



Geomorphology of the Chilliwack River Watershed

Landform Mapping at North Cascades National Park Service Complex, Washington

Natural Resource Technical Report NPS/NCCN/NRTR—2012/565



ON THE COVER

From upper right to lower left: The north face of Mt. Redoubt.; Depot Creek waterfall; Debris avalanche in upper Indian Creek; The east face of Mineral Mountain; All photographs taken within North Cascades National Park Service Complex.

Photograph by: Sharon Brady, NPS

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Abstract

The report describes the background information, methods and results of a surficial geology inventory within the North Cascades National Park Service Complex (NOCA). The study area for this report is the Chilliwack River Watershed, which flows north from NOCA before turning west to join the Fraser River in British Columbia. Tributaries of the Chilliwack River include Copper, Easy, Brush, Bear, Indian and Depot Creeks and the Little Chilliwack River. The headwaters of many of these tributaries are on the Skagit or North Cascades Crest, two significant divides that strongly affect the hydrology and climate in the North Cascades (Riedel 2007). This report focuses on how factors such as bedrock geology, glacial history, climate, hydrology, and vegetation have affected landform development in the Chilliwack River Watershed, particularly mass movements.

The Chilliwack River Watershed is defined by the Straight Creek Fault, the Hannegan Caldera Ring Fault and northeast-southwest compressional faults. The geology consists of mostly Cretaceous to Eocene intrusive plutons that are granitic in nature, with older rocks of the Skagit Gneiss Complex in the northeast section of the watershed. The topography of the Chilliwack River Watershed reflects multiple glaciations during the past 2 Ma, which have carved deep U-shaped valleys, steep valley walls and jagged horns and arêtes. The North Cascades were inundated by the south flowing Cordilleran Ice Sheet during the Fraser Glaciation (Armstrong et al. 1965). The most extensive advances of alpine glaciers since the last ice age occurred in the Little Ice Age between 1350 and 1900 AD, depositing Neoglacial moraines.

The watershed has a maritime climate with relatively mild, wet winters and cool, dry summers. Snow pack generally reaches its maximum depth at high elevation sites in April to May. Yearly temperature average highs tend to occur in July and August with winter average low temperatures occur in January. The rainy season typically lasts from November through January. Snow, bare rock and ice cover approximately 11.4 km² of the Chilliwack River Watershed. The remainder of the watershed is dominated by conifer species of trees although deciduous species dominate along major river corridors and in avalanche chutes.

A suite of 29 different landforms is currently being mapped at NOCA at the 1:24,000 scale. Landform mapping is specifically being utilized as an input in the creation of a soils distribution map for NOCA. Landforms can either be depositional in nature, such as moraines and alluvial fans, or they can be erosional such as bedrock benches and horns. Many depositional features such as moraines and terraces were formed during the last ice age. Other depositional features such as debris cones and landslides are forming today. Approximate ages are assigned to depositional landforms based on available radiocarbon dates, associated process of formation, volcanic tephra, soil development and vegetation type and age.

Within the watershed, 50% is valley wall and 23% is high elevation cirque; with only 2.8% as riparian (floodplain, valley bottom and alluvial fan). High elevation landforms (cirque, Neoglacial moraines, ridges, arêtes, other mountain, horns and passes) account for 62.5 km², which is 28.7% of the total area in the watershed. Aspect has particularly strong control on the development of cirque basins with north and east facing cirques are deeper and broader than those on southerly aspects and also containing lower elevation Neoglacial moraines.

The main stem of the Chilliwack River is a broad U-shaped glacial valley with a flat valley bottom, straight profile and low gradient, created by both the southward excursions of the Cordilleran Ice Sheet and the multiple glaciations by alpine glaciers flowing down the major tributaries. Tributary systems were left as hanging valleys with bedrock canyons or narrow, stepped waterfalls at their mouths. Where they join with the main stem of the Chilliwack River, these streams deposited alluvial fans. At the mouths of some tributaries, fan terraces were deposited at the end of the last ice age when slopes left bare by retreating glaciers fed massive quantities of sediment to streams. There are several large Pleistocene moraines along the Chilliwack River deposited by the ice sheet across the mouths of tributaries (Riedel 1987). These landforms are remnants of moraine-embankments the ice sheet built across the mouths of these valleys as it flowed up the Chilliwack. The presence of lacustrine deposits in terraces as far up the main stem of the Chilliwack River as Easy Creek, indicate ice-sheet damming of the valley at about 17 Ka (Clague 1981a and 1981b).

A total of one hundred and forty-three landslides have been mapped within the Chilliwack River Watershed, which encompass ~3.4% of the overall watershed area. By reviewing the location, size and composition of mass movements in the watershed, some general observations can be made. Debris slump/creep deposits are uncommon in the watershed and tend to occur in the valley bottom from stream-undercut of glacial till and colluvium in the debris apron. Recently active debris torrents are present in all sub-watersheds, but are uncommon overall. Most of the rock falls/topples tend to be on east to north-east facing slopes, where the effects of aspect are most pronounced. Debris avalanches encompass 2.4% of the overall watershed and are of particular importance due to their large size, potential to block streams and deliver massive amounts of large woody debris and sediment. In the Chilliwack River Watershed it appears that the largest debris avalanches are typically fault controlled, by either the Hannegan Ring Fault or northeast-southwest trending extensional faults. Debris avalanches in the watershed displaced an estimated volume of 0.046 km³ of debris.

1 - Introduction

The primary purpose of this report is to describe the background information, methods and results of a surficial geology inventory within the North Cascades National Park Service Complex (NOCA). This is one of twelve basic inventories called for in the National Park Service (NPS) National Resource Challenge. A secondary goal is to provide an overview of bedrock geology, climate and hydrology as they affect landform processes. The study area for this report is the Chilliwack River Watershed, which includes the main Chilliwack River and its tributaries (Copper, Easy, Brush, Indian and Bear Creeks and the Little Chilliwack River) along with Depot Creek, which joins the river at Chilliwack Lake in British Columbia.

Background information presented in this report focuses on key factors that influence the development of landforms in Chilliwack River Watershed. These factors include geology, glacial history, climate, hydrologic setting and vegetation. A brief discussion on landform age follows the background information, to give geomorphic processes a temporal context. A detailed description of methods is then provided before discussing the results and interpretations of the landform inventory. The results and discussion section of this report gives detailed analysis for the individual sub-watersheds mapped in this study. Discussion of each sub-watershed includes the unique characteristics of the individual valleys and specific examples of landform genesis. Detailed information is gathered for each mass movement in order to reveal both historic and on-going mass wasting occurring in each sub-watershed.

1.1 Applications of Landform Mapping Data

Understanding surficial processes and materials is critical for resource managers in mountainous terrain. Surficial processes such as landslides, floods and glaciations directly impact the human use and management of rugged landscapes. The materials produced by these processes influence soil and vegetation patterns and provide information on geologic hazards, prehistoric landscape use, habitat and ecological disturbance. Knowledge of the function of surficial processes and distribution of materials assists the National Park Service (NPS) in selection of ecological reference sites, identification of rare or threatened habitat, management of risk and cultural resources (Riedel and Probala 2005).

Landform mapping is specifically being utilized as an input in the creation of a soils distribution map for NOCA. Traditional methodologies, relative inaccessibility and estimated high costs have not allowed for extensive soil surveys in the rugged wilderness. Parent material, time (stability/age) and relief are three of five soil-forming factors, so digital landform maps are a critical component in developing new approaches to mapping soils in remote, rugged landscapes. Landforms provide a preliminary landscape delineation that can simplify the soil sampling strategy. Linking soils to landforms is a cooperative effort among NOCA, the Natural Resources Conservation Service (NRCS) state mapping program, the United States Forest Service (USFS), Washington State University and the NPS Soils Program.

Currently the Remote Area Soil Proxy (RASP) model uses GIS, remote sensing technology and a focused effort to describe soils in the field to model and map the distribution of soils (Rodgers 2000, Briggs 2004, Frazier et al. 2009). Digital GIS data layers such as digital elevation models, current vegetation, wetness index and landforms serve as proxies for the soil-forming factors that

control pedogenic processes. A digital soils model using landform data from Thunder Creek watershed shows a strong correlation between landform type and soil order (Briggs 2004). Encouraged by these results, landform maps are being used to develop soil models for the remainder of NOCA. This approach will continue to be developed to obtain soil resource inventories for all NPS units in Washington State.

The Chilliwack River Watershed provides several unique management challenges for the NPS. Landform maps can be consulted in order to relocate trails, campsites and other recreational and sanitary facilities. Identification of mass movements, active debris cones, alluvial fans and stable terraces can aid in the placement of new facilities, trails and visitor use areas. Development of soil maps provides useful information for modeling fuel loads, humidity recovery, susceptibility to erosion and possible restoration efforts related to fires. This watershed shares a boundary with British Columbia and has been identified as suitable habitat for several endangered and threatened species, notably grizzly bear (Almack et al. 1993). Detailed landform maps of this area would be a valuable resource if either the United States or Canadian governments choose to implement a recovery plan that involves reintroduction of endangered or threatened species to this area.

1.2 Project History

In 1988, staff at NOCA began using an eight landform mapping scheme to assess distribution of archeology sites. This program continued to develop in the early 1990's when a suite of fifteen landforms were mapped to support a general management plan for Lake Chelan National Recreation Area. In 1995, the program expanded to meet the needs of NOCA as a prototype Park for long-term ecological monitoring (LTEM) programs. This included the development of a twenty-three landform scheme to support classification and assessment of aquatic habitat. There are now thirty-seven distinct units in a regional landform scheme, of which twenty-nine are found in NOCA. Landform units are created by discrete geologic processes, many of which are still active and relatively easy to identify. The landform scheme has now been applied to several watersheds within five of the seven NPS units in the North Coast and Cascade Network (NCCN), including NOCA, Mount Rainier National Park (MORA) and Olympic National Park (OLYM), Ebey's Landing National Historic Reserve and San Juan Island National Historic Park.

The development of this program was assisted by the Natural Resource Challenge to obtain twelve basic inventories for all NPS areas, including surficial geology and soils. In 2001, NOCA landform mapping was linked with the United States Forest Service (USFS) multi-scaled "National Hierarchical Framework for Ecological Units" (Cleland et al. 1997) for public lands in the North Cascades. The approach uses a nested system in which each scale (eight total) fit inside one another. Together the USFS and NPS have mapped at three of these scales; 1-Subsection, 2-Landtype Association (LTA) and 3-Landform scales.

This report gives detailed results for the Chilliwack River Watershed, which includes a discussion of the unique geomorphology and history of the Chilliwack River valley and its tributaries, as well as a summary of landslide inventory data. The valley characteristics of each tributary are presented, with a fine resolution of landform description, landslide activity and any other pertinent information.

2 - Study Area

2.1 Geographic Setting

The Chilliwack River Watershed is located in the northwest corner of North Cascades National Park Service Complex (NOCA), on the boundary between the North Cascades and Coast Mountains physiographic provinces (McKee 1972) (Fig. 1). The Chilliwack River is one of the few river systems in NOCA that flows northward and is the only major river in the park that drains into British Columbia. The Chilliwack River Watershed covers approximately 215 km² of the 2,770 km² of the park. The total size of the Chilliwack River Watershed, in the United States and Canada, is approximately 1230 km² (Thomson 2001). The headwaters of the Chilliwack drain the Hannegan Caldera and flow northeast into Chilliwack Lake in British Columbia. The Chilliwack then drains west from the lake for approximately 40 km, where it merges with the Sumas and then the Fraser River via the Vedder Canal. The Fraser River then meanders approximately 90 km to reach the Pacific Ocean. The Fraser River basin is the largest watershed in British Columbia, draining more than 233,000 km².

Tributaries of the Chilliwack River include Copper, Easy, Brush, Bear, Indian and Depot Creeks and the Little Chilliwack River (Fig. 2). Depot Creek joins the Chilliwack River at Chilliwack Lake in British Columbia and supports the largest glaciers in the watershed. It is also surrounded by two of the highest peaks in the watershed; Mt. Spickard (2737 m) and Mt. Redoubt (2730 m). The two other highest peaks in the Chilliwack valley include Whatcom Peak (2309 m) at the head of Brush Creek and Middle Peak (2275 m) at head of the Little Chilliwack River. The southern and eastern edge of the watershed (Ruth Mountain to Whatcom Peak to Mt. Spickard) is bounded by the northern extent of a series of peaks and ridges known as the 'North Cascades Crest'; an important physiographic feature that strongly influences the climate, ecology and geomorphology of the region (Riedel 2007). Red Face Mountain, on the divide between Brush and Indian Creeks, marks the beginning of the "Skagit Crest," a major drainage divide that runs south through Whatcom Peak and the entire Picket Range and is breached at Skagit Gorge (Riedel 2007)(Fig. 2). The lowest elevation in the main valley is at the Canadian border (664 m), making the local relief more than 2000 m.

In the United States, this watershed is managed according to the guidelines of the National Park Service. The Chilliwack River Watershed is part of the Stephen Mathur Wilderness and falls under Wilderness regulation. On the Canadian side, Lake Chilliwack Provincial Park encompasses the watershed until the end of Lake Chilliwack. After that point, the river enters land managed in large part by the Ministry of Forests and contains sections of private land for residential homes and subdivisions. The Chilliwack River valley in British Columbia has a long history of logging and the practice continues today within the valley. At its lower end the river flows through agricultural fields and the Vedder Canal.

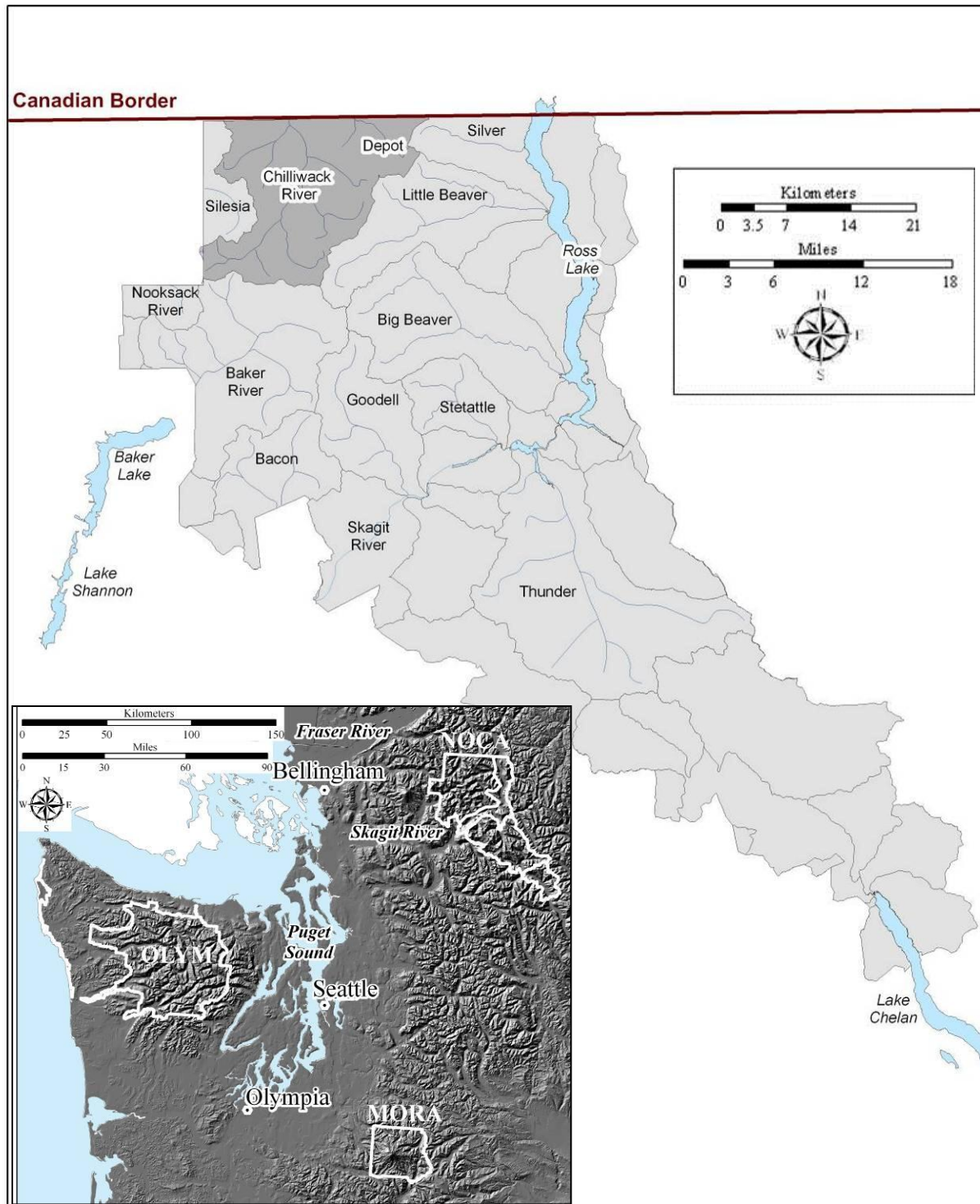


Figure 1. Map showing the location of Chilliwack River and adjacent watersheds within North Cascades National Park Service Complex (NOCA). Insert map shows the location of NOCA within Washington State, as well as Mount Rainer (MORA) and Olympic (OLYM) National Parks.

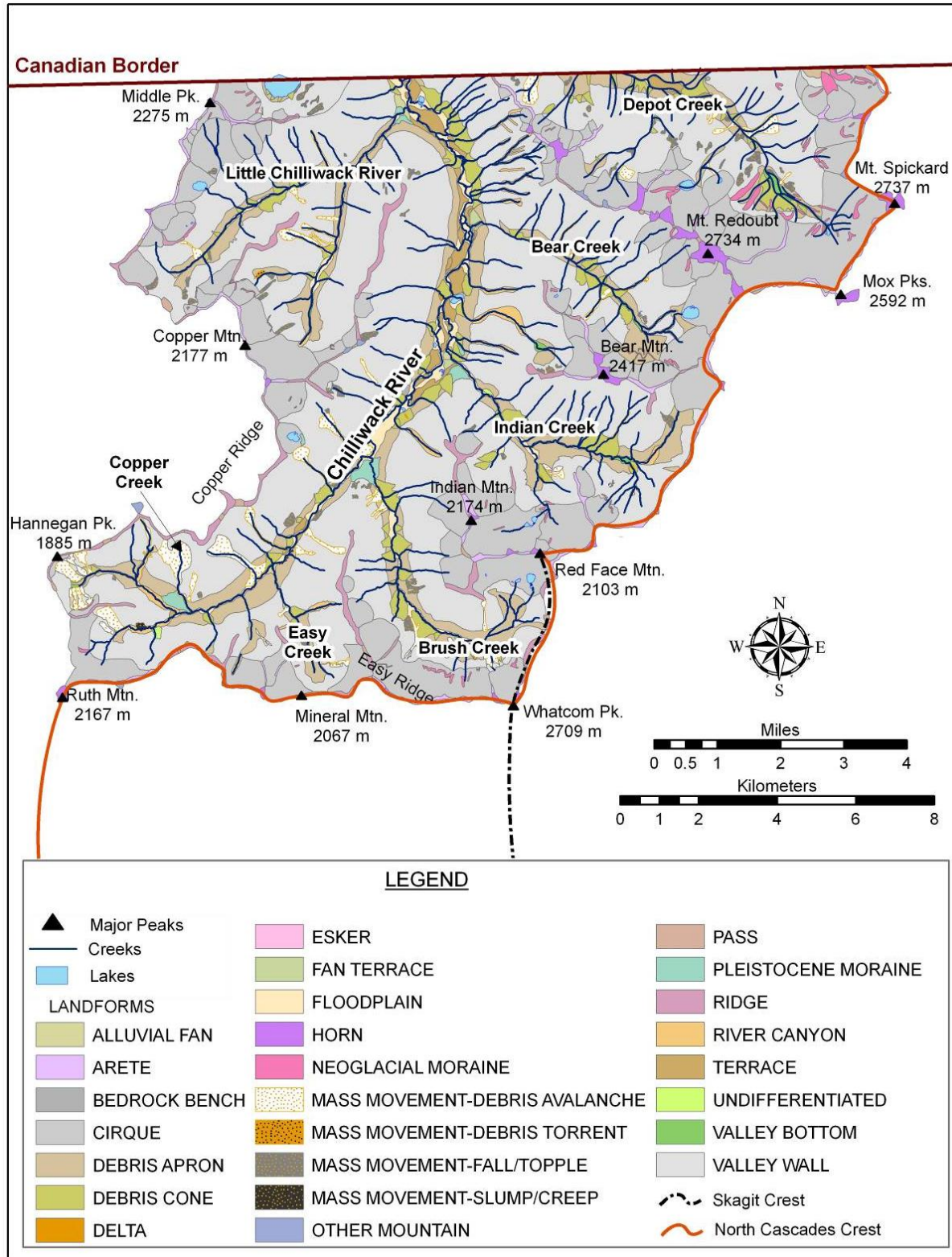


Figure 2. Landform map of the Chilliwack River Watershed with the locations of the main tributary streams and other sites referred to in the text

2.2 Geologic Setting

The bedrock geology of the North Cascades has been mapped at the 1:100,000 scale by Tabor et al. (2003). The regional geologic map is presented in this report for context (Fig. 3). Bedrock of the North Cascades was formed by a complex series of igneous, metamorphic and tectonic events beginning in the Cretaceous period, 145 – 65 millions of years ago (Ma). Numerous faulting events and intrusions in the North Cascades have created a diverse mosaic of bedrock types. Since the geology is so complicated in this corner of the United States, geologists have summarized it into five broad events:

1. Accumulation of massive bodies of rock (terrane) to the west coast of North America between 200 (Early Jurassic) and 50 Ma (Late Cretaceous);
2. Uplift and erosion of these rocks to create a pre-North Cascades mountain range between 130 (Early Cretaceous) and 50 Ma (Eocene);
3. Intensive movement and faulting 50-40 Ma that fragmented the preexisting mountains;
4. Another phase of mountain uplift that created the modern North Cascades began 40 Ma and continues today; and
5. From about 2 Ma and continuing intermittently the great ice age glaciers created not only the jagged *arêtes* and horns, but also the broadened passes, rounded ridges and deepened valleys.

2.2.1 Tectonics and Structure

Three sets of faults define the Chilliwack River Watershed. The north-south trending Straight Creek Fault is likely the overall defining structure of the main Chilliwack valley. The Straight Creek Fault is thought to be a strike-slip extensional fault that is 400 km long, beginning in Central Washington and extending 210 km into Canada, where it is named the Fraser River Fault Zone (USGS 2003). Expressions of the Straight Creek Fault have nearly been erased due to the intrusion of Tertiary arc plutons (Tabor et al. 2003). It is possible that the strong north to south expression of the main valley is due to the defining fabric of this fault. The second notable structural feature in the watershed is the Pliocene Hannegan caldera ring fault (Tucker 2006). This fault extends north through Hannegan Pass to the base of Granite Mountain, then wrapping around through Copper Creek down to Seahpo Peak (Fig. 3). It is likely that the Chilliwack River originated as a stream draining the slopes of this volcano, which at 3.72 Ma underwent its first episode of caldera collapse. The Hannegan Caldera represents the footprint of a migrating volcanic center that stretches from Silver Lake (Skagit Volcanics) to Mt. Baker (Tucker 2006).

Regional uplift and exhumation of the North Cascades that began in the Eocene (45 to 36 Ma) continues today as part of the Cascade Magmatic Arc (Reiners et al. 2002). This uplift established compressional faults in a northeast-southwest direction, which control the trend of the upper Skagit valley in British Columbia and possibly the Skagit Gorge (Riedel 2007). There are several of these unnamed extensional faults in the Chilliwack River Watershed that may influence the pattern of side streams in sub-watersheds. These faults are located in upper Copper, Brush and Indian Creeks, the Chilliwack River main stem (from Easy Creek to Indian Creek) and through the mid-sections of Bear and Depot Creeks (Tabor et al. 2003). The spectacular waterfall on Depot Creek falls over a scarp along one of these faults. At this time is unclear whether the northwest trending section of the Chilliwack River is defined by faults associated with compressional faults of the Cascade Magmatic Arc.

There appears to be no appreciable Holocene activity along any of these three fault systems within the Chilliwack River Watershed. Most are intruded by younger batholiths that do not show off-set. There appears to be no appreciable Holocene tectonic activity along any of the faults systems within the Chilliwack River Watershed (USGS 2009).

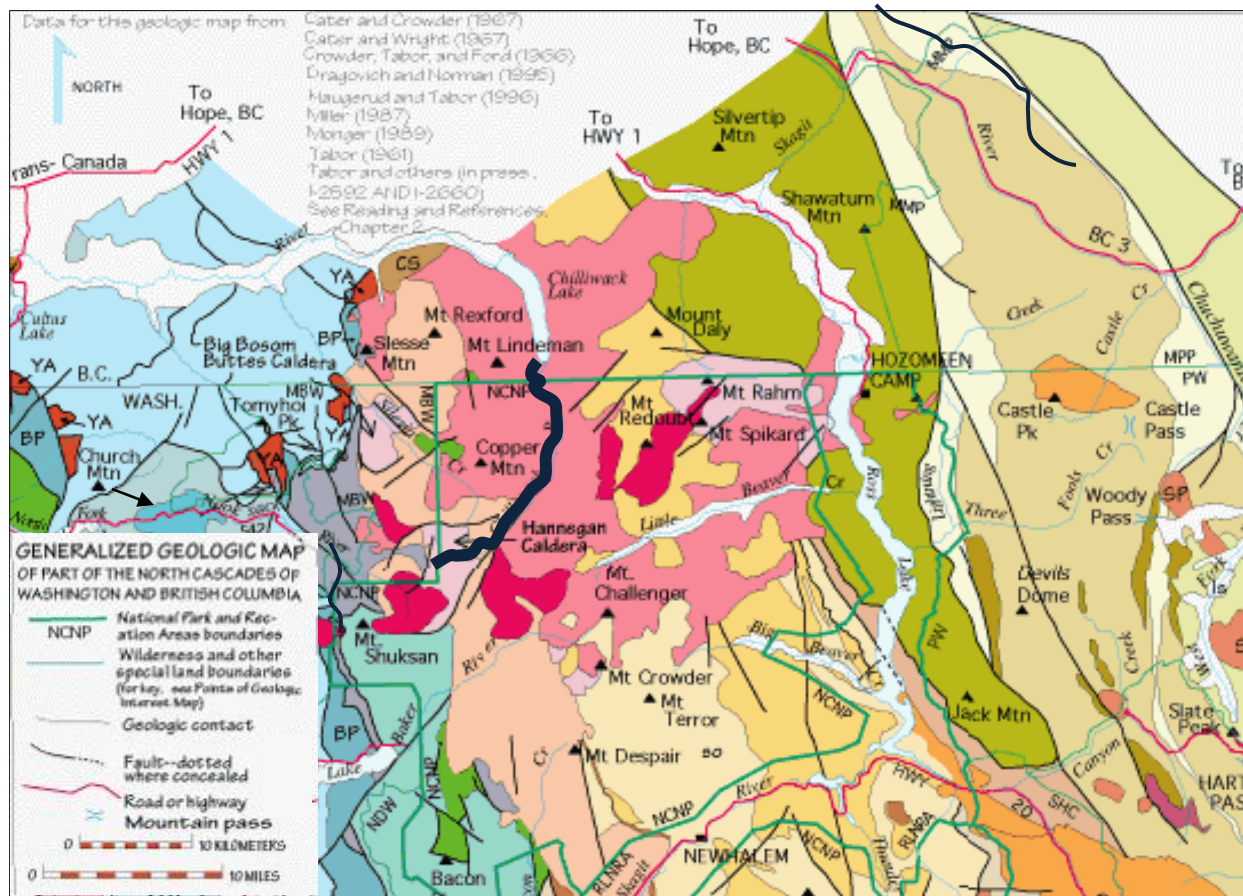


Figure 3. Bedrock map showing the Chilliwack River Watershed (river is in bold) and some of the adjoining watersheds (from Tabor and Haugerud 1999, see publication for geologic map key).

2.2.2 Geologic Units

A generalized geologic map provides a regional perspective on the geology in the Chilliwack River Watershed and neighboring watersheds (Fig. 3). A detailed description of the geology is found in the Tabor et al. publication (2003) and is summarized in the paragraphs below.

The Skagit Gneiss Complex, which was emplaced in the last 122 Ma (Tabor et al. 2003), was subsequently intruded by rocks of the Chilliwack Composite Batholith. These two rock types make up the majority of the watershed. Banded gneiss, mostly biotite gneiss, of the Skagit Gneiss Complex is still exposed at the headwaters of Brush, Bear and Indian Creek and makes up the majority of the main Depot Creek valley. Bedrock of the main Chilliwack valley and western tributaries is composed of various intrusive rocks of the Chilliwack Composite Batholith. The batholith has been divided into three families based on age. These families, all present in the watershed, are the Index family (35 to 29 Ma), Snoqualmie family (28 to 22 Ma) and Cascade Pass family (<20 Ma). Rocks of the Index family include the Pocket Peak phase

biotite granite at Chilliwack Pass, a small pocket of tonalite and granodiorite on Middle Peak, gabbro at Copper Lake and slightly south and miscellaneous gabbros and diorites on Red Face Mountain.

The majority of the watershed is composed of granite/granodiorite and tonalite of the Chilliwack valley phase, part of the Snoqualmie family of the Chilliwack Composite Batholith. This includes the majority of the Little Chilliwack sub-watershed, the main Chilliwack valley from Easy Creek to the Canadian border and the lower Bear, Indian and Brush Creek valleys. Other rocks of the Snoqualmie family in the watershed include tectonized tonalite of the Perry Creek phase, located on Whatcom Peak.

The Cascade Pass family includes the Mineral Mountain pluton, a biotite granite that composes Mineral Mountain, the headwaters of Easy Creek and part of the headwaters of Brush Creek. A pocket of granite porphyry of the Cascade Pass Family is located at Egg Lake along Copper Ridge. The quartz monzodiorite of Redoubt Creek is present at the headwaters of both Bear and Depot Creek. The granite of the Cascade Pass Family is also found at the headwaters of Depot Bear and Indian Creeks.

In southwest corner of the Chilliwack River Watershed lies the dacitic tuffs and andesitic volcanic breccias of the Pliocene Hannegan caldera that compose Hannegan and Ruth Mountains, which have been dated at 3.72 +/- 0.02 Ma (Hildreth et al. 2003). Another pocket of volcanic rocks is located in the northeast corner of the watershed at the headwaters of Depot Creek. Here the Skagit volcanic rocks were emplaced 35 to 24 Ma and consist of mainly dacitic breccias, welded tuffs and flows with sandstone and conglomerate interbeds. The drainage pattern of Depot Creek likely originated from radial drainage off of old volcanoes associated with these deposits (Riedel 2007). A third geologic unit of volcanic origin is the mudflow breccias of Pioneer Ridge, Oligocene in age, which are located on the valley wall between Easy and Brush Creeks.

Late and post-orogenic deposits of sandstone and conglomerate are preserved in small pockets at the head of the Little Chilliwack valley, the mouth of Brush Creek and just south of Copper Lake. These deposits are only preserved on or west of the Straight Creek Fault.

2.3 Glacial History

The topography of the Chilliwack River Watershed reflects multiple glaciations during the past 2 Ma, which have carved deep U-shaped valleys, steep valley walls and jagged horns and arêtes. The geomorphologies of the North Cascades during this period have been shaped by both alpine and continental glaciations. Glaciation has altered the fluvial morphology of both local and regional drainage patterns (Riedel et al. 2007). The North Cascades were inundated by the south flowing Cordilleran Ice Sheet during the Fraser Glaciation from 35 to 11.5 Ka (Armstrong et al. 1965) (Fig. 4).

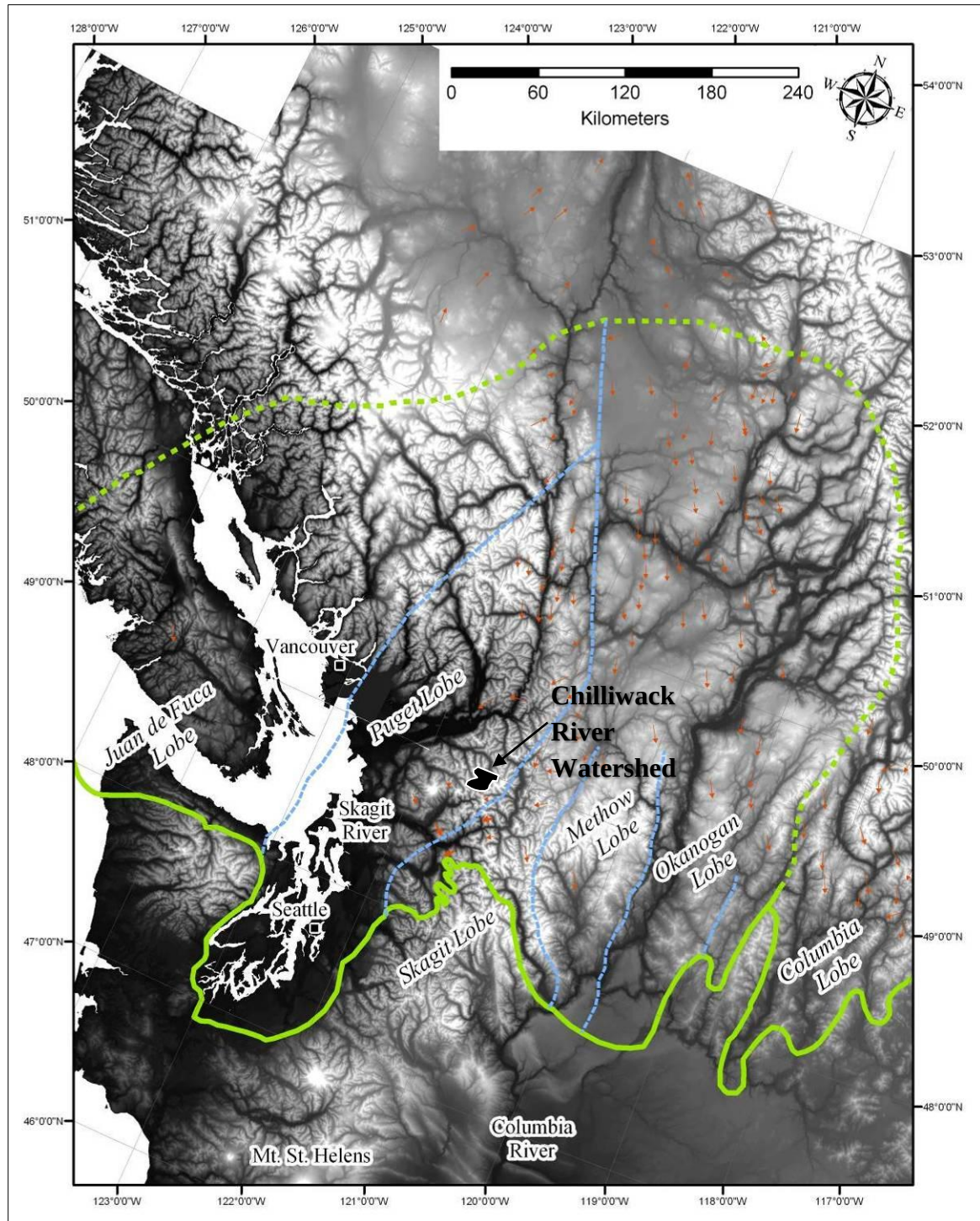


Figure 4. Map of the known extent of the Cordilleran Ice Sheet during the Fraser Glaciation. Note the various lobes of the ice sheet mapped, extending down into the United States.

Impacts from the ice sheet are evident throughout the Chilliwack River Watershed and include broadened passes and ridges, enlarged valley cross-sections, beheaded valleys, truncated valley spurs and thick accumulates of till and outwash. The ice sheet filled valleys to depths of ~ 2000

m, or more than a mile thick. In the Chilliwack River Watershed, only the horns of Mt. Spickard, Mount Redoubt and a few others stood high enough above the Cordilleran Ice Sheet as nunataks. Advance rates of the ice sheet are estimated at 130 m per year in Puget lowland, while ice funneled into the Chilliwack River valley probably reached speeds 5-6 times this rate (Evans 1990). Valleys like the Chilliwack, Skagit and Pasayten, which trend north/south, are particularly broad since they were parallel to ice sheet flow (Riedel 2007).

2.3.1 Neoglacial

Glaciers in the Chilliwack River Watershed probably reached their minimum extent in the past 10,000 years about 8 Ka. In the next several thousand years, small alpine glaciers advanced and retreated several times during the Neoglacial Period (Porter and Denton 1967), as evidenced by Neoglacial moraines mapped within the watershed and the North Cascades regionally. The most extensive of these advances for most glaciers occurred in the Little Ice Age between 1350 and 1900 AD.

Glacial advance during the Little Ice Age created hundreds of small moraines and left vast fields of unconsolidated glacial till. Small cirque glaciers and permanent snow fields of today are 45-50% less extensive than at the end of the Little Ice Age, 100 years ago. Presently, cirque alpine glaciers remain at high elevations and most have a north or east aspect and are sheltered from the sun by steep cirque walls and arêtes. The valley glaciers of the Pleistocene and alpine glaciers of the Little Ice Age left behind large amounts of glacial drift, including till and outwash, which has been reworked by subsequent surficial processes, or abandoned as terraces. This sediment fills the lower parts of the Chilliwack River valley to depths of several hundred meters.

There are three hundred and twelve glaciers present within NOCA today. NPS staff members at NOCA are currently monitoring four glaciers including; Noisy and North Klawatti glaciers are on the west side of NOCA, Sandalee Glacier on the east side and Silver Glacier near the Canadian Border. Since no glaciers within the Chilliwack River Watershed are currently being monitored, Silver Glacier will be used as a proxy since it is on the north ridge of Mt. Spickard. A summary of the results from the Silver Glacier in the Upper Skagit Watershed follows in the Hydrology section of this report.

2.4 Climate

The Chilliwack River Watershed lies on the western slopes of the North Cascade range. It is characterized by a maritime climate with relatively mild, wet winters and cool, dry summers. Climate is the primary driver of surficial processes that have shaped the watershed, including glaciers, rivers and mass wasting.

There are several Natural Resources Conservation Service (NRCS) snow and weather monitoring sites in and near the watershed, including a snowpack telemetry (SNOTEL) site in British Columbia near the Canadian Border (Fig. 5). Snow course stations are located nearby at Jasper Pass and on Brown Top Ridge. Snowpack data available from these sites is compiled in Table 1 below. Snow course data reveals that the snow pack generally reaches its maximum depth at these high elevation sites in April to May.

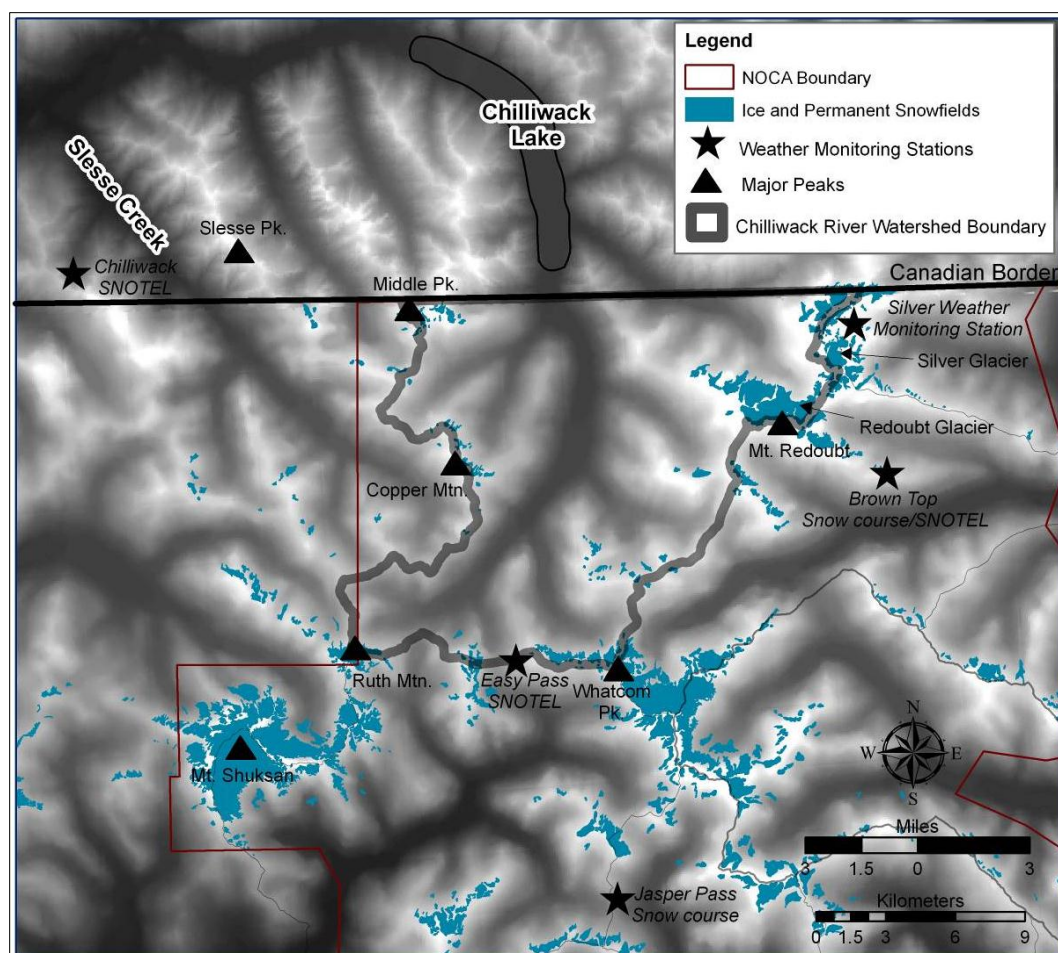


Figure 5. Digital elevation model showing permanent snowfields and glaciers in and around the Chilliwack River Watershed along with weathering monitoring sites mentioned in the text.

Table 1. Summary of snowpack data from one SNOTEL site and three snow course sites closest to the Chilliwack River Watershed (NRCS 2009a). All measurements were taken as of May 1st unless stated otherwise. Data is provisional and subject to revision.

	Chilliwack*	Jasper Pass*	Brown Top Ridge
Elevation (m)	1621	1646	1646
Period of Record	1991-In Service	1959-Present	1970-In Service
Record Snow Year	1999	1972	1972
Max. Depth (cm)	464	714	577
Max. SWE (cm)	241	340	265
Lowest Snow Year	1998	1977	2005
Min. Depth (cm)	219	290	160
Min SWE (cm)	122	124	66
Max. Depth recorded (date/cm)	April & May 1 st , 1999/464	April 1 st , 1976/744	March 1 st , 1999/638
Max. SWE recorded (date/cm)	April & May 1 st , 1999/241	May 15 th , 1974/394	April 1 st , 1999/268

* The Chilliwack site is lacking snow depth data on May 1st for all but 1998-2000. The Jasper Pass site is missing data in 1997 to 2007 for the months of April and May.

In the fall of 2008 the NRCS, in cooperation with the NPS, installed a SNOTEL on Easy Ridge. The site stopped collecting data due to equipment malfunctions and was repaired in the fall of 2009. Another SNOTEL station was installed at Brown Top Ridge in 2009 with another smaller weather monitoring station at Silver Glacier. Additional data from these sites will be useful in understanding climate variations, collecting crucial data such as temperature and precipitation, which is currently lacking in the Chilliwack River Watershed record. In the North Cascades yearly temperature average highs tend to occur in July and August with winter average low temperatures occur in January. November is routinely the wettest month; the rainy season typically lasts from November through January.

2.5 Hydrologic Setting

Hydrologic processes have significant effects on landform development, specifically in the formation of river canyons, floodplains, valley bottoms, terraces, debris cones, alluvial fans and deltas. Erosional processes related to seasonal fluxes in rainwater and snowmelt also directly influence development of mass movements. Specific examples of the effects of hydrology on landform development are addressed in the Discussion section of this report.

Rivers and creeks can typically reach flood stages during both the spring and late fall. Large rains on snow events typically occur between late October and December, have high flood peaks, but short durations. Spring snowmelt floods occur in May-June with large events occurring when higher than average snow-pack persists late in the melt season. Spring floods have durations that span weeks, with strong diurnal fluctuation and lower peak discharge volumes than fall floods. There is a gage located just above the outlet of Slesse Creek (Fig. 5) that records peak annual flow of the Chilliwack River (Fig. 6). This data reveals that the Chilliwack River is dominated by large magnitude fall rain-on-snow events.

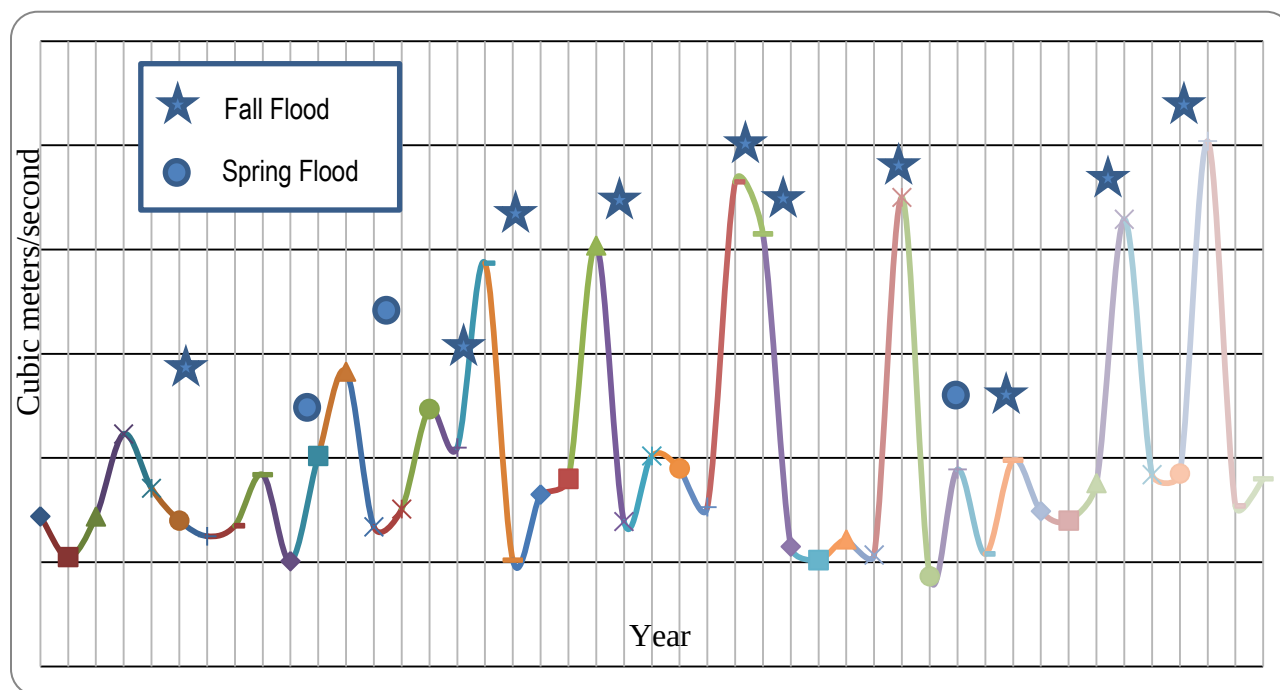


Figure 6. Peak annual flow for the Chilliwack River, from 1964 to 2008, from the gauging station just above the outlet of Slesse Creek.

During large magnitude events, water levels rise in the main stem of the Chilliwack River shifting channel and gravel bar positions and reintroducing water to old side channels, especially in the lower Chilliwack valley. Large woody debris introduced by large flood events adds an element of unpredictability to the geomorphology of the floodplain. This wood comes from mass movements, snow avalanches and bank erosion. Massive logjams are observed throughout the watershed, especially in the main channel following the 2003 flood. A study published in 2000 related the change in channel morphology of the Chilliwack River from 1952 to 1991 to bed-material transport, stating that significant morphological changes occur approximately once every five years in the Chilliwack River Watershed (Ham and Church 2000).

Glaciers have an important impact on the hydrologic regime of the Chilliwack River Watershed and help produce a continual flow of water throughout the year. This contribution from glacial ice and snowfields is critical for sustaining endangered salmon and trout species downstream. Steelhead (*Onchorhynchus mykiss*) spawn within the boundaries of NOCA in the Chilliwack River, while pink (*O. gorbuscha*), sockeye (*O. nerka*), chum (*O. keta*), coho (*O. kisutch*) and chinook (*O. tshawytscha*) salmon spawn within the river on the Canadian side of the border (FISS 2009).

Permanent snowfields and glaciers are located on the north and north-eastern slopes of peaks in the watershed (Fig. 5). Glacial inventories based on 1950 – 1960 air photos reported 9.4 km² of ice within the Chilliwack River Watershed (Post et al. 1971). Research done in 1998 placed that number at 6.7 km², an approximately 30% loss of ice (Granshaw 2001). The most notable glacier in the watershed is Redoubt Glacier, which has lost approximately 20% of its mass (Granshaw 2001). Since 1910 the Redoubt Glacier has retreated approximately 1.3 km up the Depot Creek valley (Riedel 1987).

The glacier monitoring program at NOCA provides significant insight into the contribution glaciers are making to the overall watershed total run-off. NOCA has been monitoring Silver Glacier on the north face of Mt. Spickard. Silver Glacier is one of four glaciers monitored by the NPS (Riedel et al. 2008) and the mass balance data from Silver are presented below (Fig. 7). The Silver Glacier is the highest in elevation of the four glaciers monitored at NOCA (2090 – 2710 m), so it tends to have net positive balances in years when the other glaciers do not. However the recent trend is clear that Silver has been losing mass, since 1900. While Silver Glacier does not drain into the Chilliwack River Watershed, it gives a proxy to the conditions of other glaciers within it, such as Redoubt Glacier. Historical photographs of the Redoubt Glacier reveal a substantial amount of ice loss over the last quarter century and resulted in the creation of Ouzel Lake. More detail regarding the status of glaciers, photographs of those monitored and the methods of glacier monitoring within NOCA can be found in several locations (Riedel et al. 2008, NOCA 2009, Riedel et al. *in review*).

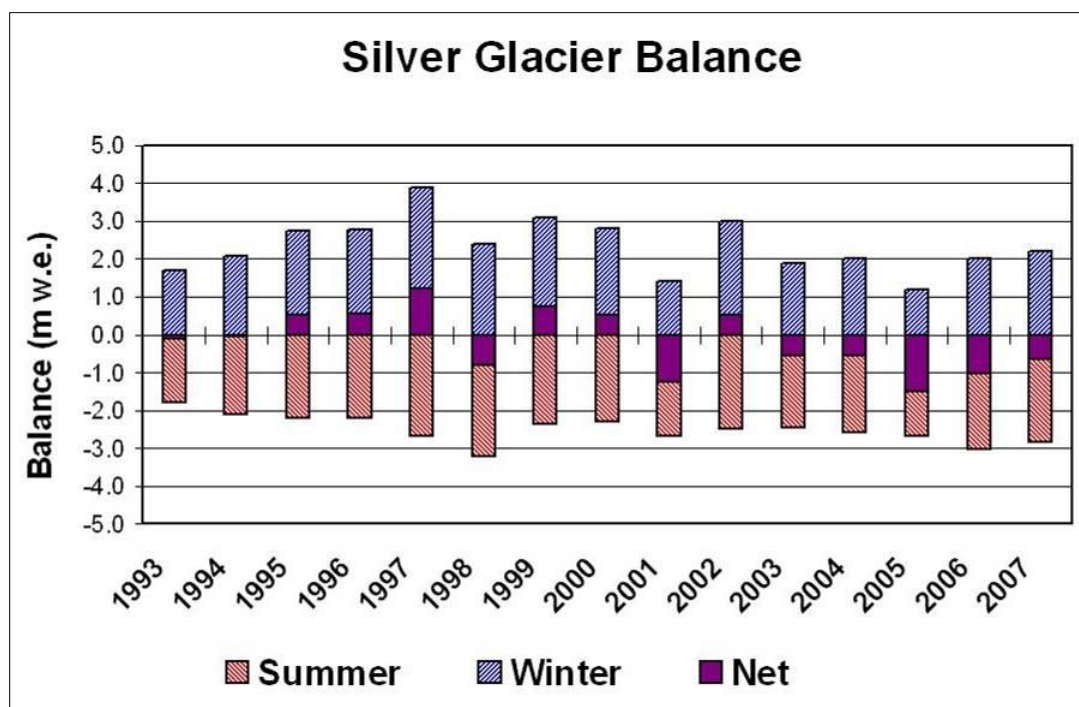


Figure 7. Mass balance chart of Silver Glacier, located on Mount Spickard. The vertical axis is the amount of water gained (winter balance), lost (summer balance) and retained (net balance – solid bar) in meters of water equivalent (m w.e.) averaged across the glacier.

2.6 Vegetation

Snow, bare rock and ice cover approximately 11.4 km² of the Chilliwack River Watershed. The remainder of the watershed is dominated by conifer species of trees although deciduous species dominate along major river corridors and in avalanche chutes. It has been noted that overall dominance of conifers over hardwoods in the coastal rainforests of Washington is likely due to climatic factors. Conifers dominate over hardwoods due to the regional high precipitation that occurs in the winter and relatively dry summers (Franklin and Dyrness 1973). Tree line, the upper limit of closed forest, occurs at 1400 m. Above forest line, with increasing elevation, scattered trees and subalpine vegetation form subalpine parkland which transitions into subalpine meadow and the upper limit of vegetation is the sparsely vegetated alpine zone. The alpine vegetation dominates at elevations above approximately 2000 m. Alpine vegetation is comprised primarily of lichens, mosses and sedges. Heavy snow creates a wide subalpine zone between 1750 m and 2000 m and this wide zone includes islands of subalpine fir (*Abies lasiocarpa*), mountain hemlock (*Tsuga mertensiana*) and open meadow communities dominated by heath shrub (*Phyllodoce* spp., *Vaccinium* spp. and *Cassiope* spp.) or moist meadow communities. Engelmann spruce (*Picea engelmannii*) is present in the watershed and has been documented to hybridize with Sitka spruce (*Picea sitchensis*) within the drainage (B.C Ministry of Environment 1999). Wildflowers such as Indian paintbrush, mountain bistort, mountain harebell, tiger lily and red columbine occur in subalpine meadows.

Below the subalpine zone is the montane forest from 750 to 1400 m. Pacific silver fir (*Abies amabilis*) and western hemlock (*Tsuga heterophylla*) dominate this zone. Douglas-fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja*

plicata)) are found on the lowland forest below about 750 m. Due to the ideal growing conditions in this ecological environment, trees in the watershed can reach remarkable size and age. Avalanche chutes are typically dominated by a dense cover of red alder (*Alnus rubra*) and vine-maple (*Acer circinatum*). Red alder and black cottonwood (*Populus balsamifera* spp. *trichocarpa*) forests dominate the riparian zone along the Chilliwack River. In areas of oxbows, isolated river channels and slow water along the river wetlands develop. These wetlands are dominated by obligate wetlands species such as sedges and rushes, which become extensive below the Little Chilliwack mouth. This location marks the old extent of Chilliwack Lake.

3 - Landform Mapping at NOCA

3.1 National Hierarchical Framework for Ecological Units

NOCA landform mapping is linked with the USFS multi-scaled “National Hierarchical Framework for Ecological Units” (Cleland et al. 1997) for public lands in western Washington (Table 2). Together the USFS and NPS have mapped at the Subsection (1:250,000), LTA (1:62,500) and Landform (1:24,000) scales. Ecological land units describe the physical and biological processes that occur across the landscape and are used for ecosystem classification and mapping purposes (Davis 2004).

Table 2. Map scale and polygon size in the National Hierarchical Framework for Ecological Units (Cleland et al. 1997).

Ecological unit	Map scale range	General polygon size
Domain	1:30,000,000 or smaller	1,000,000s of square km
Division	1:30,000,000 to 1:7,500,000	100,000 of square km
Province	1:15,000,000 to 1:5,000,000	10,000s of square km
Section	1:7,500,000 to 1:3,500,000	1,000s of square km
Subsection	1:3,500,000 to 1:250,000	10s to low 1,000s of square km
Landtype association	1:250,000 to 1:60,000	1,000s to 10,000s of ha
Landtype	1:60,000 to 1:24,000	100s to 1,000s of ha
Landtype phase (Landform)	1:24,000 or larger	<100 ha

3.1.1 Subsection (1:250,000)

The first product was a seamless coverage in the North Cascade region at the Subsection scale where the focus is on climate, bedrock geology and topography at a regional scale. The LTA scale is mapped by watershed and units are based on topography and process. Landscape mapping units are defined on the basis of climate, bedrock geology and topography at a regional scale. Features of the landscape such as regional hydrologic divides, contacts between major bedrock terranes and glaciated topography are boundaries of Subsection mapping units. In the North Cascades, the draft Subsection map (Fig. 8) identifies 17 mapping units; including: Major Valley Bottoms, Crystalline Glaciated Cascade Mountains, Volcanic Cones and Flows, Sedimentary Cascade Hills, etc. These units were developed by Wenatchee National Forest (Davis 2004) and applied to the west slope of the Cascades by staff from Wenatchee National Forest and NOCA (Riedel and Probala 2005). The Chilliwack River Watershed is part of the Crystalline Cascade Mountains subsection.

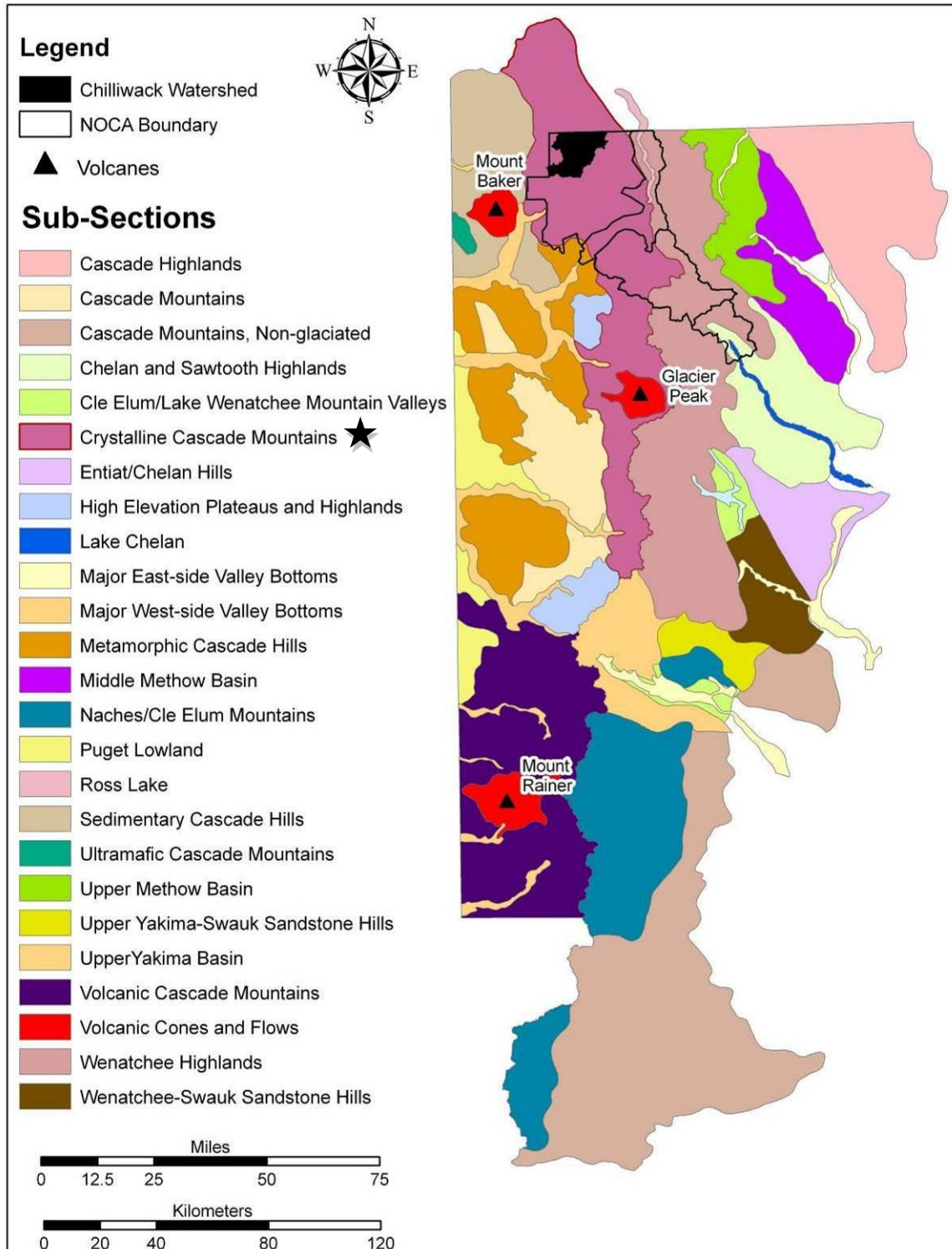


Figure 8. Subsection map (1:250,000) of the North Cascade region showing the location of the Chilliwack River Watershed within the Crystalline Cascade Mountains Sub-Section and North Cascades National Park Service Complex (Davis 2004).

3.1.2 Landtype Association (1:62,500)

Landscape scale ecological units or Landtype Associations (LTAs) are the smallest scale within the hierarchical framework that meets most NPS challenges and management needs. At this mapping scale, geomorphic process and topography become more important than climate and bedrock geology. The first step in mapping LTAs is to identify large scale erosional features of mountains and valleys such as valley bottom, cirque basin, glaciated valley and river-cut valley (Davis 2004). Final map units incorporate data on vegetation and bedrock type. For example, in the North Cascades, a valley would be broken into three units that coincide with major elevation-controlled changes in vegetation and topographic breaks. Mapping is conducted by interpretation of 1:62,500 scale stereo aerial photography and topographic maps. While the main Chilliwack Watershed has been mapped at this scale, as of the timing of this publication Depot Creek has not been mapped (Fig. 9).

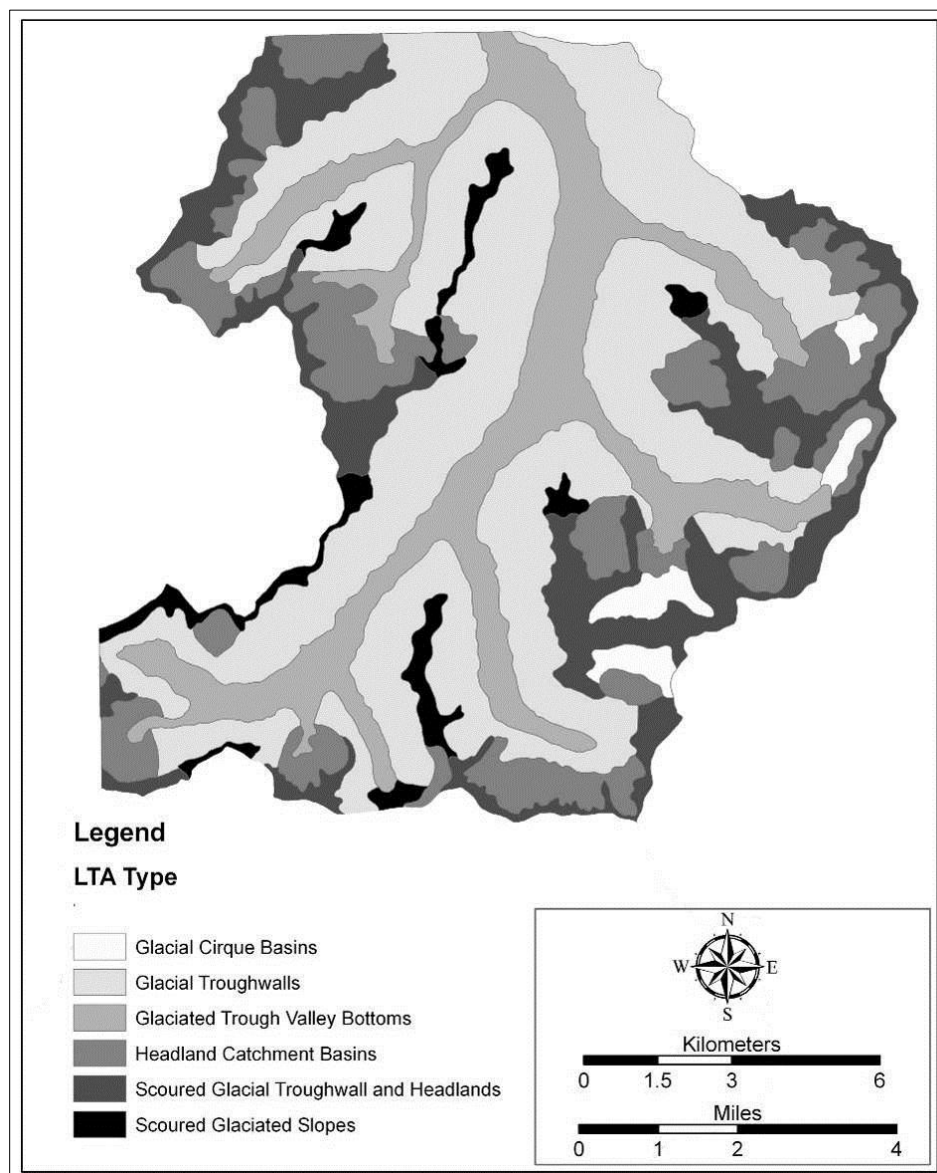


Figure 9. LTA map (1:100,000) of the Chilliwack River Watershed (Davis 2004).

3.1.3 Landtype Phase (Landform) (1:24,000)

These are the smallest functional units of the landscape that are created by discrete geologic processes, many of which are active in the watershed today. These subdivisions of Landtypes, or landforms, are based on topographic criteria, hydrologic characteristics, associations of soil taxa and plant communities. They are readily identified on topographic maps and aerial photographs, but require field-verification when beneath closed canopy forests. A suite of 29 different landforms is currently being mapped at NOCA (Table 3). A detailed description of each landform, which includes information on location, associated landforms, process, material, mapping guidelines and potential natural vegetation will be published in separate NPS Technical Report.

Table 3. Landform (1:24,000) legend for North Cascades National Park.

Unit	Description
-High elevation landforms (primarily erosional in genesis)	
H	Horn
A	Arete
C	Cirque
O	Other Mountain
R	Ridge
P	Pass
NM	Neoglacial Moraine
PG	Patterned Ground
- Valley slope landforms (primarily erosional in genesis)	
VW	Valley Wall
RC	River Canyon
BB	Bedrock Bench
-Transitional landforms between valley slope (erosion) and valley floor (deposition)	
MM-F	Rock Fall and Topple
MM-A	Debris Avalanche
MM-S	Slump and Creep
MM-DT	Debris Torrent
MM-SG	Sackung
MM-SL	Snow Avalanche Impact Landform
DA	Debris Apron
DC	Debris Cone
AF	Alluvial Fan
-Valley bottom landforms (primarily depositional in genesis)	
FP	Floodplain
VB	Valley Bottom
T	Terrace
FT	Fan Terrace
SH	Shoreline
D	Delta
-Other landforms	
PM	Pleistocene Moraine
E	Esker
U	Undifferentiated

3.2 Landform Age

Landforms can either be depositional in nature, such as moraines and alluvial fans, or they can be erosional such as bedrock benches and horns. Many depositional features such as moraines and terraces were formed during the last ice age. Other depositional features such as debris cones

and landslides are forming today. Landform age can vary greatly within a watershed depending on the surficial process that created it. Approximate ages can be assigned to depositional landforms based on their available radiocarbon dates, associated process of formation, volcanic tephra, soil development and vegetation type and age. The approximate ages of landforms at NOCA reflect their stability and are listed below in Table 4. Data were obtained from several different radiocarbon dates on a variety of landforms within NOCA by the park geology and archeology programs (Mierendorf et al. 1998, Mierendorf 1999, Riedel 2007, Riedel et al. 2007).

Table 4. Approximate landform surface ages at North Cascades National Park.

Landform	Age
Debris cone, floodplain, alluvial fan	<500 years
Most neo-glacial moraines	<300 years
Valley walls	100-12,000 years
High outwash terraces and fan terraces	10,000-12,000 years
Pleistocene moraines	12,000 and 18,000 years
Bedrock benches, horns, arêtes	12,000 years
Mass movements (landslides)	0-14,000 years

3.2.1 Landforms and Soils

The North Cascades provide a challenging environment to compile a traditional soil survey. Studies in the North Cascades and the surrounding vicinity link pedogenic processes to soil-landscape relationships and provide insight to the links between landforms and soils (Rodgers 2000, Briggs 2004, Briggs et al. 2006). Soil distribution is closely linked to the geomorphic processes at play over the last 15,000 years. NRCS soil scientists incorporate landform maps into the RASP modeling scheme as an indicator of soil stability and parent material (Rodgers 2000, Briggs 2004, Frazier et al. 2009).

As a result of the Cordilleran Ice Sheet scouring much of the North Cascades, bedrock as a parent material seldom influences soil formation. Upon retreat of the ice sheet, glacial drift was deposited unevenly across the landscape. This glacial drift, along with subsequent tephra deposits, provides the primary parent materials for soil formation. The most significant tephra layer in the North Cascades is that of Mount Mazama, deposited ~7.6 Ka calendar years before present (cal. years B.P.) (Zdanowicz et al. 1999). In large part it is the preservation, mixing and removal of this tephra that provides one indication of landform stability, age and soil type. It is theorized, for example, that the majority of slope readjustment occurred between 13 to 9 Ka cal years B.P. as evidenced by the significant amount of tephra preserved on the valley walls (Briggs et al. 2006).

Soil classification within NOCA is largely determined by the presence or absence of tephra. The dominant soil orders found within NOCA include Andisols, Inceptisols, Entisols, Spodosols and to a far lesser extent Histosols (Soil Survey Staff 1999). Andisols have a thick (>36 cm) mantle of material strongly influenced by volcanic tephra. Inceptisols have either a thin mantle (<36cm) of volcanic tephra influenced material or highly mixed volcanic tephra and glacial drift throughout the soil profile. Entisols within NOCA are distinguishable by the absence of volcanic tephra within the soil profile. Spodosols on the other hand are more a product of pedogenic processes rather than parent material. Spodosols require a certain amount of landscape stability for pedogenic process to operate over time. As such, Spodosols are typically associated with

older, more stable landforms that readily preserve tephra and provide long lived plant communities. Histosols are typically found in areas with persistent water tables that preserve organic matter within the soil profile.

Each landform inherently suggests a certain degree of stability and parent material type. The older and/or more stable landforms such as Pleistocene moraines and bedrock benches typically support the formation of Andisols and Spodosols. Stable landscapes preserve volcanic tephra in distinct mantles and allow pedogenic processes to operate over extended periods of time. The degree of pedogenic development is also determined by other soil-forming factors such as vegetation and climate. Differentiating between Andisols and Spodosols ultimately comes down to the morphological expression (presence or absence of albic and/or spodic horizons) observed within the soil profile (Soil Survey Staff 1999). Other landforms that typically support Andisol formation (valley walls, debris aprons) may lack long term stability. However, through gravitational redistribution, tephra may accumulate and ultimately result in the formation of Andisols. Landforms formed primarily through alluvial erosion tend to lack soil material strongly influenced by volcanic tephra. On landforms such as debris cones, terraces, and alluvial fans, Inceptisols dominate. Entisols are found on the youngest landforms most susceptible to recent flooding (floodplains and terraces) or recent deglaciation (cirques and little ice age moraines) that the soil profile lacks the influence of volcanic tephra. Histosols are the most independent of landform as they simply require an accumulation of organic matter (Soil Survey Staff 1999). This accumulation of organic matter can be found in micro-depressions and floodplains throughout the park where water tables are persistent and organic decomposition is slower than accumulation.

4 - Methods

4.1 Preliminary Methods

At the beginning of the mapping process each National Park was divided into watersheds that are mapped separately. This project recognizes a watershed as a major drainage system on a fourth order or larger stream. Each watershed is further broken down into smaller units referred to in the text as sub-watersheds. These landform maps represent a compilation of several quadrangles over a number of years of field work. A combination of mapping techniques used to conduct this inventory include the use of color stereo-pair 1998 air photos at the 1:12,000 scale, USFS LTA line work, bedrock geology maps and field investigations. Initially, the pattern of contour lines on United States Geological Survey (USGS) 7.5 minute topographic maps in conjunction with the 1:12,000 air photos are used to outline landforms. Though some landforms (e.g., debris avalanches, bedrock benches and debris cones) are easily identifiable using air photos and contour lines, other landforms (e.g., terraces, floodplain boundaries and small mass movements) require field identification. The minimum size for a mapping unit is approximately 1,000 m² with some exceptions for smaller units like Neoglacial moraines and slumps.

4.1.1 Field Methods

Each field trip typically focuses on a sub-watershed unit within a watershed. Before entering the field, a task list of areas to visit is developed. As much ground as possible is surveyed, but concentrate efforts within the valley bottom. Generally, walking the banks of rivers enables mapping of terraces, slumps and floodplain boundaries. Places where the valley bottom is wide or complex, cross sections are made from one side of the valley to the other. Some landforms need further exploration and are investigated in more detail as needed. While in the field, geologists transfer landform boundaries onto USGS 7.5 minute maps or update boundaries previously mapped in the office. Fieldwork also generates additional information about terrace heights and material type; this information is recorded in field notebooks along with sketches of valley cross-sections. A draft version of the landform description report is used to aid in the identification of landform units while in the field.

4.1.2 Digitizing Methods

After identifying landforms and drawing the boundaries, each area is peer-reviewed for accuracy and mapping consistency. Landform linework is then transferred onto a new 7.5 minute paper map, which serves as the final map. All boundaries of landforms are then drawn onto Universal Transverse Mercator registered Mylar and a large format scanner transfers lines into digital format. Using GIS software, scans are edited and polygons, which represent landforms, are labeled resulting in a final digitized map (Fig. 2). As each polygon is labeled, the shape and location is checked for accuracy. Using the most up to date National Agriculture Imagery Program (NAIP) imagery from the United States Department of Agriculture (USDA), small scale changes can be made in landform placement. Also, 10 meter digital elevation models (DEMs) are overlaid with the landform layer, enabling more fine-tuned editing of placement. If additional editing is needed, on screen digitizing is completed. Landform surveys are occasionally updated as new landforms are identified and new areas are surveyed. The GIS is then updated to accommodate these changes.

4.2 Areas Surveyed

There are no roads in Chilliwack River Watershed; access is mainly via a 10 km long established trail over Hannegan Pass, which follows the river north to Chilliwack Lake. Spur trails include the Copper Ridge trail, the Brush Creek trail over Whatcom Pass, a major climber's trail up Easy Ridge from the east side of Easy Creek and a climber's trail up the Depot Creek drainage. There are also unmaintained hunting, climbing and animal trails that were followed throughout the watershed when available.

All field investigations in the watershed were completed in the summer seasons of 1986-1987, 1999, 2000, 2006 and 2008 by Jon Riedel, Rob Burrows, Jeanna Wegner, Stephen Dorsch and Nicole Bowerman. These areas were accessed by trail, by traveling in the riverbed via wading and bush-whacking. Field visits to each major tributary were attempted from the main stem of the Chilliwack River. However, due to difficult travel (e.g. canyons, thick vegetation, cliffs and minimal trail availability) some areas were not field checked. The main stem of the Chilliwack River was field checked from Hannegan Pass to the Canadian border. Tributaries that were field checked include Depot, Brush and Copper Creeks. Indian, Bear and Easy Creeks, as well as the Little Chilliwack River, were mapped via aerial photographs. Future surveys of valley heads may be conducted if opportunities arise. Minimal high elevation ground surveys were performed due to abundant air photo coverage and good visibility due to lack of vegetation on high elevation landforms. High elevation surveys completed include Copper and Easy Ridges. Aerial surveys were made via several helicopter flights while in transit to other NPS research projects.

5 - Results and Discussion

5.1 General Watershed Overview

Major features of the Chilliwack River Watershed are deep-seated glacial canyons, long ridges, towering arêtes and horns, extreme local relief, tributary headwalls, striking asymmetry in geomorphology by aspect and the dominance of valley walls. The Chilliwack River begins its journey at the summits of Hannegan Peak and Ruth Mountain, which confine the southwestern corner of the watershed. Copper Ridge confines the watershed to the west; the south and eastern divides from Mineral Peak to Mt. Spickard are part of the North Cascade Crest (Fig. 2). This divide is the regional drainage divide between the southeast flowing Baker/Skagit River system and the north-flowing Chilliwack River (Riedel 2007).

Between ice sheet glaciations, valley glaciers flowed dozens of times from cirques through the Chilliwack River valley forming a large, complex valley glacier system (Riedel 2007). The main stem of the Chilliwack River is a broad U-shaped glacial valley with a flat valley bottom, straight profile and low gradient, created by both the southward excursions of the Cordilleran Ice Sheet and the multiple glaciations by alpine glaciers flowing down major tributaries (Fig. 9). Tributary systems were left as hanging valleys with bedrock canyons or narrow, stepped waterfalls at their mouths. Where they join with the main stem of the Chilliwack River, these streams deposited alluvial fans. Other glacial characteristics of the valley include over-steepened valley walls and truncated valley spurs.

The presence of lacustrine deposits in terraces as far up the main stem of the Chilliwack River as Easy Creek, indicate ice-sheet damming of the valley at about 16,000 YBP (Clague 1981a and 1981b). As the Cordilleran Ice Sheet advanced the ice-dam in the lower Chilliwack valley thickened, reaching an elevation of nearly 2100 m at the Canadian Border. The lake eventually spilled over Chilliwack Pass to the Baker River, broadening this pass and beveling most of Easy Ridge (Riedel et al. 2007). Ultimately, this water reached the Pacific Ocean via the Skagit River, joining water spilling into the Skagit across several other passes to form a major Cordilleran Ice Sheet drainage network. Terrace sediments that fine longitudinally down valley indicate that Chilliwack Lake once extended as far up-valley as the mouth of the Little Chilliwack River (elevation 700 m). Present-day Chilliwack Lake is dammed by a Pleistocene moraine and outwash fan (Clague and Luternauer 1982) and contains almost all the sediment delivered from its catchment (Tuncliffe 2008). The erosion at the outlet and the in-filling with sediment from the Chilliwack River led to the reduction in lake elevation and size. It is estimated from lake cores that the mean rate of sediment deposition in the lake is 0.48 mm/year (Tuncliffe 2008). The former lake bed is now marked by a series of shallow ponds, wetlands and a meandering Chilliwack River.

The Chilliwack River is somewhat unique in NOCA since it is one of the few north-flowing systems. As the ice sheet retreated north, sediments could not easily escape the watershed, as they did in south-flowing watersheds. There are several large Pleistocene moraines along the Chilliwack River deposited by the ice sheet across the mouths of tributaries (Riedel 1987). These features are termed moraine embankments elsewhere in the western Cascades (Booth 1986). The ice sheet obliterated moraines previously left in the Chilliwack River valley and its tributaries by alpine glaciers. A re-advance by alpine glaciers at the end of the last ice age,

however, left moraines within 5-10 km of the heads of most valleys. Copper Lake is damned by one of these moraines, but others in the watershed have not been studied.

Throughout the watershed, steep cliffs are contrasted by gentler rises in some sub-watersheds, revealing the influence of aspect in the development of valley wall landforms. Valley walls in the upper reaches contain sparse vegetation with little to no soil cover. Within the watershed, 50% is valley wall and 23% is high elevation cirque; with only 2.8% as riparian (floodplain, valley bottom and alluvial fan) (Table 5).

Table 5. Summary of area of each landform type within the Chilliwack River watershed.

Landform Type	Number Observed	Area (km ²)	Percent of the Chilliwack River Watershed (%)
Valley Wall	54	108.435	49.753
Cirque	99	50.897	23.348
Debris Apron	123	20.072	9.210
Debris Cone	101	7.787	3.573
Mass Movement – Debris Avalanche	58	5.324	2.443
Floodplain	11	5.134	2.355
Ridge	46	4.495	2.017
Arete	49	2.866	1.315
River Canyon	48	2.430	1.115
Terrace	35	2.175	0.998
Horn	25	2.114	0.970
Mass Movement – Fall/Topple	66	1.835	0.842
Neoglacial Moraine	86	1.494	0.686
Pleistocene Moraine	9	0.805	0.370
Valley Bottom	11	0.817	0.375
Pass	33	0.440	0.202
Other Mountain	8	0.235	0.108
Alluvial Fan	5	0.230	0.106
Fan Terrace	3	0.143	0.066
Mass Movement – Debris Torrent	10	0.128	0.059
Undifferentiated	2	0.077	0.036
Bedrock Bench	3	0.072	0.033
Mass Movement – Slump/Creep	9	0.040	0.018
Delta	1	0.001	0.003
Esker	1	0.001	0.003
Totals	876	217.948	100.00

5.1.1 High Elevation Landforms

High elevation landforms (cirque, Neoglacial moraines, ridges, arêtes, other mountain, horns and passes) account for 62.5 km², which is 28.7% of the total area in the watershed (Table 5). The majority of this area is cirque basin. Particularly well-developed cirque basins are located on the north faces of Mt. Redoubt, Whatcom Peak, Bear Mountain, Red Mountain and the east faces of Copper and Indian Mountains. Aspect has particularly strong control on the development of cirque basins, with those north and east facing cirques deeper and broader than those on southerly aspects. Snow and ice in the watershed totals approximately 7 km², with the Redoubt Glacier accounting for 30% of that area. An additional 2.7 km² of the alpine is classified as bare rock. Most of the lakes in the watershed are high alpine lakes, totaling 82 ha in area.

The entire watershed was inundated by the Cordilleran Ice Sheet and passes and ridges below ~ 2000-2100 m were over-run and broadened. Particularly well-developed horns in the watershed were shaped by alpine glaciers in cirques and generally stood above the level of the sheet. These islands of rock, called nunataks, included Ruth Mountain, Whatcom Peak, Bear Mountain, Mt. Redoubt, Mox Peaks, Mt. Spickard, Nodoubt Peak and Middle Peak. Lower ridges and mountains were mostly rounded by the ice sheet and contain glacial striae and polished bedrock.

Recent glacial activity is recorded in Neoglacial moraines. These landforms were deposited by alpine glaciers in the last 700 to 100 years. There are eighty-six Neoglacial moraines in the Chilliwack River Watershed. The majority of them are present in the Depot Creek drainage, where the retreating Redoubt Glacier and glaciers on Mt. Spickard have provided a visible record of climate change in the past century. Depot Creek has also been extensively mapped by field and aerial visits to the Silver Glacier on Mt. Spickard.

Depot Creek is also the location of the only esker mapped within NOCA. An esker is composed of sediment deposited in the late stages of deglaciation, when melt water flows mainly through tunnels. This esker and associated kames were deposited in the late 1950s as the Redoubt Glacier receded. When Ouzel Lake emerged in the late 1950s and early 1960s, part of the glacier finally collapsed over the lake. This likely signals the timing of the deposition of this esker adjacent to Ouzel Lake (Riedel 1987).

5.2 Characteristics of Sub-Watersheds

5.2.1 Main Stem of Chilliwack River

The valley head of the Chilliwack River is ringed with cirques that extend down to 1550 m on Hannegan Peak (Fig. 10). Hannegan Peak contains one Neoglacial moraine at 1550 m, but is dominantly valley wall with several mass movement avalanches and rock falls/topples. The high number of mass movements in the upper Chilliwack drainage is likely a direct result of the weakened and altered rock present within the Hannegan Ring Fault (Fig. 3 and Fig. 10). A northeast-southwest trending fault through Chilliwack Pass to the upper Chilliwack Valley is likely a factor in the upper valley's alignment (Fig. 10). Another northeast-southwest fault just below Copper Ridge may have also influenced debris avalanches that reached Chilliwack River.

Chilliwack River intercepts the rushing waters of Hells Gorge and enters a river canyon for 1.5 km. The cirques on Ruth Mountain extend down to 1460 m and contain three Neoglacial moraines as low as 1040 m in elevation. Where the waters of Ruth Mountain combine with the Chilliwack, the floodplain begins at 915 m. The guidelines for determining this transition are based on flood plain width, presence or absence of river terraces and gravel bars, lining of bedrock and stream gradient (Jarrett 1990).

The width of floodplain in the Chilliwack valley varies within three distinct reaches: from Brush Creek to the northern Park boundary (~0.45 km), Brush Creek to Easy Creek which fluctuates in width (~0.03 – 0.2 km) and the upper section from Easy Creek to Copper Creek (0.07 km). Between Easy and Brush Creeks several debris avalanches and rock falls/topples have constricted the valley and floodplain. The largest of these debris avalanches may be influenced by northeast-southwest trending compressional faults (Figs. 10-11). Wood from trees buried by

a landslide was sampled for age determination. The results of two radiocarbon samples yielded ages of 147 YBP and <137 YBP (Hood 2000) (Fig. 10).

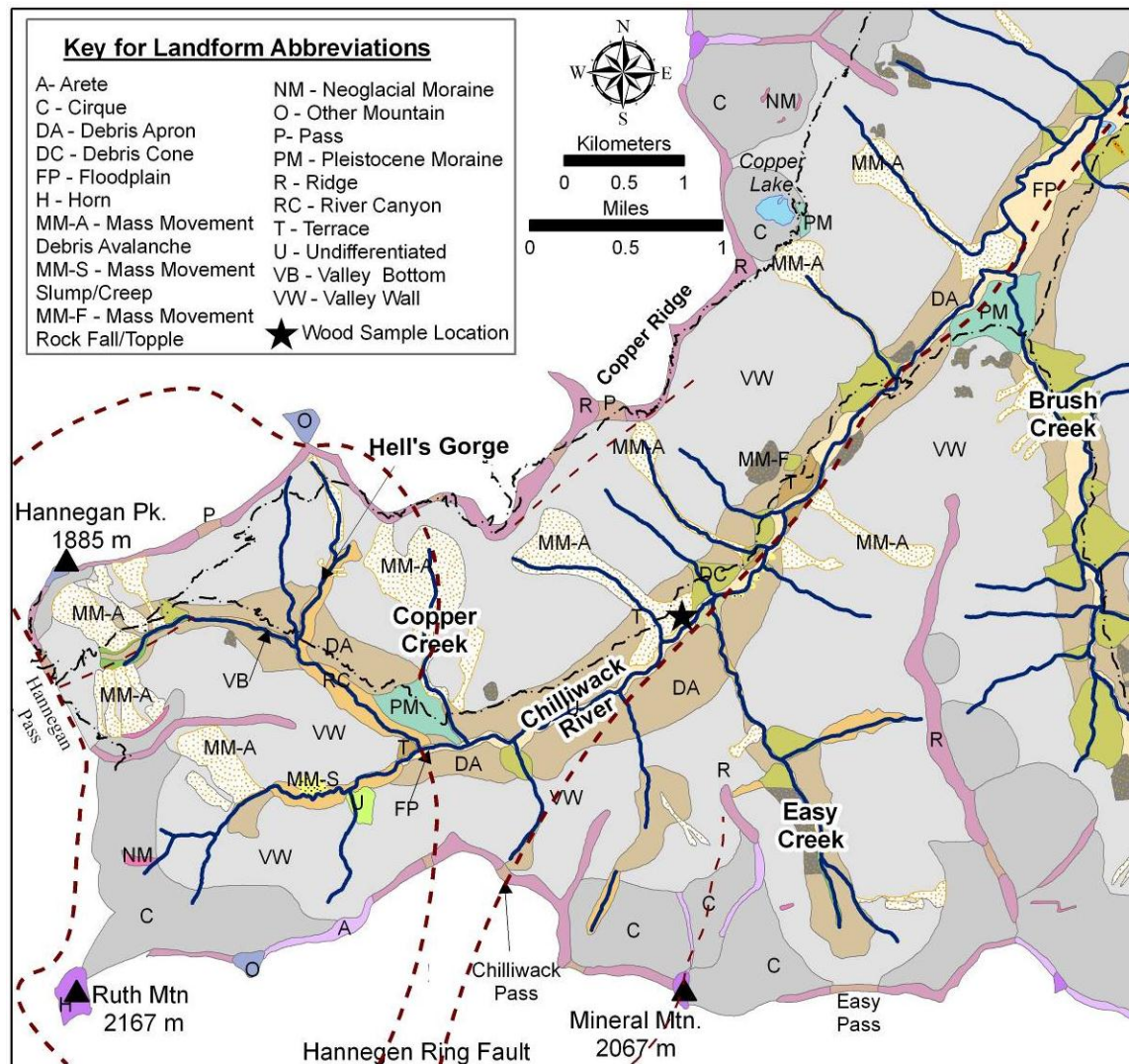


Figure 10. Landform map of the upper Chilliwack River, dot-dashed lines represent trails and red dashed lines are faults.

The floodplain contains extensive sand and gravel bars and side channels in the lower section below the mouth of Brush Creek. It also contains several terraces, varying in heights of <1.5, 1.5 and 3 m above the floodplain (Fig. 11). Terraces near the mouth of the Little Chilliwack contain deltaic deposits indicating that a lake once filled most of the lower valley. Lake sediment deposits have been observed as far up-valley as Easy Creek, where a base layer of clay-rich sediment is over-lain by sandy till. The mouths of Brush, Indian and the Little Chilliwack are all confined by moraines left by the Cordilleran Ice Sheet 15 Ka. These landforms are remnants of moraine-embankments the ice sheet built across the mouths of these valleys as it flowed up the Chilliwack. The Little Chilliwack, Bear Creek, Indian Creek and Easy Creek all enter the

Chilliwack via alluvial fans that pour sediment into the main channel. Alluvial fan terraces are also present at the mouths of Indian and Bear Creeks (Fig. 11).

Two alpine lakes are present above the main Chilliwack drainage (Figs. 10 and 11). Copper Lake, just north east of Copper Lookout and Hanging Lake which is on the Canadian Border. Copper Lake is a moderately sized high alpine lake (5.0 ha) while Hanging Lake is one of the larger alpine lakes in NOCA (36.0 ha). Both lakes have been stocked with fish and sampling of fish tissue from Copper Lake revealed an average of PCB concentrations exceeding the EPA's screening value for elevated cancer risk (NPS 2008).

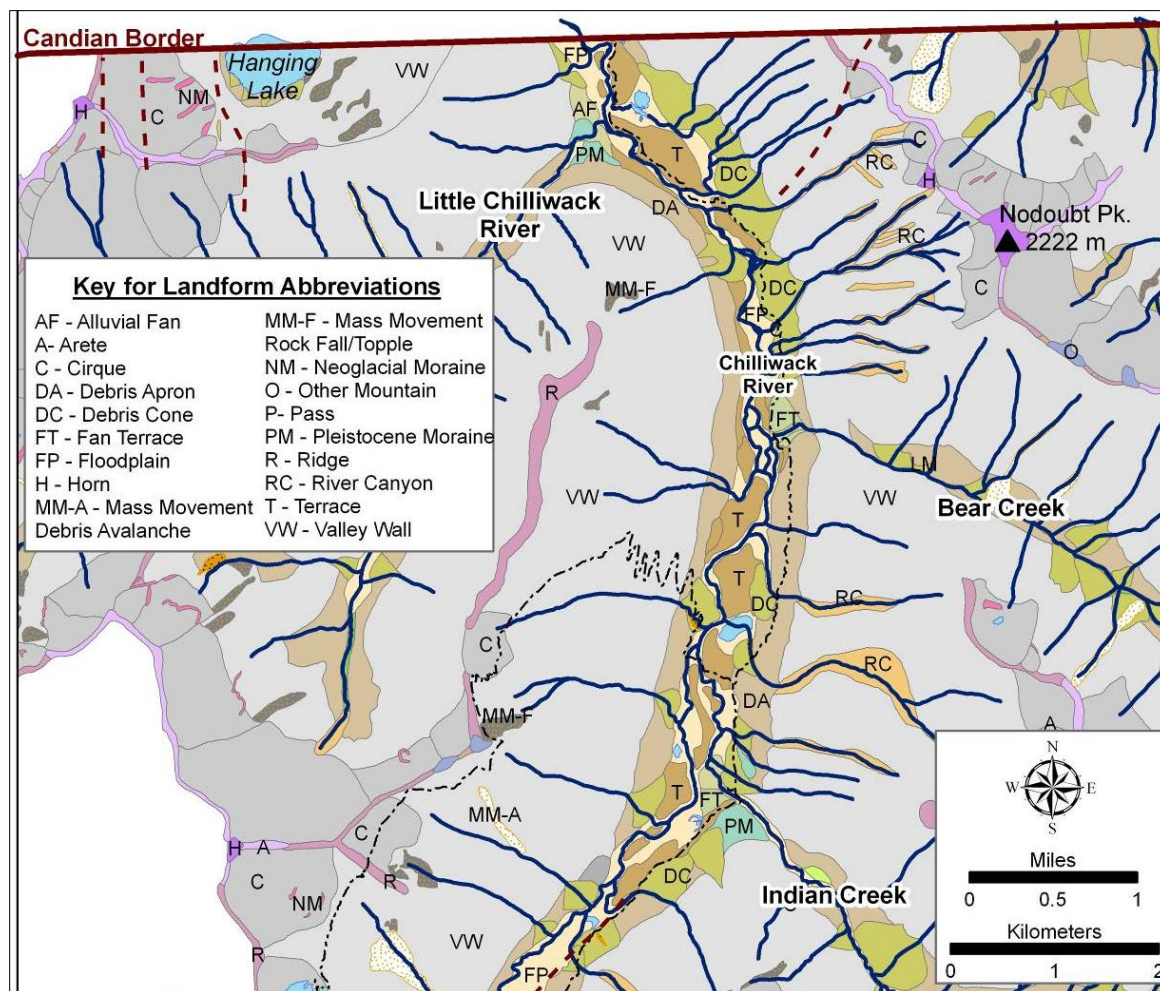


Figure 11. Landform map of the lower Chilliwack River, dot-dashed lines represent trails and red dashed lines are faults.

5.2.2 Copper Creek

Copper Creek is in a steep fault-controlled canyon that drains south to the Chilliwack River along the Hannegan caldera-collapse ring fault (Tucker 2006) (Fig. 12). This valley is mapped as a debris avalanche, originating from the top of Copper Ridge. Its formation is likely due to the instability of the bedrock, which is fractured and hydrothermally altered volcanic rock along the ring fault. This fault defines the headwaters of the valley, highly altered tuff of the Hannegan

Volcanics composing the western valley wall and biotite granite of the Index Family composing the eastern valley wall (Tabor et al. 2003). Just upstream from the floodplain of the Chilliwack River, a large (2,049 m²) Pleistocene moraine abuts the west side of Copper Creek. On the east side of the creek, across from the Pleistocene moraine is the location of the Copper Creek Camp along the Chilliwack trail. A small terrace is also present between the moraine and the creek channel. Copper Creek joins the main stem of the Chilliwack at an elevation of 896 m.

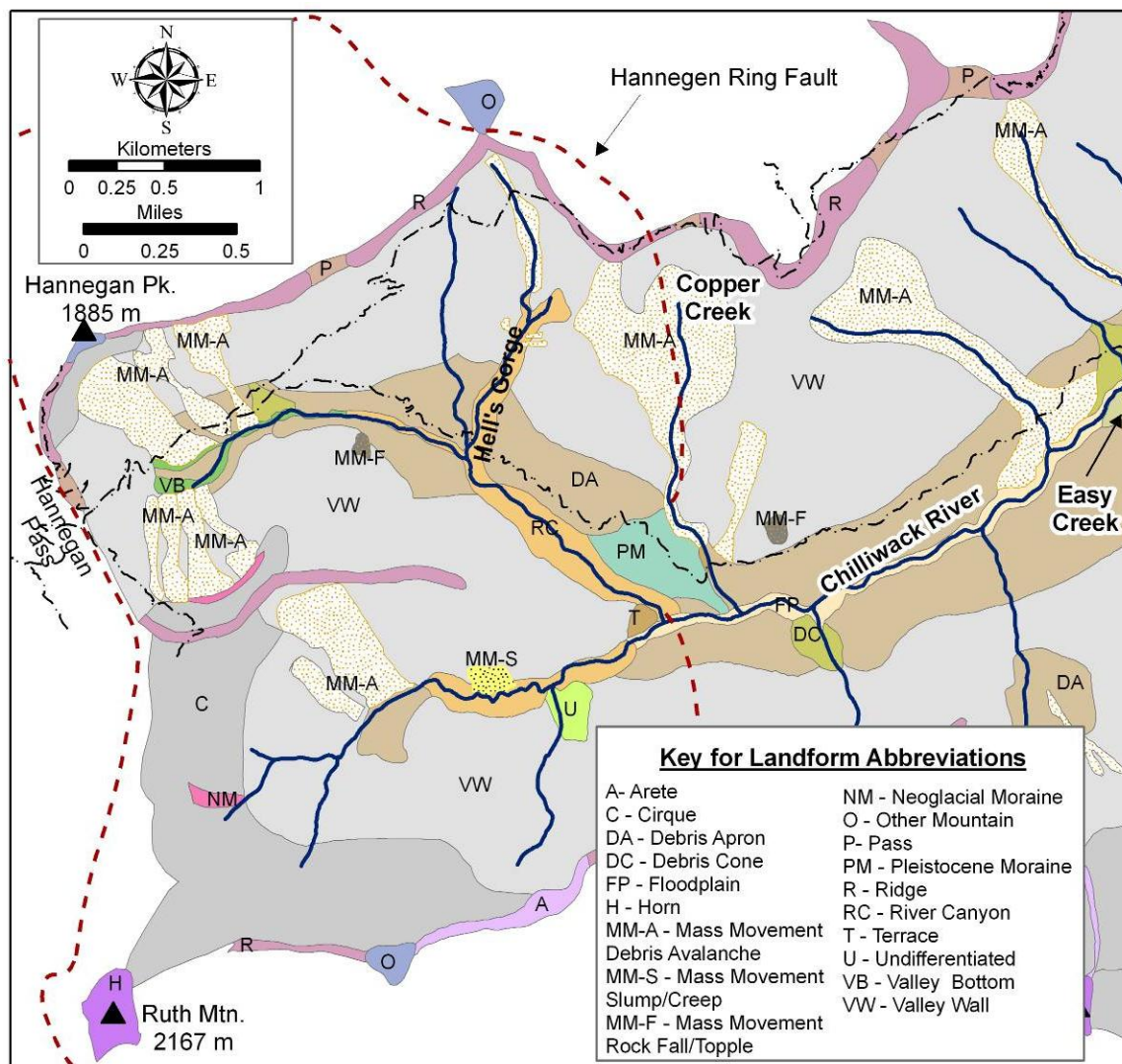


Figure 12. Landform map of Copper Creek, dot-dashed lines represent trails and red dashed lines are faults.

5.2.3 Easy Creek

Cirques on Mineral Mountain and western Easy Ridge form the headwaters of Easy Creek (Fig. 13). Cirque boundaries extend down to 1460 m. One Neoglacial moraine is present along the east facing slopes of Mineral Mountain at approximately 1400 m. Easy Pass and Easy Ridge was scoured, lowered and broadened by the Cordilleran Ice Sheet. Upper Easy Creek is mapped as valley bottom and transitions to floodplain at elevation 1020 m. The lower kilometer is

mapped as river canyon and the stream plunges deeply into the Chilliwack River at an elevation of 830 m. Easy Creek deposited an alluvial fan at the mouth of the drainage. A total of one rock fall and three debris avalanches are present in this drainage.

The side slopes of the valley consist of debris apron with a dramatic change to valley wall on the west side, while the transition is much more gradual on the eastern, southwest-facing side of the valley (Fig. 14). This illustrates the importance of aspect on the development of valley wall landforms. Freeze thaw processes are much more pronounced on the northeast-facing valley wall, resulting in steeper slopes and large accumulations of talus than the warmer, drier southwest facing valley wall. Bedrock is granitic on both sides of the valley.

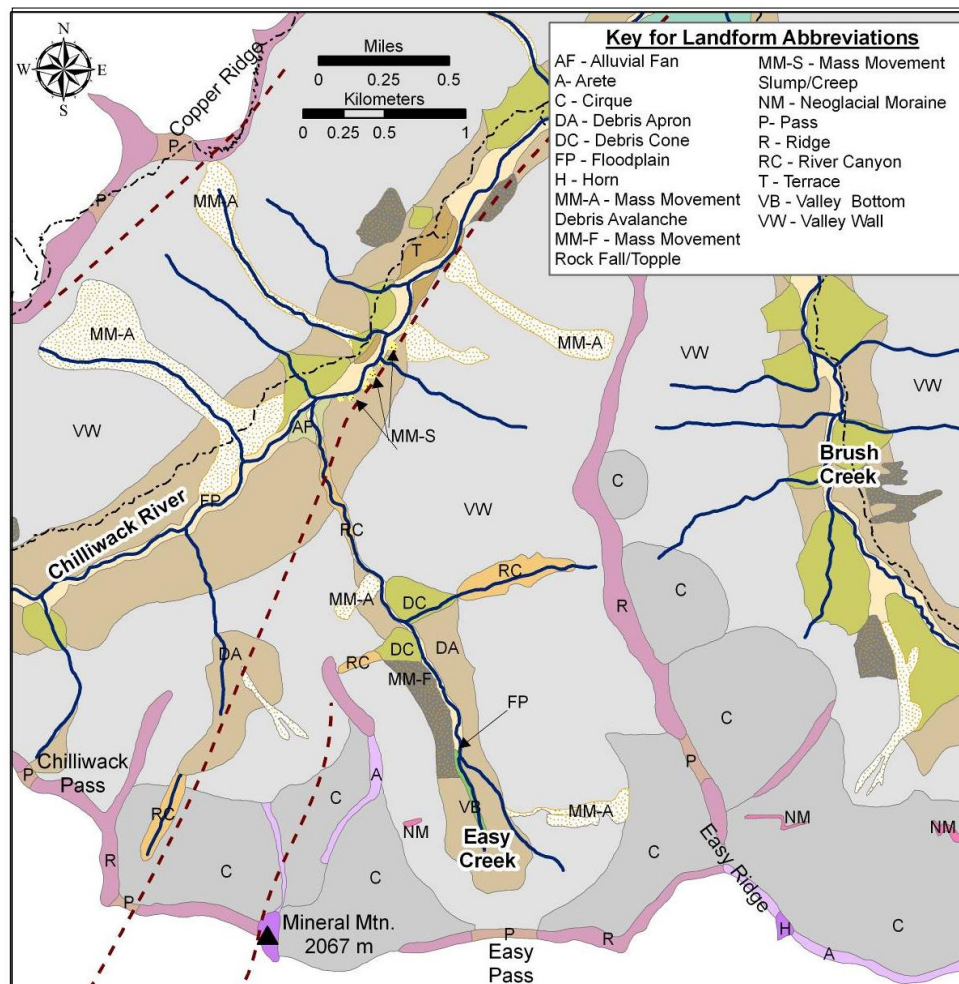


Figure 13. Landform map of Easy Creek, dot-dashed lines represent trails and red dashed lines are faults.



Figure 14. Looking northwest from near Easy Pass into Easy Creek. The asymmetry of the valley is marked by the steep valley wall and rock fall on the creek's northeast-facing side (left in photo) compared to the more gentle forested slopes on the southwest-facing side. Copper Ridge is visible to the north. NPS Photo.

5.2.4 Brush Creek

Brush Creek drains the western slopes of Whatcom Peak, the southern and eastern slopes of Red Face Mountain, the western slopes of Indian Mountain, as well as the entire north face of Easy Ridge (Fig. 15). The divide between Red Face Mountain and Whatcom Peak contains Whatcom Pass, which is the drainage divide between the Chilliwack and Little Beaver Creek systems. This pass also carried a large amount of the Puget Lobe of the Cordilleran Ice Sheet into the upper Skagit valley.

Brush Creek begins in a cirque on Red Face Mountain that extends down to 1700 m and contains Tapto Lakes (0.2, 0.5, 4.1 and 5.0 ha in size) (NPS 2008). The trend of the outlet stream from Tapto Lakes follows a northeast/southwest trending fault and forms an interesting canyon visible from the trail (Tabor et al. 2003). The slopes below the cirques grade steeply down to the beginning of the Brush Creek floodplain. At this location several side tributaries that drain Whatcom Peak and Easy Ridge enter Brush Creek. Whatcom Peak, whose cirque extends down to 1500 m, contains one Neoglacial moraine and three glaciers/permanent snowfields. The tributary draining Easy Ridge has cirques that extend down to 1340 m and contains five Neoglacial moraines and three glaciers. Three debris avalanches are also present in the upper Brush Creek valley. The occurrence of several rock and debris avalanches in this area is likely due to the over-steepened slopes (hanging valleys) present at the edge of the cirques and tectonized tonalite of the Snoqualmie Family that is highly altered.

5.2.5 Indian Creek

The headwaters of Indian Creek begin in cirques draining the northeast face of Red Face Mountain and the steep south face of Bear Mountain (Fig. 16). A series of ridges, arêtes and passes connect the two glacial horns. Facing south, the cirque at the head of the valley extends down to 1650 m. This side tributary flows in valley bottom and transitions to a river canyon at 1 km from its source. The river canyon may be fault-controlled; a northeast-southwest trending fault is mapped across and slightly down valley (Tabor et al. 2003) (Fig. 16). After a kilometer of valley bottom, the transition to floodplain occurs at elevation 1040 m.

Flowing west across its floodplain, the creek picks up several small streams draining off of Bear and Red Face Mountains. The waters of Indian Creek then turn northwest and join with a hanging valley off the north face of Red Face Mountain. This side tributary drains a cirque that extends down to 1770 m and contains Upper and Lower Lake Reveille, a glacier and a Neoglacial moraine. Below the cirque holding the lakes are four more Neoglacial moraines, the lowest of which terminates at 1650 m. The outlet to Reveille Lake drops precipitously into Indian Creek.

Below this tributary, Indian Creek flows northwest towards the Chilliwack River for 3 km between debris apron and debris cone landforms. At the mouth of the drainage, the creek has deposited an extensive alluvial fan. Standing above the active fan is a large fan terrace that is likely graded to a higher level of Chilliwack Lake. This landform, also known as a paraglacial fan, was deposited at the end of the last ice age when slopes left bare by retreating glaciers fed massive quantities of sediment to streams such as Indian Creek. A Pleistocene moraine on breached by Indian Creek is preserved above the fan terrace on both sides of the valley mouth. There are three rock falls along Indian Creek, the largest of which is on the southeast face of Bear Mountain. Only three relatively small debris avalanches are present, all of which are in the upper reaches of Indian Creek.

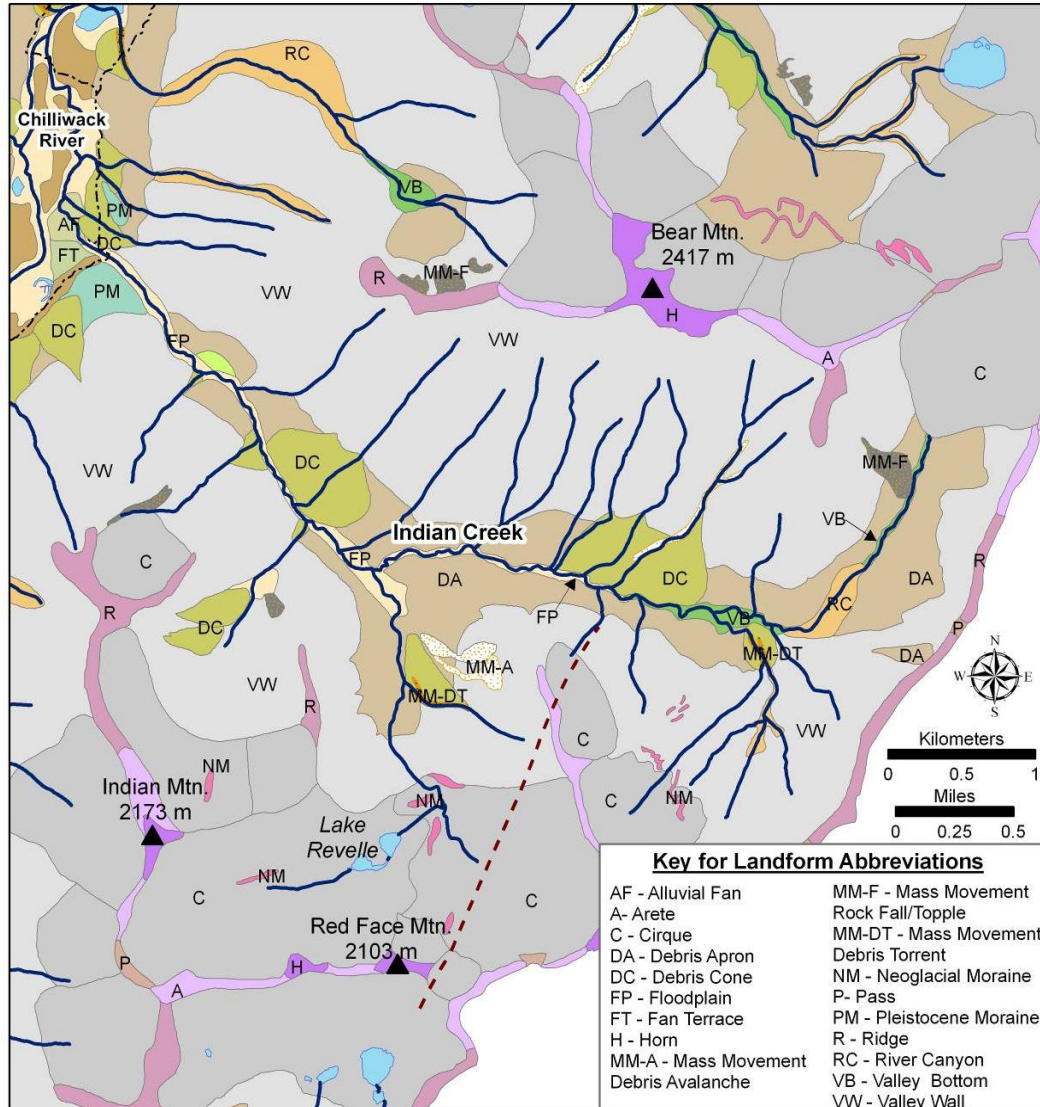


Figure 16. Landform map of Indian Creek, dot-dashed lines represent trails and red dashed lines are faults.

5.2.6 Bear Creek

Bear Creek flows northwest ~ 6.5 km to the Chilliwack River from a deep cirque holding Bear Lake (10.0 ha) (Fig. 17). The headwaters rise from well-defined cirques along the north face of Bear Mountain and the south face of Mt. Redoubt. Below the south face of Mt. Redoubt, a stream originates amidst couloirs and flying buttresses on the south face this impressive glacial horn. A cirque at the base of the peak extends down to 1770 m and contains one Neoglacial moraine. Bear Creek travels via a river canyon southwest from the outlet of Bear Lake to join waters from cirques on the north face of Bear Mountain which extend down to 1590 m. Four Neoglacial moraines were deposited on the north side of Bear Mountain, with the higher ones at 1530 – 1450 m possessing multiple crests and the lower one at 1430 m well vegetated. Creeks from these cirques travel to the valley bottom via river canyons. On the south face of Mt. Redoubt, two Neoglacial moraines are present, terminating at elevations of 1963 m and 2182 m. On the northeast face of Bear Mountain, two additional Neoglacial moraines are located in small cirque basins.

Bear Creek travels northwest across a narrow valley bottom with no floodplain along the entire valley. The Bear Creek valley is dominated by debris cone and debris aprons that provide large amounts of sediment that are beyond the streams capacity to transport. The mouth of Bear Creek contains an active alluvial fan flanked by fan terraces on either side. The alluvial fan and fan terraces are composed of boulders up to 1.8 m in diameter. No Pleistocene moraines have been mapped near the mouth of Bear Creek though a 15 – 18 m thick sequence of till is exposed in the stream banks. The Chilliwack floodplain at this location is approximately 3 km wide and contains six terraces ranging from 1.5 to 3 m in height. The terrace that is located at the Bear Creek camp is composed of a 2.4 m thick coarsening up sequence from silt to sand and gravel. These terraces are likely related to a bigger and deeper Chilliwack Lake at the end of the last ice age. Erosion of the moraine damming the lake and the flow of sediment into the lake from the Chilliwack River has steadily diminished Chilliwack Lake's size and depth.

There are a total of five mass movement avalanches in the Bear Creek valley two of which follow the trend of northeast/southwest faults (Tabor et al. 2003). The remaining three occurred in the upper reaches of the valley in till deposits and in gneiss of the Skagit Gneiss Complex.

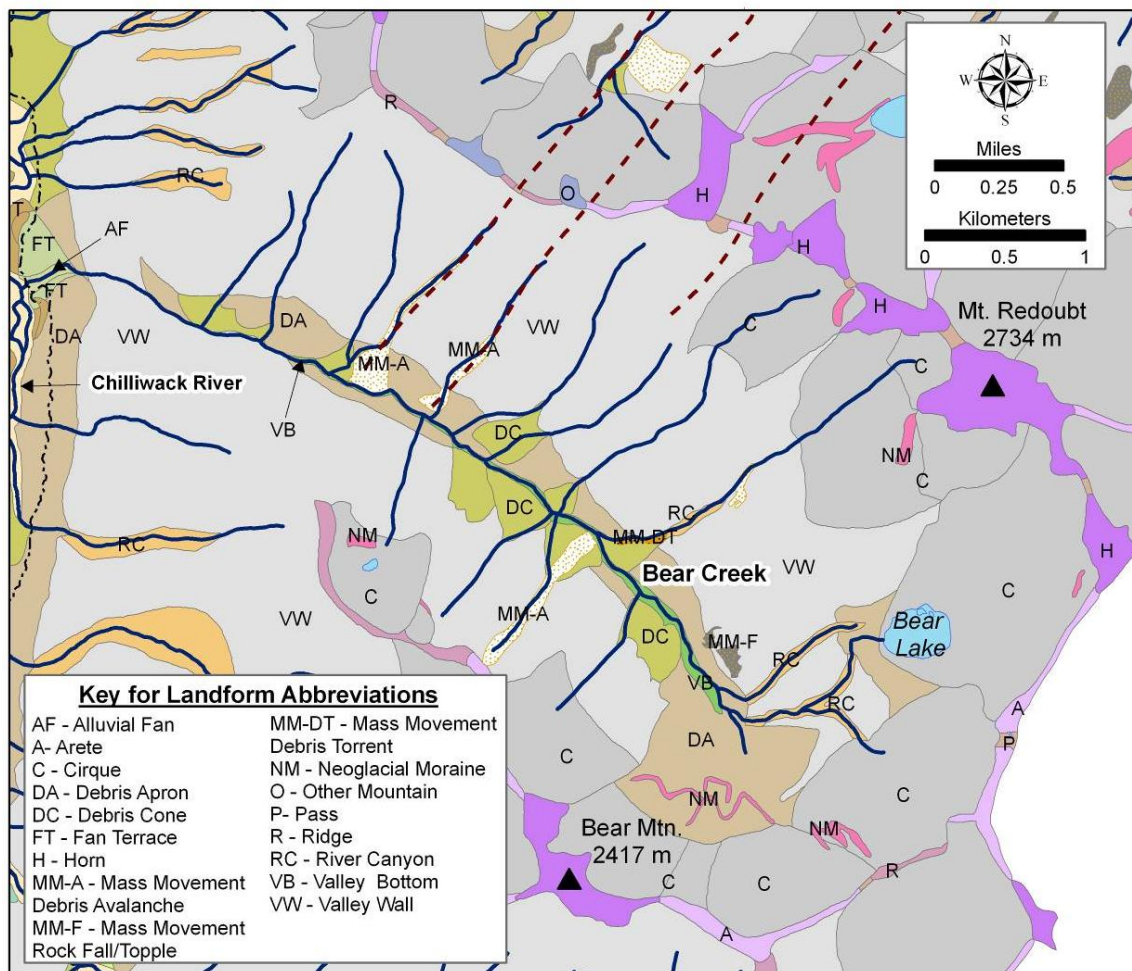


Figure 17. Landform map of Bear Creek, dot-dashed lines represent trails and red dashed lines are faults.

5.2.7 Little Chilliwack River

The Little Chilliwack River joins the Chilliwack River just prior to the Canadian Border (Fig. 18). Little Chilliwack is fed by run-off from five cirques at the valley head, the lowest of which extends down to 1670 m. Three Neoglacial moraines are present in the north-facing cirques and they are located between 1780 and 1700 m in elevation. One Neoglacial moraine is present in a south-facing cirque at an elevation of 1530 m and another is present on Middle Peak at an elevation of 2036 m. The creek then flows against a steep valley wall below the valley head and enters the valley bottom. It transitions to floodplain at elevation 1220 m and flows for 4 km until it reaches the junction with the Little Fork. The main Little Chilliwack drainage is flanked by a Pleistocene moraine on its south side of the junction with the Little Fork outlet.

Six cirques are present at the headwaters of the Little Fork, the lowest of which is at 1460 m and four rock falls are mapped near the edges of these cirques. Two of the cirques contain small glaciers on the northeast flank of Copper Mountain. A total of five Neoglacial moraines are present in the cirques as well. The Little Fork drainage travels 5 km to its outlet, intersecting four debris avalanches along the way.

Deltaic sediments are present in the terraces near the mouth of the Little Chilliwack River. These deposits indicate the presence of a lake that once filled the watershed during the end of the last ice age at about 12 Ka. The mouth of the Little Chilliwack contains an alluvial fan with a Pleistocene moraine confining the valley mouth. The main tributaries that join 2 km upstream from the mouth, with the Little Fork valley trending due north and the Little Chilliwack northeast. It is possible that northeast-southwest faults mapped in the valley influenced the development of this drainage pattern.

There only three debris avalanches in the Little Chilliwack valley and there are several rock falls below the cirques at the head of the valley. This rock fall prone area of the Little Chilliwack valley is composed of sandstone and conglomerate that is cut by southwest – northeast trending high angle faults. The rest of the valley is composed of the relatively stable granodiorite bedrock of the Chilliwack Composite Batholith.

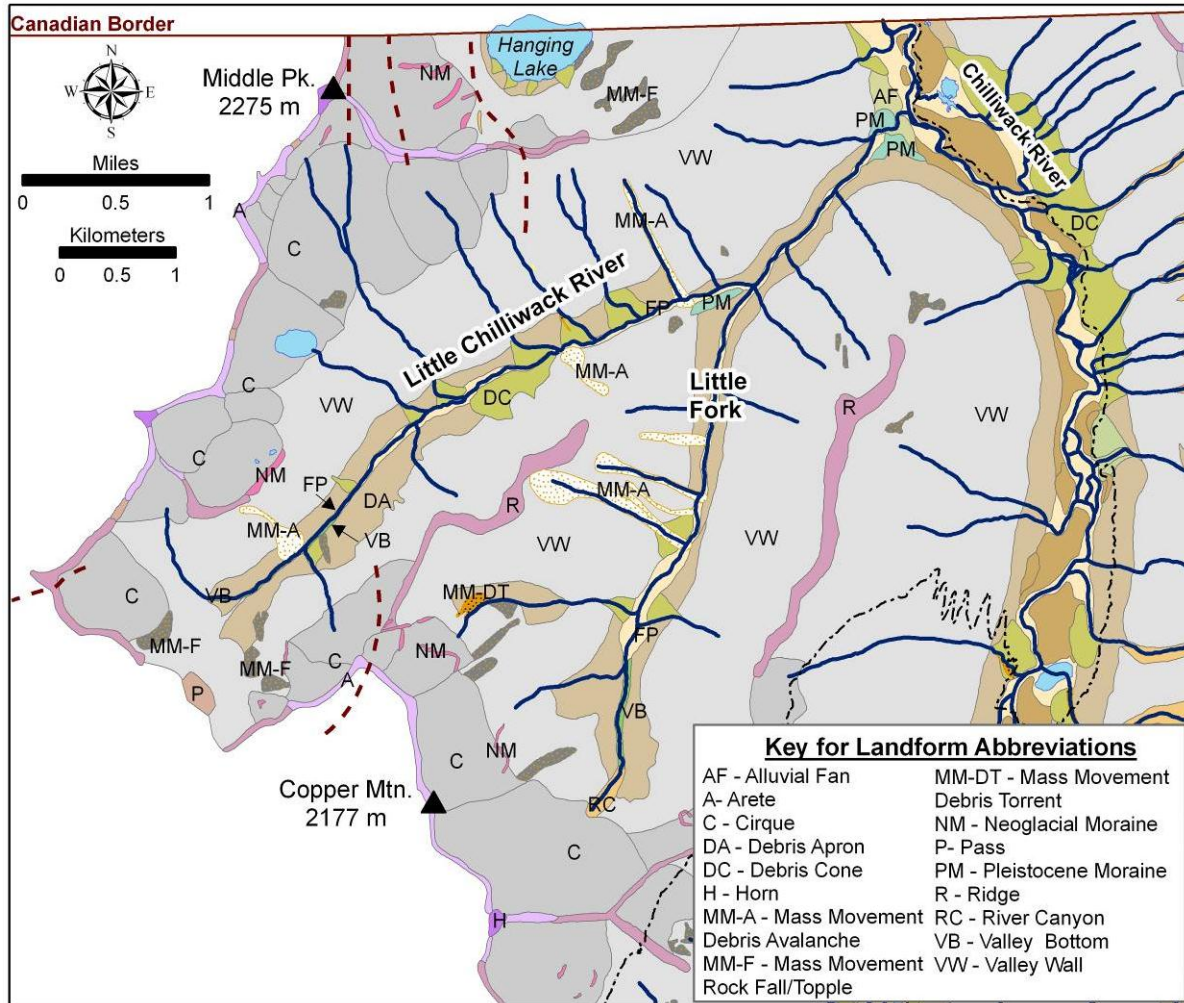


Figure 18. Landform map of Little Chilliwack River, dot-dashed lines represent trails and red dashed lines are faults.

5.2.8 Depot Creek

Depot Creek is fed by three large glaciers off the north face of Mt. Redoubt and as well as several permanent snow fields on Mt. Redoubt and Mt. Spickard (Fig. 19). At ~13.5 km in length, Depot Creek is the largest of the sub-watersheds in the Chilliwack River Watershed, but only 7.5 km of it is within NOCA. The watershed is accessible by a climber's trail that crosses into NOCA from Chilliwack Lake Provincial Park. The headwaters of Depot Creek originate from Redoubt Glacier, the largest glacier in the watershed (2.0 km²) (Fig. 5). The eastern-most cirque of Mt. Redoubt is very deep and well-developed and extends down to an elevation of 1700 m and holds seven Neoglacial moraines. These moraines are present between the elevations of 2255 m and 1700 m. All the streams in the cirque drain into Ouzel Lake (7.5 ha) whose outlet marks the beginning of the main channel of Depot Creek (Fig. 20). An esker and two small kames also were deposited on the cirque floors which are unique features in the park. Riedel (1987) describes the genesis of the esker and evidence of Neoglacial advances of glaciers in this drainage.

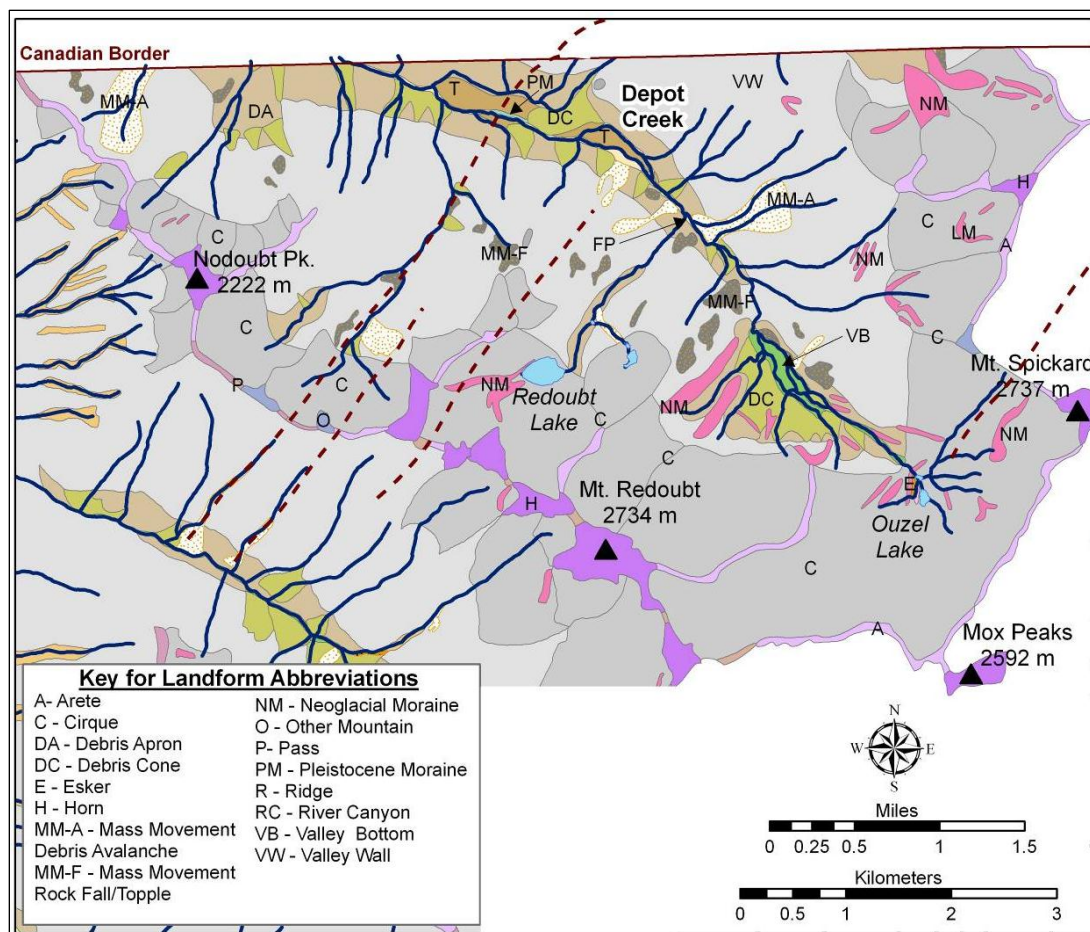


Figure 19. Landform map of Depot Creek, red dashed lines are faults.



Figure 20. Looking west from the slopes of Spickard to Ouzel Lake, Mt. Redoubt in the upper right corner of photograph. NPS Photo.

The Depot Creek drainage holds an additional fifteen Neoglacial moraines, the lowest of which is located at 1530 m in an extensive wetland (Fig. 21). The creek runs through valley bottom to the northwest for 2.3 km below the lake, picking up numerous small streams flowing off of Mt. Spickard and Mt. Redoubt. The stream then meanders through an extensive palustrine wetland before cascading down a 295 m tall waterfall composed of biotite gneiss of the Skagit Gneiss Complex. The bedrock escarpment occurs at the offset along a northeast-southwest trending fault. The creek then flows over a small section (<1 km) of debris cones and debris aprons to enter floodplain at an elevation of 1036 m. Depot Creek then drains into Chilliwack Lake to the northwest, with three terraces up to 1.5 m in height and one narrow Pleistocene moraine < 1 km south of the Canadian Border. This moraine likely was deposited during the Sumas Stade about 13 Ka (Riedel 2007). Only 4 km of the floodplain was mapped, since the remainder of Depot Creek is located outside of the Park.

North of the border, Depot Creek drains through a large wetland created by a massive landslide from the east valley wall (Tuncliffe 2009). Depot Creek has deposited a large alluvial fan delta complex into Chilliwack Lake. Although this area was not mapped, fan terraces could preserve a history of lake level lowering.

The valley walls are very steep throughout the drainage and numerous rock falls and debris avalanches are present. Two northeast-southwest trending faults are mapped in the middle portion of Depot Creek and these zones of weakened rock likely contribute to the presence of the mass movements. The largest debris avalanche in the drainage is mapped as a landslide on the geologic map on the lower west face of Mount Spickard (Tabor et al. 2003). This debris avalanche originates in volcanic rocks (dacite to andesite) that contain interbeds of sandstone and conglomerate. There is also a trace of another northeast/southwest trending fault that runs through the upper northern portion of the Depot Creek cirque basin. This fault is mapped through Silver Lake and up into British Columbia. Extending this fault to the southwest along its strike would place it near several of the rock falls and debris avalanches in the headwaters of Depot Creek.



Figure 21. Looking southwest into the upper Depot Creek valley from the lower slopes of Mt. Spickard. Note extensive palustrine wetland in mid-distance. NPS Photo.

5.3 Chilliwack River Watershed Landslide Inventory

Information on landslides can guide the selection of LTEM reference sites or building/maintaining public facilities such as trails, campgrounds and bridges. A landslide database was created to accompany landform maps with data collected on eighteen characteristics of each landslide, including age, activity, bedrock geology, material type and area. For large mass movement avalanches, depth of the cavity and the volume of sediment delivered to river/creek were also estimated. Reviewing this data can tell a great deal about the overall stability of a particular area of the watershed, which can be related to factors such as bedrock type, aspect and proximity to faults (Appendix A).

A total of one hundred and forty-three landslides have been mapped within the Chilliwack River Watershed, which encompass ~3.4% of the overall watershed area (Table 6). The fifty-eight debris avalanches encompass ~2.4% of the overall watershed. These large landslides in the steep terrain of the Chilliwack River Watershed are important events in the valley's natural history. They can block streams and create lakes and/or wetlands and fish migration barriers. They also provide large woody debris to stream that help establish log jams and influence river pattern and habitat far downstream of the landslide. Debris avalanches in the watershed displaced an estimated volume of 46,000,000 m³ of debris. A total of fifty-three of the debris avalanches mapped in the watershed either delivered sediment directly to a stream and 17 blocked streams. Evidence of blockages on the river includes massive debris piles emanating from valley walls across valley floors that displaced streams to the opposite side of the valley.

Table 6. Summary of the Chilliwack River Watershed landslide inventory data.

Mass Movement Type	# of Each Type	Surface Area (m ²)	% of Total Watershed
Debris Avalanche	58	5,324,000,000	2.443
Debris Fall/Topple	66	1,853,000,000	0.842
Debris Torrent	10	40,000,000	0.059
Debris Slump/Creep	9	128,000,000	0.018
Totals	143	7,345,000,000	3.362

In the headwaters of the Chilliwack River, in two cirque basins, several debris avalanches composed of tuff were mapped, all along the Hannegan Ring Fault. While these deposits likely did not block the headwaters, they still delivered a significant amount (7,474,700 m³) of debris from the ridges and cirques to the debris apron and valley bottom. From the headwaters of Copper Creek, along the Hannegan Ring Fault, a large (552,009 m²) debris avalanche blocked and contributed approximately 9,300,000 m³ of sediment to the main stem of the river. Between Copper and Indian Creeks, several debris avalanches along the northeast-southwest extensional faults blocked the Chilliwack at one time as well. They contributed a total of 18,117,700 m³ of sediment to the Chilliwack.

By reviewing the location, size and composition of these mass movements, some general observations can be made. Debris slump/creep deposits are uncommon in the watershed and tend to occur in the valley bottom from stream-undercut of glacial till and colluvium in the debris apron. Debris torrents are present in all sub-watersheds, but are uncommon overall. This may reflect the role that vegetation plays on the avalanche chute, debris cones and debris aprons since high vegetative cover can be a stabilizing factor on debris cones. As mentioned throughout this report, most of the rock falls tend to be on east to north-east facing slopes, where the effects of aspect are most pronounced. In the Chilliwack River Watershed it appears that the largest debris avalanches are typically fault controlled, by either the Hannegan Ring Fault or northeast-southwest trending extensional faults.

6 - Future Work

6.1 Progress Report

As of the timing of this report's publication, several areas within the Chilliwack River Watershed have not been field-checked. Indian, Bear and Upper Little Chilliwack have all not been accessed due to the difficulty of the terrain. These drainages may be field checked in future field seasons.

The field component of the landform mapping at North Cascades National Service Complex (NOCA) is 100% complete. LiDAR data for Goodell and Newhalem Creeks is to be available by December of 2009. Subsequent editing of the GIS landform layer for these two drainages is planned during the winter of 2009/2010. The field component of the landform mapping at Mount Rainier National Park (MORA) is 100% complete. The landform maps are currently being digitized and entered in the MORA GIS database. LiDAR data was also made available in May of 2009, so editing of the GIS layer is anticipated during the winter of 2009-2010. The field component of the landform mapping at Olympic National Park (OLYM) is 40% complete. Future work will focus on a continuation of the landform mapping project at these three National Parks. The scheduled completion date for NOCA is 2010; 2010 for MORA and 2012 for OLYM.

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Appendix A. Landslide Inventory for the Chilliwack River Watershed

List of landslide characteristics documented for each landslide is reviewed in this appendix. There are eighteen characteristics for all landslides, with an additional four characteristics collected for debris avalanches.

1. Quadrangle Number: Each USGS 7.5 minute quadrangle in NOCA was assigned a unique value. Quadrangle values are as follows:

USGS Quadrangle	Value	USGS Quadrangle	Value
Mt. Sefirt	1	Crater Mtn.	19
Copper Mtn.	2	Sauk Mtn.	20
Mt. Redoubt	3	Marblemount	21
Mt. Spickard	4	Big Devil Peak	22
Hozomeen Mtn.	5	Eldorado Peak	23
Skagit Peak	6	Forbidden Peak	24
Shuksan Arm	7	Mt. Logan	25
Mt. Shuksan	8	Mt. Arriva	26
Mt. Blum	9	Sonny Boy Lakes	27
Mt. Challenger	10	Cascade Pass	28
Mt. Prophet	11	Goode Mtn.	29
Pumpkin Mtn.	12	McGregor Mtn.	30
Jack Mtn.	13	McAlester Mtn.	31
Bacon Peak	14	Agnes Mtn.	32
Damnation Peak	15	Mt. Lyall	33
Mt. Triumph	16	Stehekin	34
Diablo Dam	17	Sun Mtn.	35
Ross Dam	18	Pinnacle Mtn.	36

2. Mass Movement Number: Each mass movement in the watershed is assigned a unique value.

3. Sub-Watershed: Refers to the river or creek name that dominates the drainage where the mass movement is located.

4. Mass Movement Type Number: Each type of mass movement has a number as follows:

USGS Quadrangle	Value
Rock Fall/Topple	1
Creep/Slump	2
Debris Avalanche	3
Debris Torrent	4
Sackung	5
Snow Avalanche Impact Landform (SAIL)	6

5. Identification Number: Consists of the quadrangle number, mass movement number and mass movement type number (e.g. a rock fall on the Copper Mtn. quadrangle with the assigned number of 11 would be 2-11-1)

6. Material Type: Refers to the type of material contained in the mass movement. The four different material types are rock (R), soil (S), till (T) and debris (D).

7. Age: Relative age if known, occasionally specific dates are recorded if the event was observed. When data is recorded, the type of dating will be noted.
8. Sediment Delivered to Stream: A yes or no or blocked category based on NAIP imagery and aerial photographs
9. Bedrock Type: Used Tabor et al (2003) to identify bedrock type of the landslide. Refer to this map for a key to the symbols used in the database.
10. Length: Refers to the average length (from top to bottom) of the total mass movement. For debris avalanches both the cavity and the deposit is included in the average length measurements. For debris torrents and rock falls/topples, only the deposit is measured. Due to the small size of slumps, the length is taken in the field if possible by measuring the height exposure including any cracking above the crown. Measurements are in 2-D. The measurement is taken off GIS with the measuring tool and is recorded in meters.
11. Width: Refers to the average width (generally following on contour) of the total mass movement. For debris avalanches both the cavity and the deposit is included in the average width measurements. For debris torrents and rock falls/topples, only the deposit is measured. Due to the small size of slumps, the length is taken in the field if possible by measuring the width of the exposure. The measurement is taken off GIS with the measuring tool and is recorded in meters.
12. Volume of Sediment of Debris Avalanches: Refers to the amount of material deposited by a debris avalanche. Measurements are taken by calculating volume only of the cavity and are recorded in meters. Formula as follows:
- $$((1/6)*3.14*Length\ of\ Cavity*Width\ of\ Cavity*Depth\ of\ Cavity)$$
13. Length of Cavity: Used to calculate volume of sediment in debris avalanche. Refers to the average length (from top to bottom) of the cavity and measurement is taken off the GIS and is recorded in meters.
14. Width of Cavity: Used to calculate volume of sediment in debris avalanche. Refers to the average width of the cavity and measurement is taken off the GIS and is recorded in meters.
15. Depth of Cavity: Used to calculate volume of sediment in debris avalanches and refers to the thickness of material. Depth is recorded in the field if possible. If not possible, measurement should be taken by the cavity of the debris avalanche. The cavity can be estimated using a topographic map in lieu of field information. Depth is recorded in meters.
16. Surface Area: Refers to the exposed area in 2-D and is recorded in m² and km². Measurement is taken off the GIS for all mass movements.

17. Slope Aspect: Refers to the slope aspect that the mass movement originated from and not the deposit. It is measured off the quadrangle using a compass and is recorded in degrees from true north.

18. Percent Slope: Recorded for each landslide, value is calculated by rise over run (45 degrees = 100% slope).

19. Position: Refers to four possible locations of where landslides originated; Valley Bottom (VB) defined as anything below the valley wall unit, Divide (D), Valley Wall (VW), or Channelized (CH) if confined to a channel.

20. Form: Refers to the general slope form of the landslides; concave (CC), convex (CV), flat (FL) and complex (COMP).

21. Top Elevation: Refers to the top most extent of the mass movement. Recorded in meters and measurement is taken from a 7.5 Minute Quadrangle.

22. Toe Elevation: Refers to the lowest extent of the mass movement. Recorded in meters and measurement is taken from a 7.5 Minute Quadrangle.

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
2	1	Little Chilliwack	2-1-3	3	D		Y	Tccv
2	2	Little Chilliwack	2-2-4	4	D		Y	Tccv
2	3	Little Chilliwack	2-3-3	3	D		Y-BLKD	Tccv/Tcht
2	4	Little Chilliwack	3-4-1	1	R		N	Tccv
2	5	Chilliwack	2-5-1	1	R		N	Tccv
2	6	Little Chilliwack	2-6-3	3	D		Y-BLKD	Tccv
2	7	Little Chilliwack	2-7-1	1	R		N	Tccv
2	8	Little Fork	2-8-3	3	D		Y-BLKD	Tccv
2	9	Little Fork	2-9-3	3	D		Y-BLKD	Tccv
2	10	Little Fork	2-10-3	3	D		Y-BLKD	Tccv
2	11	Little Chilliwack	2-11-1	1	R		N	Tos/Tccv
2	12	Little Chilliwack	2-12-1	1	R		N	Tos/Tccv
2	13	Little Chilliwack	2-13-1	1	R		N	Tccv
2	14	Chilliwack	2-14-3	3	D		Y?	Tccv
2	15	Indian Creek	2-15-1	1	R		N	Tcig
2	16	Chilliwack	2-16-3	3	D		Y-BLKD	Tcclg
2	17	Chilliwack	2-17-1	1	R		Y	Tcclg/Qf
2	18	Copper Creek	2-18-3	3	D		Y	Tcp
2	19	Chilliwack	2-19-3	3	D		Y-BLKD	Tcp/Tcclg
2	20	Chilliwack	2-20-1	1	R		N	Tcls
2	21	Chilliwack	2-21-1	1	R		Y	Qt/Tccv
2	22	Brush Creek	2-22-3	3	D		Y	Tccv
2	23	Copper Creek	2-23-3	3	D		Y-BLKD	Tcgp/Tcip/Tht
2	24	Chilliwack	2-24-3	3	D		Y-BLKD	Ql
2	25	Chilliwack	2-25-2	2	T		Y	Qag
2	26	Chilliwack	2-26-2	2	T		Y	Qag
2	27	Chilliwack	2-27-2	2	T		Y	Qag
2	28	Chilliwack	2-28-2	2	T		Y	Qag
2	29	Chilliwack	2-29-2	2	T		Y	Qag
2	30	Chilliwack	2-30-2	2	T		Y	Qag
2	31	Chilliwack	2-31-1	1	R		N	Tcp

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
2	32	Easy Creek	2-32-3	3	D		Y-BLKD	Tcm
2	33	Chilliwack	2-33-4	4	D		Y	Qf
2	34	Chilliwack	2-34-3	3	D		Y	Tht
1	35	Chilliwack	1-35-3	3	D		Y	Tht
1	36	Chilliwack	1-36-3	3	D		Y	Tht
2	37	Chilliwack	2-37-3	3	D		Y	Tccv
1	38	Chilliwack	1-38-1	1	R		Y	Tht
1/8	39	Chilliwack	1-39-3	3	D		Y	Tht
1/8	40	Chilliwack	1-40-3	3	D		N	Tht
1	41	Chilliwack	1-41-3	3	D		Y	Tht
1	42	Chilliwack	1-42-3	3	D		Y	Tht
1	43	Chilliwack	1-43-3	3	D		Y	Tht
1	44	Chilliwack	1-44-3	3	D		Y	Tht
1	45	Chilliwack	1-45-3	3	D		Y-BLKD	Tht
1	46	Chilliwack	1-46-3	3	D		Y	Tht
1	47	Chilliwack	1-47-3	3	D		Y	Tht
9	48	Chilliwack	9-48-3	3	D		N	Tcm
9	49	Easy Creek	9-49-1	1	R		Y	Tcm
2	50	Brush Creek	2-50-1	1	R		Y	Tcig
9/2	51	Brush Creek	9-51-1	1	R		Y	Tcm
9/2	52	Brush Creek	9-52-3	3	D		Y	Tcm
9	53	Brush Creek	9-53-3	3	D		Y	Tcm
9	54	Brush Creek	9-54-5	4	D		Y	Tcm
9	55	Brush Creek	9-55-3	3	D		Y	Tcm
9	56	Brush Creek	9-56-3	3	D		Y	Tcm
9	57	Brush Creek	9-57-3	3	D		Y	Tcm
2/9	58	Brush Creek	9-58-3	3	D		Y	Tcig
3	59	Indian Creek	3-59-3	3	D		Y	Tcig
3	60	Indian Creek	3-60-3	3	D		Y	Tcig
3	61	Indian Creek	3-61-3	3	D		Y	TKsbg
3	62	Indian Creek	3-62-1	1	R		Y	Tcrq/TKsbg

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
3	63	Chilliwack	3-63-1	1	R		N	Tccv
3	64	Chilliwack	3-64-1	1	R		N	Tccv
3	65	Chilliwack	3-65-1	1	R		N	Tccv
3	66	Bear Creek	3-66-1	1	R		Y	Tcwb
3	67	Bear Creek	3-67-3	3	D		Y	Tcwb
3	68	Bear Creek	3-68-3	3	D		Y	TKsbg/Qam
3	69	Bear Creek	3-69-3	3	D		Y	Tcwb
3	70	Bear Creek	3-70-4	4	D		Y	Qag/Tcwb
3	71	Bear Creek	3-71-3	3	D		Y	Tcwb
3	72	Bear Creek	3-72-3	3	D		Y	Tcwb/Tccv
3	73	Bear Creek	3-73-3	3	D		Y-BLKD	Tccv
2	74	Little Chilliwack	2-74-4	4	D		Y	Tccv
1/2	75	Little Chilliwack	2-75-1	1	R		N	Tos
2	76	Little Chilliwack	2-76-1	1	R		N	Tos
2	77	Little Chilliwack	2-77-1	1	R		N	Qag
2	78	Little Chilliwack	2-78-1	1	R		N	Qag
2	79	Little Chilliwack	2-79-1	1	R		N	Tos/Tccv
2	80	Little Fork	2-80-4	4	D		Y	Tccv
2	81	Little Fork	2-81-1	1	R		Y	Tccv
2	82	Little Fork	2-82-1	1	R		N	Tccv
2	83	Little Fork	2-83-1	1	R		N	Tccv
2	84	Little Fork	2-84-1	1	R		N	Tccv
2	85	Chilliwack	2-85-1	1	R		Y	Tccv
2	86	Chilliwack	2-86-1	1	R		N	Tccv
2	87	Chilliwack	2-87-1	1	R		N	Tccv
2	88	Chilliwack	2-88-3	3	D		Y-BLKD	Tccv
9	89	Brush Creek	9-89-3	3	D		Y	Tcm
2	90	Little Fork	2-90-3	3	D		Y	Tccv
2	91	Little Chilliwack	2-91-1	1	R		Y	Tccv

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
2	92	Little Fork	2-92-3	3	D		Y	Tccv
2	93	Little Chilliwack	2-93-1	1	R		N	Tccv
2	94	Chilliwack	2-94-4	4	D		Y	Qf/Tcig
2	95	Chilliwack	2-95-4	4	D		Y	Qag
3	96	Indian Creek	3-96-4	4	D		Y	Tcig/Qt
3	97	Little Chilliwack	1-97-2	2	S		Y	Tcht
2	98	Indian Creek	3-98-4	4	D		Y	Qt/Tcig
1	99	Indian Creek	2-99-1	1	R		Y	Tcig
9	100	Chilliwack	1-100-3	3	D		Y	Tht
2	101	Easy Creek	9-101-1	1	R		N	Tcig
2	102	Chilliwack	2-102-3	3	D		Y	Tccv
2	103	Brush Creek	2-103-3	3	D		Y	Tccv
2	104	Brush Creek	2-104-3	3	D		Y/BLKD	Tccv
2	105	Brush Creek	2-105-3	3	D		Y	Tccv
2	106	Brush Creek	2-106-1	1	R		N	Tccv
2	107	Chilliwack	2-107-1	1	R		N	Tccv
2	108	Chilliwack	2-108-1	1	R		N	Tccv
2	109	Chilliwack	2-109-1	1	R		N	Tccv
2	110	Little Chilliwack	2-110-1	1	R		N	Tccv
3	111	Little Chilliwack	2-111-1	1	R		N	Tccv
3	112	Depot	3-112-1	1	R		N	TKsbga
3	113	Depot	3-113-3	3	D		Y BLKD?	TKsbga
3	114	Depot	3-114-1	1	R		N	TKsbga
3	115	Depot	3-115-1	1	R		N	TKsbga
3	116	Depot	3-116-1	1	R		N	TKsbga
3	117	Depot	3-117-1	1	R		N	Tcpc
3	118	Depot	3-118-3	3	D		N	Tcpc
3	119	Depot	3-119-1	1	R		N	Tcpc
3	120	Depot	3-120-1	1	R		N	TKsbg
3	121	Depot	3-121-1	1	R		N	TKsbg

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
3	122	Depot	3-122-1	1	D		N	TKsbg
3	123	Depot	3-123-1	1	R		N	TKsbg
3	124	Depot	3-124-1	1	R		N	TKsbg
3	125	Depot	3-125-3	3	D		N	TKsbg
3	126	Depot	3-126-1	1	R		Y	Qag
3	127	Depot	3-127-2	2	S		Y	Qag
3	128	Depot	3-128-3	3	D		Y	Tksbg
3	129	Depot	3-129-1	1	R		N	Tksbg
3	130	Depot	3-130-3	3	D		N	Tksbg
3	131	Depot	3-131-1	1	R		N	Tksbg
3	132	Depot	3-132-1	1	R		N	Tksbg
3	133	Depot	3-133-1	1	R		N	Tksbg
3	134	Depot	3-134-1	1	R		N	Tksbg
3	135	Depot	3-135-3	3	D		Y BLKD?	Ql (Tvr)
3	136	Depot	3-136-1	1	R		Y	Qam
3	137	Depot	3-137-1	1	R		N	Tcrq
3	138	Depot	3-138-3	3	D		Y BLKD?	Tcrq
3	139	Depot	3-139-1	1	R		N	Tcrq
4	140	Depot	3-140-1	1	R		Y	Qam
8	141	Depot	4-141-1	1	R		N	Tvr
2	142	Chilliwack	8-142-2	2	D		Y	Tht
2	143	Chilliwack	2-143-1	1	R		N	Tccv

MM#	For all Types				Values for Volume Calculations: For MM-As Only			
	Length m.	Width m.	Surface Area m ²	Surface Area km ²	Length m.	Width m.	Depth m.	Volume m ³
1	647	107	72517	0.073	126.00	65.00	12.19	52256.13
2	164	14	2777	0.003				
3	1230	80	93404	0.093	377.00	73.00	12.19	175597.19
4	81	46	4200	0.004				
5	164	151	40234	0.040				
6	534	83	51565	0.052	176.00	91.00	12.19	102189.77
7	90	108	12492	0.012				
8	1504	153	219571	0.220	336.00	295.00	27.43	1422974.65
9	1020	84	84212	0.084	211.00	163.00	24.38	438887.70
10	612	71	49332	0.049	136.00	60.00	12.19	52064.72
11	155	90	13744	0.014				
12	169	56	8679	0.009				
13	49	429	21719	0.022				
14	754	64	56383	0.056	161.00	60.00	24.38	123270.87
15	53	476	26062	0.026				
16	1165	150	166492	0.166	389.00	282.00	121.92	6999258.95
17	95	221	20894	0.021				
18	678	71	71777	0.072	368.00	135.00	12.19	316982.25
19	1414	122	148814	0.149	379.00	192.00	60.96	2321473.84
20	182	345	67364	0.067				
21	93	330	36681	0.037				
22	387	52	20892	0.021	192.00	51.00	12.19	62477.66
23	1555	302	552009	0.552	476/479	187/353	61/73	9301246.77
24	1407	302	510206	0.510	478.00	397.00	60.96	6053990.84
25	24	36	967	0.001				
26	26	39	1157	0.001				
27	32	43	1451	0.001				
28	31	46	1729	0.002				
29	22	29	705	0.001				
30	41	43	1829	0.002				
31	129	107	14079	0.014				
32	329	80	30489	0.030	162.00	65.00	6.10	33593.23
33	270	33	9353	0.009				
34	748	90	63595	0.064	309.00	62.00	18.29	183355.85
35	129	130	3849	0.004	49.00	51.00	10.67	13951.72

MM#	For all Types				Values for Volume Calculations: For MM-As Only			
	Length m.	Width m.	Surface Area m ²	Surface Area km ²	Length m.	Width m.	Depth m.	Volume m ³
35	129	130	3849	0.004	49.00	51.00	10.67	13951.72
36	612	140	81531	0.082	223.00	214.00	6.10	152344.53
37	521	97	61719	0.062	149.00	60.00	13.72	64171.68
38	99	81	9352	0.009				
39	719	278	160269	0.160	264.00	385.00	100.58	5350223.89
40	442	87	48613	0.049	173.00	115.00	30.48	317349.12
41	536	62	31323	0.031	63.00	45.00	6.10	9044.33
42	576	76	55586	0.056	149.00	119.00	6.10	56566.15
43	568	113	74011	0.074	178.00	233.00	12.19	264624.03
44	417	80	49237	0.049	107.00	187.00	6.10	63833.51
45	815	215	231427	0.231	307.00	357.00	18.29	1048941.34
46	671	105	76955	0.077	172.00	193.00	12.19	211806.41
47	88	21	2109	0.002	35.00	29.00	7.62	4047.62
48	539	34	29160	0.029	145/199	49/39	6.1/6.1	47457.23
49	159	782	110711	0.111				
50	193	305	81500	0.082				
51	187	343	71169	0.071				
52	1072	75	90638	0.091	268/243	42/19	6.1/6.1	40626.85
53	463	112	64150	0.064	168.00	88.00	6.10	47164.51
54	413	43	14586	0.015				
55	605	30	18981	0.019	149.00	22.00	9.14	15686.41
56	727	39	29554	0.030	209.00	40.00	6.10	26670.41
57	897	101	105527	0.106	188.00	159.00	30.48	476813.27
58	799	59	52257	0.052	150.00	77.00	9.14	55270.91
59	392	49	18941	0.019	184.00	44.00	12.19	51656.37
60	608	55	44761	0.045	246.00	99.00	15.24	194237.76
61	1091	40	56295	0.056	430.00	59.00	12.19	161872.78
62	400	131	65417	0.065				
63	65	210	15606	0.016				
64	169	191	29906	0.030				
65	99	81	9352	0.009				
66	719	278	160269	0.160	264.00	385.00	100.58	5350223.89
67	442	87	48613	0.049	173.00	115.00	30.48	317349.12
68	536	62	31323	0.031	63.00	45.00	6.10	9044.33
69	576	76	55586	0.056	149.00	119.00	6.10	56566.15
70	568	113	74011	0.074	178.00	233.00	12.19	264624.03

MM#	For all Types				Values for Volume Calculations: For MM-As Only			
	Length m.	Width m.	Surface Area m ²	Surface Area km ²	Length m.	Width m.	Depth m.	Volume m ³
71	382	75	33557	0.034	138.00	92.00	6.10	40503.29
72	617	62	48194	0.048	293.00	63.00	12.19	117777.28
73	1016	83	90718	0.091	485.00	50.00	12.19	154726.64
74	353	47	16035	0.016				
75	232	110	21716	0.022				
76	359	122	47756	0.048				
77	189	74	19446	0.019				
78	243	116	29302	0.029				
79	168	129	25598	0.026				
80	258	101	28828	0.029				
81	112	154	20220	0.020				
82	495	77	33161	0.033				
83	286	96	27602	0.028				
84	527	113	49077	0.049				
85	132	388	54769	0.055				
86	80	150	13254	0.013				
87	76	87	8971	0.009				
88	1415	235	341565	0.342	373.00	259.00	51.82	2619695.88
89	767	46	36384	0.036	268.00	40.00	6.10	34199.37
90	663	34	24790	0.025	114.00	44.00	6.10	16002.24
91	249	64	14624	0.015				
92	369	47	15600	0.016	160.00	35.00	9.14	26798.02
93	121	190	24181	0.024				
94	152	25	4064	0.004				
95	335	40	14452	0.014				
96	238	57	15488	0.015				
97	67	15	1221	0.001				
98	437	35	20207	0.020				
99	163	93	14639	0.015				
100	134	26	3577	0.004	33.00	28.00	12.19	5895.56
101	246	94	21513	0.022				
102	1097	94	133650	0.134	352.00	159.00	24.38	714205.41
103	456	79	41075	0.041	92.00	53.00	12.19	31111.22
104	459	95	57134	0.057	126.00	36.00	12.19	28941.86
105	355	52	23127	0.023	83.00	51.00	24.38	54017.14

MM#	For all Types				Values for Volume Calculations: For MM-As Only			
	Length m.	Width m.	Surface Area m ²	Surface Area km ²	Length m.	Width m.	Depth m.	Volume m ³
106	94	163	20312	0.020				
107	90	95	11371	0.011				
108	120	152	19597	0.020				
109	47	232	15783	0.016				
110	182	39	7056	0.007				
111	139	42	5546	0.006				
112	148	212	32719	0.033				
113	812	313	267823	0.268	312.00	382.00	30.48	1901127.82
114	260	76	22215	0.022				
115	130	47	6344	0.006				
116	136	108	15419	0.015				
117	213	62	23141	0.023				
118	333	283	85439	0.085	119.00	252.00	12.19	191337.83
119	105	146	20071	0.020				
120	180	70	11442	0.011				
121	116	76	10830	0.011				
122	134	320	50627	0.051				
123	131	139	19090	0.019				
124	241	64	20244	0.020				
125	438	105	57914	0.058	147.00	80.00	21.34	131310.28
126	94	144	11469	0.011				
127	19	58	743	0.001				
128	632	84	56587	0.057	278.00	133.00	15.24	294889.83
129	135	183	28216	0.028				
130	353	71	27682	0.028	99.00	65.00	24.38	82116.78
131	281	51	13048	0.013				
132	128	311	42195	0.042				
133	129	218	37468	0.037				
134	230	203	65177	0.065				
135	872	297	268806	0.269	306.00	489.00	33.53	2625526.05
136	196	56	14448	0.014				
137	144	44	8493	0.008				
138	421	63	24498	0.024	110.00	85.00	25.91	126772.16
139	157	285	43927	0.044				
140	45	110	6626	0.007				
141	56	138	11416	0.011				
142	133	207	29766	0.030				
143	470	145	18089702	18.090				

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
1	COMP	140	67	VW	1695	1292
2	CC	140	41	VB	1128	1067
3	COMP	150	48	VW	1561	927
4	FL	145	61	VW	1036	975
5	COMP	20/90	58	VW	1448	1183
6	COMP	320	80	VW	1475	1049
7	FL	340	70	VW	1103	1000
8	COMP	100	47	VW	1682	975
9	COMP	105	54	VW	1512	963
10	COMP	95	58	VW	1366	936
11	FL	310	63	VW	1829	1719
12	FL	335	85	VW	1829	1658
13	FL	300	42	VW	1865	1670
14	COMP	145	71	VW	1585	1024
15	FL	40	72	VW	1646	1231
16	COMP	140	77	VW/CH?	1829	853
17	FL	135	42	VB	817	768
18	COMP	195	45	VW	1414	914
19	COMP	160	54	VW/CH?	1670	853
20	FL	135	100	VW	1036	841
21	FL	310	52	VB	866	792
22	COMP	40	40	VW	1207	866
23	COMP	170	48	VW/CH?	1695	902
24	COMP	135	54	VW/CH?	1585	902
25	CV	10	52	VB	829	817
26	CV	5	52	VB	829	817
27	CV	310	52	VB	829	817
28	CV	310	52	VB	841	817
29	CV	335	52	VB	841	817
30	CV	310	52	VB	829	817
31	FL	150	61	VW	1073	1000
32	COMP	50	50	VW	1207	927
33	CC	150	51	VB	732	677
34	COMP	140	61	VW	1795	1512
35	COMP	160	93	VW	1402	1280
36	COMP	150	89	VW	1646	1317

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
37	COMP	300	48	VW	1219	805
38	FL	30	79	VB	1231	1158
39	COMP	140	67	VW	1670	1109
40	COMP	140	78	VW	1524	1231
41	COMP	10	61	VW	1591	1372
42	COMP	0	61	VW	1609	1366
43	COMP	0	61	VW	1585	1366
44	COMP	350	69	VW	1597	1366
45	COMP	120	62	VW	1707	1335
46	COMP	130	61	VW	1707	1335
47	COMP	270	80	VW	1292	1268
48	COMP	320	37	VW	1317	1146
49	FL	55	38	VB	1158	1012
50	FL	270	73	VW	1231	927
51	FL	35	46	VW	1158	975
52	COMP	30	30	VW	1341	975
53	COMP	20	47	VW	1353	1049
54	CC	320	35	VB	1280	1128
55	COMP	350	53	VW	1463	1146
56	COMP	320	48	VW	1512	1158
57	COMP	340	40	VW	1524	1158
58	COMP	180	62	VW	1768	1265
59	COMP	300	58	VW	1609	1341
60	COMP	20	28	VW	1524	1341
61	COMP	225	39	VW	1707	1207
62	COMP?	140	59	VW	1878	1585
63	FL	20	61	VW	1774	1707
64	FL	350	61	VW	1768	1646
65	FL	340	61	VW	1695	1585
66	FL	355	100	VW	1646	1426
67	COMP	30	30	VW	1329	1219
68	COMP	300	47	VW	1548	1311
69	COMP	210	30	VW	1561	1481
70	CC	260	28	VB	1280	1207
71	COMP	30	52	VW	1366	1158
72	COMP	230	43	VW	1280	1076

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
73	COMP	230	45	VW	1469	1049
74	CC	150	70	VW	1512	1317
75	FL	40	67	VW	1768	1634
76	FL	25	58	VW	1823	1597
77	FL	345	50	VW	1573	1451
78	FL	340	55	VW	1646	1524
79	FL	290	66	VW	1817	1670
80	CC	50	29	VB	1500	1390
81	FL	20	54	VW	1451	1341
82	FL	40	53	VW	1707	1439
83	FL	45	158	VW	1768	1609
84	FL	75	46	VW	1646	1378
85	FL	145	38	VW	1634	1414
86	FL	80	61	VW	1707	1646
87	FL	170	82	VW	1439	1341
88	COMP	135	40	VW	1341	732
89	COMP	10	59	VW	1731	1207
90	COMP	110	80	VW	1341	975
91	FL	350	100	VB	1366	1256
92	COMP	140	100	VW	1341	1109
93	FL	85	76	VW	1682	1536
94	CV	335	28	VB	792	750
95	CC	355	14	VB	732	683
96	CC	345	22	VB	1341	1280
97	CV	185	73	VW	1402	1332
98	CC	310	60	VW	1341	1134
99	FL	340	54	VW	1244	1207
100	COMP	260	66	VW	1366	1210
101	FL	270	72	VW	1475	1113
102	COMP	290	55	VW	1670	799
103	COMP	60	62	VW	1250	866
104	COMP	60	60	VW	1280	853
105	COMP	50	68	VW	1158	850
106	FL	20	50	VW	975	853
107	FL	330	43	VW	1097	988
108	FL	330	40	VW	890	829

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
109	FL	130	35	VW	1457	1390
110	FL	0	48	VW	1487	1390
111	FL	0	48	VW	1408	1329
112	FL	20	68	VW	1585	1402
113	COMP	25	91	VW	1646	829
114	FL	35	44	VB	1036	914
115	FL	330	48	VW	1402	1341
116	FL	340	64	VW	1402	1317
117	FL	30	37	VW	1585	1463
118	COMP	330	89	VW	1768	1451
119	FL	30	51	VW	1402	1305
120	FL	335	49	VW	1219	1183
121	FL	325	54	VW	1463	1402
122	FL	60	84	VW	1829	1524
123	FL	345	82	VW	1646	1524
124	FL	300	47	VW	1585	1463
125	COMP	20	70	VW	1280	951
126	FL	25	47	VB	1036	988
127	CC	30	29	VB	981	975
128	COMP	60	73	VW	1439	975
129	FL	30	52	VW	1164	1024
130	COMP	340	47	VW	1646	1451
131	FL	345	24	VW	1646	1585
132	FL	30	32	VW	1768	1658
133	FL	25	71	VW	1573	1341
134	FL	20	57	VW	1341	1146
135	COMP	250	59	VW	1524	1000
136	FL	240	24	VB	1524	1487
137	FL	285	56	VW	1622	1548
138	COMP	230	61	VW	1707	1487
139	FL	230	74	VW	1670	1500
140	FL	230	38	VB	1524	1500
141	FL	310	79	VW	1829	1768
142	CC	150	106	VB	1158	1012
143	FL	75	66	VW	1768	1463

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National Park Service
U.S. Department of the Interior



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