5.0 Post-Glacial History

5.1. Incision of Post-Glacial Drainage System

As glaciers retreated from the Puget Lowland, they left a landscape highly susceptible to a variety of non-glacial erosional processes. This susceptibility was due to a number of characteristics of this post-glacial landscape. These include:

- The lack of vegetative cover;
- The lack of surficial organic soil horizons, and
- A drainage network developed to convey subglacial and ice marginal runoff, and thus largely out of equilibrium with the post-glacial topography and climate.

In a geomorphic context, this was a quintessential "youthful" landscape. Under these circumstances, a period of rapid erosion was inevitable. This erosion occurred through a variety of geomorphic processes. Where runoff collected in swales or depressions in the post-glacial topography and discharged over steep slopes, ravines were quickly incised. Alluvial fans formed at the base of these steep slopes (Figure 10). Steep slopes, previously buttressed by glacial ice or undercut by rapid stream incision, failed in massive landslides. Closed depressions at all scales in the glacial landscape filled progressively with water, organic detritus, and sediment, forming lakes, wetlands, and alluvial lowlands. From a geologic standpoint, the Snoqualmie watershed remains a youthful landscape. Most of the area underlain by glacial substrate (Figure 3) has undergone little post-glacial geomorphic modification. Much of the active geomorphic activity in the Snoqualmie watershed consists of equilibrating this recently glacial landscape to the current, temperate, non-glacial conditions.

5.2. Active Fluvial Geomorphic Processes in the Snoqualmie Valley

Modern geomorphic activity is being expressed at a variety of scales across the modern landscape.

5.2.1. Valley Scale

The gross topography of the Snoqualmie watershed is dominated by a series of large valleys, now largely occupied by rivers. In the upper watershed, these valleys are scoured in bedrock, and bedrock is still exposed on the valley walls and intervening ridges. These valleys record a long history of both glacial and non-glacial erosion. The gross geomorphic activity in these valleys consists of gradual erosion of bedrock uplands and transport of the resulting sediment down valley.

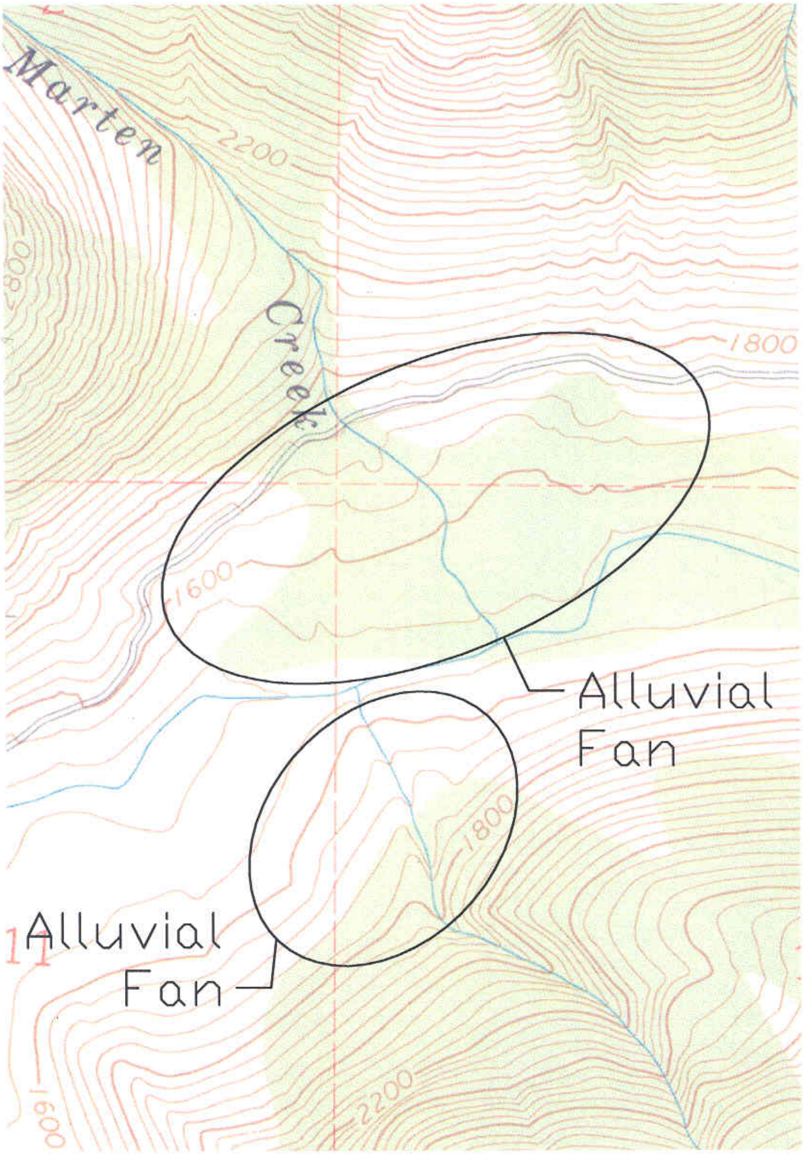


Figure 10. Alluvial Fans at the mouth of Marten Creek and an unnamed tributary on the Taylor River

In the lower portions of the watershed, these valleys are troughs that are largely relict glacial features. The geometry of these troughs was largely a product of subglacial erosion, and the modern rivers occupying these valleys are generally significantly underfit. Examples of these relict valleys include the Snoqualmie Valley from the Three Forks area downstream to Snoqualmie Falls, the lower Snoqualmie mainstem from the vicinity of Fall City downstream to its confluence with the Skykomish River, lower Cherry Creek, and lower Patterson Creek. Immediately following deglaciation, it is likely that lakes were present in portions of these troughs (features presumably similar to Lakes Washington and Sammamish to the west). Any such closed depressions have been subsequently filled with sediment, but the watercourses in these valleys are still incompetent to transport the coarse sediment supplied by tributary streams. As a result, these valleys are gradually but inevitably filling with sediment. Because these watercourses are unable to transport the supplied bedload, they are also subject to being displaced within their broad valleys by alluvial fans from tributary streams. Examples include the Snoqualmie River at the confluence with the Tolt and Raging Rivers, and the confluence of the North Fork and mainstem of Cherry Creek.

5.2.2. Reach Scale

At the reach scale, the various geomorphic processes (Section 2) interact to create channels with distinctive attributes. A variety of classification schemes has been developed to group and summarize the range of channel character. The classification scheme proposed by Montgomery and Buffington (1997) was developed in the Pacific Northwest and encompasses the range of channel types present in the Snoqualmie watershed. The key elements of this classification are summarized in Table 1. In general, the Montgomery and Buffington classification is organized based on a typical down-valley progression of channel types as encountered in mountainous terrain and in a temperate climate.

Table 1: Summary of the Channel Classification System Proposed by Montgomery and Buffington (1997)

	Dune ripple	Pool riffle	Plane bed	Step pool	Cascade	Bedrock	Colluvial
Typical Bed Material	Sand	Gravel	Gravel-Cobble	Cobble-Boulder	Boulder	Rock	Variable
Dominant Roughness Elements	Sinuosity, bedforms (dunes, ripples, bars), grains, banks	Bedforms (bars, pools), grains, banks	Grains, banks	Bedforms (steps, pools), grains, banks	Grains, banks	Bed and banks	Grains
Typical Confinement	Unconfined	Unconfined	Variable	Confined	Confined	Confined	Confined
Typical Pool Spacing (in channel widths)	5 to 7	5 to 7	None	1 to 4	<1	Variable	
Typical Slopes		<0.015	0.015 – 0.03	0.03 – 0.065	>0.065		

Typically, small headwater streams in the alpine portion of the watershed are cascade and step-pool channels. These tributaries are characterized by steep gradients and coarse channel substrate. Sediment delivery to these channels commonly occurs by debris flows. Photo 7 shows a step-pool channel reach on a small, unnamed tributary to the Middle Fork Snoqualmie River. Cascade and step-pool channels of more limited extent are also found in the lowland portions of the watershed. Here they are often present in steep channel reaches where modern channels descend from rolling glacial uplands or relict glacial channels down to modern river valley bottoms. Bedrock is occasionally encountered in these channels, but frequently they are entirely underlain by glacial sediments. The presence of abundant cobble- and boulder-sized clasts in the glacial substrate and/or effective LWD in the channel are critical to the stability of these channels. Most small lowland tributaries to the Snoqualmie River include this type of steep channel morphology somewhere along their profile. Typical examples include Tokul Creek, upper Patterson Creek, Tuck Creek, and Peoples Creek.

Photo 8 shows cascade morphology on Peoples Creek. Photo 9 shows a step-pool channel formed with a combination of boulders and LWD in Tuck Creek.

Photo 7: Step-pool morphology on an unnamed tributary to the Middle Fork Snoqualmie River.

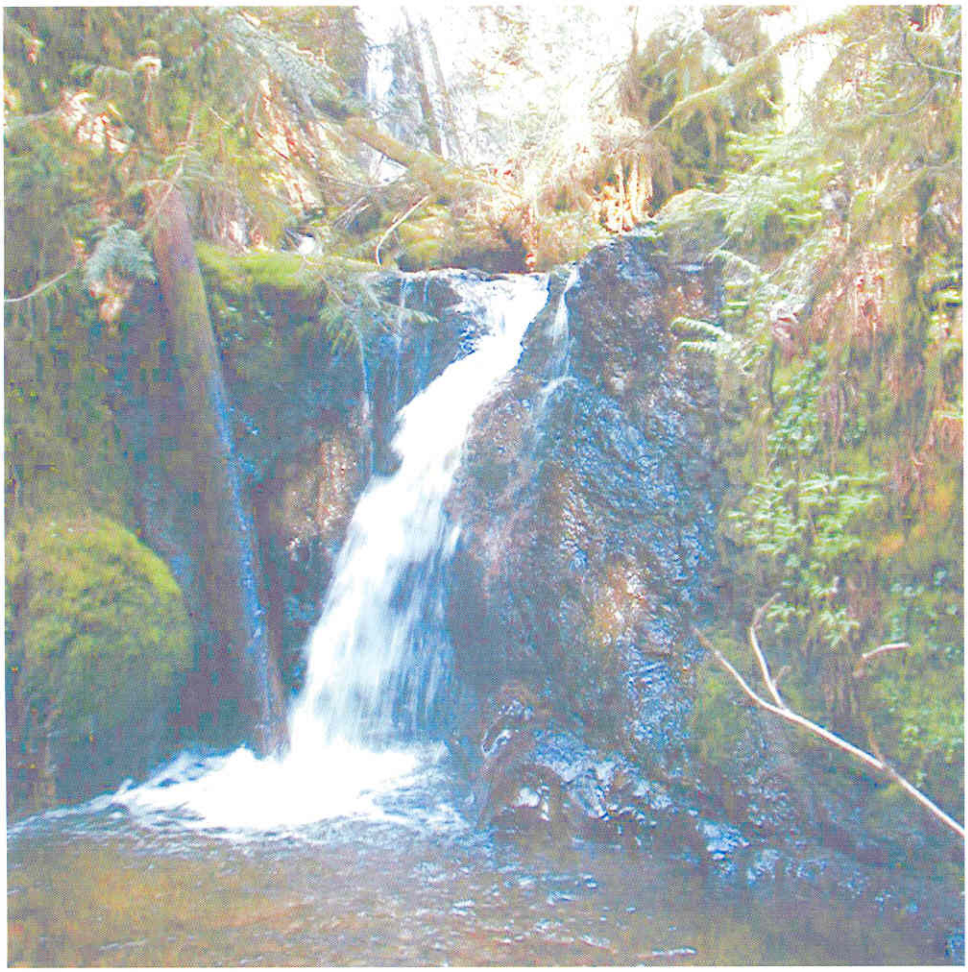


Photo 8: A cascade in an area where Peoples Creek flows over an exposure of Tertiary bedrock

Photo 9: A step-pool reach on Tuck Creek. Note that steps in this channel are formed by a combination of woody debris and boulders.

Lower gradient channels in bedrock or post-glacially incised valleys often form plane-bed channels. Some portions of mainstem rivers in the alpine portions of the watershed have a plane-bed morphology. This morphology is also common in lowland channels. It is likely that many lowland channels that now have plane-bed morphology were step-pool channels under pristine conditions. Human activities have removed wood from these channels or removed the source of LWD from riparian zones. In many such streams, boulders and cobbles are absent, and LWD formed the primary step-forming element in the channel. Without LWD, step formation was not possible, and these streams then transitioned to the plane-bed character evident today. Photo 10 shows plane-bed morphology in the Raging River.

In gravel-bedded channel reaches where the quantity of bedload supplied to the channel exceeds the channel's ability to move it, there is net sediment accumulation. Reaches of this type are common in the alpine portion of the watershed, notably in areas where a rapid downstream decrease in channel gradient reduces the local sediment transporting capacity. Typically in these areas, the channel develops a braided character with multiple active channels and rapid migration of the channels and intervening bars (Photo 11). Braided morphology is locally present on all three forks of the Snoqualmie, and on both forks of the Tolt.

Moving downstream, both channel gradient and valley confinement typically decrease and channels develop a pool-riffle pattern. Pool-riffle channels typically occur in valleys with relatively well-developed floodplains. Typically, these channels have little contact with valley walls and are therefore not strongly affected by fluvial or mass-wasting processes originating from outside the channel perimeter. Pool-riffle channels, which are common in both the alpine and lowland portions of the watershed, are characterized by a well-developed meandering pattern in map view (Photo 12).

The lowest gradient channel types found in the Snoqualmie Valley show a dune-ripple morphology. These channels are generally incompetent to transport bedload larger than sand. Flow resistance in these channels comes from channel geometry, and also from ripples and dunes formed on the streambed. Dune-ripple channels typically show a well-developed meander pattern. Much of the Snoqualmie River mainstem in the lower valley has a dune-ripple character. Photo 13 shows dune-ripple morphology on the lower Snoqualmie River in the vicinity of the city of Duvall.

5.2.3. Local Processes

Some geomorphic phenomena occur at discrete locations with relatively limited horizontal extent. These phenomena are a result of a specific local combination of topographic, geologic, and hydrologic factors. Examples of these types of processes in the Snoqualmie Valley include landsliding and alluvial fan construction.

5.2.3.1. Landslides

Various styles of landsliding occur in the Snoqualmie watershed. Collectively, they represent one of the most important mechanisms supplying sediment to the fluvial system. The style of landsliding that occurs at a given location depends on local geologic, topographic, and hydrologic conditions. Figure 11 shows diagrams of several styles of slope failure common to the Snoqualmie watershed.

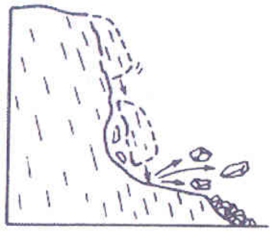
Photo 10: Plane-bed morphology on the Raging River between Preston and Fall City.

Photo 11: A braided reach on the Tolt River a short distance upstream of Carnation at approximately river mile 2.

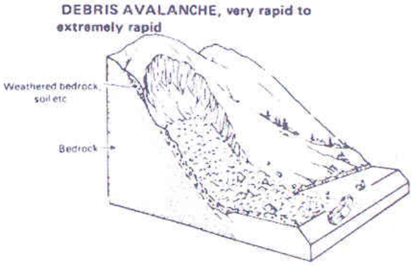
Photo 12: Pool-riffle morphology on the Middle Fork Snoqualmie River.

Photo 13: Ripple marks in fine sand on the bed of the Snoqualmie River in the vicinity of Duvall. Such ripple marks are an indication of dune ripple morphology on this reach of the river.

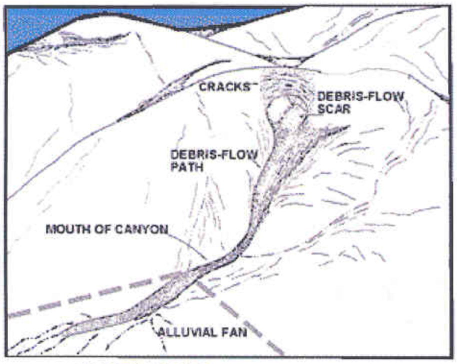
Figure 11: Common Landslide Types in the Snoqualmie Valley Watershed



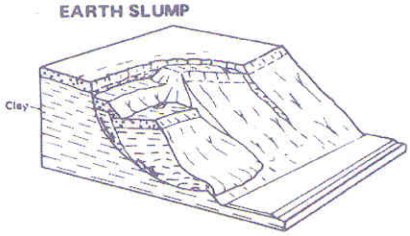
Rock Fall: (Varnes, 1978)



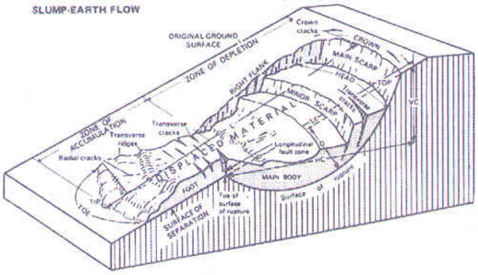
Debris Avalanche (Varnes, 1978)



Debris Flow (U.S. Geological Survey Open-File Report 83-635)



Earth Slumps (Varnes, 1978)



Slump-Earth Flow (Varnes, 1978)

In the high Cascades, rock fall is a common mass-wastage process in glacially sculpted peaks and ridges. Areas of active or recent rock fall activity are often indicated by the accumulation of a talus at the base of the slope (Photo 14). Rock fall can also be indicated by a more diffuse scattering of angular boulders near the base of a bedrock cliff. A field of such boulders is present along the Moon Valley Road along the base of the northwest face of Mount Si (Photo 15).

On steep slopes in the alpine portions of the watershed, landsliding is dominated by shallow debris avalanches. This type of failure occurs when a shallow layer of soil overlying bedrock becomes saturated and slides downslope. These types of failures often occur in swales or hollows on steep slopes. Debris avalanches are often seen where fill slopes and landings on logging roads are located on steep, alpine hillslopes. As the detached soil layer slides, it often disaggregates into a fluid mass that accelerates downslope as a debris flow. This mechanism creates the characteristic spoon-shaped scars common in steep alpine valleys. Debris flows typically erode more soil and incorporate downed wood or standing trees as they move downslope. These flows are a major source of both sediment and LWD in alpine stream channels.

Debris avalanches are also common in lowland portions of the watershed. In these features, the surficial soil layer typically slides over consolidated glacial sediments rather than bedrock, but the mechanism is identical. Because slopes are generally shorter and less steep, it is less common for slumps in lowland settings to transition into debris flows. Larger deep-seated landslides are also common in the lowland portion of the Snoqualmie Valley. These slides are typically located on valley walls often in areas where the valley wall is underlain by fine-grained glacial units (Figure 12). Most of these larger landslides are prehistoric features, some probably dating back to immediately post-glacial time. Although old, many of these landslides remain marginally stable and could be reactivated by periods of wet weather, seismic activity, or human modification.

5.2.3.2. Alluvial Fan Construction

Alluvial fans are a common feature throughout the Snoqualmie watershed, and most of these fans are still active and growing. Alluvial fans form where high-energy streams with the ability to transport relatively coarse sediment discharge into a low-energy environment with insufficient stream energy to transport this sediment. Progressive accumulation of immobile sediment at these locations results in relatively frequent changes in channel location, leading to the development of the characteristic fan-shaped deposit in map view.

Photo 14: Rockfall from cliffs on the west face of Mt. Si has created the taluses seen here. Note areas of lighter gray on the cliff, suggesting active spalling of the cliff face.

Photo 15: A boulder derived from rockfall on the west face of Mt. Si. This boulder and others like it are located along Moon Valley Road, an area of residential development outside of North Bend.

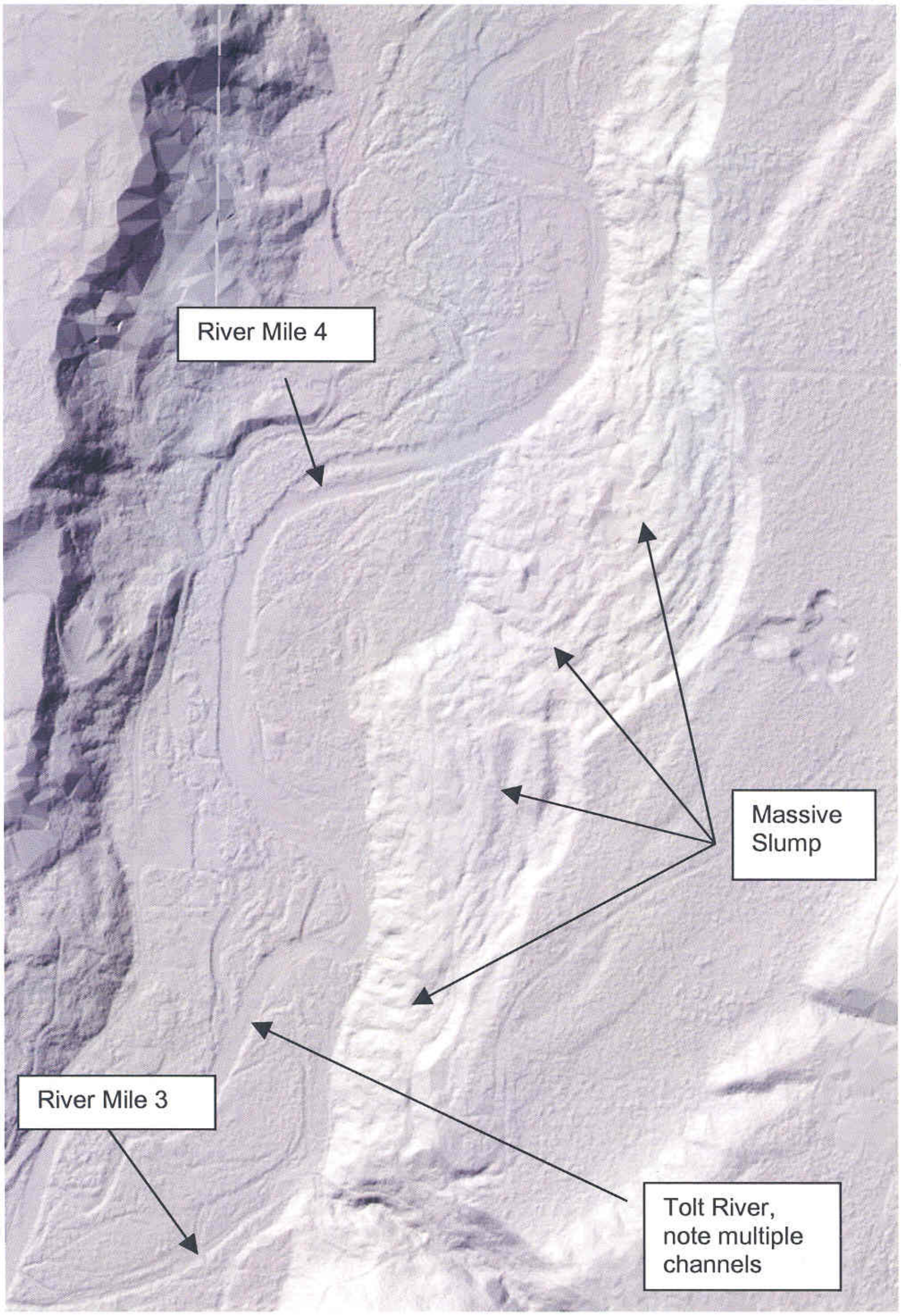


Figure 12: Lidar image of the Tolt Valley showing a massive slump on the south valley wall. This slump is likely prehistoric but it is also likely to be active or marginally stable and subject to reactivation if disturbed. Note braided character of adjacent Tolt River.

Alluvial fans form at a variety of scales, from features below the resolution of available mapping up to features like the Tolt River fan at Carnation, which covers an area of approximately 2 square miles (5 square kilometers). Figure 10 shows examples of several alluvial fans in the Snoqualmie watershed.

5.2.3.3. LWD Recruitment and Incorporation

An extensive body of recent geomorphic literature has identified the critical role that LWD plays in the function of Pacific Northwest streams and rivers (Bilby and Ward, 1989). LWD interacts with stream channels in a variety of ways, in settings ranging from steep ephemeral headwater swales to large, low gradient mainstem river channels.

Woody debris that falls into small, steep headwater channels is often too large for the stream to move. Wood can play a primary role in stabilizing these channels. Stems and rootwads often constitute the largest structural elements in these steep channels and limit channel erosion by creating “hard points” that directly limit channel incision or widening. In addition, these woody elements, often in association with boulders, constitute the primary roughness elements in small steep channels. By increasing channel roughness, these elements help dissipate the kinetic energy of stream flow through increased turbulence, thereby decreasing the energy available for channel or bank erosion.

As stream size increases, the character, abundance, and distribution of LWD continues to be a controlling factor in fluvial geomorphic processes, but the nature of the interaction changes between the wood component and channel form changes. Most significantly, as channel size increases, progressively larger wood pieces become increasing mobile. In mainstem rivers, flood flows are typically capable of moving the largest pieces of supplied woody debris. Stable LWD structures can still form, but these now consist of multiple logs that achieve their stability not only because of the size of individual pieces but also because of the architecture of the entire assemblage. A number of common debris jam types have been identified by Abbe et al. (2003) (Figures 13, 14, and 15; Photos 16, 17, and 18). Debris jams can obstruct and deflect flow, leading to increased channel migration. Jams can sometimes persist for centuries, remaining as stable features in the floodplain as the channel migrates around them (Abbe et al., 2003).

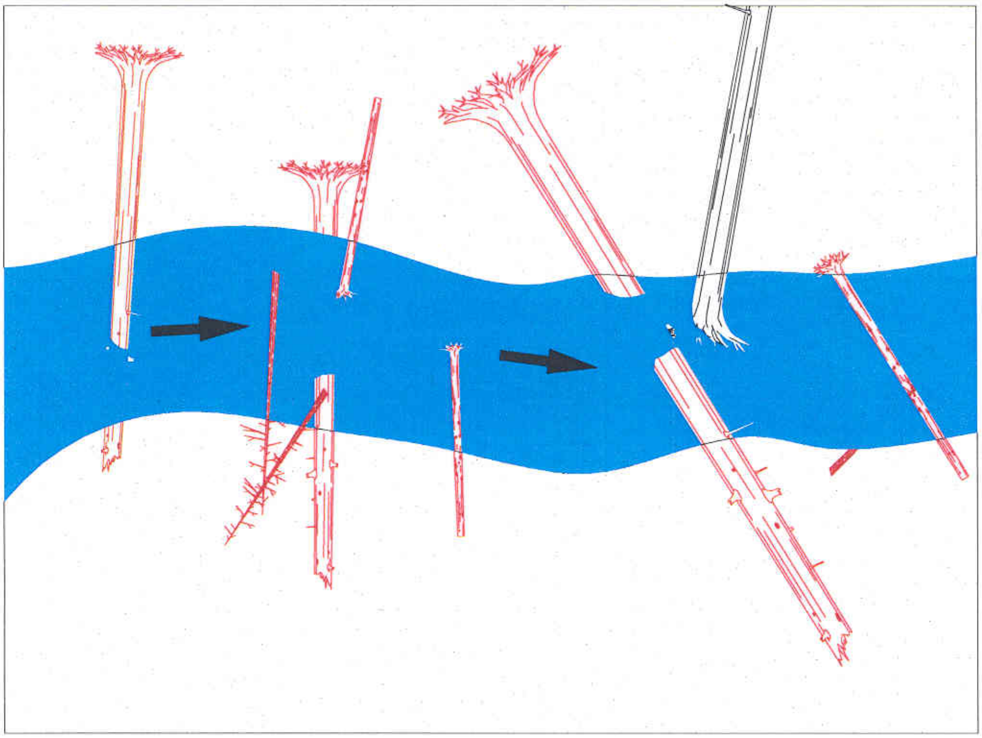


Figure 13: Step jam (after Abbe et al. (2003))

Photo 16: Step jam on Peoples Creek

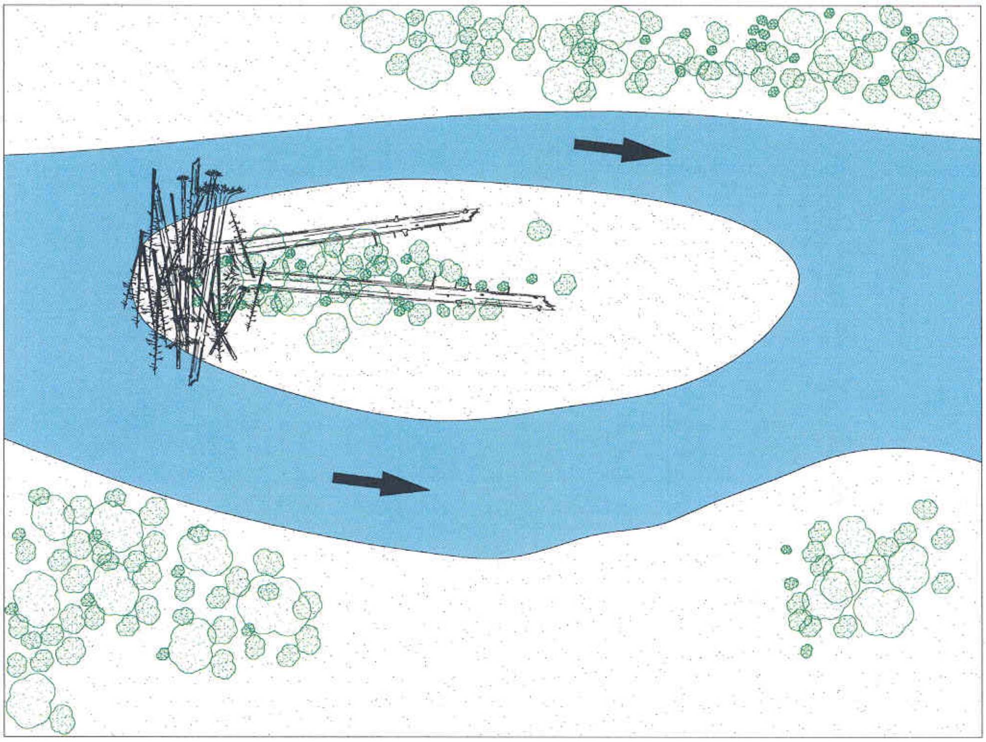


Figure 14: Bar-apex jam (after Abbe et al., 2000)

Photo 17: Mature bar-apex jam on North Fork, Tolt River

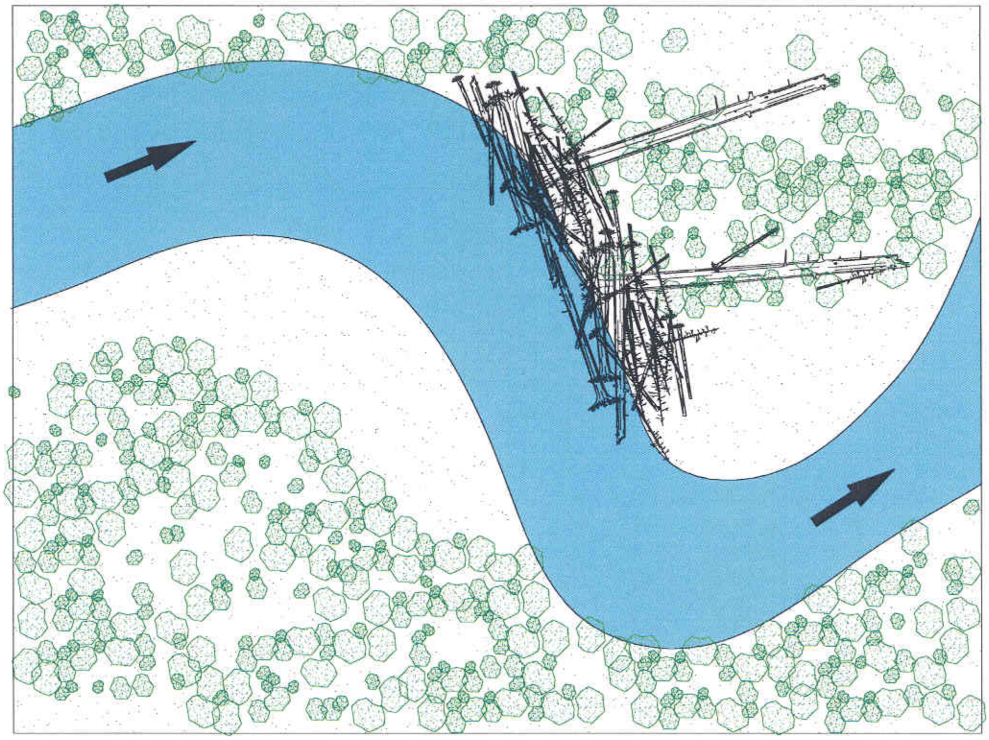


Figure 15: Meander jam (after Abbe et al. 2002)

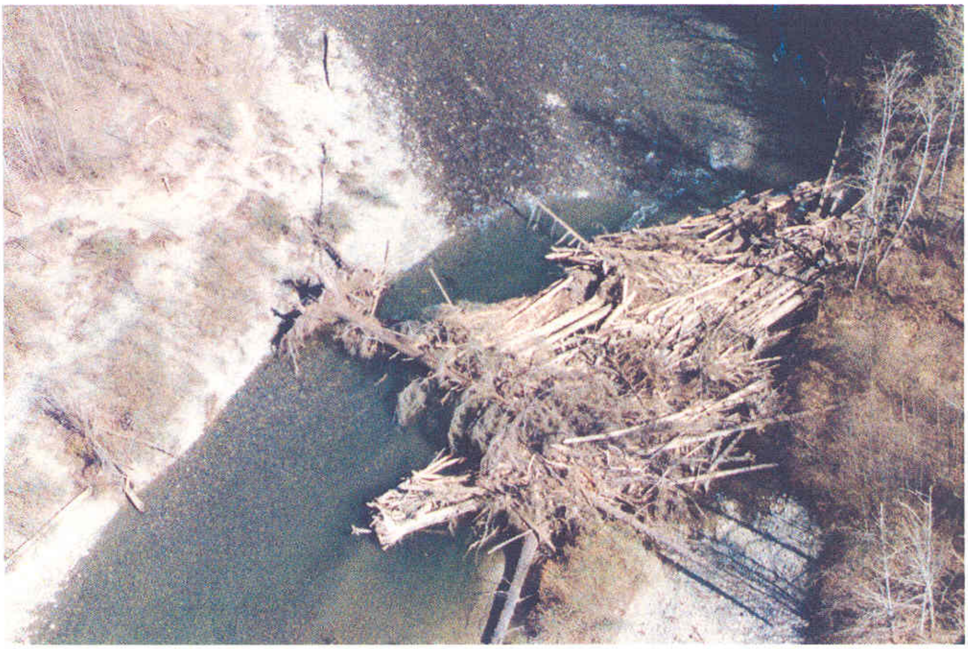


Photo 18: Meander jam on the North Fork, Tolt River

Wood can be supplied to channels in a variety of ways. Trees adjacent to steep headwater swales may be fallen as a result of landslides, avalanches, or windthrow. These woody pieces may remain in these steep swales until debris flows move them downslope into larger tributary or mainstem channels. In larger channels, the primary local source of LWD is streamside trees that fall directly into the channel as a result of lateral channel migration, intense weather events, or beaver activity. Regardless of location in the watershed, the quantity and character of the natural LWD input depends on the areal extent, stem density, species distribution, and maturity of the forested riparian zone.

LWD jams in the lower Snoqualmie River are less common than in other Puget Lowland rivers. This is, in part, a result of the drastic reduction in the extent of riparian forest and armoring of channel banks that limits lateral erosion. However, there is some evidence based on historical accounts that the lower Snoqualmie had a relatively low LWD loading even before non-native human settlement. Collins et al. (2003) suggests that this comparatively low LWD abundance may be typical of Puget Lowland rivers that occupy relict glacial troughs. These rivers typically have low gradients and low confinement compared with rivers in self-formed valleys. As a result, these channels tend to have lower average boundary shear stress and therefore lower natural rates of channel migration. Lateral migration and undermining of riparian trees is an important source of LWD recruitment.

5.3. Post-Glacial Deposits

5.3.1. Alluvial Valley Fill

Following glacial retreat, the freshly exposed land surface was covered with a complex pattern of channels and depressions. Since deglaciation, sediment has progressively accumulated in these features. The character of the depression and its location in the post-glacial drainage network largely determine the character of the sediment that it collects. Where such features occur high in the drainage network, with little upstream sediment supply, they tend to fill gradually with organic sediments, with varying content of fine-grained mineral sediment. This type of sedimentation created wetlands like the ones shown in Figure 16. Where such depressions occur lower in the drainage network, they typically fill with sediment from the watershed upstream. This sediment may range from fine-grained lacustrine deposits through silty or sandy alluvium to gravelly fluvial deposits. Deposits of this type fill the major alluvial valley bottoms, including the upper mainstem valley from the Three Forks confluence to Snoqualmie Falls, the lower Snoqualmie Valley, and smaller valley segments on the lower Tolt River and Patterson Creek.

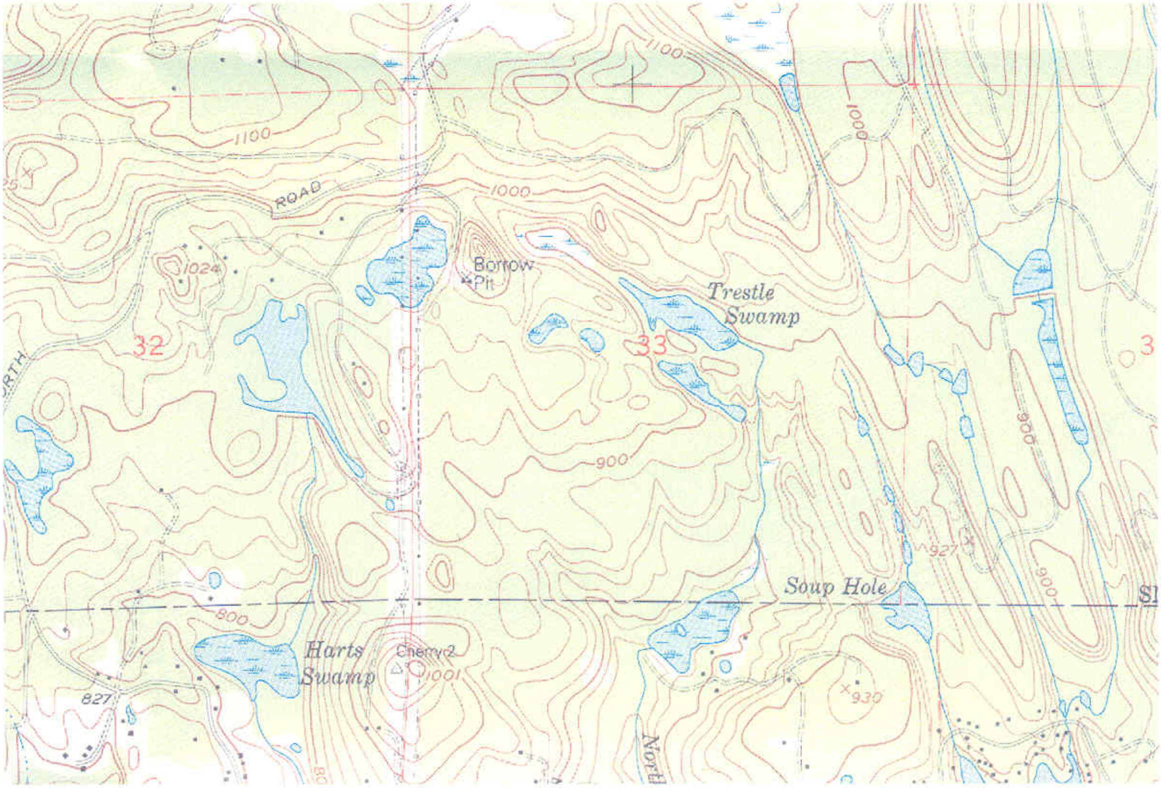


Figure 16: Wetlands developed in depressions in the glacial landscape in the Cherry Creek basin.

5.3.2. Alluvial Fan Deposits

Alluvial fan deposits are typically coarser than adjacent alluvial deposits. They are often gravelly with crude stratification. They may show surficial evidence of multiple abandoned channels. The pattern of patchy, multi-aged vegetative cover may indicate a history of repeated local disturbance due to frequent channel migration.

5.3.3. Landslide Deposits

Landslide deposits have variable textures depending on the geologic substrate from which they were derived. Depending on the style of landsliding, the debris can range from being slightly to completely disturbed. In the case of slumps, large blocks may appear relatively undisturbed, although they have moved and rotated during slide movement. Debris flow and debris avalanche deposits on the other hand are typically disaggregated. Because of their disturbance history, landslide debris is typically soft or loose. Landslide deposits are often most easily recognized based on their distinctive topography rather than on the nature of their constituent sediments. Such distinctive topography can include steep arcuate head scarps, mid-slope benches, stepped topography, lobate toes, and hummocky topography. Active landslides are often marked by bent or leaning trees.