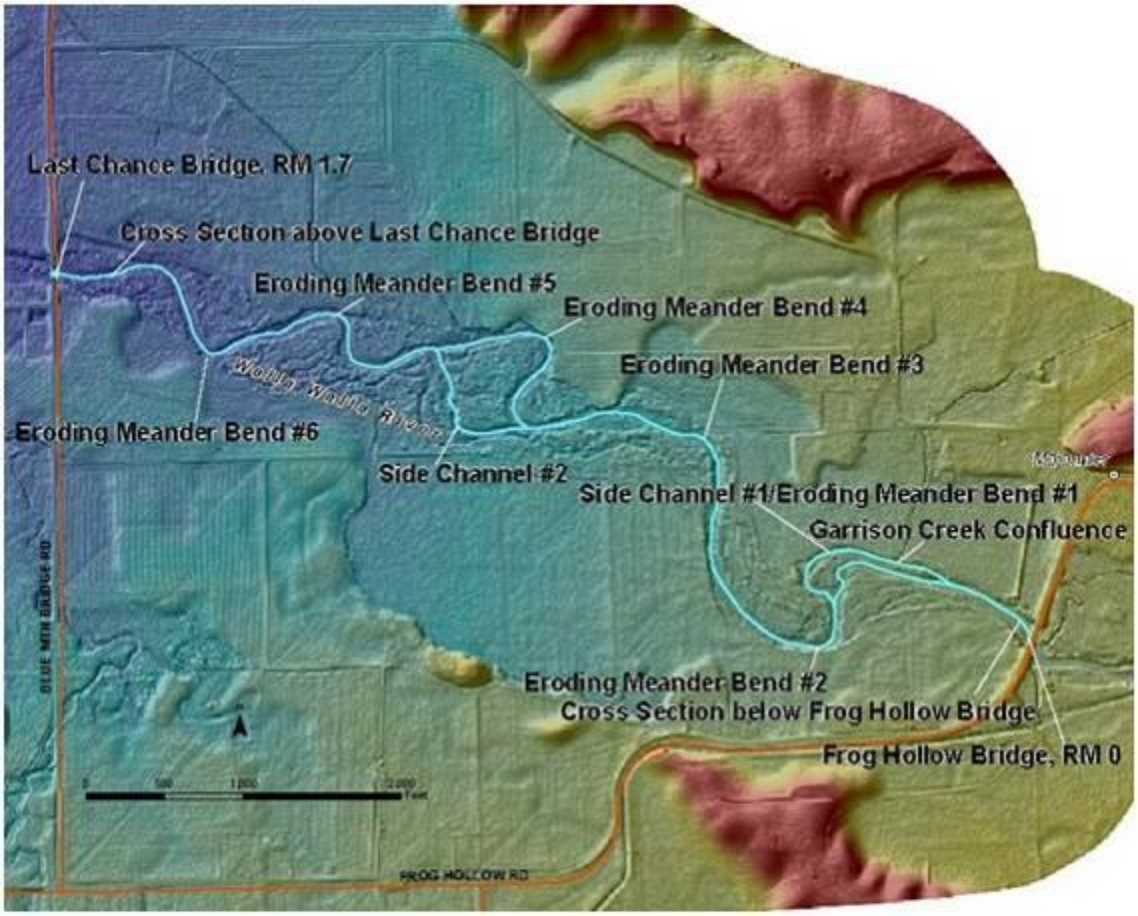


Figure 17. Walla Walla River assessment area map (flow is from southeast to northwest)

Mill Creek

The Mill Creek assessment reach is approximately 3.2 river miles long and flows from the south just above Wickersham Road Bridge at river mile 0 to the north/northwest until just downstream of the Blue Creek confluence at river mile 3.2. Mill Creek Road is located east of the reach along the entire valley. There is a private bridge at RM 2.7 with a large eroding bank just upstream (figure 18). The stream flows through a forested valley that has been impacted by urban development mainly east of the channel. See figure 19 for a map of the assessment reach.

Figure 18. Eroding stream bank just above private bridge at RM 2.7

Coppei Creek

The Coppei Creek assessment reach is approximately 1.2 river-miles long. The reach initiates at the McCown Road Bridge at river mile 0 and flows from the south to the north/northwest until it reaches the antique car lot on the Laverne Filan property at river mile 1.2. Coppei Creek has been channelized throughout this reach and, thus, is highly entrenched. A riparian forest with a width of between 50 and 230 feet is located along the reach. A portion of the riparian area includes about 75 feet-wide streamside buffer plantings implemented in 1999 through the Farm Service Agency (FSA) Conservation Reserve Enhancement Program (CREP). Agricultural lands are located beyond the riparian buffer. There is a private bridge located at RM 0.7. See figure 20 for a map of the assessment reach.

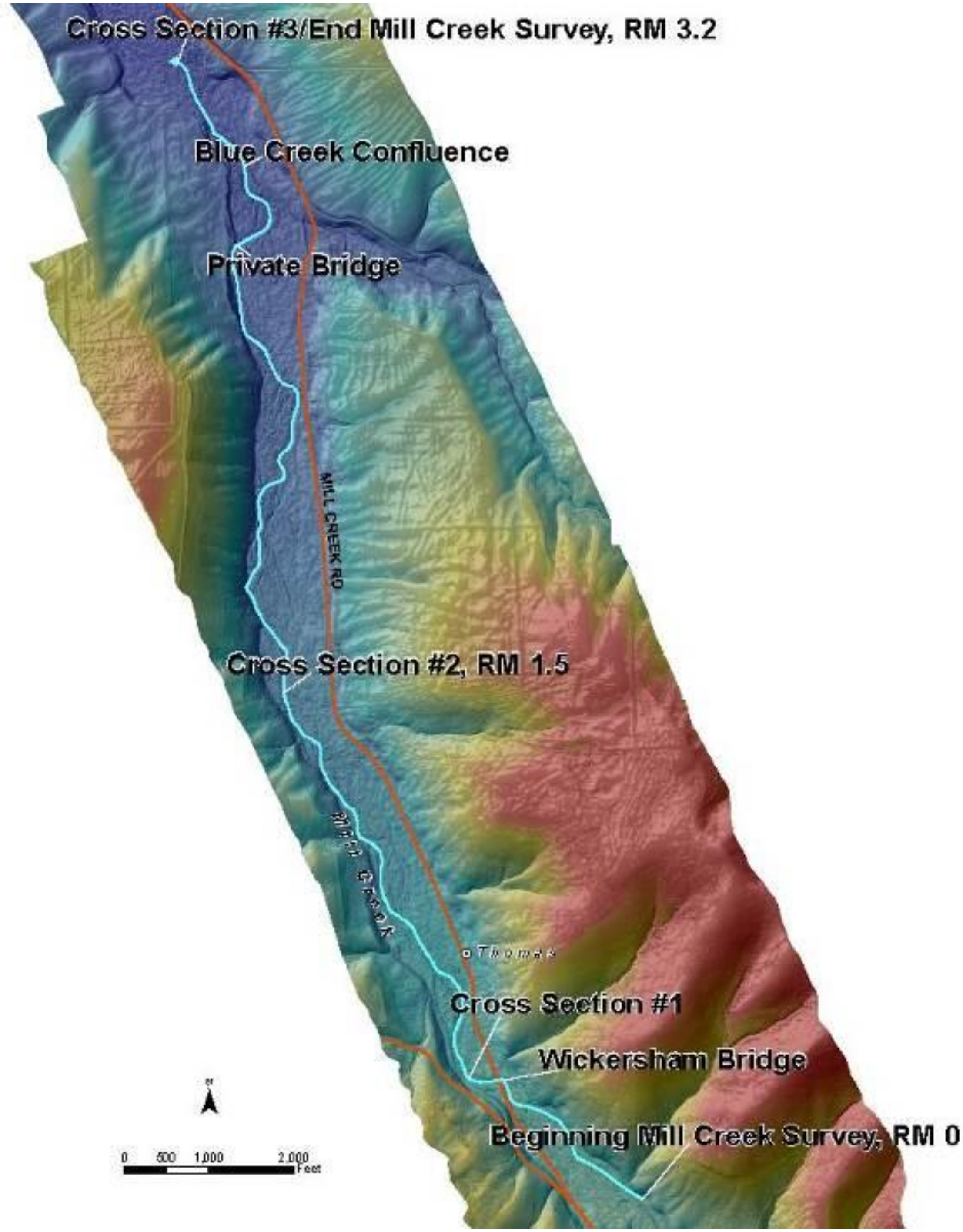


Figure 19. Mill Creek assessment area map

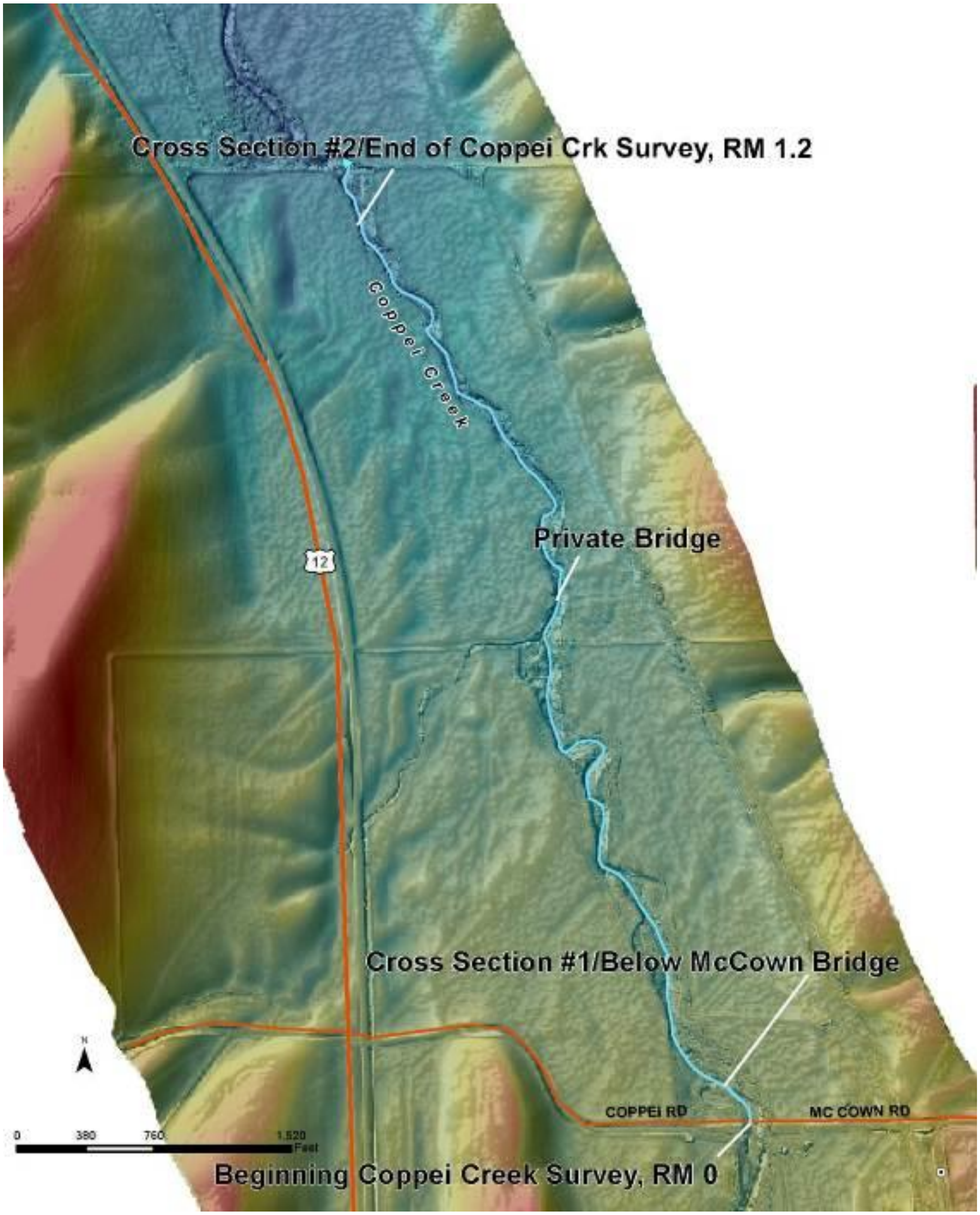


Figure 20. Coppei Creek assessment area map

Confinement, Entrenchment Ratio, and Floods

Channel confinement along each of the study reaches varies considerably from areas where the stream is confined by past channelization, for example at Coppei Creek, to areas where floodplains are more intact as was found in parts of the Walla Walla River and Mill Creek assessment reaches. Confinement is often described by the term "entrenchment ratio," which is the flood-prone area width divided by the bankfull width. The floodprone area is defined by a horizontal surface measured at a cross-section at two times the maximum bankfull depth, extended onto the floodplains on either side of the river. Generally, where the channel is confined by past channelization, and especially at or near bridges, channel entrenchment ratio values are much smaller. For the Walla Walla River assessment reach, the average entrenchment ratio is 4.8. For the Mill Creek reach it is 3.1; the Coppei Creek reach is 2.5.

Since higher entrenchment values indicate that the river has more room to spread out, generally, the higher the entrenchment values, the lower the risk of destructive flooding by the river. Where a wider floodplain or flood-prone area exists, overall flood flow velocities slow down as the river rises above flood stage. Flood water flows into the floodplain where it is "stored" until the peak is over and the water level drops before it flows back into the river. Floodplains are said to be "functional" or connected to the river when flood waters are allowed to spread out and be "stored" on floodplains, thereby reducing their erosive energy; the slower flow velocities in floodplains allow more sediment to accumulate on streambanks, which in turn helps build streambanks, and create sites for riparian vegetation like cottonwoods, which are important for bank stability and stream shade to become established. For much of their length, the Walla Walla River and Mill Creek assessment reaches are functional in terms of their stream channels being connected to the active floodplain. However, there are isolated sections of both the Walla Walla and Mill Creek assessment reaches that would not be considered functioning properly for entrenchment. For the Walla Walla River reach, entrenchment is low and the floodplain constricted:

- Just downstream of the Frog Hollow Bridge; and
- Halfway between eroding meander bend #5 and eroding meander bend #6.

For the Mill Creek reach, there are three locations where floodplains are confined:

- ~ 300 to 900 feet above the private bridge at RM 2.7;
- ~ 800 feet both upstream and downstream of cross-section #2; and
- ~ 300 to 1,200 feet below cross-section #1.

For wider floodplains, flood flows tend to be less erosive and destructive due to lower velocities. In contrast, where flood flows are confined by past channelization or structure confinement from a bridge other feature, flood flow velocities increase and floods can become much more destructive and dangerous. This occurs in the Coppei Creek assessment reach where the stream channel has down-cut between 6 to 10 feet in some sections, or at the Wickersham Bridge on Mill Creek where the channel is confined or partially blocked by the bridge.

For effective flood damage control along the assessment reaches, not only do the channels need higher entrenchment values to ensure floodplain function, but there needs to be a consideration of where water will tend to go during floods, and consideration of plans and strategies for human infrastructure protection need to be considered. When rivers flood, often old channels and other lower elevation features in the floodplain are accessed by flood waters. These "flood relief" channels are important to identify and maintain to reduce the destructive force of floods. An overall strategy like the floodflow "cell" approach proposed by the U.S. Army Corps of Engineers (1997) retains or temporarily stores flood water in selected locations on the valley floor. "Cell" flooding is an inverse of traditional flood protection methods. Instead of restricting flow within a channel, flow is allowed to spread out over a broad floodplain. Critical infrastructure, homes, and emergency transportation corridors are located out of areas prone to flooding, or protected locally with ring dikes or other appropriate measures. This allows for maximum energy dissipation and flood storage, minimizes dike breaches and overtopping, and allows for much more rapid drainage of farm fields after the flood peak has receded. A similar plan should be developed for the assessment reaches before any river management or further development takes place.

Figure 21. Ring dike protecting property in floodplain in areas where levees failed

Channel Properties: Width/Depth, Slope, Substrate

Channel properties including bankfull width, bankfull width-to-depth ratios, floodprone width, entrenchment ratios, channel substrate, and slope were measured and characterized at seven representative cross-sections. A summary of this data can be found in appendix B.

The cross-sections were surveyed at two representative locations in the Coppei Creek and Walla Walla River assessment areas and in three locations in the Mill Creek assessment area. Each assessment reach had a cross-section taken in the upstream part and one downstream to determine values for bankfull width-to-depth ratio, slope, and other attributes. In addition to the upstream and downstream cross-sections in Mill Creek, a cross-section was taken above the Blue Creek confluence.

Walla Walla River

The Frog Hollow Bridge, just upstream of the Frog Hollow Bridge cross-section, constricts flow through this section of the Walla Walla River. When the river opens up and flows around the first meander bend just past the Garrison Creek confluence at RM 0.1, the bedload sediment transported from upstream at higher flows drops out and deposits in gravel bars. At this point the river has a larger floodplain and sediment accumulates. As the channel leaves this area and flows downstream, the Walla Walla River channel becomes slightly more confined and the river gradient is steeper, reducing the floodwater storage capacity and increasing the sediment transport by the channel over most of the rest of the assessment reach.

The upstream cross-section is located at a riffle approximately 125 feet below the Frog Hollow Bridge. The river slope is 0.3 percent, entrenchment is 4, and the bankfull width-to-depth is 37. Streambed material in this area is all composed of alluvium transported by the stream. The D50 and D84 of the surface stream substrate are 41 and 63 millimeters, respectively. With the slightly entrenched channel in this location, the channel is able to spread out during flooding and access the floodplain easily during high flows (see figure 22).

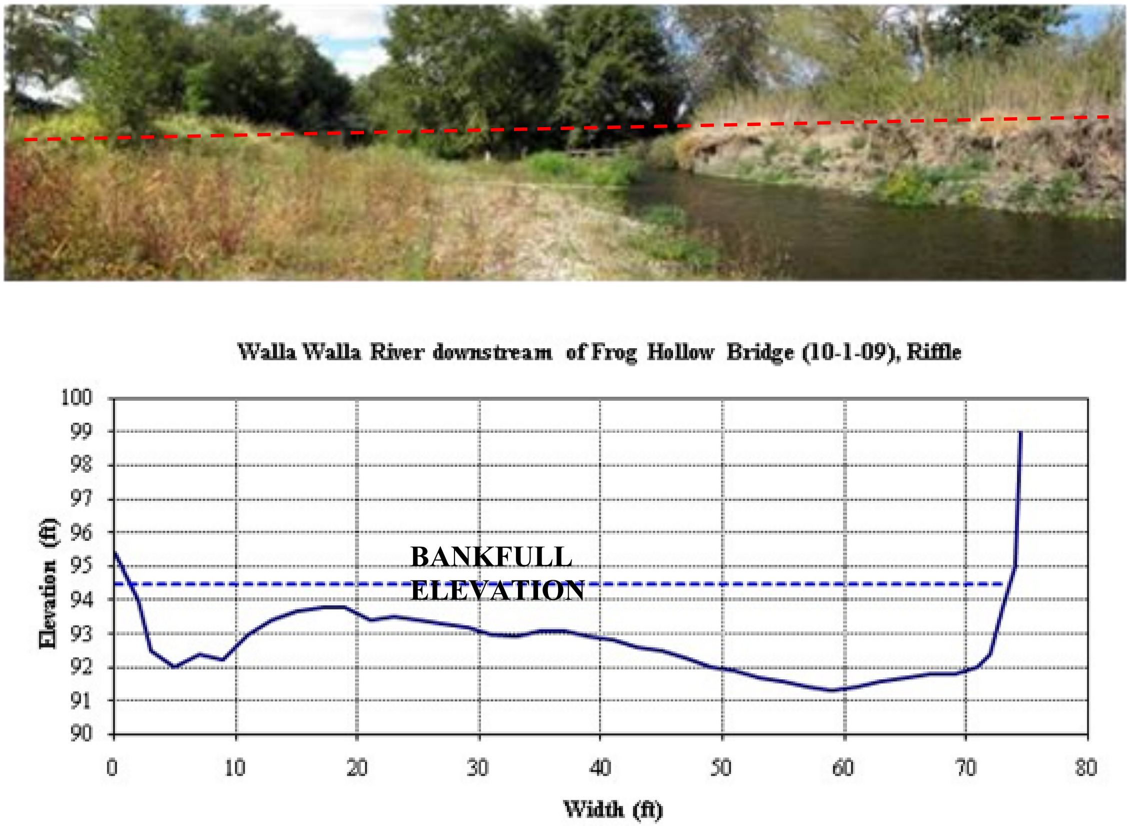


Figure 22. Channel cross-section below the Frog Hollow Bridge, Walla Walla River, Walla Walla County, Washington

Note: Dashed red line in the photos is where the cross-section was surveyed.

The downstream cross-section was surveyed at a riffle above the Last Chance Bridge at RM 1.6. The river slope is 0.4 percent, the entrenchment is 3, and the bankfull width-to-depth ratio is 39. Streambed material in this area is all composed of alluvium transported by the stream. The D50 and D84 of the surface stream substrate were 45 and 71 millimeters, respectively. With a slightly more entrenched stream channel and a slightly steeper slope in this downstream location, the stream is not able to access the floodplain as much as areas upstream (figure 23).

Differences in the sediment transport properties of the stream at these cross-sections are discussed in the section on sediment.

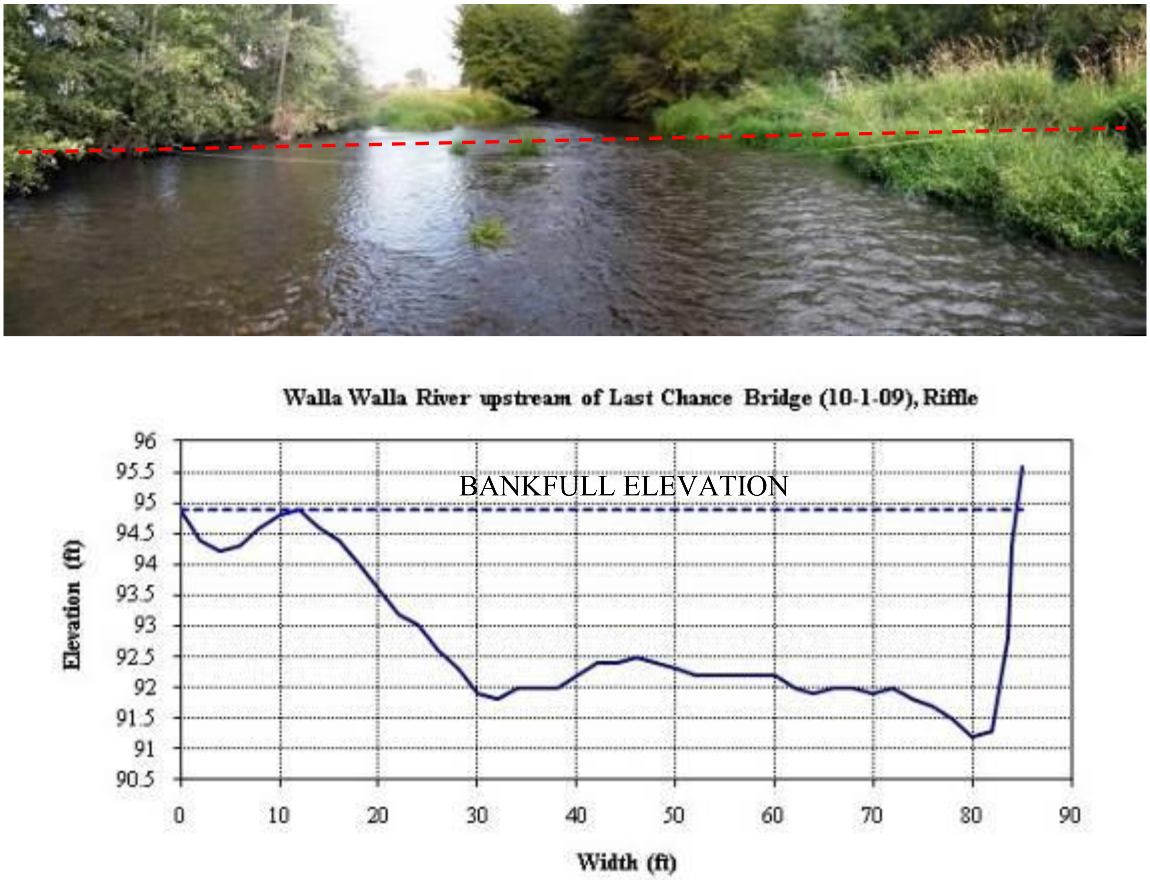


Figure 23. Channel cross-section above the Last Chance Bridge, Walla Walla River, Walla Walla County, Washington

Note: Dashed red line in the photos is where the cross-section was surveyed.

Mill Creek

All three cross-sections have similar entrenchment and width-to-depth ratios. As Mill Creek continues past the Wickersham Bridge and downstream, the channel slope gets progressively steeper (from 0.4 percent at the Wickersham Bridge cross-section to 1.5 percent at the assessment reach end).

The Wickersham Bridge has created an artificial bedload “sink” or depositional area upstream (figure 24). There is a large depositional “wedge” of sediment deposited upstream of the bridge (figure 25) After the stream drops the majority of its bedload at this site, Mill Creek flows under the bridge and the stream channel gradient begins to progressively steepen throughout the assessment reach, as indicated in the stream longitudinal profile in figure 26. Without fully knowing the history of the Mill Creek assessment reach stream channel, there are three possible reasons for this increase in gradient. The Wickersham Bridge acts as a sediment trap, and may be causing increased erosion of channel sediments downstream of the bridge, steepening the channel gradient. This is because the greater the sediment supply, such as the area upstream of the bridge, then the more room is required for sediment storage, as we observed. Conversely, if the sediment supply is cut off below the bridge, the stream channel will tend to degrade and steepen. Another reason may be due to the fact that channel manipulations over time have led to a steeper channel through this reach. Past management such as channel straightening and channelization has kept the Mill Creek channel up against the western side of the valley. This was done to protect homes and the Mill Creek Road to the east. Because of this the Mill Creek channel does not move laterally as it did historically. To compensate, the channel has found sediment to carry by down-cutting and becoming steeper through the reach. The third possible reason may be that underlying bedrock plays a role in the steeper gradient. As the channel has adjusted to the human changes that have occurred to it over time, the bedrock underlying the valley has been exposed in places and is acting as a control on channel gradient. These factors are the primary forces driving channel morphology and sediment transport throughout the reach. The differences in the sediment transport properties throughout the reach are discussed in the section on sediment.

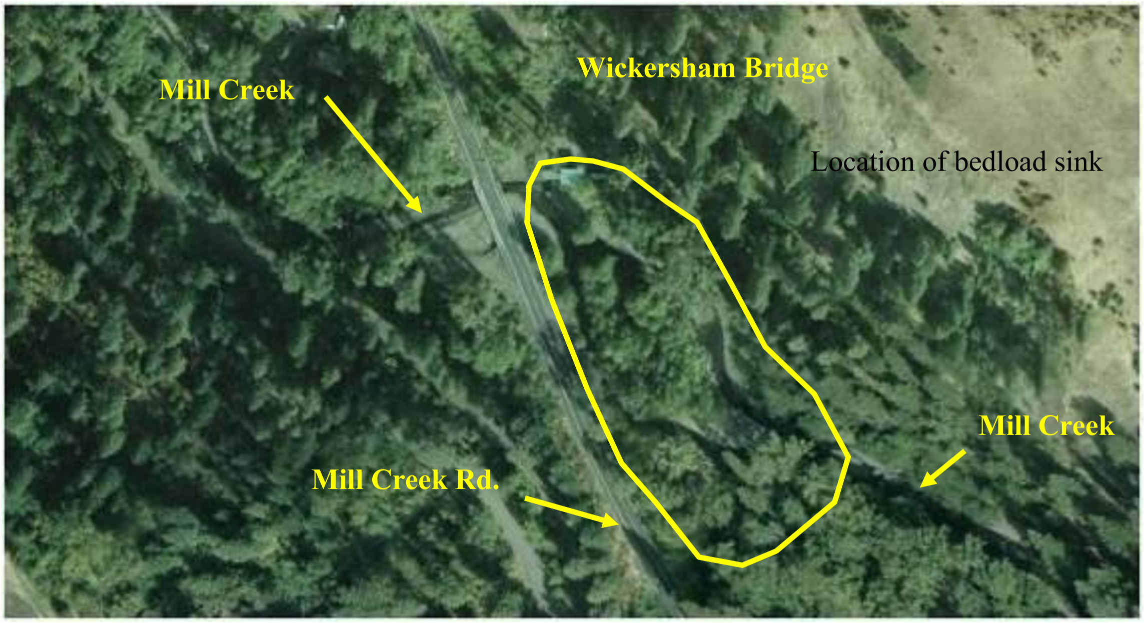


Figure 24. Photo of artificial bedload trap caused by the placement of the Wickersham Bridge, Mill Creek, Walla Walla County, Washington (flow is from the bottom right corner to the top left corner)

Figure 25. Photo of upstream sediment deposition as a result of flow constriction created by the Wickersham Bridge, Mill Creek, Walla Walla County, Washington

Derived from Lidar data collected in 2009 (units in feet)

Figure 26. Channel profile, derived from LiDAR data flow in September of 2009 during the low flow period, of Mill Creek above and below the Wickersham Bridge

Note: Observe the location of the artificial sediment trap above the Wickersham Bridge and subsequent steepening of the channel below the bridge.

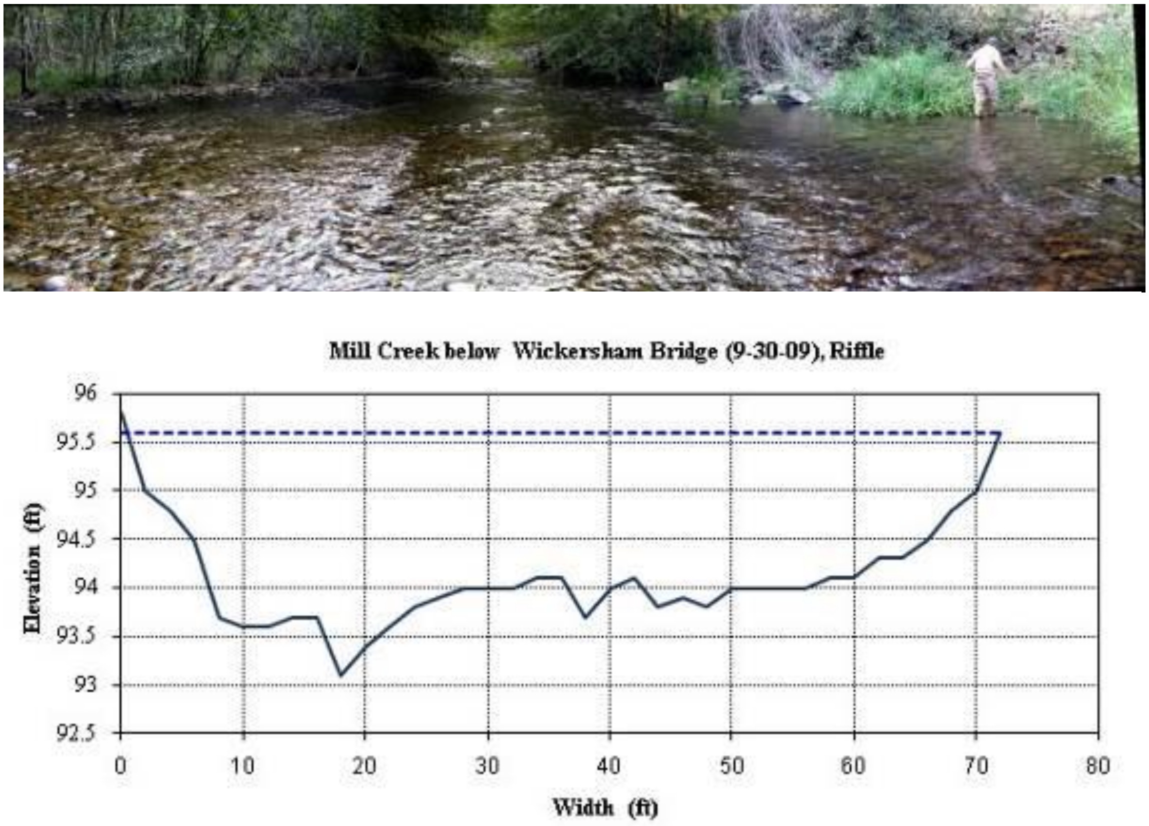


Figure 27. Channel cross-section below the Wickersham Bridge, Mill Creek, Walla Walla County, Washington

Note: Dashed red line in the photos is where the cross-section was surveyed.

The upstream cross-section is located at a riffle approximately 300 feet below the Wickersham Bridge. The river slope is 0.4 percent, entrenchment is 3, and the bankfull width-to-depth is 47. Streambed material in this area is all composed of alluvium transported by the stream. The D50 and D84 of the surface stream substrate were 63 and 131 millimeters, respectively.

The downstream cross-section was surveyed at a riffle below the confluence with Blue Creek at RM 3.2. The river slope is 1.5 percent, the entrenchment is 3, and the bankfull width–to-depth ratio is slightly more than the Wickersham Bridge cross-section at 48. Streambed material in this area is all composed of alluvium transported by the stream. The D50 and D84 of the surface stream substrate were 58 and 117 millimeters, respectively, and are slightly finer than the Wickersham Bridge cross-section.

BANKFULL ELEVATION

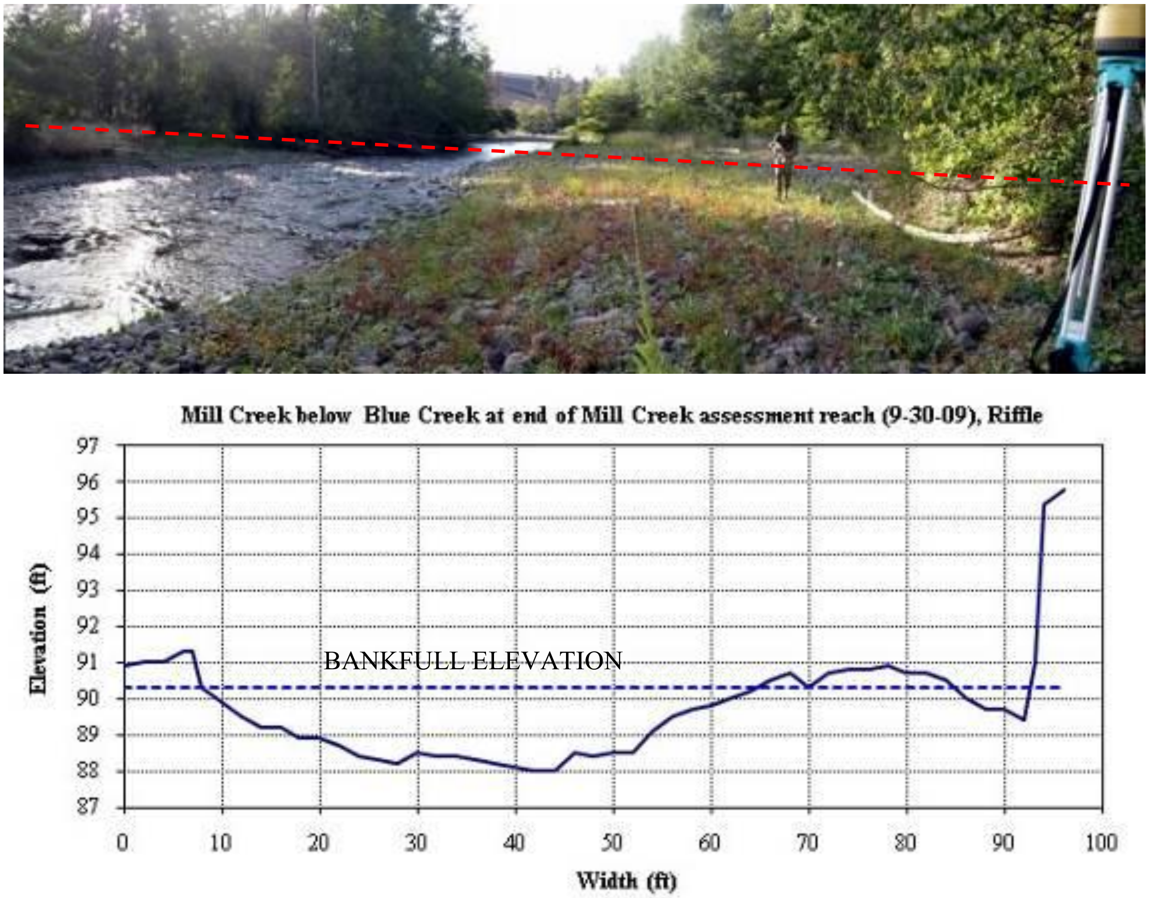


Figure 28. Channel cross-section below the Blue Creek confluence, Mill Creek, Walla Walla Country, Washington

Note: Dashed red line is where the cross-section was surveyed.

In addition to the upper and lower cross-sections taken for Mill Creek, an additional cross-section was taken above the confluence with Blue Creek to show how Blue Creek impacts the Mill Creek stream channel downstream. This cross-section was surveyed at RM 1.5. The river slope is 0.7 percent, the entrenchment is 3, and the bankfull width-to-depth ratio is 42, slightly less than that measured in the cross-section below Blue Creek. Streambed material in this area is all composed of alluvium transported by the stream. The D50 and D84 of the surface stream substrate were 67 and 121 millimeters, respectively; similar to both the Wickersham Bridge and below the Blue Creek confluence cross-section.

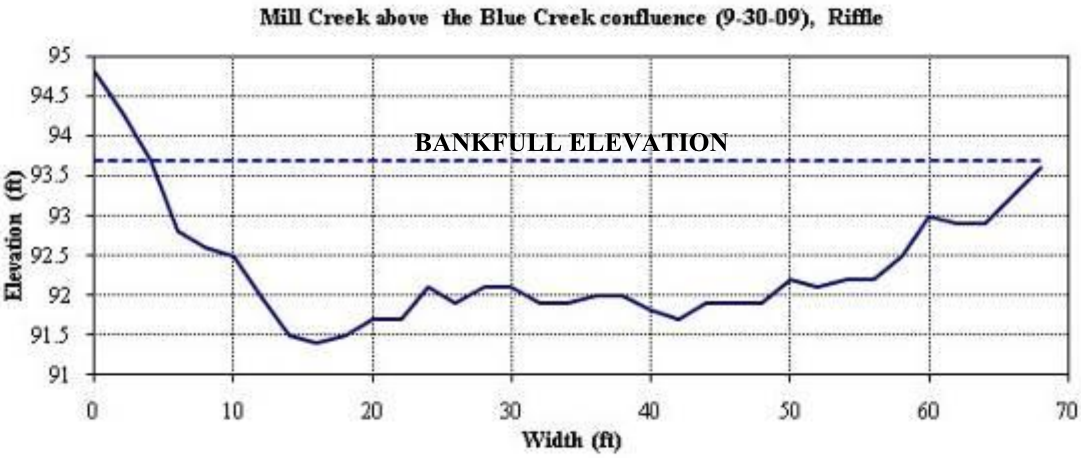
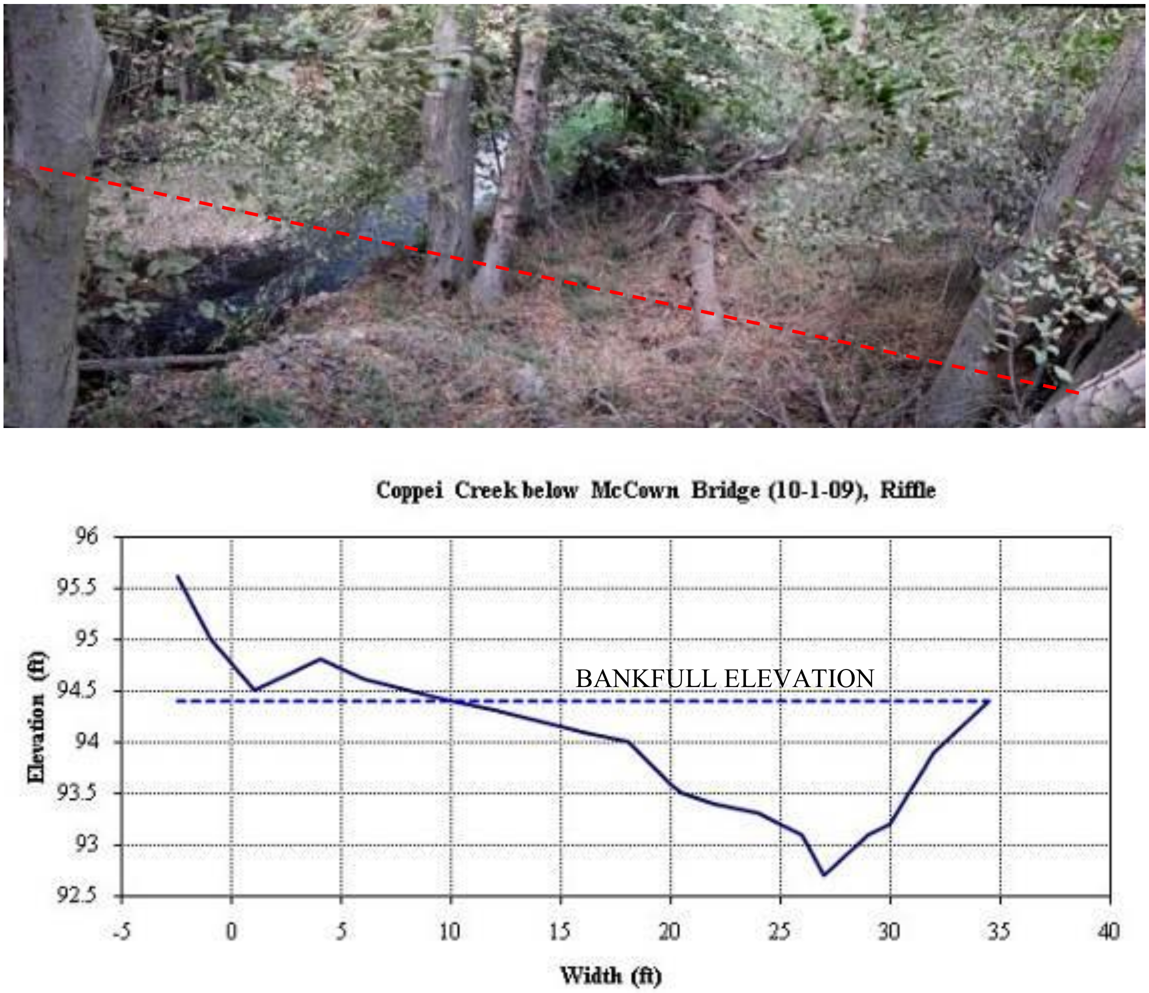


Figure 29. Channel cross-section above the Blue Creek confluence, Mill Creek, Walla Walla County, Washington

Note: Dashed red line in the photo depicts where the cross-section was surveyed.

Coppei Creek

The upstream cross-section is located at a riffle 300 feet below McCown Bridge. The river slope is 2.2 percent, entrenchment is 2, and the bankfull width-to-depth is 35. The entrenchment ratio is indicative of a moderately incised stream channel (figure 30). Streambed material in this area is composed of alluvium transported by the stream. The D50 and D84 of the surface stream substrate was 34 and 78 millimeters, respectively.



Coppei Creek below McCown Bridge (10-1-09), Riffle

Figure 30. Channel cross-section below the McCown bridge, Coppei Creek, Walla Walla County, Washington.

Note: Dashed red line in the photo depicts where the cross-section was surveyed.

The downstream cross-section was surveyed in a riffle above the antique car lot property at RM 1.2. The river slope is 1.6 percent, the entrenchment is 1, and the bankfull width-to-depth ratio is 25, similar to the upstream McCown Bridge cross-section. At this cross-section, the entrenchment ratio was indicative of a highly incised stream channel from past channelization of this reach. Streambed material in this area is all composed of alluvium transported by the stream. The D50 and D84 of the surface stream substrate were identical to the McCown Bridge cross-section at 34 and 78 millimeters, respectively.

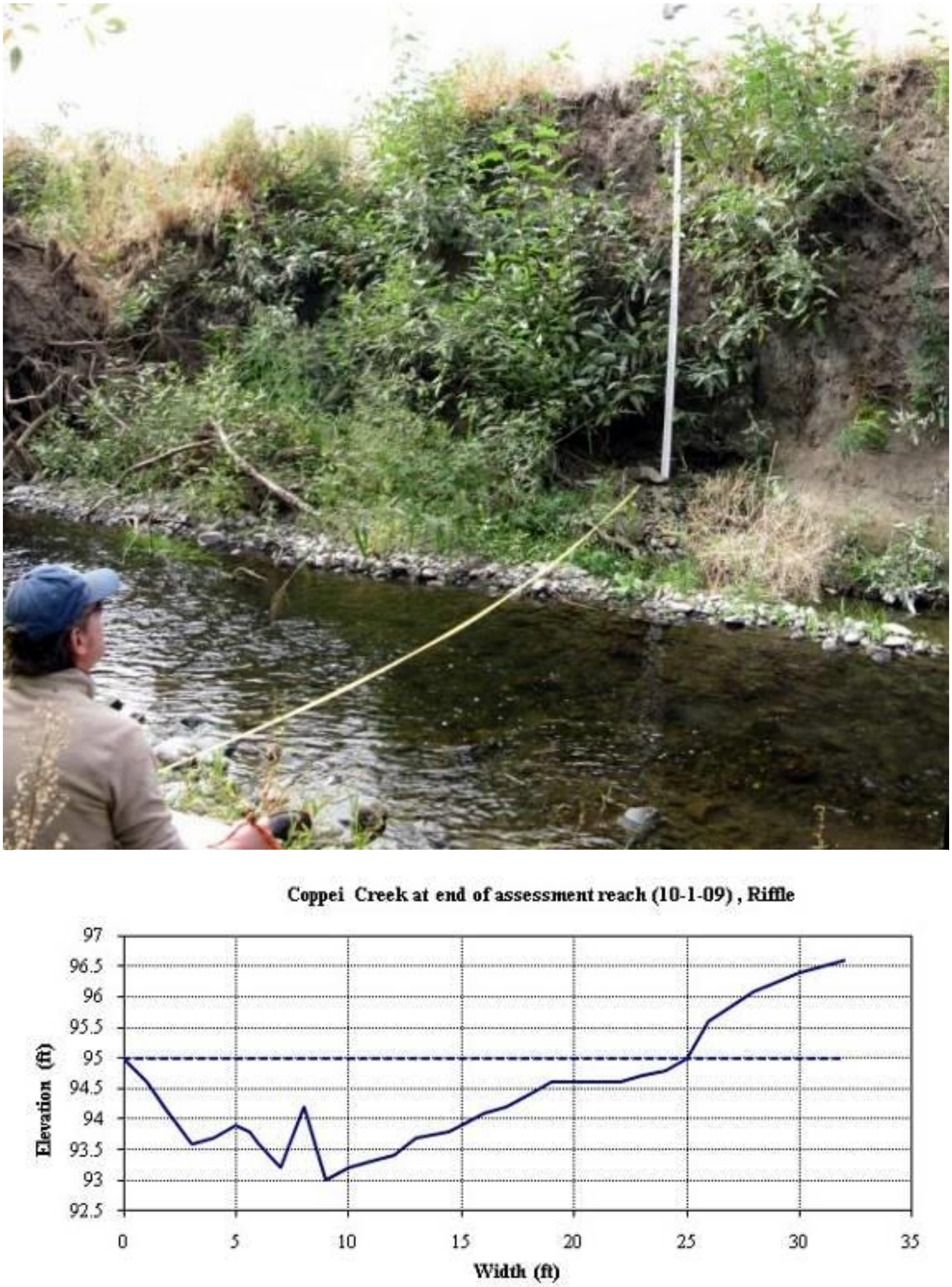


Figure 31. Channel cross-section above the antique car lot at downstream end of assessment reach, Coppei Creek, Walla Walla County, Washington

Both cross-sections indicate a stream channel that has recently down-cut due to past land use impacts (channelization). Entrenchment values indicate a channel with a limited flood storage capacity. Because of this, increased flows are more apt to cause excessive erosion and channel migration. Coppei Creek, through this reach, is attempting to adjust back to its natural channel geometry, with a wider floodplain and more meanders. The channel will continue to erode a wider floodplain in the future until it reaches equilibrium to stream discharge and sediment transport regimes.

Differences in the sediment transport properties of the stream at these cross-sections are discussed in the section on sediment.

Large Woody Debris

Large woody debris (LWD) is essential for regulation of sediment and the creation of pools and other complex habitat. A woody debris survey was conducted during the summer of 2009 for all large woody debris in the active stream channel for the Walla Walla River, Mill Creek, and Coppei Creek assessment reaches. The LWD count within the active stream channel is low for Mill Creek and the Walla Walla River, and very low for Coppei Creek. A survey of wood on the floodplains was not conducted, but a general observation showed that LWD was also below average on the floodplains. Instream wood with a minimum diameter of 6 inches by 12 feet in length was inventoried; to be counted, the pieces needed to be wholly or partially within the bankfull stream cross-section. The average bankfull stream width in the assessed reaches is 63 feet for the Walla Walla River, 64 feet for Mill Creek, and 25 feet for Coppei Creek. Sixty-three pieces per mile of LWD were counted in the Walla Walla River assessment reach; of those, 37 were small wood (<12 inches in diameter) and 26 large wood (>12 inches in diameter). For Mill Creek, 48 pieces per mile of LWD were counted; of those, 26 were small wood and 22 large wood. For Coppei Creek, 44 pieces per mile of LWD were counted; of those, 34 were small wood and 10 large wood. Most of the inventoried LWD is composed of cottonwood and alder.

Wood loading that likely existed in the assessment reaches prior to recent (pre-1850) human disturbance can be predicted using Fox and Bolton's (2007) research on the distribution of large wood in channel reaches in the Douglas-fir-ponderosa pine forest zone. For a stream bankfull width of 20 to 98 feet, historical predictions indicate the Walla Walla River, Mill Creek, and Coppei Creek (using the ponderosa pine forest zone category) would have had over 200 pieces per mile. Survey findings counted substantially less in all three assessment reaches. Reductions in the riparian quantity and quality through conversion to residential developments, land clearing, and agricultural uses along the assessment reaches are the main reason for these low values.

Recent History of Large Wood Quantities in the Nearby Touchet River

Wood loading in the Walla Walla River, Mill Creek, and Coppei Creek assessment reaches has been significantly reduced by land use (e.g., land development, farming, logging, roads, etc.) since the 1850s. There have been no known LWD surveys conducted in the assessment reaches other than the ones conducted in 2009. A LWD survey was conducted along the nearby Touchet River in 1998 from the mouth of Coppei Creek downstream to the Highway 125 Bridge (a distance of approximately 8 miles). The Touchet River is a tributary to the Walla Walla River (figure 1) and has experienced similar land management activities as the three assessment reaches. An average of 20.8 pieces of wood per mile (Tice, B., 2001, *personal communication*, as cited in Kuttel [2001]) was found in the Touchet reach. Only 37 percent of the Touchet River riparian zone remains in native riparian vegetation (Ashley and Stovall 2004, as cited in U.S.

Army Corps of Engineers [1997]); hence, future wood recruitment will be low unless conditions change. Similar reductions would be expected for the Walla Walla River, Mill Creek, and Coppei Creek assessment reaches.

Historical References on Wood within the Walla Walla River Basin

The following journal entries from Lewis, Clark, and Gass of the Corps of Discovery were made as they passed along the Touchet River in the Walla Walla Basin on May 1, 1806:

> "the timber on the creek becomes more abundant and its extensive bottoms affords a pleasant looking country"—*Lewis*
>
> "We set out early and travelled up the branch, which is a fine stream about twenty yards wide, with some cottonwood, birch and willows on its banks"—*Gass*

Assuming that the Umatilla River (near Pendleton) may have resembled the Walla Walla River, Mill Creek, or Coppei Creek, and based on our personal observations of the rivers to date, Robert Stuart's 1812 description of the Umatilla River near Pendleton on a journey eastward from Astoria is instructive:

> "bottoms well covered with cottonwood pofsefs (a good) many Swamps and Ponds in which reside a great multitude of beaver"—*Rollins*, 1935 (as cited in USFWS 2002).

Gary Lentz, Park Ranger, Lewis and Clark Trail State Park near Dayton, Washington, said on the Touchet River in the days of Lewis and Clark (1806), there was more wood in the river and the riparian area probably extended 1,200 feet (e.g., 600 feet per side) of the channel.

Other historical references provide insight about why LWD is lacking in the assessment reach areas. A scientist named Dice (1916) conducted vertebrate studies in the Touchet River Basin from 1904 to 1914 (Kuttel 2001, page 22). He wrote,

> "The animal habitats of southeastern Washington have been greatly altered by the work of man. Farming is extensively carried on and in the prairie area a very large percentage of the land is under cultivation. Irrigation is also practiced in valleys of both prairie and sagebrush areas. All of the land not under direct cultivation has been heavily grazed by cattle and stock. Part of the timber along the streams has been cut down and much of the brush has been cleared away…These changes in the environment have caused great changes in the abundance of the different species of vertebrates"—*Dice*, 1916 (cited in Mudd (1975), as cited by Kuttel [2001], page 22).

Figure 32. Large wood and channel conditions along the Walla Walla River assessment reach, Walla Walla County, Washington

Figure 33. Large wood and channel conditions along Mill Creek assessment reach, Walla Walla County, Washington

Figure 34. Large wood and channel conditions along the Coppei Creek assessment reach, Walla Walla County, Washington

Sediment

Stream channel dimensions are maintained over time if their ability to transport water and sediment remains in balance or equilibrium. The morphology of the Walla Walla River, Mill Creek, and Coppei Creek depends on a complex set of watershed processes and factors related to the transport of sediment and stream hydrology. The amount of stream flow needed to maintain the channel depends on the amount and sizes of sediment entering the channel. A channel's shape will adjust to stream flow and sediment inputs, thus maintaining a dynamic equilibrium that reflects the prevailing flow and sediment regimes (Rosgen 1986). Large instantaneous inputs of sediment from massive storms, landslides, or fires, may cause channel changes, especially if the channel cannot process such a large amount of sediment. However, essentially all of the bed material transported into the study reach must be conveyed through the reach over time, otherwise the reach will aggrade and the channel will shift. Stream reaches where sediment accumulates are said to be response reaches, and areas where sediment is transported through are called transport reaches.

Sediment transport by the Walla Walla River, Mill Creek, and Coppei Creek must account for fluctuations in flow and the quantity and characteristics of the sediment and other debris supplied to the channel over time. While sediment may accumulate during one period of time, accumulated sediments are eventually removed. The transport of water and sediment occurs at vastly different scales. While water from a major storm event may take days or weeks to pass through the channel, it can take years or decades for the sediment from the same event to pass through. Sediment transport often occurs for only several days per year, and hence there is a need for areas of sediment storage in and along the channel. The greater the sediment supply, then the more room is required for this temporary storage.

This complex response is evident in the following example: erosion of streambanks or sediment influx from tributaries may locally increase bed elevations leading to flooding and flow diversion, with sediments eventually transported and redistributed to downstream areas. Accumulations of bed sediments can lead to bank instability, increased flood extent, and a tendency of channels to migrate and erode new channels. Often, sediment can be eroded from one section of river, and then re-deposited in another. In the channelized Coppei Creek assessment reach, sediments generally do not accumulate, but instead are transported beyond the assessment reach to potentially cause flooding problems downstream. In the Walla Walla River and Mill Creek reaches, there exists both response and transport sections. Sediment accumulation on the Walla Walla River below the Garrison Creek confluence in the vicinity of the Johnson ranch has caused a braided channel through this section. The removal of riparian vegetation on the right bank through this reach and the subsequent avulsion of the stream channel are causing active erosion of streambanks in this area. For Mill Creek, as the river leaves the upper sections of the assessment reach and progresses downstream, the slope, entrenchment, and particle size all increase slightly, indicating a shift from a response reach to a transport reach. Channel constriction on Mill Creek above the Wickersham Bridge has caused a bedload trap or sink and deposited a sediment “wedge” in this area. Once the channel passes through the deposition area the channel becomes steeper and is able to once again carry increased amounts of bedload downstream.

The frequency and duration of moderately higher streamflows, especially flows around bankfull and larger, are particularly important (Hill et al. 1991) for controlling channel morphology. Bankfull flows are those flows that fill the channel up to the stage where the stream just begins to overflow into its floodplains. In gravel-bed streams, bankfull flows over time result in significant rates of bedload transport. Bankfull flows occur more frequently than larger flood flows, so over time they can move large amounts of stream sediments.

Large floods are very effective at altering channel form since they are able to transport significant amounts of sediment. However, large events occur so infrequently that ultimately they have less influence on channel form over longer periods of time. In contrast, flows that fill the channel to the level of the floodplains (i.e., bankfull flows) are most effective at moving sediment over time and are the dominant channel-forming flows (Wolman and Miller 1960) because they occur much more often. The mean recurrence interval of bankfull flows (on an annual flood frequency series) for a large variety of rivers has been found to be about 1.5 to 2.2 years (Dunne and Leopold 1978). Bankfull flow on the Walla Walla River, Mill Creek, and Coppei Creek reaches is approximately 732, 642, and 322 cfs, respectively.

Adequate characterization of stream bed material is a fundamental part of establishing a bedload sediment rating curve, which shows how much bedload sediment is moving at different flows. Bed material distributions are used (1) in the bedload sediment transport modeling process, (2) to characterize channel roughness, and (3) to determine the flows that transport bedload. During the summer of 2009, stream bed pebble counts were done at two cross-sections in the Walla Walla and Coppei Creek assessment reaches and three cross-sections in the Mill Creek assessment reach. This data was used to help estimate bedload in transport by the stream using a sediment transport model.

Bed material in alluvial, gravel-bed rivers is often poorly sorted, spatially heterogeneous, and can include a large variety of size classes. Differences in bed material size can be caused by a variety of processes, including mass wasting, logs or other debris, tributary inflow, and the migration of channel bedforms. The specific geomorphic, hydrologic, and geologic context of a stream will influence the patterns of sediment delivered to the stream and the character of the bed material.

Types of Sediment Transport

Bedload and suspended load are the two major modes of sediment transport. Suspended sediment mainly consists of finer particles such as silts and clays, which are completely supported by the turbulence of flowing water. Bedload usually consists of particles of sand, gravel, cobbles, and boulders that are transported by traction—they roll, slide, and bounce along the streambed. Bedload transport rates vary both spatially and temporally, even during constant flow conditions. Generally, bedload transport increases rapidly with increasing discharge; that is, as discharge increases, bedload transport rates increase at an exponentially greater rate than the flow. Movement of the bedload has been found to be more important in the formation of channel geomorphic features than the finer suspended sediments (Leopold 1992). For the Walla Walla River, Mill Creek, and Coppei Creek assessment reaches, the bedload transported by the stream annually determines and comprises the major features of the channels' morphology. Bedload builds the stream, while suspended load builds the floodplains.

In flowing water, the smallest particles, such as silt and clay, are held in suspension within the water column. Suspended concentrations typically show considerable variation over time, and respond to changes in flow and sediment availability. Suspended sediment may be important in channel-forming processes where it is a dominant component of the sediment supplied to the stream. For the Walla Walla River, Mill Creek, and Coppei Creek gravel-bed streams, suspended sediment likely plays a small role in the bankfull channel formation. However, fine sediment deposits occur along the Walla Walla River, Mill Creek, and Coppei Creek when flood waters flow into heavily vegetated or backwater areas on the floodplains or terraces, and flow velocities are reduced. In addition, large amounts of suspended sediment (silts and clays) in flood flows are often transported very long distances through a stream reach without significant deposition.

Estimation of Bedload Transport

Various concepts have been used to describe the rates and mechanisms of bedload transport in rivers and streams. Where measured bedload transport data and long-term flow data exist, rating curves have been applied relating bedload discharge (B) to stream discharge (Q). Rating curves typically take the form:

$$B=dQf$$

In this equation, d and f are coefficients determined by applying a linear regression model to the log transformed variables B and Q, and B is expressed as mass per unit time.

Another approach which is widely used to estimate bedload transport rates where extensive bedload samples and long-term flow information may not exist is to apply a physically-based bedload prediction model. Physical bedload transport models are based on the premise that a specific relation exists between hydraulic variables, sedimentological parameters, and the rate at which bedload is transported. They utilize information including channel dimensions and profile, the size distribution and characteristics of bed material, stream hydraulics, energy slope, and bed-shear stress (Parker and Klingeman 1982; Dawdy et al. 1986). Bedload transport equations generally assume an infinite sediment supply and a stable cross-sectional shape.

Bedload transport was estimated for two locations on the Walla Walla River and Coppei Creek assessment reaches and three locations on the Mill Creek assessment reach using the model developed by Wilcox and Crowe (2003). The model was applied to estimate bedload just downstream of the Frog Hollow Bridge and upstream of the Last Chance Bridge for the Walla Walla assessment reach, downstream of the Wickersham Bridge and upstream and downstream of the Blue Creek confluence for the Mill Creek assessment reach, and downstream of the McCown Bridge and upstream of the antique car lot site for the Coppei Creek reach. This bedload transport model requires data obtained from surface samples, otherwise known as pebble counts to estimate transport.

The Wilcox and Crowe bedload sediment model was used to generate a bedload rating curve at the seven locations within the three assessment reaches. Stream cross-sections were surveyed at these locations. These cross-sections, along with data on stream slope, channel roughness, and the characteristics of the bed material, were used as input parameters to the bedload model.

Walla Walla River

The cross-section below the Frog Hollow Bridge indicates a channel with a relatively well established floodplain (figure 22), with a width-to-depth ratio at bankfull of 37, a bankfull channel width of 72 feet, an average bankfull depth of 1.9 feet and entrenchment ratio of 4 and a channel slope of 0.3 percent. The Last Chance Bridge cross-section is similar to the Frog Hollow site in that it has a relatively well established floodplain (figure 23). However, the width-to-depth ratio of 39, the bankfull channel width of 85 feet, the average bankfull depth of 2.2 feet, and the channel slope of 0.4 percent are all slightly higher than the upstream cross-section. This data indicates that the Last Chance Bridge site becomes slightly more entrenched at 3, which increases bedload transport at higher flows. The sinuosity overall for the Walla Walla River assessment reach is 1.4.

Estimates of bedload transport for both the Frog Hollow and Last Chance Bridge sites are provided in figure 35, and show that bedload transport initiates at approximately 700 cfs in the Frog Hollow cross-section and approximately 900 cfs in the Last Chance cross-section. Bankfull flow, estimated to be about 732 cfs in the Walla Wall assessment reach, transports about 25 tons per day of bedload at the Frog Hollow site and less than 5 tons per day at the Last Chance Bridge site.

As flows increase, sediment transport increases exponentially, as shown in figure 35. At 8,000 cfs, approximately 4,980 tons per day of bedload is transported through the Frog Hollow reach and 7,230 tons per day through the Last Chance reach. The stream through the Frog Hollow cross-section in the upper reaches of the assessment area is less confined than the downstream Last Chance Bridge cross-section. This would indicate that as the stream gets slightly steeper, deeper and more confined, it has an increased ability to transport sediment introduced from upstream.

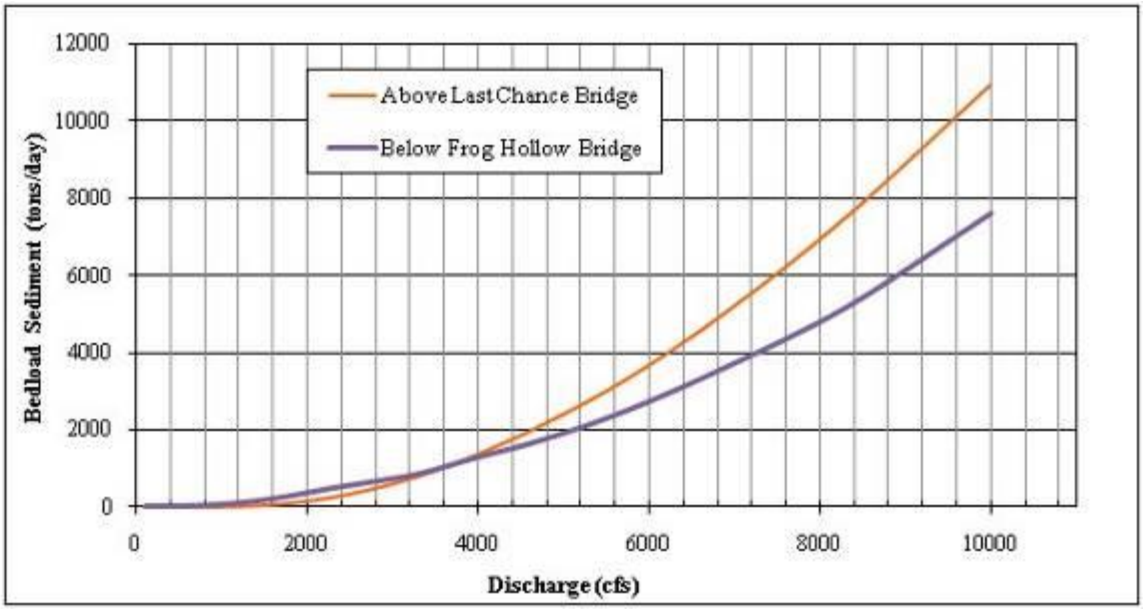


Figure 35. Bedload rating curve, below Frog Hollow Bridge and above Last Chance Bridge during all flows, Walla Walla County, Washington

Mill Creek

The cross-section below the Wickersham Bridge indicates a slightly entrenched stream channel at 3, with a width-to-depth ratio at bankfull of 47, a bankfull channel width of 72 feet, an average depth of 1.5 feet and a channel slope of 0.4 percent. Mill Creek above the Blue Creek confluence cross-section has similar channel morphology as the Wickersham Bridge cross-section with a width to depth ratio of 42, a channel width of 64 feet, and an average depth of 1.5 feet. However, the cross-section above the Blue Creek confluence has a slope of 0.7 percent, indicating that as the channel moves downstream it becomes gradually steeper. This is also the case for the cross-section below the Blue Creek confluence. The channel morphology is similar to the two upstream cross-sections as the channel has a width-to-depth ratio of 48, a channel width of 64 feet, and average depth of 1.3 feet. However, the slope increases to 1.5 percent below the Blue Creek confluence. This is the steepest channel slope throughout the entire assessment reach. The sinuosity for the entire reach is 1.1. The assessment team suggests that this steepening of the stream gradient in the lower part of the assessment reach is a result of years of channel straightening, in-stream large wood removal, ad hoc levee construction, bull dozing of channels, and other river alterations throughout the assessment reach.

Estimates of bedload transport for the Mill Creek cross-sections are provided in figure 35, and show that bedload transport initiates at around 800 cfs just below the Wickersham Bridge site, at approximately 450 cfs above the Blue Creek confluence site and approximately 700 cfs below the Blue Creek confluence site. Bankfull flow, estimated at this site to be about 642 cfs, transports less than 1 ton per day of bedload at the Wickersham Bridge site, around 7 tons per day above the Blue Creek confluence site, and approximately 1 ton per day below the Blue Creek confluence site.

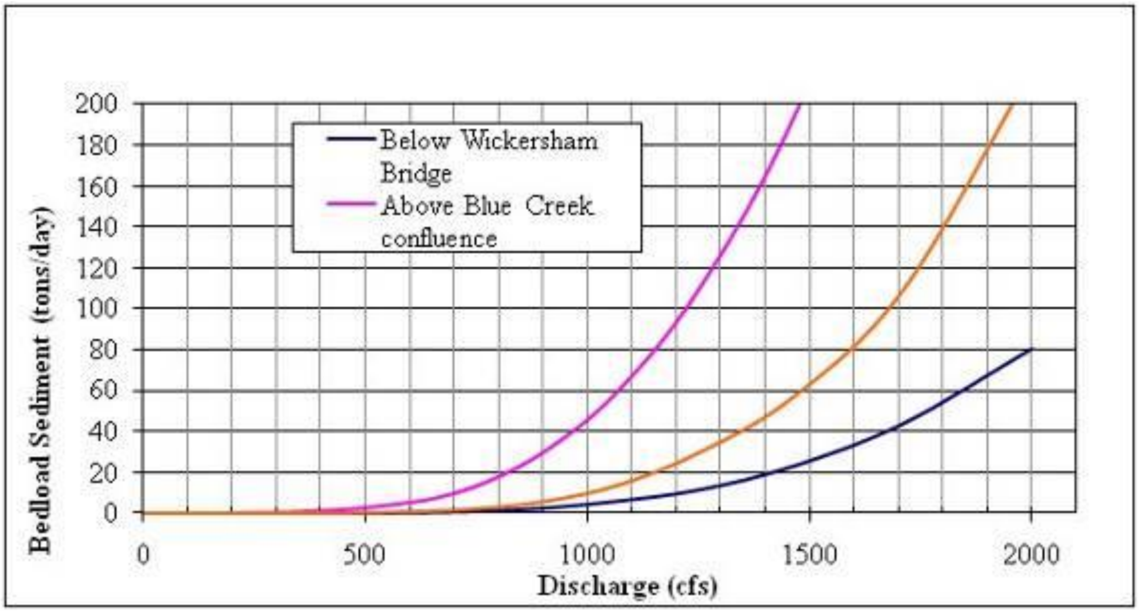


Figure 36. Bedload rating curve, below Wickersham Bridge and above and below the Blue Creek confluence during all flows, Walla Walla County, Washington

As flows increase, sediment transport increases exponentially, as shown in figure 36. At 1,400 cfs, about 20 tons per day of bedload is transported through the Wickersham Bridge site. The cross-section above the Blue Creek confluence has 160 tons per day transported through at 1,400 cfs while the cross-section below the Blue Creek confluence has 45 tons per day transported.

The reason why the site below the Wickersham Bridge does not transport more bedload at bankfull and at higher flows is probably because the channel has a lower channel slope in this location. The bridge upstream and the levee adjacent to the cross-section structures constrict the stream channel, and may play a role in the lower channel slope. Visual evidence shows that the bedload in this reach becomes trapped above the Wickersham Bridge. Figures 25 and 26 (see section “4. Assessment Reach Conditions”) clearly show that the capacity of the Wickersham Bridge is reduced by bedload deposition.

As the channel flows downstream from the Wickersham Bridge site it becomes steeper through the middle sections of the assessment reach and beyond the Blue Creek confluence. Although we have no older aerial photos to support this, the assessment team suggests this may be a natural channel shift, or partially due to ad hoc levees, bull dozing channels, large wood removal, and other river management tools that have been put in place to protect the infrastructure on the east side of the river. The levees have straightened meanders, and forced Mill Creek to slightly incise and become steeper, instead of moving across the valley floor, as it did before development of the valley. This has led to a steepening of the channel, and has been the catalyst for the increases in bedload transport through the middle of the assessment reach and downstream.

Coppei Creek

The cross-section below the McCown Road Bridge indicates a moderately entrenched channel at 2, with a width-to-depth ratio at bankfull of 35, a channel width of 25 feet, a sinuosity of 1 and an average depth of 0.7 feet. In comparison, Coppei Creek above the antique car lot at the end of the assessment reach is highly entrenched at 1, has a width to depth ratio of 26, a bankfull channel width of 25 feet, and an average depth of 1.0 feet.

The channelization that has occurred here has created the present channel configuration. The channelization has been created by the construction of ad hoc levees along most of the assessment reach. To develop agriculture in the valley, soils were bull dozed to form levees on either side of the channel, pushing it to the middle of the valley into a narrower zone than it occupied historically and straightening the channel. Because of the levees and the constriction of the channel, the levees concentrated the streams erosive energy, and the stream dramatically down-cut. As a result, the stream cross-sections are narrower, and the stream has higher transport capacity, since shear forces on the bed increase faster with increasing water depths resulting from a confined channel.

Estimates of bedload transport for the Coppei Creek cross-sections are provided in figure 37 and show that bedload transport initiates somewhere below 20 cfs, most probably closer to below 5 cfs. Bankfull flow, estimated at this site to be approximately 322 cfs, transports about 5,600 tons per day of bedload at the McCown Bridge cross-section and approximately 3,100 tons per day at the antique car lot cross-section.

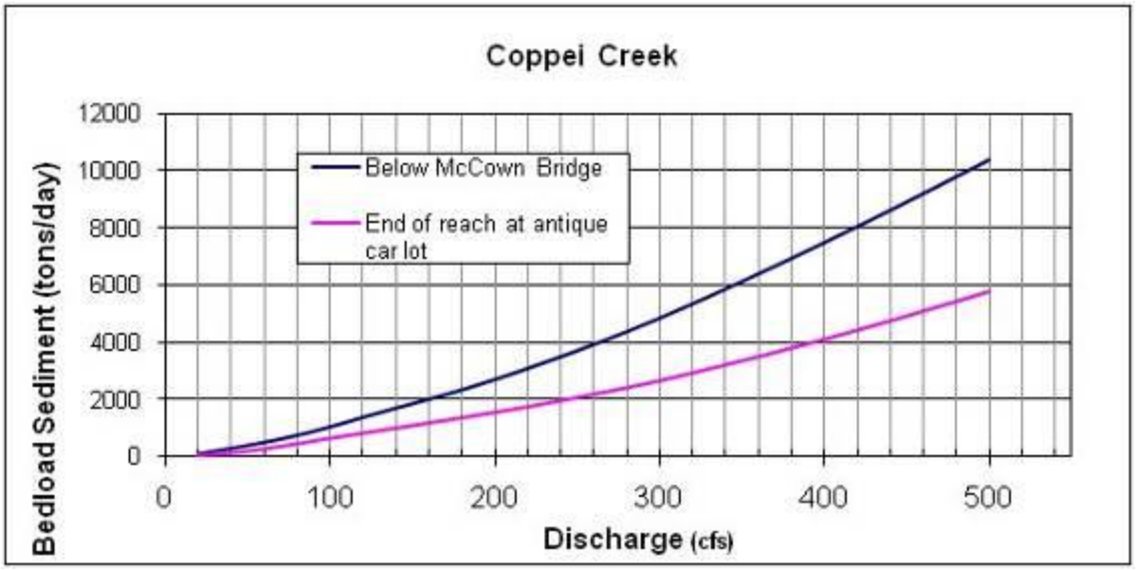


Figure 37. Bedload rating curve below McCown Bridge and above the antique car lot at the end of the assessment reach, Coppei Creek, Walla Walla County, Washington

As flows increase, sediment transport increases exponentially, as shown in figure 37. At 500 cfs, about 10,300 tons per day of bedload are transported through upper sections of the reach while approximately 5,800 tons per day are transported through the lower sections. As mentioned, the entire Coppei reach is confined, with very little floodplain, so as flows increase the stream gets deeper and has substantially more ability to transport sediment introduced from upstream. Most of the leveed section of Coppei has similar sediment transport characteristics.

Bank Stability

Walla Walla River

Overall, approximately 84 percent of the banks along the Walla Walla River study reach are stable. However, several areas show a high degree of instability, with a high likelihood of further failure. There were nine individual failure locations that averaged 160 feet in length and 6 feet in height. The average root depth at these locations was 1.1 feet and the overall root density was low.

Typically, unstable banks are located at the outside of meander bends, and are a sign that the stream is actively adjusting its course. Along the Walla Walla River assessment reach, bank instability and channel incision are active, thus indicating that the stream is altering its course. There are complex reasons for this, but reductions in the riparian canopy and changes to land management since the 1850s are the primary reasons.

The most significant unstable banks are located at RMs 0.1, 0.4, 0.7, 1.0, 1.3, and 1.5 (figure 17 in section “4. Assessment Reach Conditions”). These stream banks are composed of predominantly fine material with low cohesion, and minimal structural support from rooted vegetation. Many of the sites showed signs of active erosion. The mechanisms for failure of banks varied along the study reach. Evidence for toe slope erosion and bank collapse was observed, as well as direct fluvial erosion of bank surfaces.

Mill Creek

Overall, approximately 92 percent of the banks along the Mill Creek study reach are stable. However, several areas show a high degree of instability, with a high likelihood of further failure. There were six individual failure locations that averaged approximately 225 feet in length and 5 feet in height. The average root depth at these locations was 0.8 feet and the overall root density was low. Overall, the reach data indicates that Mill Creek is relatively stable.

Coppei Creek

Overall, approximately 47 percent of the banks along the Coppei Creek study reach are stable. This reach is highly unstable due to past channelization. Essentially every meander bend is unstable as the reach has down-cut in response to the past disturbance. The stream is in the process of developing a new floodplain and a functioning geomorphic pattern. There were 17 individual failure locations that averaged approximately 200 feet in length and 9 feet in height. The average root depth at these locations was 1.1 feet and the overall root density was low.

Aerial Photo Comparisons

Historical information derived from interpretation of aerial photography can be essential for developing an understanding of river dynamics. Historical assessment can (1) define the sequence of past disturbances that have affected the drainage basin, (2) indicate the extent of adjustment to those events, (3) reveal past changes in environmental conditions that have led to fundamental alterations of river dynamics, (4) provide the context for predictive understanding of future trends, and (5) help predict how future landuse/landcover changes are likely to affect managed reaches.

The earliest dated aerial photos available for the assessment were from the U.S. Army Corps of Engineers (USACOE), flown in 1949. Aerial photo flights examined for this assessment were flown in 1949, 1956, 1979, 1996, 2006, and 2009. The aerial photos were obtained from

USACOE, National Agriculture Imagery Program (NAIP) and Walla Walla County. In addition, 2009 intensity images were included in the aerial photo analysis. An intensity image is an image derived from intensity values returned by each laser pulse of a LiDAR flight. The intensity values can be displayed as a gray-scale image and can serve as a surrogate to aerial photography.

Walla Walla River

A significant change to the channel pattern has occurred between 1949, 1979, 1996, and 2009 (figure 38). An increase in riparian vegetation and channel roughness has also occurred over this time period. For ease of analysis, this section compares aerial photos from 1949, 1979, and 2009 LiDAR intensity image.

A measure of the amount that a river meanders within its valley is termed sinuosity and is calculated by dividing total stream length by valley length or channel slope to valley slope. Sinuosity for the Walla Walla River is currently measured to be 1.4. It was estimated to be 1.2 in 1949 and 1.3 in 1979. In a functioning alluvial river system, higher sinuosity generally indicates that a stream channel has more access to move laterally across the valley, and also there is likely to be more side channel and groundwater channel habitat that typically form in abandoned meanders. This migration indicates that the stream channel has access to a floodplain during higher flows. This is important for reducing velocities during floods, capturing sediment, providing spawning gravels for fish, building stable stream banks, and providing a wide range of tree and plant age classes within the riparian zone. From the past photos, it appears that the stream channel conditions are improving since 1949.

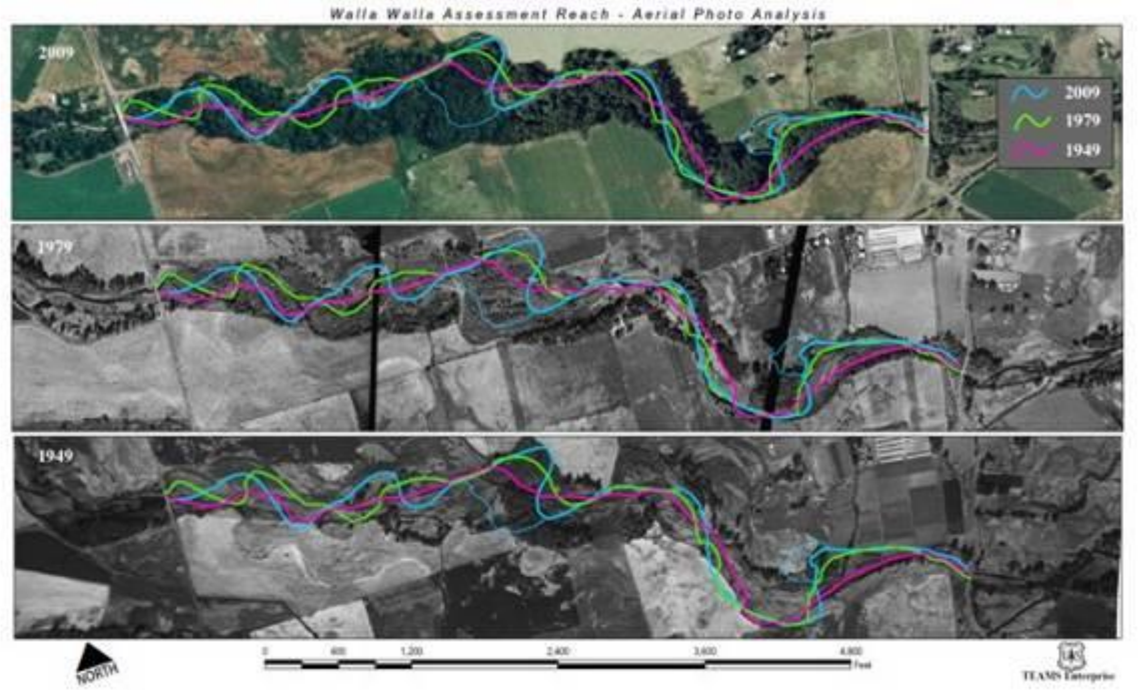


Figure 38. Location of the stream channel thalweg in 1949, 1979, and 2009 for the Walla Walla River assessment reach, Walla Walla River, Walla Walla County, Washington

Mill Creek

Sinuosity in the Mill Creek assessment reach is currently 1.1 due to past channel straightening. In the oldest photo available (1956), the sinuosity is 1.1 as well (figure 39). It is likely that sinuosity in the reach was higher before development of the valley began. There are areas of the assessment reach where the stream channel has shown signs of migration. The photos indicate a channel managed to remain confined along the eastern side of the valley. This has caused the channel gradient to be steeper than what would be expected historically. Vegetation in the valley has not changed significantly, with the exception of the forest stands becoming thicker and more decadent due to ongoing fire suppression.

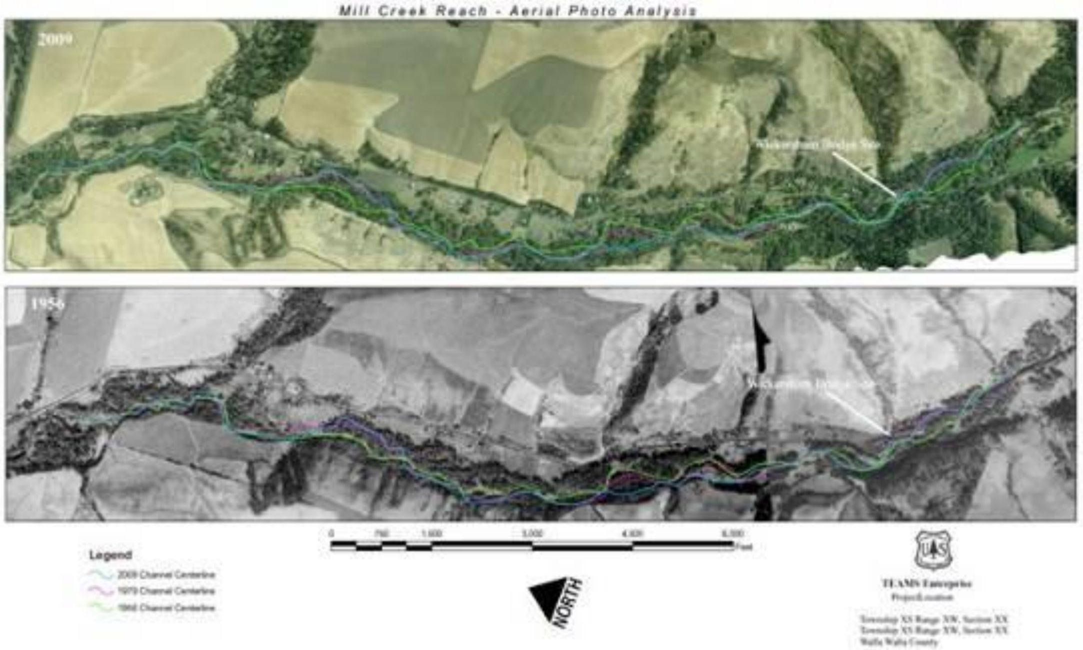


Figure 39. Location of the stream channel thalweg in 1956, 1979, and 2009 for the Mill Creek assessment reach, Mill Creek, Walla Walla County, Washington

Coppei Creek

The oldest photos available for the Coppei Creek assessment reach are from 1979. The photos indicate that the stream was channelized prior to these photos being taken. It is unclear when channel manipulation occurred. Sinuosity in the Coppei Creek reach is currently 1.0. It appears from the 1979 photos that the sinuosity was also 1.0 at that time (figure 40). The riparian width in 1979 constituted a small band of trees that lined the stream; this is generally still the case. However, the 2009 photo show the implementation of the CREP work completed through the FSA in 1999.

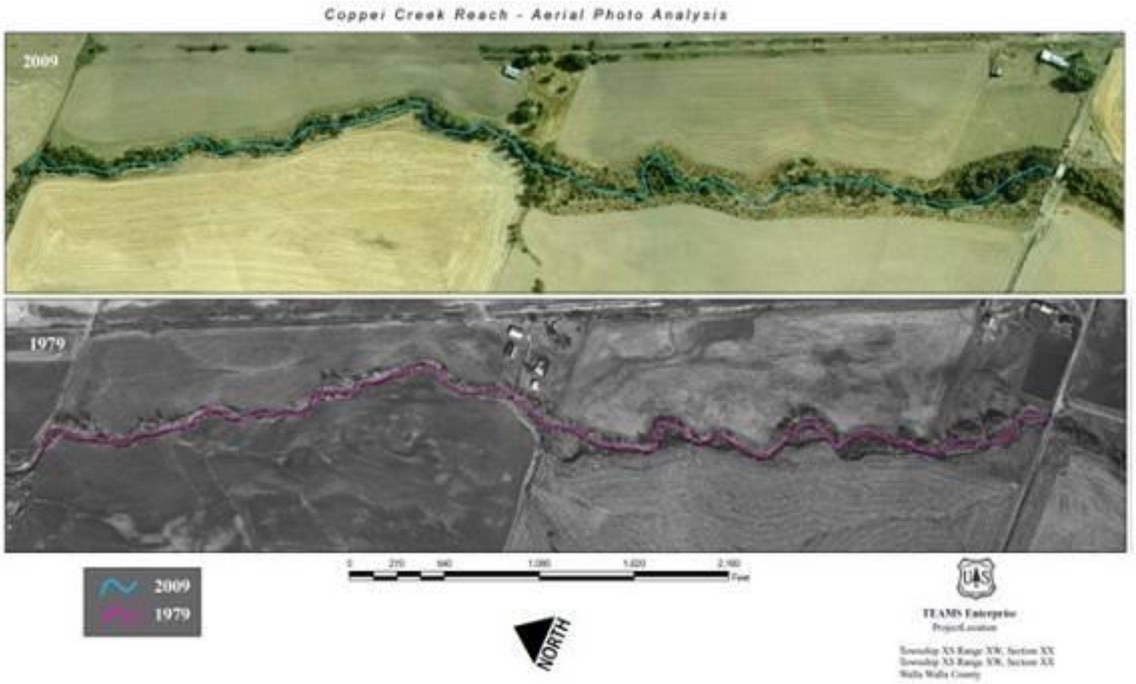


Figure 40. Location of the stream channel thalweg in 1979 and 2009 for the Coppei Creek assessment reach, Coppei Creek, Walla Walla County, Washington

Floodplain Mapping Analysis

A HEC-RAS (Brunner 2002) analysis was performed to model the extent of flooding for a given flow rate for the Walla Walla River and Mill Creek assessment reaches. The Coppei Creek assessment reach was not modeled because there are little to no values at risk associated with this reach and the stream channel is entrenched to the point that flooding would not likely overtop the ad hoc levees that have been constructed along the reach. HEC-RAS is a computer program designed to perform one-dimensional, water-surface profile calculations using geometric data and steady flow data. Model results show flooding extent for the bankfull, 50-, 100-, and 500-year flood events.

Walla Walla River

Preliminary analysis shows that a 50-year flood would access much of the Walla Walla River floodplain and riparian areas throughout the assessment reach (figure 42). A 100- or 500-year event would not necessarily cover more land area (figures 43 and 44), but would have a larger volume of water. Overall, the modeling indicates that flood dynamics throughout the reach are, for the most part, functioning properly. Further, the modeling indicates that infrastructure, other than bridges, would not be impacted and are currently located out of the bankfull, 50-, 100-, and 500-year flood areas.

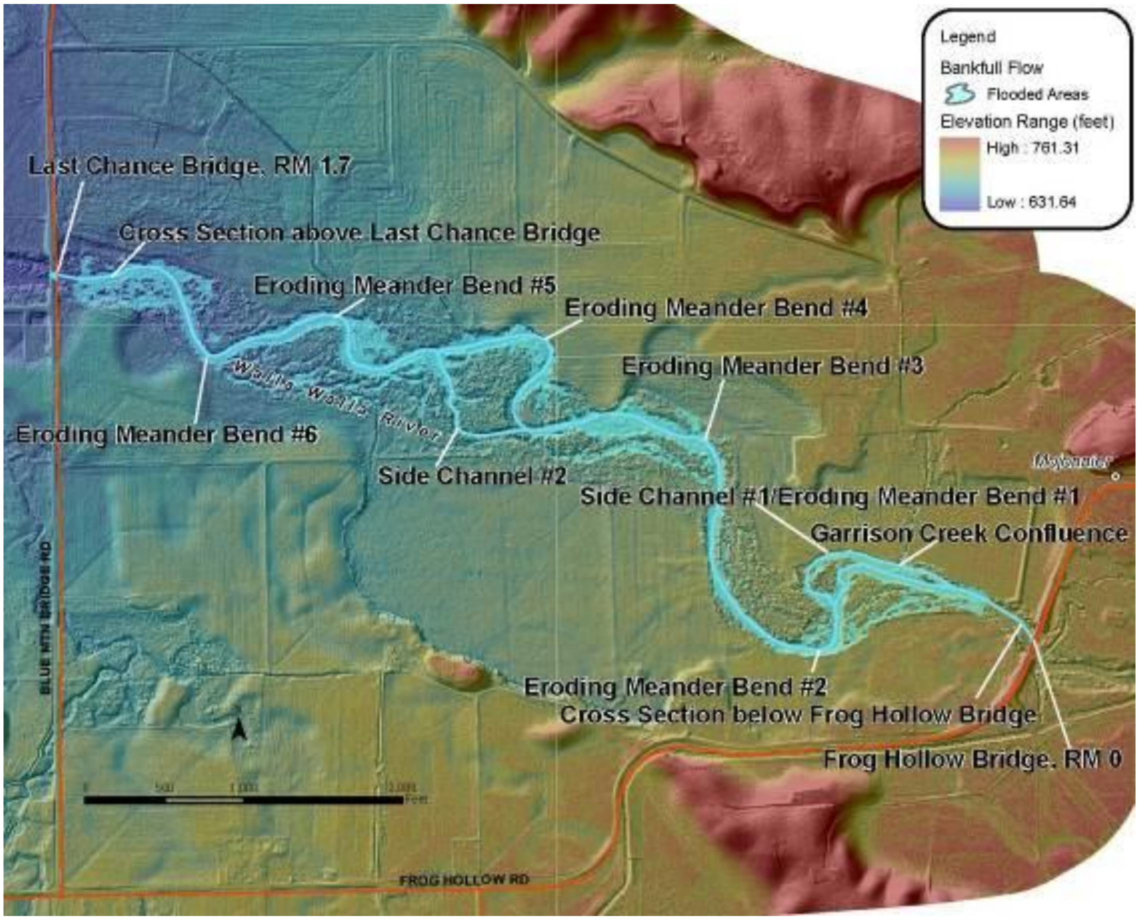


Figure 41. Modeled bankfull flow of the Walla Walla River, Walla Walla County, Washington

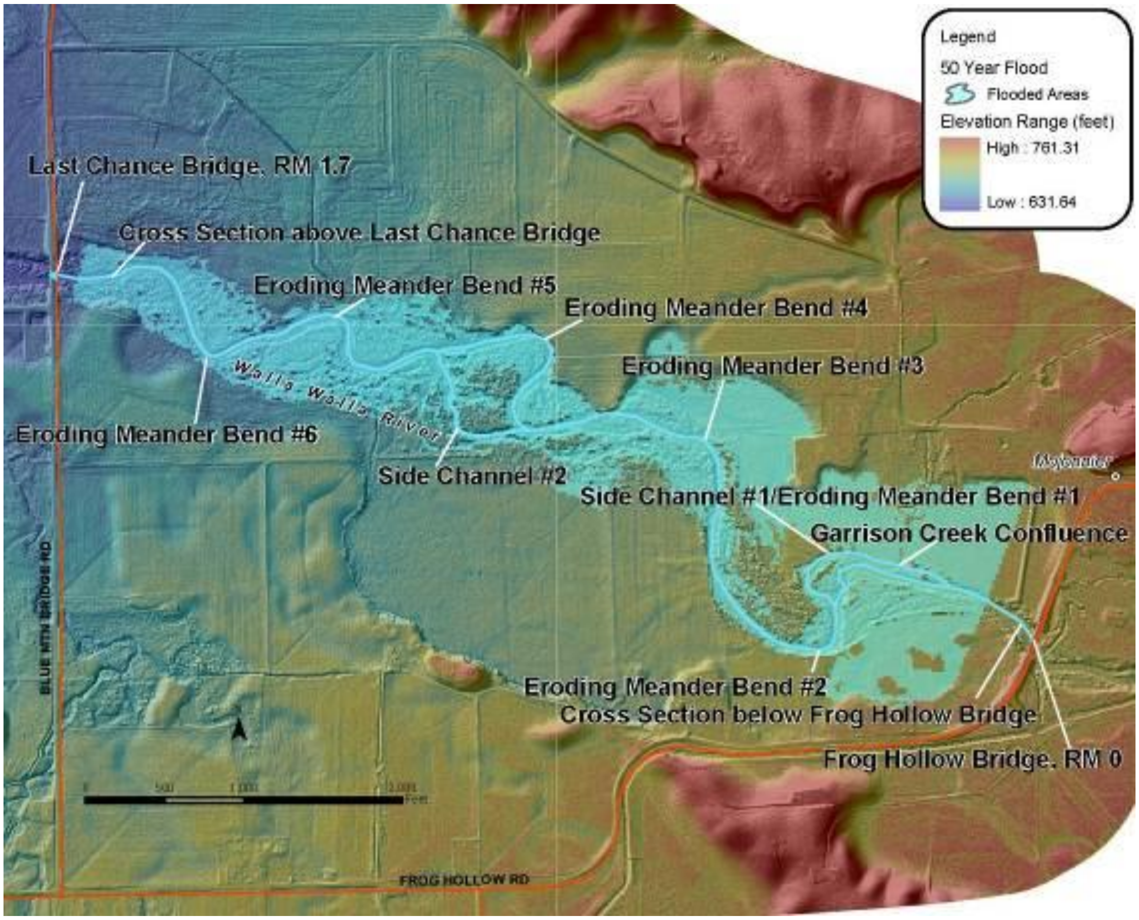


Figure 42. Modeled 50-year flood event of the Walla Walla River, Walla Walla County, Washington

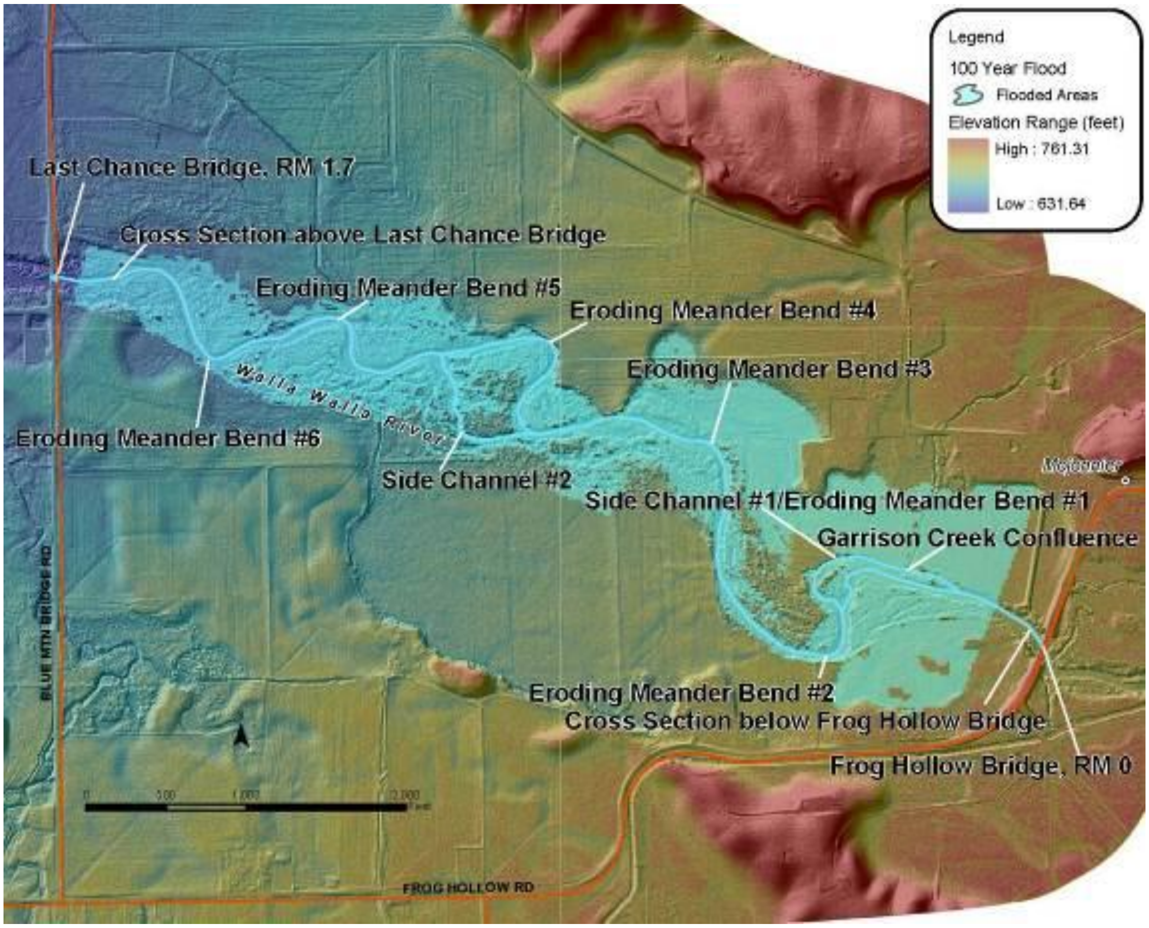


Figure 43. Modeled 100-year flood event of the Walla Walla River, Walla Walla County, Washington

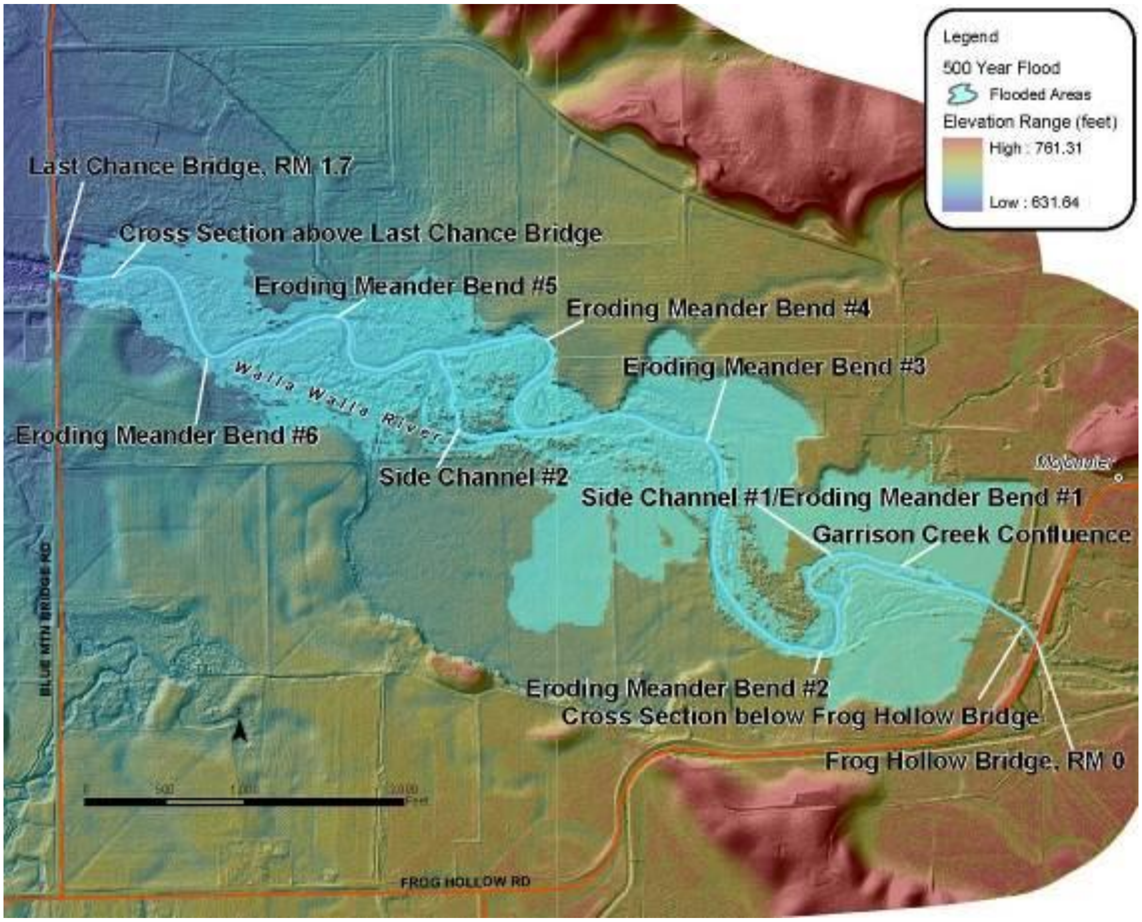


Figure 44. Modeled 500-year flood event of the Walla Walla River, Walla Walla County, Washington

Mill Creek

Preliminary analysis illustrates that a 50-year flood would access much of the Mill Creek Valley throughout the assessment reach (figure 46). Unlike the Walla Walla River assessment reach, flooding at this level would impact a majority of the infrastructure in the valley. Similar to the Walla Walla River assessment reach, the flooding area would not increase substantially with the 100- and 500-year events, however depth would increase. The volume and subsequent flow velocities of these events could impact homeowners along this reach. Overall, the modeling indicates that flood dynamics throughout the reach are, for the most part, functioning properly.

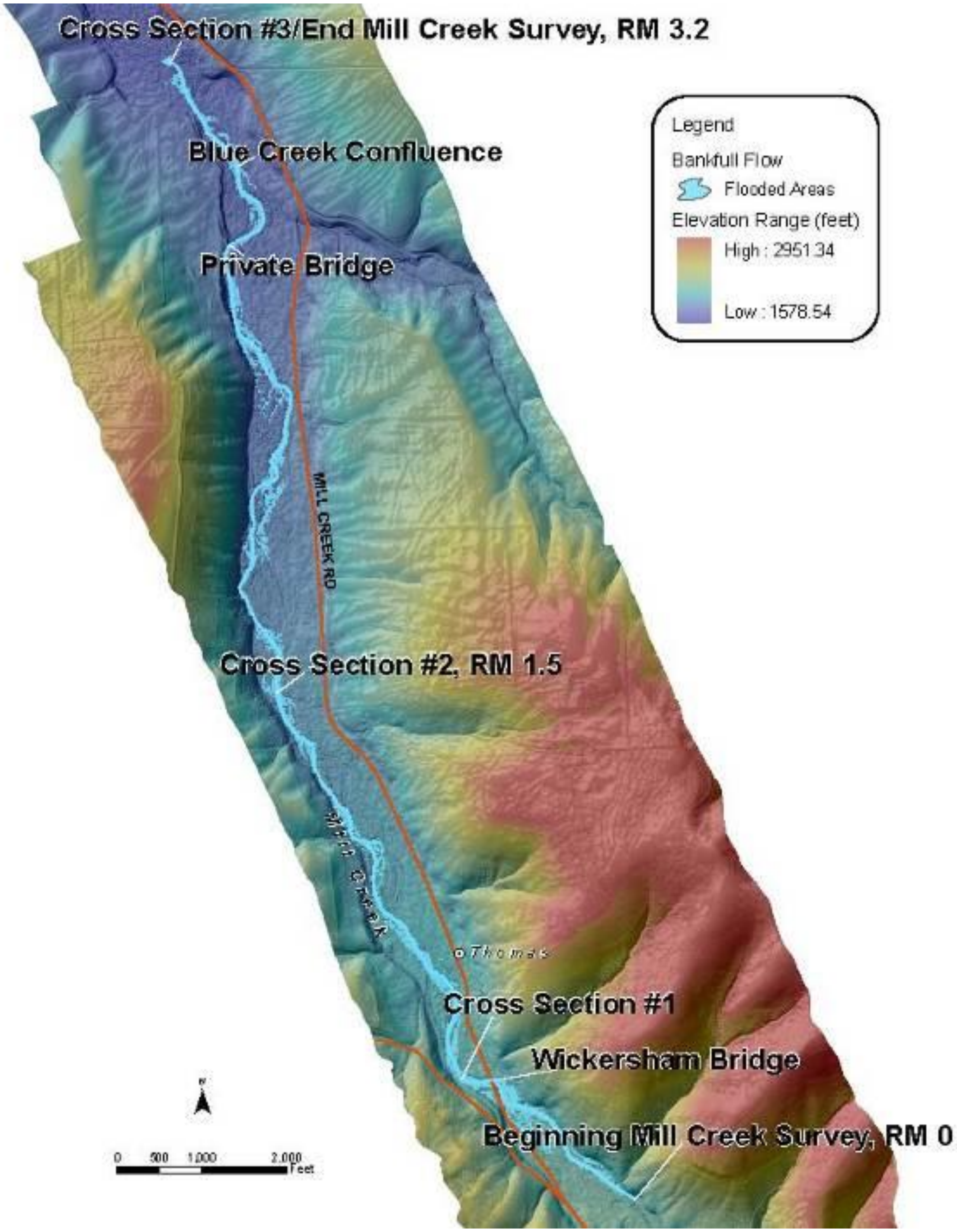


Figure 45. Modeled bankfull flow of Mill Creek, Walla Walla County, Washington

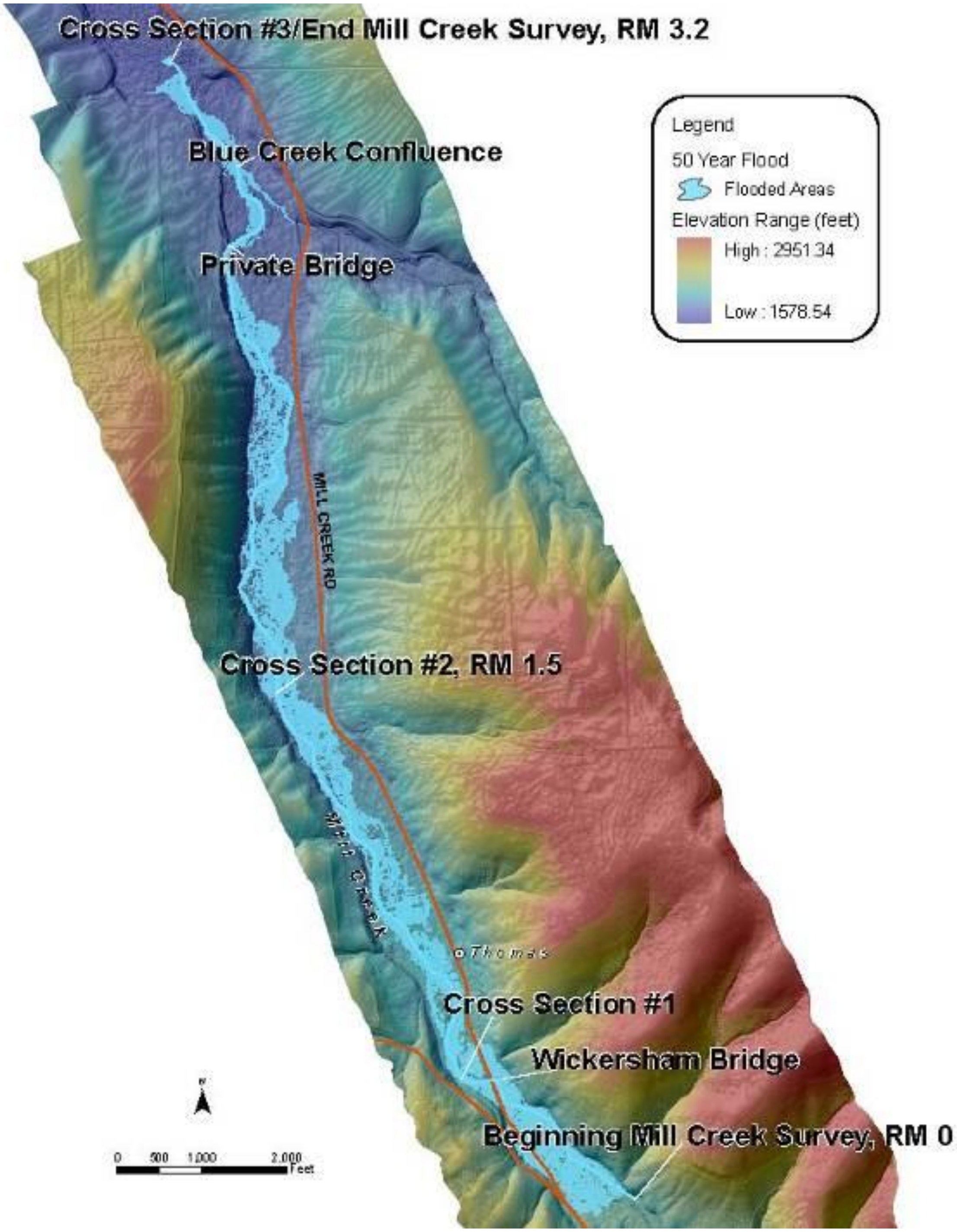


Figure 46. Modeled-50 year flood event of Mill Creek, Walla Walla County, Washington

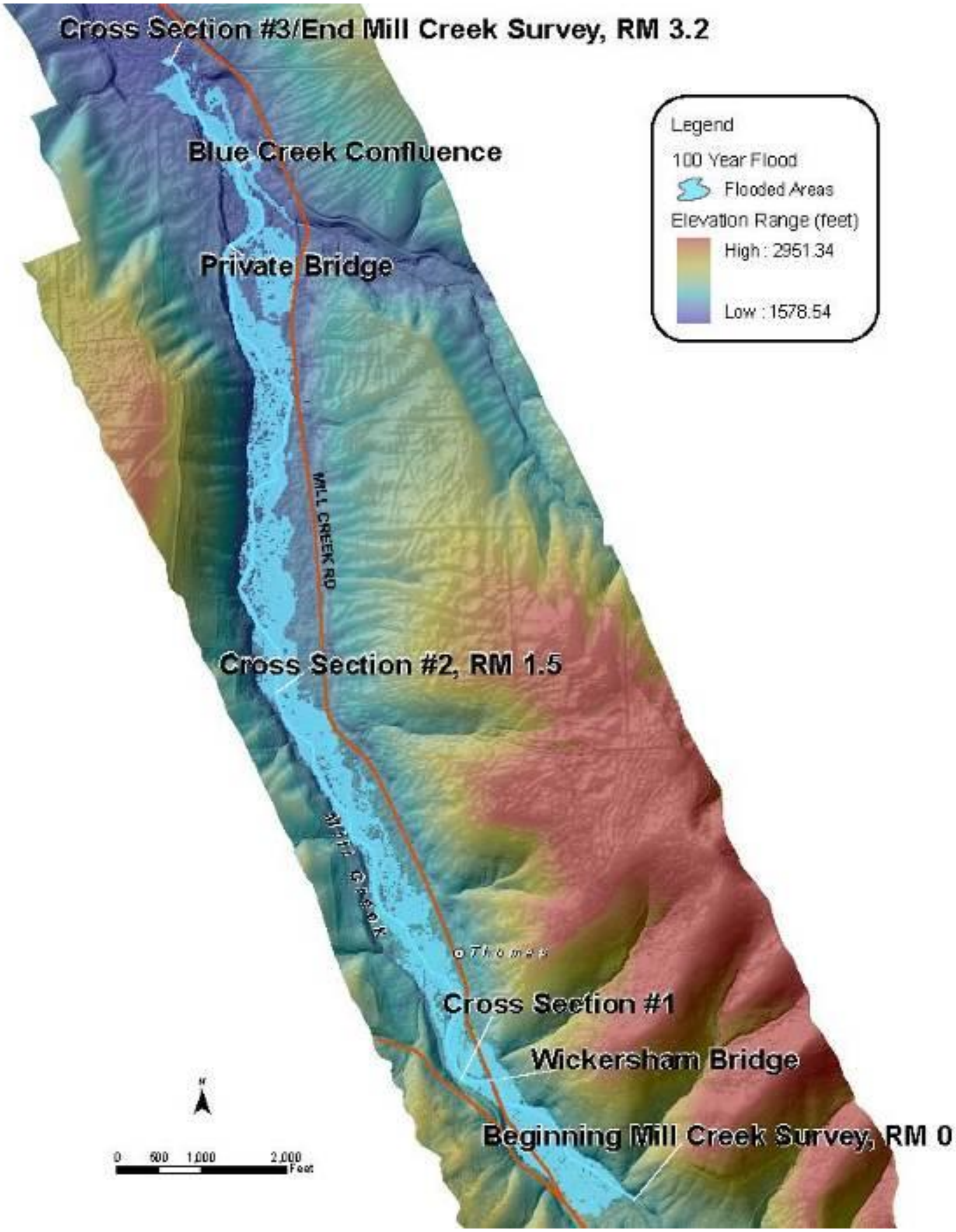


Figure 47. Modeled 100-year flood event of Mill Creek, Walla Walla County, Washington

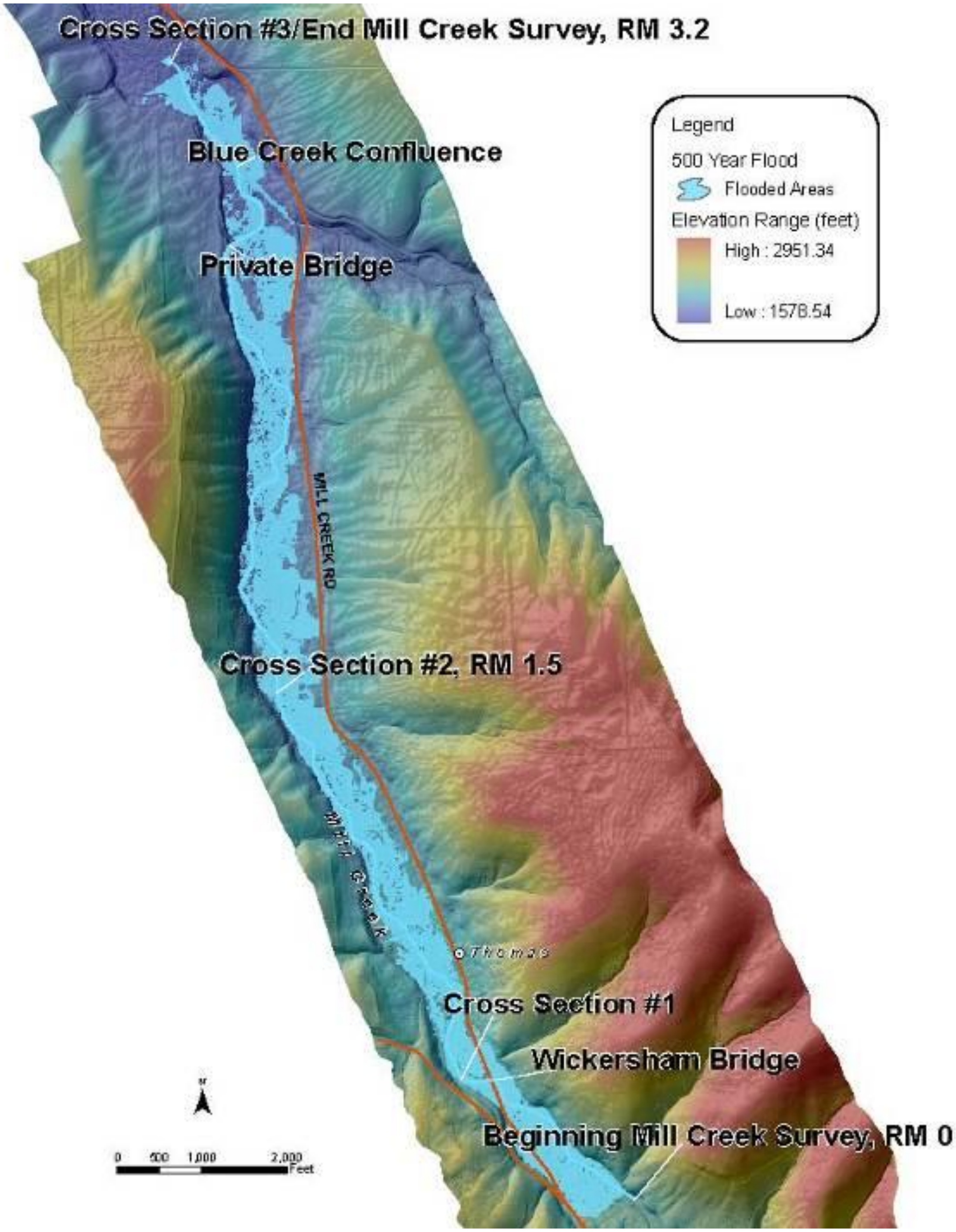


Figure 48. Modeled 500-year flood event of Mill Creek, Walla Walla County, Washington

Riparian Vegetation

Riparian vegetation along the sections of the streams that were surveyed is dominated by black cottonwood and alder and generally fits the description of the Black Cottonwood-White Alder association described by NatureServe Explorer (2008). The reference area at Lewis and Clark State Park on the Touchet River appears to represent the Black Cottonwood/Mountain Alder association described by Kovalchik and Clausnitzer (2004) although vegetation on the Touchet River has also been described as Black cottonwood-white alder (NatureServe 2010). The Black Cottonwood/Mountain Alder association is common in eastern Washington, Idaho, and western Montana, and occurs in scattered locations in western Washington, Utah, Nevada, Wyoming, and North Dakota. The Black Cottonwood-WhiteAlder association is described as restricted to south-central and southeastern Washington and adjacent Oregon. Alder trees observed in assessment surveys for this project appeared to be white alder, but it is possible that some mountain alder or red alder may also occur in assessment reaches.

Vegetation in the assessment reach is dominated by medium-sized to mature black cottonwood-white alder (*Populus balsamifera* ssp. *trichocarpa*-*Alnus rhombifolia*) stands with a subcanopy of both species and a few patches of regeneration. Cottonwood communities typically establish on active fluvial surfaces such as point bars since the trees need abundant, well-oxygenated water and bare mineral soils for establishment and good growth (Borman and Larson 1999). River and floodplain alterations from activities such as agriculture, irrigation, and channelization have created conditions less suitable for cottonwood establishment and development, and these communities are now less common than in the past (Kovalchik and Clausnitzer 2004).

Other tree species on the assessment reaches include: Siberian elm (*Ulmus pumila*), peachleaf willow (*Salix amygdaloides*), black locust (*Robinia pseudoacacia*), Oregon ash (*Fraxinus latifolia*) and ponderosa pine (*Pinus ponderosa*). Siberian elm is not native; black locust is considered a native species by PLANTS Database, but Hitchcock and Cronquist (1973) imply that it is not native to this area. Peachleaf willow is a native riparian species that was probably more common in the past. The few remaining trees are large and decadent, and the species does not appear to be reproducing. Oregon ash is a native species (USDA NRCS 2010), but more typically occurs in most soils along the coast (Hitchcock and Cronquist 1973). Ponderosa pine likely occurred in the vicinity historically judging by the fact that it was mentioned by the Lewis and Clark expedition and it occurs in the reference area at Lewis and Clark State Park. However, it is likely that it naturally occurred toward the back of the riparian area where conditions are drier.

Assessment Reaches

Physical characteristics of the streams reaches are discussed in the “Introduction,” “Watershed Conditions,” and “Hydrology” sections of this report.

Walla Walla River Assessment Reach

Vegetation in the assessment reach is dominated by medium-sized to mature black cottonwood-white alder stands with a subcanopy of both species and a few patches of regeneration. Other scattered and infrequent trees encountered in surveys include peachleaf willow, black locust, and Siberian elm. Older cottonwoods are typically 12 to 24 inches dbh (diameter at breast height), 50 to 70 feet tall, and occasionally have side sprouts. Cottonwood regeneration was observed in two of the four plots; young cottonwoods range between 0.5 and 10 feet tall. They are typically scattered, but occasionally numerous on gravel bars. In many cases the cottonwood regeneration did not look healthy but was surviving. Younger alder typically occur in patches; they often make up the subcanopy layer and are between 6 and 10 inches in diameter and 30 to 40 feet tall. Cottonwood stands have increased 1.5 times in extent on the floodplain since the earliest available air photos.

Figure 49. Dense riparian areas along the Walla Walla River assessment reach, Walla Walla River, Walla Walla, Washington

The understory is dominated by reed canarygrass, a common invasive in this area. Shrubs are rare in this reach, but there was some cover of snowberry and nonnative blackberry in surveyed plots. Except on the bars, there is little bare ground. Downed wood accounts for 5 to 20 percent of the ground cover.

Disturbances along this reach are recent and historic, natural, and man-made. Invasive plants are common in disturbed areas such as along road edges. There is a particularly dense patch of weeds (Scotch thistle, teasel, yellow spike, cheatgrass, poison hemlock) between the riparian zone and the adjacent field on the north side of the river near the middle of the reach.

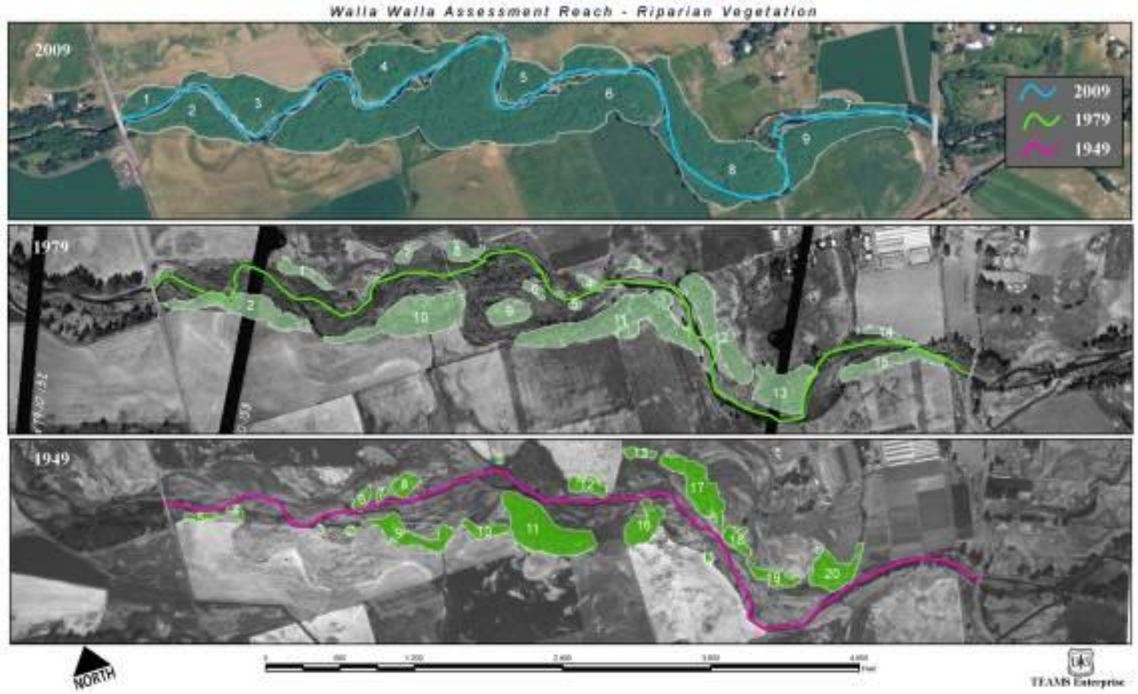


Figure 50. Historical extent of cottonwoods, Walla Walla River reach

Mill Creek Assessment Reach

Vegetation along Mill Creek is dominated by medium-sized to mature black cottonwood-white alder stands with a subcanopy of both species and patches of smaller trees in the subcanopy. The only other trees encountered in surveys were black locust and a few small ponderosa pines. Cottonwoods in the reach are typically 12 to 24 inches dbh, but larger trees up to 36 inches dbh were observed outside survey plots. Alder, cottonwood, and black locust (30 to 45 feet tall) make up the subcanopy. Tree regeneration is very limited along this reach. The younger alders are approximately 3 inches dbh and 30 feet tall. Three trees were found in the youngest age class: two ponderosa pines approximately 6 feet tall and one black locust approximately 10 feet tall. Few young cottonwoods were present in surveyed stands, with the smallest being about 25 feet tall.

The understory is composed mostly of herbaceous nonnative invasive species. There is essentially no bare ground. Downed wood was observed to be 14 percent of the ground cover. The dominant herbaceous species is reed canarygrass.

Residential development and agricultural fields occur on both sides of the creek, apparently limiting the width of the riparian vegetation. There are several areas of CREP revegetation plantings in and at the back of the riparian zone dominated by ponderosa pine and black locust.

Invasive plants are common and occurred in all plots. Among the most common are several naturalized species—reed canarygrass, blackberries, and sweetbriar rose. Houndstongue is also common, as are pasture grasses such as timothy and orchard grass. Other species (mullein, bull thistle, and poison hemlock) are less common, but could easily spread in the future. Japanese knotweed occurs in the stream and poses a serious long-term threat to the natural vegetation of this reach.

Figure 51. Mill Creek has a more open riparian area along the channel

Coppei Creek Assessment Reach

Vegetation along the stream is similar to that of the Walla Walla River and Mill Creek. Cottonwood and white alder form the forest canopy and subcanopy. In addition to the two main species, only two other tree species were encountered in survey plots, Oregon ash, and black locust. This reach of Coppei has a more open canopy than the other assessment reaches, possibly due to the fact that the stream is so entrenched and the riparian vegetation is often high above the stream on the terrace. Of the three assessment reaches, this one has the fewest trees and the lowest average canopy cover. In surveyed plots, cottonwood regeneration was concentrated on one cobble bar survey plot and shrub cover was concentrated in drier areas, either sites raised well above the stream or at the back edge of the riparian zone. Similar to the other assessment reaches, the herbaceous layer was dominated by nonnative species. Reed canarygrass is common, especially on bars and the lowest terraces; on some of the raised terraces, it is much less frequent and abundant. There is little bare ground except on gravel bars; between 2 and 25 percent of the ground cover is composed of downed wood (an average of 12 percent).

Disturbances along this reach include an abundance of weeds, a road through the riparian vegetation to the creek, an old car on the streambank near the McCown Bridge, CREP revegetation plantings, and agricultural fields on both sides of the stream.

Invasive species were less common in survey plots on the Coppei Creek assessment reach than on the other reaches. However, reed canarygrass is abundant and a wide strip of weeds (approximately 10-feet wide) divides much of the riparian vegetation from the fields on either side of the stream.

Figure 52. Coppei Creek riparian area

Note: Channel down-cutting with dryer terraces above the stream.

Comparison of Reference and Assessment Reaches

The riparian area at Lewis and Clark State Park on the Touchet River northeast of Waitsburg, Washington, was used as the best available comparison reference area for the evaluation of potential riparian vegetation in the three assessment reaches. The park has a fairly undisturbed riparian area with vegetation consisting of a dense assemblage of mostly native plants. Cottonwoods in the park, however, are managed (hazard trees, some young trees, and sprouts are cut). Park Manager, Gary Lentz, estimates the riparian zone along this section of the Touchet to be approximately 1,200 feet wide (Lentz, G., 2008, *personal communication*). Due to the time of year of the survey, few herbaceous species were visible. See appendix B for a list of species observed by the Lewis and Clark expedition.

Canopy cover on the Walla Walla River reach approaches that of the reference reach; on Mill and Coppei Creeks the forest canopy is more open. Sub-canopy cover is much higher on all three assessment reaches than on the reference reach. The amount of downed wood in assessment areas away from the streams is comparable to amounts in the reference reach. The amount of cottonwood regeneration in assessment and reference reaches is also comparable; however, in both cases, cottonwood regeneration may be more limited than historically due to stream entrenchment which creates higher flow velocities that dislodge young cottonwoods and willows from point bars before they are well established.

On assessment reaches, riparian forests and woodlands occur mainly on raised terraces adjacent to entrenched streams; however, some banks of each reach are bare or covered by nonnative weedy vegetation. Residential development and agricultural fields border the riparian vegetation and dirt roads border or pass through all assessment reaches. Throughout the surveyed reaches, stream channel elevations are lower than the adjacent terraces, with areas of Coppei and Mill

Creek entrenched up to 10 feet. Riparian forests occur mainly on raised terraces; lower point bars along the streams have sparse, mostly weedy vegetation. In many places, homes and other structures occur on the stream terrace just outside the riparian zone and in the path of high flood waters. In some areas along the assessment reaches, the active floodplain is not wide enough to dissipate the energy of normal high flows, and in other areas, the riparian zone may not be wide enough to filter overland runoff before it reaches the river. In a few places, banks are bare or are covered with weedy vegetation that does not stabilize soils.

Cottonwoods may still regenerate in backwater areas when floods waters rise high enough to cover terraces. The main changes from reference conditions on the assessment reaches are in the width of the riparian zone, the depth of stream entrenchment, and diversity of the understory.

Riparian Zone Width. The width of the riparian zone is one measure of the health and proper functioning of a stream system. In undisturbed systems, the zone varies with the size, gradient, and sinuosity of the stream and the width of the valley. The riparian zones along the assessment reaches are constrained by agricultural and residential development on all three reaches and are narrower than the riparian area of the reference reach. The State of Washington (SHRG 2004) recommends a minimum riparian width of 250 feet for healthy stream conditions for streams the size of those in the assessment area. The riparian zone on the Walla Walla River reach is the widest found in the assessment area, reaching a maximum width of 965 feet. Almost one-fourth of the reach supports a riparian zone of less than 250 feet. Most of the riparian zone on Mill Creek reaches 250 feet in width, but the zone varies from approximately 49 feet to only 607 feet, which is only half as wide as the reference reach. Coppei Creek is the smallest of the three streams. Its riparian zone reaches nearly 250 feet toward the southern end of the reach, but due to the deep entrenchment of most of the stream, the riparian zone along about two-thirds of the reach is much less than 250 feet wide.

Diversity. Assessment reaches have very little vegetation diversity; the primary native species are black cottonwood and alder. The nonnative invasive species, reed canarygrass, forms an almost solid understory throughout much of the area. Regeneration and riparian development are limited by stream entrenchment which lowers the water table and dries out terraces. The lack of a shrub layer is one of the most significant differences between the assessment and reference reaches.

Canopy Cover. There are generally more trees (540 to 870 per acre) in the assessment reaches than in the reference reach (120 to 144 per acre). Canopy cover on the Walla Walla reach is similar to that on the reference reaches, but is lower on the other two reaches. Trees in the reference area canopy are larger and probably older than in the assessment area. The subcanopy (smaller trees that form a lower canopy) in the assessment reaches is, however, much more dense than the reference reach subcanopy (table 4). This is partly due to the lack of a well-developed shrub cover in the understory of assessment reaches. A diverse native shrub layer is a major component of the reference reach, but only a very small component of assessment reaches.

Table 4. Comparison of reference and assessment reaches

	Measure (Average # Per Plot/Average Cover [%])				
	Regeneration	**Subcanopy**	**Canopy**	**Shrub**[1]	**Down wood**[1]
Walla Walla River	7 / <1	9 / 19	17 / 41	1	10
Mill Creek	<1 / <1	8 / 21	5 / 27	15	14
Coppei Creek	5.5 / <1	9 / 33	2 / 20	2	12
Reference Area	<1[1]	3 / 6	2 / 45	55	8

[1] Average cover only.

Fish Habitat

In general, fish habitat along the assessment reaches has been severely degraded by a variety of factors including:

a. Low pool quantity and poor quality caused by elevated sediment load, low stream bank and channel stability, and lack of large woody debris.

b. Disconnection of floodplains and loss of associated side and hyporheic channel habitat.

c. Loss of predator cover due to poor pool quality and lack of large woody debris and habitat diversity.

d. High stream temperatures from widened channels, lack of overhanging vegetation, loss of hyporheic function, and irrigation withdrawals.

The primary factors contributing to the degradation of aquatic habitat are many of the same factors that have led to poor channel conditions such as decreased bank and channel stability, lack of large woody debris, poor riparian vegetation amounts and conditions, and channelization. Fish hereafter will refer primarily to salmonids, the species of concern within the assessment reaches. The condition of existing native fish habitat along the assessment reaches are described in further detail below:

Fish Habitat Condition

For streams with gradients less than 2 percent, a stream reach is rated as high quality habitat if it contains more than 55 percent pools by length in addition to other high ranking values including embeddedness less than 50 percent in post-pool-tail crests (Washington State Fish and Wildlife Commission 1997). In addition, good habitat is associated with riparian canopy of at least 80 percent and a high component of conifers with poor habitat associated with riparian canopies under 70 percent. Brown et al. (1994) and Chen (1992) suggested that pools of 3 feet in depth or greater were necessary for successful rearing juvenile salmonids. When substantial erosion occurs in a watershed, pool habitats diminish by aggradation (filling in) and spawning gravels become embedded (Madej 1984). Good salmonid habitat is characterized by a diversity of pools, including those formed by large wood.

Table 5. Physical characteristics of pools for the assessment reaches used as indicators of fish habitat condition

Assessment Reach	Percent of Pool Length per Stream Length [1]	Percent Canopy Cover (shade) [2]	Average Pool Depth [3] (feet)	Average Instream Large Wood Pieces/Mile
Walla Walla River	58%	39%	3.5	26
Coppei Creek	12%	50%	2.2	10
Mill Creek	24%	33%	1.9	22

[1] The Washington State Fish and Wildlife Commission (1997) pool frequencies by length recommendation: For streams less than 15 meters wide, the percent pools should be greater than 55%, greater than 40% for streams with gradients less than 2% and between 2 to 5%, respectively.
[2] Good habitat is associated with riparian canopy of at least 80% and a high component of conifers. Poor is riparian canopies under 70%.
[3] Fish habitat considered good for pools 3 feet in depth or greater (Brown et al. 1994).

Walla Walla River Reach. This reach is considered to be in a degraded state but shows signs of recovery. Percent pool length and pool depths appear adequate (table 5); however, fine sediment from eroding banks and upstream sources cover streambed sediments that clogs interstitial spaces between streambed gravels reducing cover and food for juvenile salmonids. In addition, artificial rip-rap placed along the banks and within the channel to prevent erosion offers little fish habitat (figure 53). Shading over the channel is poor with an average value of 39 percent. Large woody debris values are also low at 26 pieces per mile (see previous section for discussion of large woody debris). Habitat quality and productivity for fish are limited in this reach by the lack of deep pools or other slow water habitat, the lack of channel complexity, limited large wood material, and poor riparian health.

Figure 53. Concrete rip-rap along the channel banks offers little fish habitat; Walla Walla County, Washington

Mill Creek Reach. This reach is considered to be in a degraded state but shows signs of recovery. Percent pool length and pool depths are poor at 24 and 1.9 feet, respectively. Channel modification and infrastructure such as roads and bridges in some areas cause channel instability which affects the quality of fish habitat. Pool tail crests (spawning habitat) appear adequate with little fines, however there are few backwater or slow water areas for rearing juvenile salmonids. Shading over the channel is poor with an average value of 33 percent. Large woody debris values are also low at 22 pieces per mile (see discussion of instream wood). Habitat quality and productivity for fish are limited in this reach by the lack of deep pools or other slow water habitat, the lack of channel complexity, limited large wood material, and poor riparian health.

Figure 54. Concrete rip-rap along the channel banks offers little fish habitat; Walla Walla County, Washington

Coppei Creek Reach. This reach is considered to be in a highly degraded state. Percent pool length and pool depths are low (table 5) and fine sediment from eroding banks and upstream sources cover streambed sediments that clogs interstitial spaces between streambed gravels reducing cover and food for juvenile salmonids. Artificial rip-rap placed along banks in some areas to prevent erosion offers little fish habitat (figure 54). The high banks and lack of floodplain connectivity increase shear stresses during high stream flows limiting off channel habitat and flood refuge for fish. Shading over the channel is poor with an average value of 50 percent. Large woody debris values are also low at 10 pieces per mile. Habitat quality and productivity for fish are limited in this reach by the lack of deep pools or other slow water habitat, the lack of channel complexity, limited large wood material, and poor riparian health.

Figure 55. Car body placed in channel presumably to prevent erosion; Walla Walla County, Washington

5. Recommendations – Assessment Reaches

In summary, the following factors negatively affect watershed and stream channel processes, degrade aquatic habitat and water quality, and may increase the risk of catastrophic flooding within local communities:

1) Disconnection of floodplains and flood-prone areas near the channel by:
    a) reduction of flood relief and side channels for floodwaters
    b) disruption and diversion of surface and subsurface water flow and hydrology by:
        i. river levees
        ii. transportation system road and railroad networks within the valley
        iii. Irrigation diversions and withdrawals
2) Elevated sediment load due to headwater and river valley land management practices caused by:
    a) agricultural runoff
    b) severe bank erosion, stream channel degradation, and streambed erosion generated by poor riparian conditions
    c) stream channel confinement by levees and stream corridor manipulation
    d) lack of in-stream and floodplain large woody debris
3) Reported elevated maximum water temperature caused by:
    a. Poor or limited riparian vegetation conditions and lack of stream shade
    b. Stream channel confinement, channelization and subsequent bed elevation degradation and reduction of hyporheic flow
    c. Increased solar input caused by high stream channel width-to-depth ratios as a result of increased sediment load, delivery and deposition, reduced riparian vegetation, lack of instream large woody debris and poor stream bank and channel stability
    d. Irrigation withdrawals
4) Poor fish habitat conditions:
    a. Poor pool quantity and quality caused by elevated sediment load and substrate embeddedness, poor stream bank and channel stability and lack of large woody debris
    b. Disconnection of floodplains and loss of associated side and groundwater channel habitat
    c. Loss of predator cover due to poor pool quality, resting areas, and lack of large woody debris and habitat diversity

The primary factors contributing to both the increased risk of flooding and degradation of aquatic habitat along assessment streams are housing development or agriculture in river floodplains, combined with ad hoc levee and rock barb construction, stream channel manipulation, and the road network within the valleys.

For the Walla Walla River and Mill Creek, the lack of lateral stability and streambank stability in certain areas produces high stream width-to-depth ratios, thus exposing a large surface area to solar input. The cumulative effects can result in increased maximum water temperatures that are at times harmful to salmon and steelhead.

Due to the development of infrastructure and the extent of development, agriculture, and other impacts along the assessment reaches, full recovery or restoration of stream channel conditions and processes and aquatic resources to a pristine state is not feasible. However, rehabilitation of the stream and river systems within the assessment reaches is very plausible and will significantly improve flood protection for local communities and infrastructure, water quality, and aquatic habitat. In order to achieve any significant or measurable rehabilitation of stream channel processes, rehabilitation efforts will need to extend beyond individual landowners, be developed on a community scale, and will require a high degree of coordination and cooperation among the various municipalities, local land owners, and Federal and State agencies and departments.

Walla Walla River Goals

The rehabilitation goals for the Walla Walla River assessment reach are to allow the channel to connect to historic floodplains and valley stream-channel flood-relief networks, and while allowing for human uses, restore stream channel and bank stability, restore and maximize riparian areas, which will help to moderate the effects of large floods, and to recover the natural range of aquatic and riparian habitat conditions to which native fish and wildlife are adapted. Also, because actions on one section of river affect downstream or upstream areas, it is important to integrate restoration activities along the river by developing a coordinated, community-based river management plan. A range of different completed projects were observed along the assessment reach including bank stabilization, rip-rapped banks, ad hoc levees, rock barbs, and irrigation withdrawal improvements. These projects would be more effective if they were coordinated across land ownerships. For instance, the channel instability observed at the Johnson’s ranch should be rehabilitated with bank treatments, establishment of flood relief channels, riparian plantings, and other treatments. Delineation of flood relief channels and construction of features that are required for them to be effective would involve multiple landowners and require landowner cooperation to be effective.

Goals for channel improvement are to improve channel conditions by decreasing channel widths at bankfull and lower flows, maintain and develop flood relief channels that the river will access at higher flows to reduce flow velocities, decrease the extent of unstable banks along the reach, increase the depths and numbers of pools to increase habitat for fish, find opportunities to increase large woody debris in the stream and floodplain, maintain adequate sinuosity, and restore shade along the channels. In many places along the reach these numbers are being met, and in others there is room for improvement.

Short-Term Objectives (5 years)

Short-term objectives were based on survey data collected at each site. Numerical objectives were developed based on where the survey team determined that conditions were near potential for the reach.

1. Reconnect and maintain a mile of flood relief channels with grade controls.

2. Increase flood-prone width to bankfull width ratio (entrenchment ratio) to >5 everywhere along the reach.
3. Decrease low flow stream channel width-to-depth ratios to 12:1.
4. Decrease bankfull stream channel width-to-depth ratios to <25:1.
5. Increase bank stability to >90 percent along the reach.
6. Maintain or increase sinuosity to 1.4.
7. Increase pools with residual pool depths >3 feet to at least 21 per river mile.
8. Increase large in-stream and floodplain woody debris (>12 inches in diameter, >50 feet in length) from 26 pieces/river mile to >50/river mile.
9. Restore riparian tree over-story and understory species compositions to near historic levels along river corridor in study reach.

Long-Term Objectives (5 to >20 years)

Short-term objectives plus:

1. Refine and implement a community based flood control and awareness strategy for the Walla Walla River.
    a. Coordinate river projects, including irrigation withdrawal site development, CREP and other bank stabilization, and flood relief channel development through the assessment reach and other areas up and downstream where possible.
    b. Acquire additional easements and dedicate lands to maintain or construct flood relief channels where possible.
2. Restore riparian stand structure to near historic optimum conditions.
3. Restore the channel meander patterns, bankfull widths, pool and riffles, and banks throughout the study reach for maximum dynamic channel stability, ability to be resilient to floods, and provide fish habitat.

Recommended Actions/Strategy for Walla Walla R

- Restore more normative flows by implementing projects to improve the efficiency of irrigation.
- Analyze LIDAR and other existing data to determine the location of natural floodways
    1. seek funding to purchase an easement to ensure continued function of floodway
    2. work with county planning to ensure they understand the importance of floodways and use their permitting process to ensure floodways remain undeveloped.

- At locations where active erosion makes a site ineligible for programs to reestablish a riparian forest buffer (e.g. CREP) a panel of experts including RCO geomorphologists will be convened to formulate a recommendation.

- To identify locate salmonid temperature refugia which are created by ground water intrusion, forward looking infrared (FLIR) flights should be repeated on the mid and lower Touchet and Walla Walla Rivers during late summer. This will would confirm data collected by FLIR flights conducted in 2002. At locations where cool temperatures persist during base flow conditions, projects to scour out pool habitat with large wood cover should be considered.

- To allow reestablishment of a more natural meander pattern it would be desirable to have a mature riparian corridor meander belt at least ¼ mile wide set aside for this reach of the Walla Walla R. To this end, landowners should be apprised of the benefits of a conservation easements and offered the opportunity to enter into a permanent contract.

- Participation in future planning by landowners could be encouraged by a successful local pilot project that demonstrates the benefits of fish friendly project designs. When a project that addresses landowner concerns and benefits fish is completed within reasonable proximity to this reach an effort should be undertaken to convene landowners and solicit their input on a strategy to restore the stability and habitat quality characteristic of a more natural channel geometry.

Proposed Projects

- Provide bank stability revetments, flood relief channels with grade controls, and channel stabilization features at the Johnson's ranch and in the vicinity.
- Mechanically modify or remove ad hoc river levees to increase flood-prone area and reduce entrenchment.
- Identify and develop through surveying gradients and establishing grade controls multiple relief channels within the floodplains.
- Consider constructing large wood structures at strategic locations to increase bank and stream channel stability and protect young re-generating riparian vegetation.
- Consider developing a community-based group of river adjacent landowners that work to coordinate river management to reduce negative effects of flooding and promote healthy river conditions.

The priority projects for the Walla Walla assessment area are located on the Johnson property where bank and channel instability and flood plain competence are a high risk to aquatic habitat, water quality, and private land. There are a number of factors contributing to the problems within this area including channel constriction from the Frog Hollow Bridge, increased sediment load from a small tributary and removal of riparian vegetation from streambanks and historic floodplains.

The projects proposed to address these issues for the long and short term are as follows:

At the Johnson property, streambanks are raw and exposed and actively eroding during higher flood events. Treatment is proposed for unstable streambanks using large wood and rock structures, wood barbs created from live trees, and extensive riparian species planting in bank setbacks. Also, during larger overbank peakflow events, extensive overland flow occurs on the historic floodplain to the north (right bank). Floodplain vegetation has been removed and converted to pasture which has led to significant erosion and topsoil loss during large flood events similar to 1996 within the pasture areas, especially near a small pond. In addition, there is risk that during another event such as the 1996 flood, the entire Walla Walla could avulse through the pasture causing significant long-term resource damage.

Vegetated, earthen floodplain grade controls are proposed for this area to allow flood waters to spread across the flood plain naturally while reducing erosive water velocities and encouraging sediment deposition within the historic floodplain. The vegetated earthen structures would be constructed along fence lines or along strategic areas to maximize the effectiveness of the structures (see figure 56). This will reduce the overall gradient across the pasture, decreasing the erosive energy of larger floods.

Garrison Creek enters the Walla Walla River just downstream of the Frog Hollow Road Bridge contributing flow and substantial sediment. The fanning effect of the sediment deposition at the confluence with the Walla Walla River creates channel braiding and lateral migration. The right bank of the fan area below the tributary is devoid of riparian and floodplain vegetation and is actively eroding. A combination of large wood structures, soil bio-engineering and riparian CREP buffer strip plantings are proposed to rehabilitate the site.

Estimated cost for implementation of the Johnson property project is $227,000.

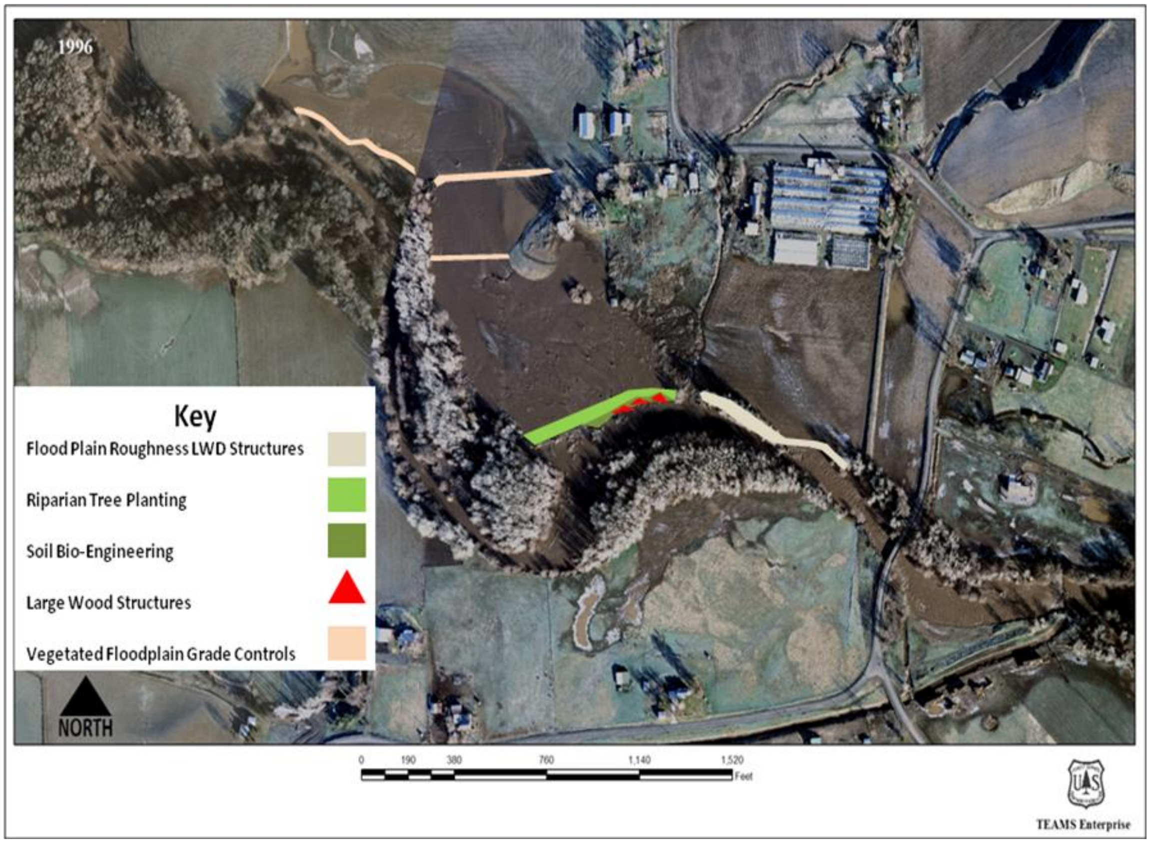


Figure 56. Walla Walla River Johnson property restoration plan and design

Mill Creek Goals

The rehabilitation goals for the Mill Creek assessment area are to allow the channel to connect to historic floodplains and valley stream channel flood relief networks while still allowing for human uses, restore stream channel and bank stability, and restore and maximize riparian areas, which will help to moderate the effects of large floods, and to recover the natural range of aquatic and riparian habitat conditions to which native fish and wildlife are adapted. A range of different completed stream projects were observed along the assessment reach including bank stabilization, rip-rapped banks, ad hoc levees built by private landowners and constructed levees built by government agencies, and a private road bridge. These projects would be more effective if they were coordinated across land ownerships. Also, because actions on one section of river affect downstream or upstream areas, it is important to integrate restoration activities along the river by developing a coordinated community-based river management plan. For instance, the channel instability and sediment buildup or aggradation observed at the Wickersham Bridge should be rehabilitated with bridge enlargement and channel relocation, riparian plantings, and other treatments. This will decrease the risk of adverse flooding for landowners downstream of the bridge and significantly reduce maintenance and long-term costs.

On Mill Creek, overall goals and objectives for channel improvement are to improve channel conditions by increasing flood-prone widths and flood relief channels along the reach in order to accommodate larger flood flows without causing damaging floods. Enlarging floodplain widths will reduce the damage caused by large floods by allowing flood waters to spread out and slow flow velocities. Increasing flood-prone area will allow the channel to migrate within the floodplain area, and help increase sinuosity, and narrow channel widths. Also, because the river has adapted to a wider floodplain than at present, there will be less unstable banks and river instability. These efforts, when combined with increased low flow water depths and pool depths, large wood increases for cover and sediment regulation, will increase the quality of habitat for fish.

Short-Term Objectives (5 years)

Short-term objectives were based on survey data collected at each site. Numerical objectives were developed based on where the survey team determined that conditions were near potential for the reach.

1. Increase flood-prone width to bankfull width ratio (entrenchment ratio) to >3.
2. Reconnect and maintain flood relief channels with grade controls where possible.
3. Increase bankfull channel sinuosity from 1.1 to 1.4.
4. Decrease low flow stream channel width to depth ratios to 12:1 or less.
5. Decrease bankfull stream channel width to depth ratios to <30:1.
6. Increase bank stability to >90 percent.
7. Increase pools with residual pool depths >3 feet to at least 21 per river mile.
8. Increase large in-stream and floodplain woody debris (>12 inches in diameter, >50 feet in length) from 26 pieces/river mile to >50/river mile.
9. Restore riparian tree over-story and understory species compositions to near historic levels along river corridor in study reach and maintain at least 50 percent shade for channel at low flow.

Long-Term Objectives- (5 to >20 years)

Short-term objectives plus:

1. Refine and implement a community-based flood control and river awareness strategy for the Walla Walla River.
   a. Coordinate river projects, including any river or bridge adjustments made to the Wickersham Bridge, CREP and other bank stabilization, and flood relief channel development through the assessment reach and other areas up and downstream where possible.
   b. Acquire additional easements and dedicate lands to maintain or construct flood relief channels or increase stream sinuosity where possible.
2. Restore riparian stand structure to near historic optimum conditions.
3. Restore the channel meander patterns, bankfull widths, pool and riffles, and banks throughout the study reach for maximum dynamic channel stability, ability to be resilient to floods, and provide fish habitat.

Recommended Actions/Strategy for Mill Cr

- Restoration of habitat quality and stability in Mill Creek depends largely on setting aside and protecting a corridor where a riparian forest community would be allowed to mature and the channel would be allowed to reestablish its natural meander pattern. This would require unprecedented flexibility by potential easement funding agencies and unprecedented cooperation between landowners, county government and fish restoration stakeholders.
- LIDAR and on-the-ground surveys should be used to identify natural floodways and ensure they remain functional. Regulatory authorities should be apprised of floodway locations so they can control the type of development allowed in these areas.
- The problem on Mill Creek is the density of houses, roads etc. that dictate channel and floodway alignment. To have any meaningful success in restoring a more natural channel geometry (meander pattern, width to depth ratio, etc.) in Mill Creek will require a substantial planning effort and commitment by landowners, restoration entities, land use regulatory authorities and funding agencies.
- This geomorphic assessment is the first of a series of reach assessments that will be conducted upstream to downstream on Mill Creek. In each reach we hope to get landowners involved in planning future restoration work that could potentially affect their property.
- A key to bringing all parties together may be a successful habitat restoration demonstration project that addresses landowner concerns and improves conditions for fish.

Proposed Projects

- Due to the alignment, the current Wickersham Bridge is not efficiently passing peakflows and sediment, causing aggradation of the streambed upstream of the structure, degradation downstream, and significantly increasing maintenance and risk to the bridge and infrastructure of downstream landowners. This project proposes to construct a new bridge with better alignment and capacity and reconstruct sections of the stream above and below the new structure to improve peakflow capacity and sediment routing and transport and fish habitat at and below the bridge. Re-align stream and construct a new bridge at Wickersham to improve the ability of Mill Creek to move sediment and higher flows through this site and reduce the chance of flood damage from overtopping the existing bridge. Estimated cost is $650,000 to $1 million.
- Improve floodplain conditions at Farrens' ranch by removing levees, and establishing large floodplain wood-grade controls in flood relief channels. Estimated cost is $125,000.
- Mechanically modify or remove ad hoc river levee above the private road bridge above Blue Creek to increase flood prone area and reduce entrenchment. Acquire additional easements and dedicate lands to maintain or construct flood relief channels or increase stream sinuosity where possible. Estimated cost is $115,000.
- Consider constructing large wood structures to protect banks at Margaret Scotts' house to increase bank and stream channel stability. Estimated cost is $65,000.
- Consider developing a community-based group of river adjacent landowners that work to coordinate river management to reduce negative effects of flooding and promote healthy river conditions.

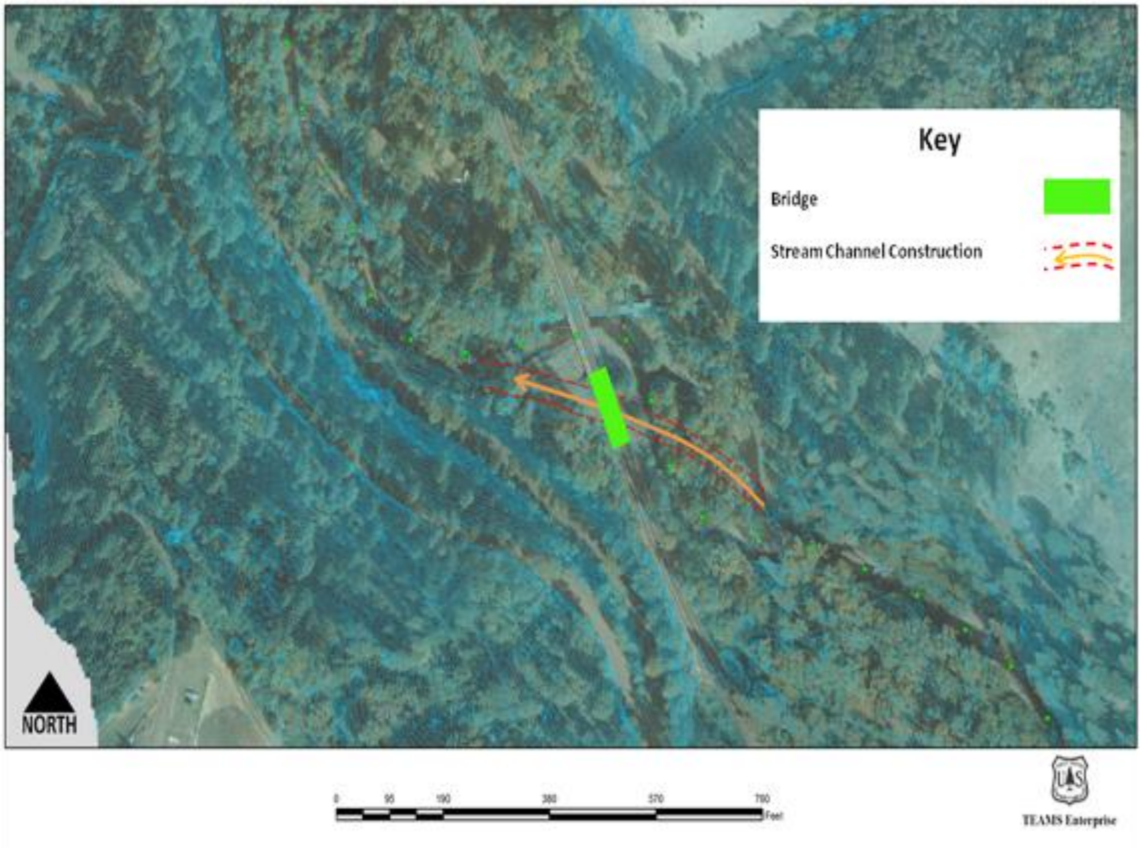


Figure 57. Mill Creek Wickersham Bridge Restoration area

Coppei Creek Goals

The rehabilitation goals for the Coppei Creek assessment reach are to allow the channel to connect to historic floodplains while still allowing for human uses, restore stream channel and bank stability and restore and maximize riparian areas, which will help to moderate the effects of large floods, and to recover the natural range of aquatic and riparian habitat conditions to which native fish and wildlife are adapted. Most of the assessment reach is deeply incised or down-cut, which limits options for expansion of floodplains. The channel along the assessment reach appears to be purposefully confined by push-up berms that were designed to expand agriculture in the valley. The berms or levees concentrated stream energy and initiated the channel down-cutting. Without extensive excavation, little can be done to recover the stream and expand the floodplain. The channel will erode streambanks and create more floodplain over time, but it will take many years for the stream to adjust. As a result, the channel and banks will chronically erode every year and continue to be a large source of fine sediment to downstream areas for many years as it expands the floodplain through lateral erosion. Beaver dams that have been established in recent years may help settle fine sediment and cause the channel to aggrade, but this will require many years of channel adjustment.

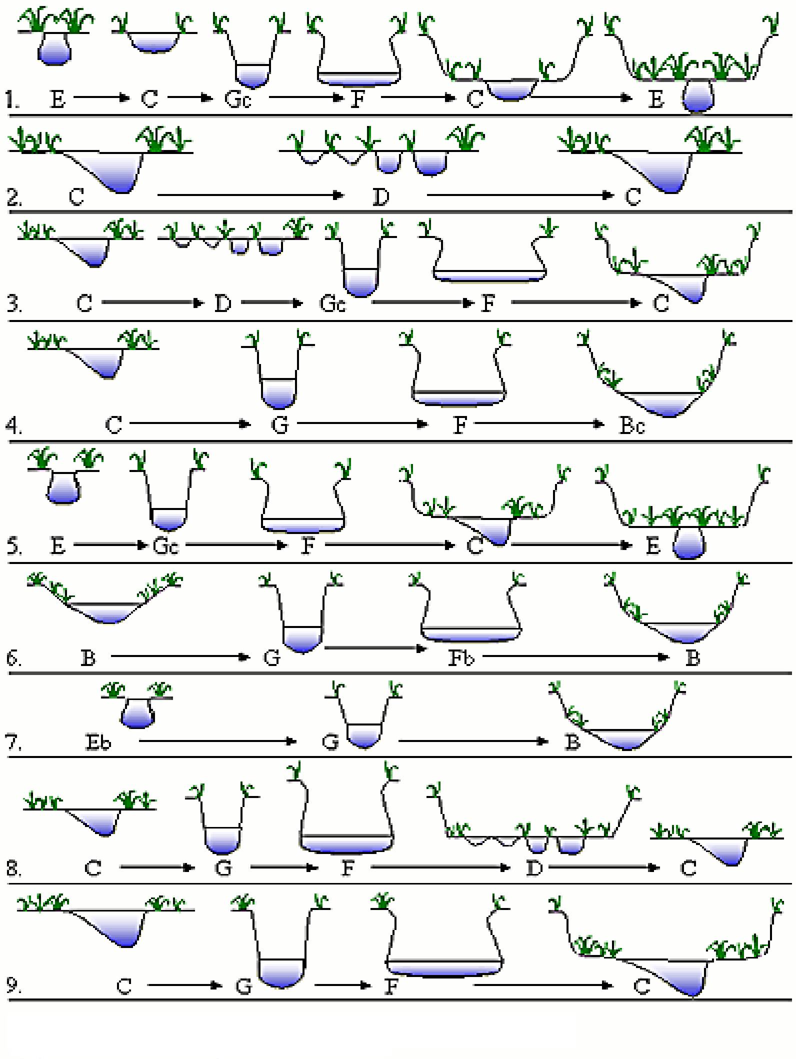


Figure 58. Possible channel evolution scenarios for Coppei Creek channel in the incised portion of the assessment reach using Rosgen (1999) classification

Note: For deeply incised stream like Coppei, channels must widen to create a new floodplain within the incised channel.

On Coppei Creek, overall goals and objectives for channel improvement are to improve channel conditions by increasing floodplains along the reach in order to accommodate larger flood flows without causing damaging floods. Enlarging floodplain widths will allow for greater channel sinuosity and improved habitat conditions. Increasing the flood-prone area will allow the channel to migrate within the floodplain area, and help increase sinuosity, create deeper pools, provide a wider zone of riparian vegetation, and narrow channel widths. Also, because the stream has adapted to a wider floodplain than at present, there will be less unstable banks and river instability.

Short-Term Objectives (5 years)

Short-term objectives were based on survey data collected at each site. Numerical objectives were developed based on where the survey team determined that conditions were near potential for the reach.

1. Increase flood-prone width to bankfull width ratio (entrenchment ratio) to >3.

2. Increase bankfull channel sinuosity from 1 to 1.3.
3. Decrease low flow stream channel width-to-depth ratios to 12:1 or less.
4. Decrease bankfull stream channel width to depth ratios to <25:1.
5. Increase bank stability to >80 percent.
6. Increase pools with residual pool depths >2 feet to at least 21 per river mile.
7. Increase large in-stream and floodplain woody debris (>12 inches in diameter, >50 feet in length) from 10 pieces/river mile to >50/river mile.
8. Widen and restore riparian tree over-story and understory species compositions to near historic levels along river corridor in study reach and maintain at least 50 percent shade for channel at low flow.

Long-Term Objectives (5 to >20 years)

Short-term objectives plus:

1. Work with landowners to develop a coordinated management plan for the stream.
    a. Acquire additional easements and dedicate lands to maintain or construct flood plains and increase stream sinuosity where possible.
    b. Expand bank stabilization efforts such as CREP projects in the upper end of the assessment reach to the lower half of the reach.
2. Restore riparian stand species and structure to near historic optimum conditions.
3. Restore the channel meander patterns, bankfull widths, pool and riffles, and banks throughout the study reach for maximum dynamic channel stability, ability to be resilient to floods, and to provide fish habitat.

Recommended Actions/Strategy for Coppei Cr

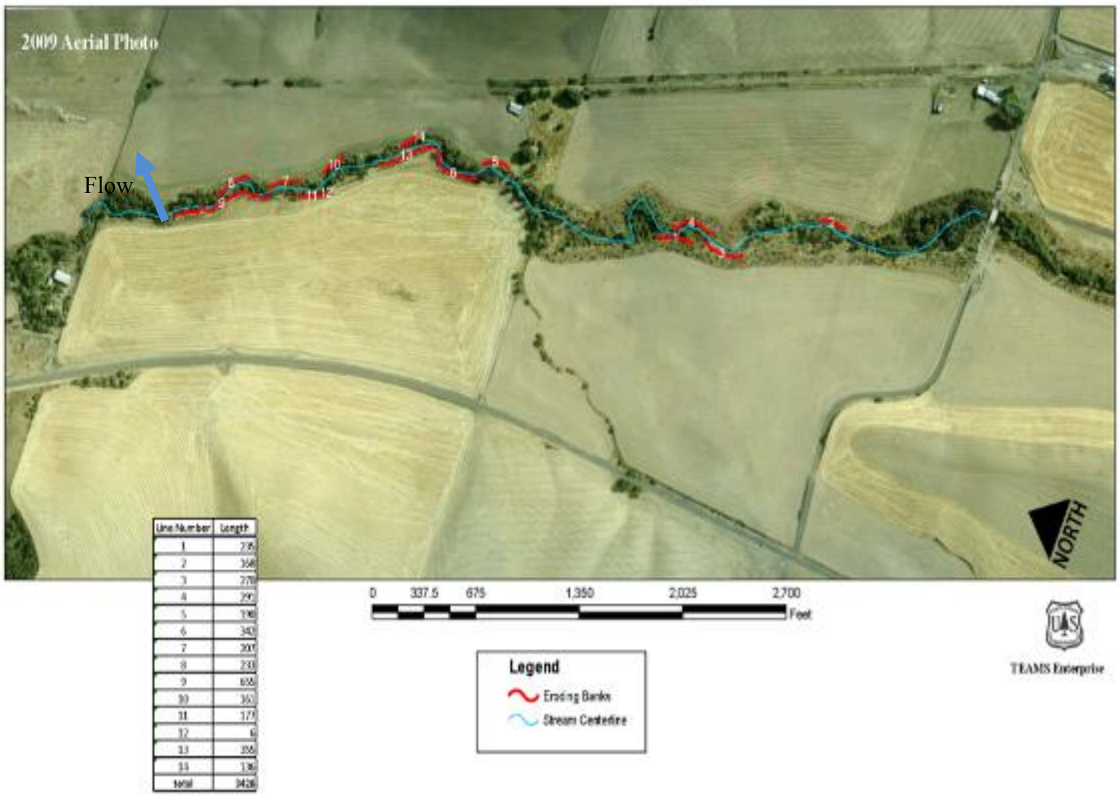
- This assessment reach is located immediately downstream from several miles of Coppei Creek where a considerable restoration work was done in about 1998-2003. Since that time Coppei Cr has rebounded significantly in terms of habitat quality and steelhead production. Existing Coppei Cr habitat improvement projects remain a showcase to demonstrate what SRFB funding can do. Restoration of Coppei Cr downstream from the previously improved reach is logical progression and should produce dramatic results.

Proposed Projects

The lower half of the assessment reach is highly entrenched and actively eroding streambanks are contributing significant amounts of fine sediment to the downstream reaches. In addition, pool frequency and quality has been significantly impacted by stream entrenchment and fine sediment deposition. This project proposes to reduce erosion and improve aquatic habitat by excavating or pulling back streambanks on the outside of meander bends to reduce entrenchment, allowing peakflows to spread out over a greater area and reduce near bank shear stress. This project will also be designed to increase pool frequency and quality and hiding cover for fish.

- Implement bank stabilization along the assessment reach in combination with excavating banks to create more floodplain on the outside of existing meander bends in the incised channel. Along the reach where banks are actively eroding streambanks will be pulled back to provide a more flood prone width. Bank excavation will pull back the banks to a 3:1 slope with spoils spread out over the adjacent terrace. Excavated slopes and exposed soil will be mulched and revegetated with native grasses, shrubs and trees. Estimated cost for implementation of this project is $220,000. Plant riparian tree species along the channel and created floodplain. Enlarge floodplain where needed in the upper end. Once floodplain is widened place trees with rootwads in the channel at existing pools to increase channel pool scour and cover for fish.

Coppei Creek Reach - Eroding Banks



Line Number	Length
1	235
2	358
3	270
4	[illegible]
5	[illegible]
6	342
7	207
8	233
9	655
10	361
11	177
12	6
13	356
14	136
total	3426

Figure 59. Coppei Creek restoration area

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7. Glossary

Aggradation ~ The geologic process by which streambeds are raised in elevation and floodplains are formed; the opposite of degradation.

Alluvial stream ~ Self-formed channels composed of silts, clays, sands, and gravel. Alluvial streams are characterized by the ability to alter their boundaries and patterns in response to changes in discharge and sediment supply.

Alluvium ~ A general term for all deposits resulting directly or indirectly from the sediment transport of streams; thus including the sediments laid down in streambeds, floodplains, lakes, fans, and estuaries.

Armoring ~ The development of a coarse surface layer in a streambed through winnowing and redistribution of the bed sediment particle sizes; or the gradual removal of fines from a stream, leaving only the larger substrate particles, sometimes caused by a reduction in the sediment load.

Avulsion ~ A significant and abrupt change in channel alignment resulting in a new channel across the floodplain.

Bankfull discharge ~ The discharge corresponding to the stage at which flow begins to spill onto the active floodplain.

Bankfull channel ~ The stream channel formed by the dominant discharge, also referred to as the active channel, which meanders across the floodplain as it forms pools, riffles, and point bars.

Bankfull stage ~ The elevation at which the water surface of a stream or river begins to overtop its banks. There are many interpretations of bankfull depending on discipline and individual.

Bankfull width/depth ratio ~ The ratio of bankfull width divided by average bankfull depth.

Bar or gravel bar ~ (1) A sand or gravel deposit found on the bed of a stream that is often exposed during low-water periods; or (2) an elongated landform generated by waves and currents, usually running parallel to the shore, composed predominantly of unconsolidated sand, gravel, stones, cobbles, or rubble and with water on two sides.

Bed load ~ (1) Sediment particles up to rock, which slide and roll along the bottom of the streambed; (2) material in movement along a stream bottom, or, if wind is the moving agent, along the surface; or (3) the sediment transported in a stream by rolling, sliding, or skipping along or very close to the bed. In USGS reports, bed load is considered to consist of particles in transit from the bed to an elevation equal to the top of the bed-load sample nozzle (usually within 0.25 feet of the streambed). Contrast with material carried in suspension or solution.

Bed shear stress ~ The force per unit area exerted by water as it flows over a surface.

Channel stabilization ~ Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, vegetation, and other measures.

Cross section ~ A graph or plot of ground elevation across a stream valley or a portion of it, usually along a line perpendicular to the stream or direction of flow.

D50 ~ Median particle/grain size of sediment.

Disturbed reference ~ A disturbed reach of stream that possesses similar channel morphology, hydrology, sediment regime, and biota relative to the reach of stream to be analyzed, rehabilitated, or restored.

Effective discharge ~ The discharge of a stream/river mainly responsible for shaping a channels hydraulic geometry (width, depth, x-s area) and pattern (wavelength, sinuosity) of unconstrained alluvial rivers. The 'effective discharge' is found to be similar to the bankfull discharge of stable systems. It was also found to be the flow or discharge, with recurrence intervals averaging 1 to 2 years.

Entrenchment ratio ~ Flood-prone width divided by bankfull width; a measure of floodplain accessibility and inundation. The lower the value, the greater the entrenchment (e.g., entrenched gully ER=1.3, moderately entrenched ER=1.8 to 2.0, slightly entrenched or unentrenched ER ≥3.8).

Floodplain ~ (1) (FEMA) Any normally dry land area susceptible to being inundated by water from any natural source. This area is usually low land adjacent to a river, stream, watercourse, ocean or lake. (2) The land adjacent to a channel at the elevation of the bankfull discharge, which is inundated on the average of about 2 out of 3 years; the floor of stream valleys, which can be inundated by small to very large floods. The one-in-100-year floodplain has a probability of 0.01 chance per year of being covered with water.

Flood-prone width ~ Width or extent of floodwaters within a valley. The stream width at a discharge level defined as twice the maximum bankfull depth.

Geomorphology ~ Science of describing and interpreting landform patterns and processes of landscape formation. For rivers, this includes the distribution and movement of substrate (sediment and larger material) that makes up the channel bed and banks.

Head cut ~ **(**1) Location where there is a sudden change in elevation or knickpoint at the leading edge of a gully causing bed lowering in the upstream direction. Head cuts can influence channel stability over an extensive length of the river or stream system. (2) A break in slope or knickpoint of a channel that forms a "waterfall", which in turn causes the underlying soil to erode uphill.

Hydraulic geometry ~ The physical measurements of a stream (cross-sectional area, width, depth, and slope).

Hyporheic zone ~ This zone may be defined conceptually as the saturated interstitial areas beneath the streambed and into the stream banks that contain some proportion of channel water or that have been altered by channel water infiltration (advection). This definition separates the hyporheic zone from the groundwater zone in the classical sense that groundwater represents water beneath the water table that has not yet been influenced by channel processes.

In-stream large woody material or debris (LWD) ~ Coarse wood material such as twigs, branches, logs, trees, and roots that fall into streams.

Length of meander ~ One full sine wave of a stream meander.

LiDAR (Light-Imaging Detection and Ranging) ~ Light detection and ranging uses the same principle as RADAR; the LiDAR instrument transmits light out to a target, the transmitted light interacts with and is changed by the target. Some of this light is reflected or scattered back to the instrument where it is analyzed. The change in the properties of the light enables some property of the target to be determined. The time for the light to travel out to the target and back to the LiDAR is used to determine the range to the target.

Meander ~ (1) The turn of a stream, either live or cut off; the winding of a stream channel in the shape of a series of loop-like bends. (2) A sinuous channel form in flatter river grades formed by the erosion on one side of the channel (pools) and deposition on the other side (point bars).

Meander belt width ~ Amplitude or width containing the meander.

Morphology ~ The external structure form and arrangement of rocks in relation to the development of landforms. River morphology deals with the science of analyzing the structural make-up of rivers and streams. Geomorphology deals with the shape of the Earth's surface.

Organics ~ Matter derived from living organisms.

Pool ~ (1) A location in an active stream channel, usually located on the outside bends of meanders, where the water is deepest and has reduced current velocities. (2) A deep reach of a stream; a part of the stream with depth greater than the surrounding areas frequented by fish. The reach of a stream between two riffles; a small and relatively deep body of quiet water in a stream or river. Natural streams often consist of a succession of pools and riffles.

Reference reach ~ Undisturbed reach of stream that possesses similar channel morphology, hydrology, sediment regime and biota relative to the disturbed site to be analyzed, rehabilitated or restored.

Residual pool depth ~ The standardized measurement of pools; elevation of deepest part of pool minus the elevation of the pool tail crest (downstream riffle). Residual pool depth is considered an important indicator of fish habitat quality; large residual pool depth indicates good habitat.

Return period (or recurrence interval) ~ In statistical analysis of hydrologic data, based on the assumption that observations are equally spaced in time with the interval between two successive observations as a unit of time, the return period is the reciprocal of 1 minus the probability of a value equal to or less than a certain value; it is the mean number of such time units necessary to obtain a value equal to or greater than a certain value one time. For example, with a 1-year interval between observations, a return period of 100 years means that, on the average, an event of this magnitude, or greater, is not expected to occur more often than once in 100 years. Also see *exceedence interval*, *recurrence interval*, *flood frequency*, and *frequency curve*.

Redd ~ A depression in gravel created by salmon and trout to deposit and incubate their eggs.

Riffle ~ (1) A shallow rapids, usually located at the crossover in a meander of the active channel; (2) shallow rapids in an open stream, where the water surface is broken into waves by obstructions such as shoals or sandbars wholly or partly submerged beneath the water surface; or (3) also, a stretch of choppy water caused by such a shoal or sandbar; a rapid; a shallow part of the stream.

Riparian areas (habitat) ~ (1) Land areas directly influenced by a body of water. Usually such areas have visible vegetation or physical characteristics showing this water influence. Stream sides, lake borders, and marshes are typical riparian areas. Generally refers to such areas along flowing bodies of water. The term "littoral" is generally used to denote such areas along nonflowing bodies of water. (2) (USFWS) Plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent lotic and lentic water bodies (rivers, streams, lakes, or drainage ways). Riparian areas have one or both of the following characteristics: (a) distinctively different vegetative species than adjacent areas, and (b) species similar to adjacent areas but exhibiting more vigorous or robust growth forms. Riparian areas are usually transitional between wetlands and uplands.

Sediment ~ (1) Soil particles that have been transported from their natural location by wind or water action; particles of sand, soil, and minerals that are washed from the land and settle on the bottoms of wetlands and other aquatic habitats. (2) The soil material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by erosion (by air, water, gravity, or ice) and has come to rest on the earth's surface. (3) Solid material that is transported by, suspended in, or deposited from water. It originates mostly from disintegrated rocks; it also includes chemical and biochemical precipitates and decomposed organic material, such as humus. The quantity, characteristics, and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land usage, and quantity and intensity of precipitation. (4) In the singular, the word is usually applied to material in suspension in water or recently deposited from suspension. In the plural the word is applied to all kinds of deposits from the waters of streams, lakes, or seas, and in a more general sense to deposits of wind and ice. Such deposits that have been consolidated are generally called sedimentary rocks. (5) Fragmental or clastic mineral particles derived from soil, alluvial, and rock materials by processes of erosion, and transported by water, wind, ice, and gravity. A special kind of sediment is generated by precipitation of solids from solution (i.e., calcium carbonate, iron oxides). Excluded from the definition are vegetation, wood, bacterial and algal slimes, extraneous lightweight artificially made substances such as trash, plastics, flue ash, dyes, and semisolids.

Shear stress ~ The force per unit area (e.g., pounds per square inch); force exerted parallel to the bed and banks of a stream channel.

Side channels ~ Typically small stream channels which branch off of the mainstream channel.

Snag ~ A tree or branch embedded in a lake or streambed; a stub or stump remaining after a branch has been lopped or torn off.

Smolt ~ A juvenile, silvery salmon up to 15 centimeters long, which has lost its parr marks and has attained the silvery coloration of the adult. This coloration signifies the readiness of the young fish to migrate to the seas and its ability to adapt to the salt water environment.

Spawning gravel ~ Streambed substrate suitable for salmonid spawning.

Succession ~ (Biology) (1) The ecological process of sequential replacement by plant communities on given site as a result of differential reproduction and competition; or (2) directional, orderly process of change in a living community in which the community modifies the physical environment to eventually establish an ecosystem which is as stable as possible at the site in question.

Thalweg ~ (1) The line connecting the deepest points along a stream; (2) the lowest thread along the axial part of a valley or stream channel; (3) a subsurface, ground-water stream percolating beneath and in the general direction of a surface stream course or valley; (4) the middle, chief, or deepest part of a navigable channel or waterway.

Turbidity ~ A measure of light obscuration by water; turbidity increases as the amount of suspended sediments in the water column increase.

Woody debris ~ Coarse wood material such as twigs, branches, logs, trees, and roots that fall into streams. Also referred to as large woody debris and commonly abbreviated in reports as LWD.

8. Appendices

Appendix A: Riparian Planting Guidelines

Until specific project sites and activities are identified it is possible only to make general recommendations. Once sites are chosen, specific plans for vegetation restoration methods, materials, and arrangements may be developed. The stream reaches are similar, but each has its own characteristics and may require different restoration methods. See the Stream Habitat Restoration Guide (SHRG 2004) for more detailed restoration planning and planting information

Site Preparation – Weed Control

Before any project work is initiated, it will be important to begin to inventory and control weeds that are already established on the site and in adjacent fields. Many of the species observed on the three streams are highly invasive and can pose serious threats to the success of restoration efforts. Many of the infestations are currently rather small and could be eradicated over several years with annual treatments. None of the species found are on the Washington State Noxious Weed Class A list (must be eradicated). Species on the Washington State Noxious Week Class B list are among the most invasive and critical to control while infestations are small and scattered. Once established they are extremely difficult to control or contain. Because reed canarygrass is so widespread and abundant, it is on the Washington State and Walla Walla County Class C Noxious Weed Lists. Counties are not required to control class C species; however, unless adequately treated, reed canarygrass will pose a serious threat to restoration efforts. Cheatgrass is common on Coppei Creek and present on the other two streams. It is also extremely invasive and difficult to control, but it is not on the Washington State, Walla Walla County, or Columbia County noxious weed lists. A survey during the growing season at sites chosen for restoration efforts could identify other species that should be treated prior to restoration.

In order to reduce the effects of invasive plants on restoration success, a weed treatment plan should be developed for each project site. Important aspects of the plan would include treating weeds at the site with appropriate methods, limiting disturbance to the minimum possible during project implementation, and planning for weed monitoring and treatment following restoration.

Washington State Noxious Weed Class B Species

Positive identifications are still needed for two species, oxeye daisy and perennial pepperweed. If present, these two species currently appear to be restricted to very small areas. They are both highly invasive and would need to be treated prior to project implementation.

Queen Anne’s lace is also restricted in extent. This plant of the carrot family has apparently escaped from cultivation. Its ability to naturalize is not known, but it has been described as “a pernicious weed of older pastures and meadows” (Whitson et al. 2006). Queen Anne’s lace is a biennial, making it easier to treat than many perennial species. Species posing the greatest threats to restoration success are discussed below.

Japanese knotweed (*Polygonum cuspidatum*). Japanese knotweed is a rhizomatous perennial species imported as an ornamental from Japan to the United Kingdom in 1825, and from there to North America (Conolly 1977; Patterson 1976). Japanese knotweed is extremely invasive; once it has formed large stands, it is extremely difficult to eradicate. Its early emergence and great height combine to shade out other vegetation and prohibit regeneration of other species. It reduces species diversity and damages wildlife habitat (Department of Ecology, Washington State 2009). It does not appear to be a threat in undisturbed low light areas, but if left unchecked it will likely continue to expand its range in open areas (Seiger 1991). Due to its rhizomatous nature, the plant may form large patches. Rhizome fragments may be carried by water or transported in fill dirt and sprout in new locations.

For small patches, control may be accomplished by mechanical or chemical methods. Removal by digging is extremely difficult due to the plant's deep roots and extensive rhizomes. Shoots may be repeatedly cut (at least three times per season) to gradually reduce nutrient reservoirs in the rhizomes. For chemical treatment, it is best to first cut stalks and "paint" the chemical application on stalks. This method provides a more concentrated application and minimizes adverse effects to other plants and soils in the area (Seiger 1991); Seiger also discusses various herbicides that may be used.

Reed canarygrass (*Phalaris arundinaceae*). Reed canarygrass is a rhizomatous grass species that has been planted in the United States since the 1800s for forage and erosion control. The species is extremely invasive and has taken over as the main understory species in the assessment reaches. The species is very difficult to eradicate once established. It will be important to survey restoration sites prior to beginning restoration so that any reed canarygrass present may be adequately treated. Treatment may take more than one growing season.

One possible method of controlling small patches of reed canarygrass is to cover plants with black plastic for at least one growing season and then plant with native species. Another approach would be to cultivate the plant repeatedly during the growing season and plant with natives near the first frost date. Frequent and continued cultivation is critical; with only one or two cultivations, the number of plants may increase (WDNR 2004).

A restoration on Trout Creek on the Gifford Pinchot National Forest (LTNPLTPRC 2009) provides an example of an aggressive approach to the treatment of reed canarygrass. Initial removal of reed canarygrass was by excavation of root masses with mechanical equipment, weed whacking to control seed spread, and chemical application. After removal, restoration sites will be densely planted with native species that are expected to rapidly provide shade. A variety of native species and planting methods will be used to maximize the potential for establishing native vegetation and minimizing the potential for reestablishment of reed canarygrass. The success of these methods cannot be determined since the project has not been completed, but some of the strategies, such as dense plantings and the use of a diverse species and methods, appear likely to promote restoration success and could be used in appropriate sites.

Yellow starthistle (*Centaurea solstitialis*). Yellow starthistle is an invasive species that is a major threat to pastures, rangelands, and roadsides (Zimmerman et al. [undated]). The plant produces enormous quantities of seed and rapidly reaches stand sizes that are extremely difficult to eradicate. A single plant may produce up to 150,000 seeds (Zimmerman et al. [undated]) and only two million seeds per acre are needed to repopulate the stand with only yellow starthistle (CBARCD 2000).

Numbers and extent of starthistle in the project area are currently low. The plant may still be eradicable with treatments beginning in 2009 and continuing for several years. A number of control methods have been tried (see numerous articles on the internet). Grazing by horses is not advisable since prolonged consumption by horses can lead to a fatal nervous disease called equine nigropallidal encephlomalacia or "chewing disease" (CBARCD 2000). Prevention and early treatment are the best methods; once starthistle is well established eradication is often impossible and control is effective only with continuous monitoring.

Houndstongue (*Cynoglossum officinale*). Houndstongue is a biennial with prickly fruit that may be distributed by wildlife or livestock. It contains alkaloids that are toxic to livestock. The plant requires bare ground to establish; once established it may quickly form dense monocultures.

Houndstongue may be controlled by mechanical or chemical methods. The most appropriate method at restoration sites may be to pull, bag, and remove plants from the site. The entire root crown should be removed to prevent re-sprouting. Treatment should be repeated for several years.

Scotch thistle (*Onopordum acanthium*). Scotch thistle is a biennial producing large spiny leaves the first year and growing up to 8 feet tall and 5 feet wide the second year. Under poor growing conditions, the plant may be less than 1 foot tall, but may produce as many seeds as larger plants (Douglas County 2009). The plant is covered with fine gray hairs, giving it a silvery appearance. The species can form impenetrable stands due to its spiny nature and large size.

Colonies can be eradicated by pulling, but treatment will need to be continued until the seedbed is exhausted (Douglas County 2009). Preventing established plants from going to seed will reduce the seedbed. Herbicides can provide good control if applied when plants are small (Idaho's Noxious Weeds 2009).

Yellow hawkweed (*Hieracium caespitosum*). Yellow hawkweed is a perennial that spreads by seeds, aboveground stolons, and underground rhizomes. Yellow hawkweed is a recent introduction to Washington State, but has already spread over much of the state (King's County 2009).

Small patches may be eliminated by digging if all underground parts are removed. Biocontrol methods are under study. Early season treatment with herbicides can be effective in controlling the species (Pierce County Weed Control Board 2009).

Planting

See the guides listed in the reference section for restoration planting guidelines and techniques. The Washington State publication Stream Habitat Restoration Guidelines (SHRG 2004) provides a table of tree and shrub species suitable for riparian restoration projects; the table gives wetland indicator status, typical soil moisture needs, light requirements, and other characteristics and will be helpful in deciding where to place each species. Table A-1 provides guidelines for species especially suitable for the assessment reaches. Plants may need to be protected from predation with barriers. If used, the barriers will need to be removed as the plants grow. Biodegradable weed cloth around the base of plants may help prevent competition from weeds and injury from herbicides if used to control weeds at the site. Plantings in contact with the water table will survive best.

Sources of Plant Materials

If adequate numbers of container or bare root native stock are not available, cuttings of local cottonwoods and willows may be used. Lezberg and Giordanengo (2008) provide specific guidelines for planting willows. For the most part, the guidelines are applicable for cottonwoods as well; with cottonwoods it is especially important to choose small diameter cuttings (no larger than thumb size) and to leave the terminal bud to encourage a tree shape (Giordanengo, 2008, *personal communication*). Cuttings need to be long enough to reach the late summer water table and project at least 8 inches above the ground level and overtop the surrounding vegetation (Lezburg and Giordanengo 2008). For container or bare root stock not in contact with the water table, it will be important to provide adequate supplemental water. Small shrubs or herbaceous plants might be transplanted from nearby sites (see SHRG 2004 for guidelines). Seeds from native plants in the local area could be grown out or broadcast.

Numbers of Plants

Giordanengo (2008, *personal communication*) suggests planting approximately 50 percent more plants than the final desired number to account for mortality. Heavy plantings may also increase the amount of shade at the site more rapidly and result in deteriorating conditions for establishment of weedy species. A number of the suggested plants will spread well once established, so “overplanting” may be less necessary. Black cottonwoods, for instance, tend to sprout from the base and will increase in numbers of stems, if not numbers of plants. Snowberry and roses tend to be fairly aggressive and will likely spread rapidly once established.

Lezberg and Giordanengo (2008) suggest planting shrubs 3 to 8 feet apart. The Washington State Guide (SHRG 2004) recommends 5 to 10 feet between shrub plantings.

Distribution of Plantings

In general, shrub willows such as narrowleaf willow are the best species to plant near the river edge. Black cottonwoods also tolerate the high water levels typically found near the river edge and would be suitable for planting. Red-osier dogwood may be planted fairly near the river edge and alder may be planted slightly farther back. Cottonwoods could be planted just back from the alder and birch; or willows and alder could be planted in depressions farther back from the shore. Most of the shrubs listed below need slightly drier conditions and can be scattered throughout the site.

Table A-1. Possible species to plant at restoration sites

Common Name	Scientific Name	Comments*
Trees		
Black cottonwood	*Populus balsamifera* ssp. *trichocarpa*	Plant slightly back from stream edge but close to water table. May also be planted in lower backwater areas. May "deep sink" container plants (plant lower than surrounding ground surface). If using cuttings (sprouts from local trees are good), they should be no larger than thumb size (Giordanengo, 2008, *personal communication*). Suggested number to plant: 50–75/acre (Zimlinghaus, 2008, *personal communication*).
Peachleaf willow	*Salix amygdaloides*	If using local cuttings, choose young shoots (no larger than thumb size (Giordanengo, 2008, *personal communication*). Water or plant to reach the water table. Infrequent in current riparian zone but probably more common in the past (Carsey, 2009, *personal observation*).
White alder	*Alnus rhombifolia*	Often found in pure patches (especially younger trees) near the river edge. Young stands typically occur in patches rather than being spread across the entire floodplain. With cottonwood, this is the dominant species in the current riparian zone (Carsey, 2009, *personal observation*). Suggested number to plant: patches of 25–50 slightly back from edge of river or in depressions farther back.
Tree/Shrub		
Black hawthorn	*Crataegus douglasii*	Good bank stabilizer, moderate tolerance for deposition, prefers well-drained soils, forms thickets.
Blue elderberry	*Sambucus nigra* ssp. *cerulea*	Good soil binding qualities, grows well in a variety of soils.
Shrubs		
Chokecherry	*Prunus virginiana*	Forms dense stands, moderate drought tolerance. Plant in drier areas.
Narrowleaf willow	*Salix exigua*	Plant at stream edge; tolerates flooding; forms thickets.
Ocean spray	*Holodiscus discolor*	Drier areas, very drought tolerant. Observed only a dry raised bench above Mill Creek, may not be suitable for other sites.
Red-osier dogwood	*Cornus sericea*	Thicket former, excellent soil binding, tolerates seasonal flooding.
Snowberry	*Symphoricarpos albus*	Forms dense thickets. Usually on drier sites, but tolerates some flooding while dormant.
Woods rose	*Rosa woodsii*	Prefers moist, well-drained soils, forms thickets.
Herbaceous species		
Common cowparsnip	*Heracleum maximum* (*lanatum*)	Some tolerance for saturation, low drought tolerance (USDA NRCS 2008).
Native brome	*Bromus sitchensis* or other native species	Tolerate low light.
Tall goldenrod	*Solidago* sp. (appears to be *S. canadensis*)	Considered native but may be invasive (Hitchcock and Cronquist 1973).

* Unless otherwise noted this information is from SHRG 2004.

At sites where restoration projects will be confined to the river banks, plants of drier areas may not be suitable. Reed canarygrass may be more common in these areas and more likely to compete with restoration plantings. If possible, the reed canary roots and rhizomes may be removed from the areas to be planted. Sites should be surveyed early in the season to determine if there are other nonnative plant species that need treatment prior to restoration.

Monitoring

Implementation and effectiveness monitoring will be important to determine success of weed control, restoration plantings, and bank stabilization techniques. Weeds will likely need to be treated for several seasons. If mortality of restoration plantings is high, new plantings may be needed to have adequate native plant coverage.

Appendix B: Reference Condition Plant List

Plants mentioned by Captain Meriwether Lewis from the Touchet Valley in 1806.

April 30–"…there are many large banks of pure sand which appear to have been drifted up by the wind to the height of 15 or 20 feet, lying in many parts of the plain through which we passed today."

Capt. Lewis's Name	**Common Name**	**Scientific Name**
Aromatic Shrub	Big Sagebrush	*Artemisia tridentate*
Herbaceous Plants	Various	
Esculent Roots	Cous, Biscuit Root, etc.	*Lomatium* spp.
Short Grass	Sandberg's Bluegrass	*Poa secunda*
Cottonwood	Black Cottonwood	*Populus balsamifera*
Birch	Water Birch	*Betula occidentalis*
Crimson Haw	Black Hawthorn	*Crataegus douglasii*
Redwillow	Red Osier Dogwood	*Cornus stolonifera*
Sweetwillow	Willow	*Salix* spp.
Chokecherry	Chokecherry	*Prunus virginiana*
Yellow Currants	Golden Currant	*Ribes aureum*
Gooseberry	Wild Gooseberry	*Ribes divaricatum*
White-berried Honeysuckle	Common Snowberry	*Symphoricarpos albus*
Rose Bushes	Wild	*Rosa* spp.
Seven Bark	Pacific Nine Bark	*Physocarpus capitatus*
Shoemate	Smooth Sumac	*Rhus glabra*
Corngrass	Basin Wildrye	*Elymus cinereus*
Rushes	Scouring Rush	*Equisetum hyemale*

May 1–"…the creek, it's bottom lands, and the appearance of the plains were much as those of yesterday only with this difference that the latter were not so sand…I see very little difference between the apparent face of the country here and that of the plains of the Missouri only that these are not enlivened by the vast herds of buffaloe Elk &c which ornament the other."

May 2–"…more timber than usual on the creek…"

Capt. Lewis's Name	**Common Name**	**Scientific Name**
Long-leafed Pine	Ponderosa Pine	*Pinus ponderosa*
Qua-mash	Common Camas	*Camassia quamash*
Missouri River Parsnip	Cow Parsnip	*Heracleum lanatum*

Appendix C: Reach-Scale Existing Geomorphic Characteristics and Channel Geomorphic Data Summary

Table C-1. Reach-scale existing geomorphic characteristics

Stream Name	Location of Cross-section	Bank-full Width	Bank-full Width/ Depth	Flood-prone Width	Entrench-ment Ratio	D50	D84	Channel Slope (%)
Walla Walla River	125’ downstream of the Frog Hollow Bridge	72	37	279	4	41	63	0.3
Walla Walla River	102’ upstream of the Last Chance Bridge	85	39	279	3	45	71	0.4
Mill Creek	110’ downstream of Wickersham Bridge	72	47	200	3	63	131	0.4
Mill Creek	280’ downstream of RM 1.5	64	42	200	3	67	121	0.7
Mill Creek	RM 3.2 below the Blue Creek confluence	64	48	200	3	58	117	1.5
Coppei Creek	300’ downstream of the McCown Road Bridge	25	35	60	2	34	78	2.2
Coppei Creek	RM 1.2 at the antique car lot	25	26	35	1	34	78	1.6

Table C-2. Channel geomorphic data summary for all data

Variables (Existing)	Walla Walla River Reach	Copei Creek Reach	Mill Creek Reach
Rosgen stream type	C4	F or C4	C4
Bankfull width (W_{bkf})	64	25	64
Bankfull mean depth (d_{bkf})	0.8	0.8	1.5
Width/depth ratio (W_{dkf}/d_{bkf})	31.8	32	42.7
Bankfull X-sect. area (A_{bkf}) (ft^2)	50.4	20	96
Bankfull discharge, cfs (Q_{bkf})	732	322	642
Bankfull max. depth (d_{max}) (ft)	1.9	1.9	2.5
Width of flood-prone area (W_{fpa}) (ft)	62.3	62	200
Entrenchment ratio (W_{fpa}/W_{bkf})	4.8	2.5	3.1
Valley width (ft)	2400	1792	779
Meander length (L_m)	1120	462.5	
Radius of curvature (R_c) (ft)	264	181	377
Belt width (W_{blt}) (ft)	681	135	350
Sinuosity (str. Length/valley dist.)	1.4	1.2	1.12
Valley slope (ft/ft)	0.006	0.013	0.017
Average channel slope (ft/ft)	0.0043	0.019	0.009
Riffle length (ft)	86	34	
Max pool depth (d_{pool}) (ft)	7	4.1	
Pool width (W_{pool}) (ft)	46	27	
Pool length (ft)	218	62	87
Pool to pool spacing (p-p)	318		237
Major pool type	Alluvial Scour	Alluvial Scour	Alluvial Scour
$D_{50\ (mm)}$	43	34	63
$D_{84\ (mm)}$	64	78	123
Shade (percent cover)	39	50	33