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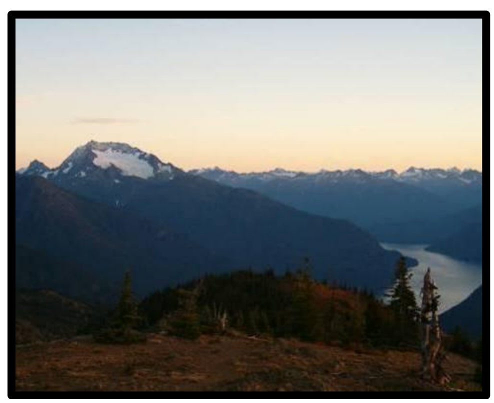
Natural Resource Stewardship and Science

Geomorphology of the Upper Skagit Watershed

Landform Mapping at North Cascades National Park Service Complex, Washington

Natural Resource Technical Report NPS/NCCN/NRTR—2012/568



ON THE COVER

From upper right to lower left: Photograph of the north face of Mt. Spickard from Silver Glacier taken by Stephen Dorsch of the NPS; Perry Creek taken by Nicole Bowerman of the NPS; The south slope of Desolation Peak with Mt. Hozomeen visible to the north taken by Sharon Brady of the NPS; The north face of Jack Mountain and the Nohokomeen Glacier from south face of Desolation Peak.

Photograph by: Sharon Brady, NPS

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

This report is available from the North Coast and Cascades Network (http://science.nature.nps.gov/im/units/nccn/reportpubs.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

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Contents

Contents (continued)

Page

Figures

Page

Figures (continued)

Page

Tables

Page

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 Upper Skagit Watershed, which includes all creeks that flow into Ross Lake. On the west side of Ross Lake are Big Beaver, Little Beaver, Silver, Arctic, NoName, and Skymo Creeks. On the east side of Ross Lake are Hozomeen, Lightning, Dry, Devils, May, Roland, Ruby, and Panther Creeks. 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 Upper Skagit Watershed, particularly mass movements.

The Upper Skagit Watershed is defined by the Straight Creek Fault, the Ross Lake Fault Zone, the Hozomeen Fault and northeast-southwest compressional faults. Between the Straight Creek Fault and Ross Lake Fault Zone is the Chelan Mountain terrane, composed mainly of Skagit Gneiss Complex orthogneiss. West of the Ross Lake Fault Zone include intrusive plutons that were emplaced during a period of crustal extension. To the east of the Ross Lake Fault Zone are the older rocks of the Hozomeen and Methow terranes which are mostly sedimentary in nature. The topography of the Upper Skagit Watershed reflects multiple glaciations during the past 2 Ma. The west side valleys are U-shaped troughs that extend all the way to Ross Lake, that enter Skagit Valley as hanging valleys. The east side valleys, experiencing alpine glaciation restricted to upper valleys, enter the Skagit Valley as winding narrow river canyons. 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.

Climatic conditions vary widely in the Upper Skagit Watershed with large gradients in temperature and precipitation. The most pronounced difference is between watersheds on the wetter and cooler west side and drier and hotter east side of Ross Lake. Snow course data reveals that the snow pack generally reaches its maximum depth at the higher elevation sites by late April while the lower elevation sites generally reach their maximum in March. November is routinely the wettest month, most precipitation occurs during the winter months of November through January. Vegetation variation between the west and east sides of the lake dramatically illustrate the difference between climate and hydrologic regimes. Douglas-fir, western hemlock and western red-cedar make up the lowland forest on the wetter west side of Ross Lake. Ponderosa pine, Douglas fir and lodgepole pine dominate on drier sites found on the east side of Ross Lake.

A suite of twenty-nine 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 west of Ross Lake sub-watersheds, 56.7% is valley wall and 12.7% is high elevation cirque; with only 0.91% as riparian (floodplain, valley bottom and alluvial fan). On the west side of Ross Lake, the main stem of both the Big and Little Beaver Creek are classic U-shaped glacial valleys with a flat valley bottom, straight profile and low gradient. Other glacial characteristics of the valleys include, oversteepened valley walls, hanging tributary valleys and truncated valley spurs. 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.

Within the east of Ross Lake sub-watersheds, 58.2% is valley wall and 2.3% is river canyon, reflecting the steep and narrow nature of the V-shaped east side tributaries. Drainage of glacially dammed lakes caused divide lowering and migration northwards, as well as modification of dendritic, trellis and other drainage patterns. Lightning Creek is an example of glacial rearrangement of drainage due to the advance/retreat of the Cordilleran Ice Sheet. High elevation landforms are under-represented on the east side of Ross Lake, since the headwaters of these creeks are outside of NOCA, with the exception of Panther Creek.

On the west side of Ross, mass movements constitute 2.8% of the landforms. The forty-two debris avalanches on the west side total an area of 7,387,600 m^2. Of these debris avalanches, thirty-one delivered an estimated total of 178,283,400 m^3 of sediment to streams. On the east side of Ross, mass movements constitute 3.2% of the landforms, with a total of seventeen debris avalanches were mapped. Of these debris avalanches, fifteen delivered a total of ~ 57,450,000 m^3 of sediment to streams. The glacially over-steepened valley walls, aspect influenced erosion on the north -facing slopes and structural weakness associated with faults and hydrothermal alternation are likely responsible for the majority mass movement avalanches and rock falls throughout the sub-watersheds. The low number of slumps and creeps throughout the Upper Skagit Watershed may be reflecting the high amount of bedrock, the overall stability of vegetated valley walls (especially on the west side of Ross Lake) and the lack of large exposed deposits of glacial drift/till in the floodplain. Such small deposits are difficult to identify in the field and in aerial photographs and thus may be under-represented.

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, hydrology and vegetation as they affect landform processes. The study area for this report is the Upper Skagit Watershed, which is defined as drainages within NOCA that flow into Ross Lake. On the west side of Ross Lake this includes Little Beaver, Big Beaver, Silver, Arctic, Skymo and No Name Creeks. On the east side of Ross Lake this includes Lightning, Hozomeen, Dry, May, Roland, Devils, Ruby and Panther Creeks.

Background information presented in this report focuses on key factors that influence the development of landforms in Upper Skagit 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 topographic 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 effect 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 Upper Skagit Watershed provides several unique management challenges for the NPS. Containing the largest lake in the NOCA complex, it is estimated that 20-25% of all visitor use in NOCA occurs along the shores of Ross Lake and thus careful management of Park resources is warranted (NPS, Rosemary Seifried, Wilderness Ranger, phone call, May 9, 2009). Landform maps can be consulted in order to relocate trails, campsites and other recreational and sanity 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. 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 and mapping of soils (Riedel and Probala 2005).

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 Rainer National Park (MORA) and Olympic National Park (OLYM), Ebey's Landing National Historical Reserve and San Juan Island National Historical 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" (Davis 2004, 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 Upper Skagit Watershed, which includes a discussion of the unique geomorphology and history of the Upper Skagit 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 Upper Skagit Watershed is located in the northeast portion of North Cascades National Park Service Complex (NOCA), in the North Cascades physiographic provinces (McKee 1972) (Fig. 1). The Skagit River begins in British Columbia and flows into Ross Lake, just north of the Canadian border. Ross Lake is a reservoir created in 1950 by Seattle City Light by damming of the Skagit River for a hydroelectric power project. The lake is 34 km long and on average 1.5 km wide. This report defines the Upper Skagit Watershed as the headwaters of the Skagit River, which includes Ross Lake and its tributaries (Fig. 1). Ross Lake flows into Diablo Lake and Gorge Lake, two other reservoirs created for hydroelectric projects. Upon being released in the Newhalem area, the Skagit River resumes its journey west to the Puget Sound. The Skagit River basin is the largest drainage in the Puget Sound, supplying more than 30% of its total freshwater input and draining more than 8,000 km^2.

The west side of Ross Lake contains the sub-watersheds of Big Beaver, Skymo, Arctic, No Name, Little Beaver and Silver Creeks (Fig. 2). Across the lake on the east side are the drier and slightly warmer sub-watersheds of Hozomeen, Lightning, Dry, Roland, May, Devils, Ruby and Panther Creeks. This report focuses on the Big Beaver, Little Beaver, Silver, Lightning, Hozomeen and Panther drainages due to their size and the field time spent at these locations. With the exception of Panther and Hozomeen Creek, the east side sub-watershed's headwaters were not as extensively mapped since the NOCA boundary extends only 6 km east of Ross Lake.

The local relief exceeds 2000 m in the Upper Skagit Watershed, starting at an elevation of 489 m at Ross Lake and climbing over 2500 m in the Picket Range (Fig. 2). Two major divides compose the western boundary of the Upper Skagit Watershed. The northwestern boundary of the watershed, from Whatcom Peak to Mt. Spickard, is 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 Mountain, on the divide between the Chilliwack and Skagit systems, marks the beginning of the "Skagit Crest," a major drainage divide that runs south through the Picket Range and is breached at Skagit Gorge (Riedel 2007) (Fig. 2). The glaciated peaks of the Skagit and North Cascades Crest provide meltwater to all the sub-watersheds that drain from the west into Ross Lake.

Notable peaks on the east side of Ross Lake include Hozomeen, Desolation, Skagit Peak, Jack Mountain, Crater Mountain and Spratt Mountain. Many of the smaller sub-watersheds (Dry, May and Roland Creeks) are re-charged from the waters off of Jack or Crater Mountain, whose summits are both located outside of the NOCA complex. Jack Mountain, at 2763 m, is the tallest peak on the east side of Ross Lake. Panther Creek drains the north face of Ragged Ridge (the collective peaks of Cosho, Katsuk, Kimtah, and Mesahchie) and the south-eastern side of Ruby Mountain. This sub-watershed contains the highest concentration of glacial ice on the east side and shares many characteristics with the west Ross Lake sub-watersheds. Throughout this report the variation of climate and geology will be highlighted between the sub-watersheds on the east and west side of Ross Lake and how they have influenced landform development.

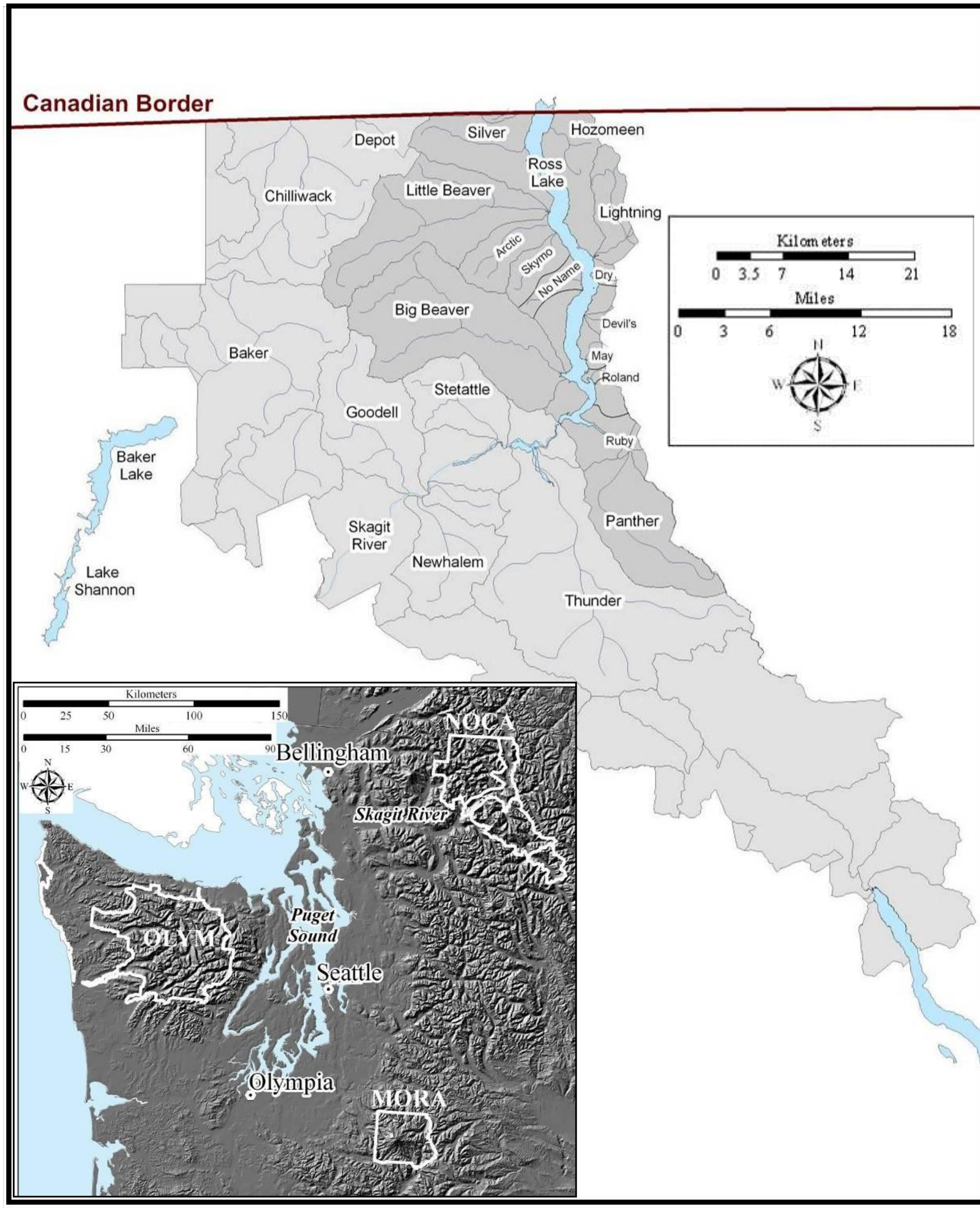

Figure 1. Map showing the location of Skagit River and adjacent watersheds within North Cascades National Park Service Complex (NOCA). Insert map shows the location of NOCA within Washington State, as well as Mount Rainer (MORA) and Olympic (OLYM) National Parks.

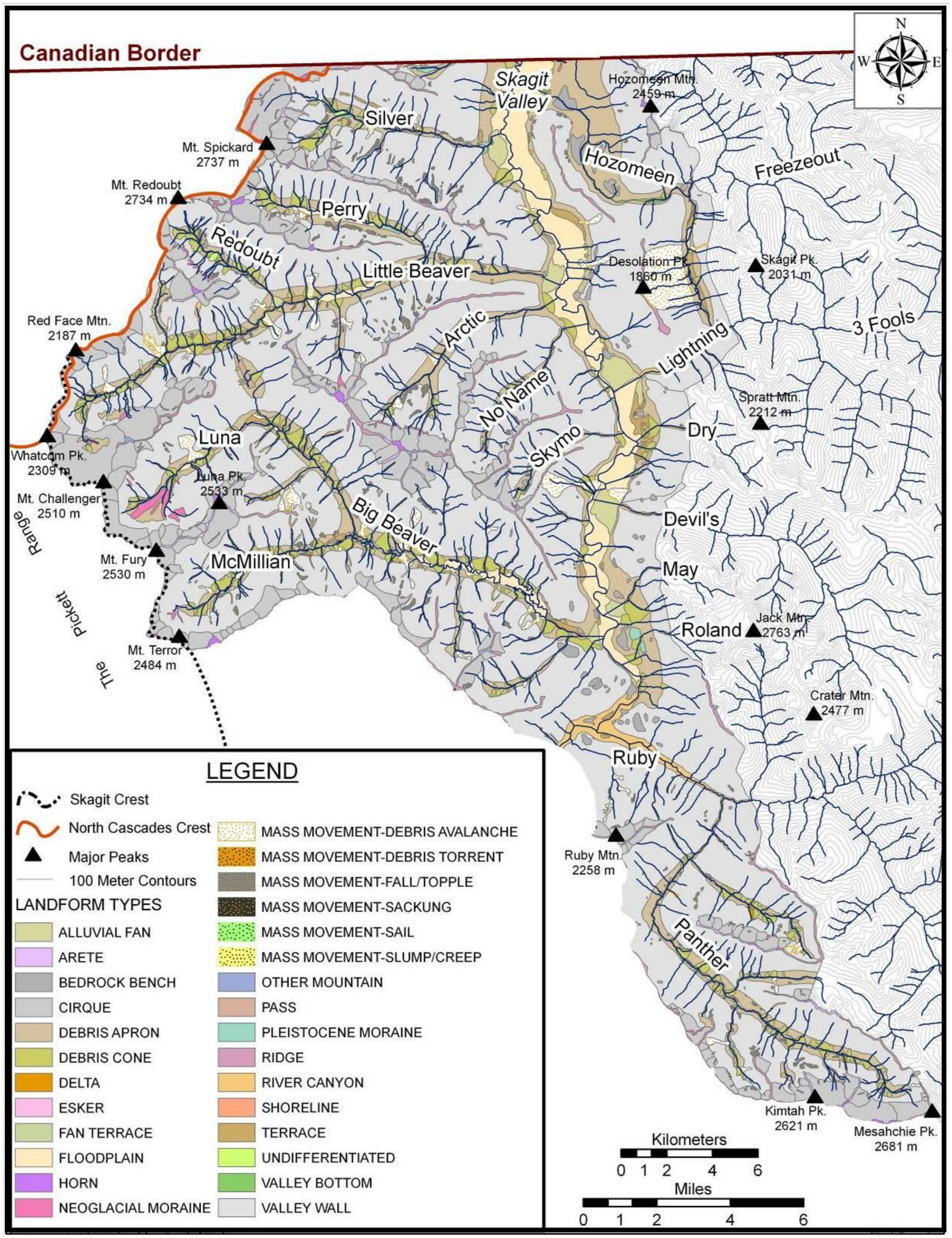

Figure 2. Landform map (1:24,000) showing the distribution of landforms in the Upper Skagit Watershed as well as the locations of the sub-watersheds and peaks referred to in the text.

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). Bedrock of the North Cascades was formed by a complex series of igneous, metamorphic and tectonic events beginning in the Cretaceous period 145-65 million 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 (terranes) to the west coast of North America between 200 million (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

The Upper Skagit Watershed is positioned between the three major fault zones: the Straight Creek Fault, the Ross Lake Fault and the Hozomeen Fault (part of the Ross Lake Fault Zone) (Tabor and Haugerud 1999) (Fig. 3). The Straight Creek Fault is thought to be a 400 km long north-south trending strike-slip extensional fault. It begins in Central Washington and extends 210 km into Canada, where it is named the Fraser River Fault Zone (USGS 2003a). The fault separates low-grade metamorphic rocks to the west from highly metamorphosed rocks of the North Cascades core to the east. The Ross Lake Fault separates the metamorphic core of the Cascades from the sedimentary and volcanic deposits of the Methow Domain to the east. The Ross Lake Fault System is part of a 500 km long zone of high angle faults in the northern Cordillera that trends northwest-southeast. The Big Beaver valley and other sub-watershed that drain into Ross Lake are influenced by the preferential trend of this fault system. Tertiary arc plutons, primarily of the Chilliwack Composite Batholith, have erased some evidence of both faults in Washington and southernmost British Columbia. The Hozomeen Fault is east of Ross Lake and defines the trend of upper Lightning Creek. Lesser faults include the Thunder Lake fault, which crosses McMillan Creek up into Arctic Creek follows the trend of the Straight Creek Fault.

Regional uplift and exhumation of the North Cascades that began in the Eocene (45-36 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, Lightning Creek in Manning Park, British Columbia and possibly the Skagit Gorge (Riedel 2007).

There appears to be no appreciable Holocene tectonic activity along any of these three faults systems within the Upper Skagit Watershed. Most are intruded by younger batholiths that do not show off-set. Recorded seismic activity within the Upper Skagit Watershed has been minor over the past 100+ years. From 1963 to 2009, four <3 magnitude earthquakes had epicenters located within the Ross Lake area (USGSa 2009). Two occurred near the mouth of Big Beaver, one on the slopes of Ruby Mountain and one near the mouth of Hozomeen Creek. It was once proposed that the Ross Lake area was the epicenter of the largest earthquake in the state of Washington's history, a 6.8 magnitude event that occurred on December 15, 1872 (Malone and Bor 1979). However recent research places the epicenter closer to Lake Chelan (Bakun et al. 2002)

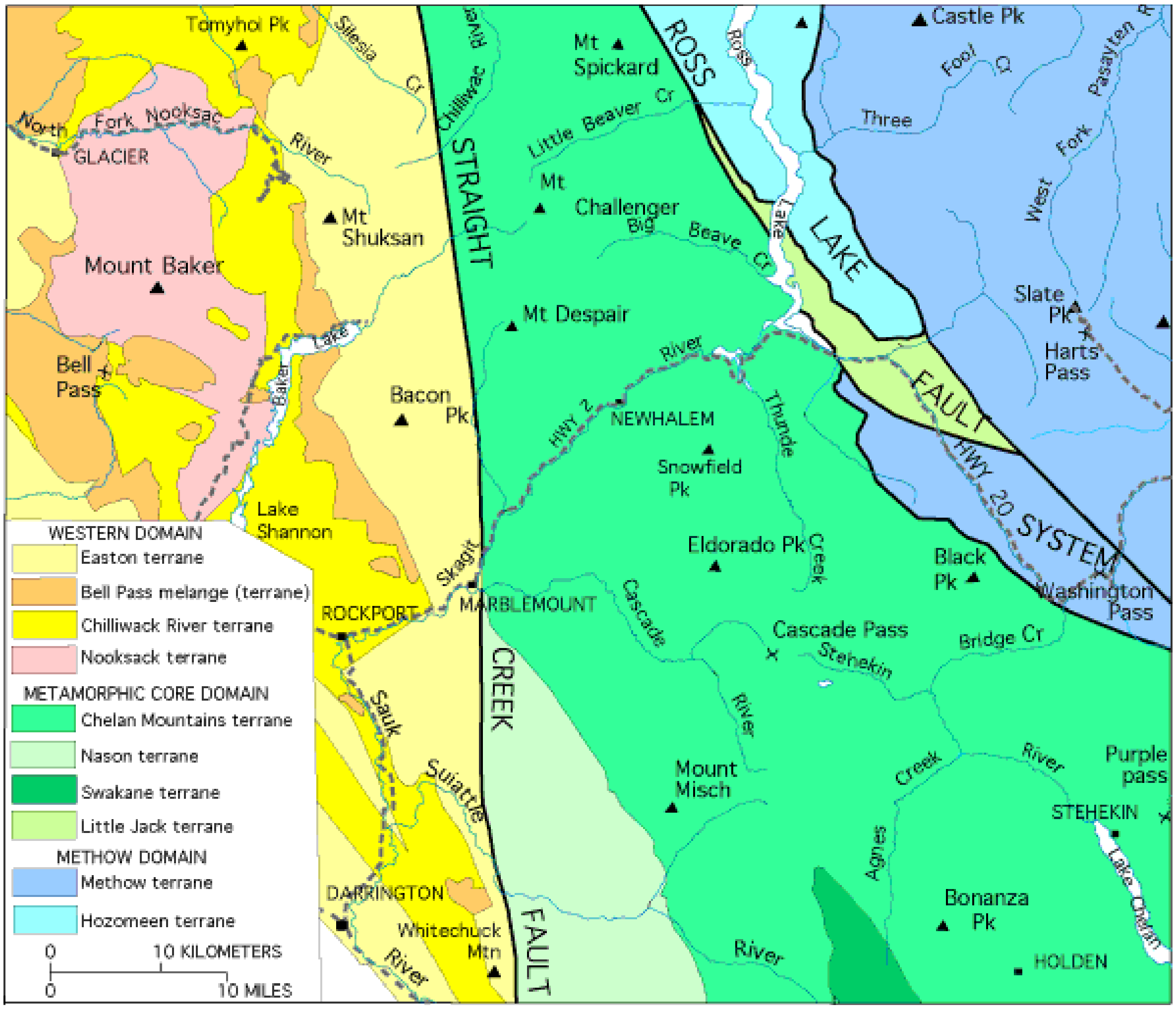

Figure 3. Major fault systems and terranes in the North Cascades (from Tabor and Haugerud 1999).

2.2.2 Geologic Units

A generalized geologic map provides a regional perspective on the geology in the Upper Skagit Watershed and neighboring watersheds (Fig. 4). A detailed description of the geology is found in the Tabor et al. publication (2003) and is summarized in the paragraphs below.

Between the Straight Creek Fault and Ross Lake Fault Zone is the Chelan Mountain terrane, composed mainly of Skagit Gneiss Complex (Fig. 3 and 4). The Skagit Gneiss Complex is easily viewed in outcrops along State Highway 20 from Newhalem through Skagit Gorge to Pumpkin Mountain. Consisting of mainly banded biotite/amphibolite gneiss and banded tonalite, these rocks are thought to be derived from intense metamorphism of the Cascade River Schist and Napeequa Schist, both thought to be arc-derived.   The exception to this is the banded tonalite, which is thought to be intrusive igneous material (Haugerud et al 1991). The Skagit Gneiss Complex composes major sections of Little Beaver, Big Beaver, Panther and Ruby Creeks, as well as small parts of upper Arctic and No Name Creeks. Lower Panther Creek is composed mainly of orthogneiss of the Skagit Gneiss Complex with Fourth of July Pass containing schist, amphibolite, rare marble and ultramafic rocks.

Other rocks west of the Ross Lake Fault Zone include intrusive plutons that were emplaced during a period of crustal extension that began at 35 Ma and by crustal shortening that continues today. These plutons include the intrusive rocks of the Chilliwack Composite Batholith, mainly of the Snoqualmie Family, which are mostly biotite-hornblende tonalite and granodiorite in composition. These intrusive rocks are on display along International, Little Beaver, Arctic, Upper Big Beaver and the southern slopes of Silver Creek. Pockets of the Index Family, in the vicinity of Pass Creek, on Mt. Spickard and just north of Whatcom Pass, are composed of gabbro and diorite. The headwaters of Redoubt Creek and Silver Creek contain quartz monzodiorite of the Cascade Pass Family.

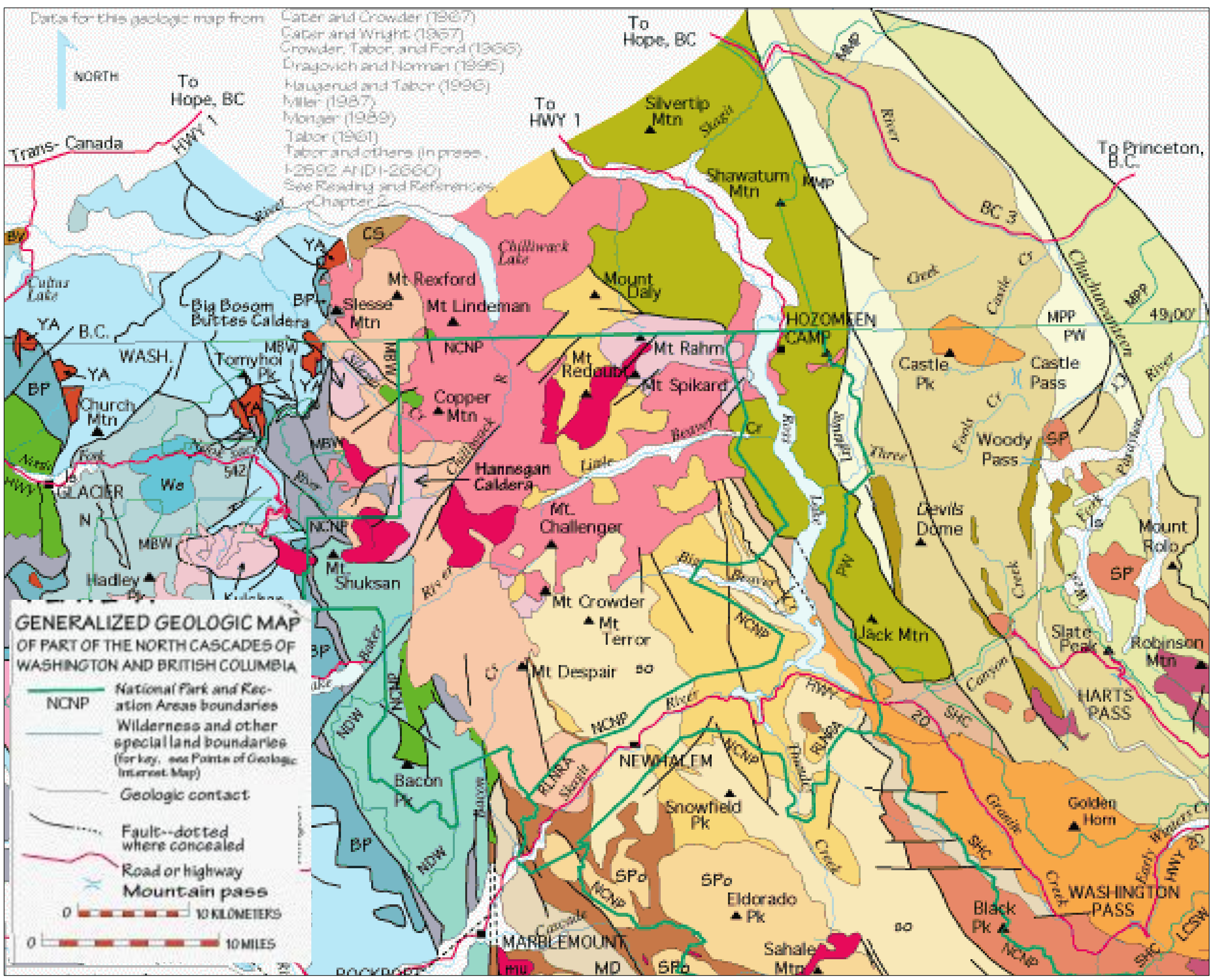

Figure 4. Bedrock map showing the Upper Skagit Watershed (note location of Ross Lake) and some of the adjoining watersheds (see Tabor and Haugerud 1999 for geologic map key).

The Napeequa Schist, part of the Chelan Mountains terrane, is exposed on the top of Ruby Mountain and within Panther Creek. This deposit has an oceanic origin and is composed of hornblende-biotite schist with local serpentinite, talc, tremolite and olivine-talc rocks. The remainder of Ruby Mountain is composed of the Skagit Gneiss Complex. The headwaters of Panther Creek are composed of tonalitic orthogneiss with pockets of schist and ultramafic rocks of the Chelan Mountains terrane. The north side of Elija Ridge contains the Elija Ridge schist (metamorphosed rocks of the Methow Ocean). Pockets of the Chelan Mountains terrane are typically fault-bound in a myriad of directions that will be discussed in detail later in the report under the sub-watershed of Panther Creek.

A small portion of the Upper Skagit Watershed includes the volcanic rocks of Mount Rahm, which are along the north side of Silver Creek and compose the headwaters of International Creek. Emplaced 35 – 24 Ma, these volcanic rocks are mainly dacitic breccias, welded tuffs and flows with sandstone and conglomerate interbeds. The drainage pattern of Silver and Little Beaver Creeks likely originated from radial drainage off of old volcanoes associated with these rocks (Riedel 2007). A small outcrop of this unit is also at the outlet of Hozomeen Creek.

To the east of the Ross Lake Fault Zone are the older rocks of the Hozomeen and Methow terranes (Fig. 3 and 4). The Hozomeen terrane is composed of mostly greenstone, chert, clastic sedimentary rock, gabbro and minor argillite. An oceanic rock assemblage, the Hozomeen Group represents the accretion of terranes along the west coast of North America between 200 and 50 MYA. These rocks are exposed in a continuous north to northwest trending belt ~132 km long from Crater Mountain to the Fraser River Fault in British Columbia. They make up the majority of Hozomeen, Devils, Dry and May sub-watersheds, as well as the outlets for Lightning, Skymo, Arctic, No Name and Little Beaver Creeks. The Cretaceous Methow terrane is exposed along the east face of Desolation Peak and the Lightning Creek drainage. Known as the Three Fools sequence of the Methow terrane, this unit is mainly thick-bedded quartzofeldspathic marine sandstone with thin beds of sandstone and argillite. It is bounded to the west by the Hozomeen Fault. This unit is also exposed at the headwaters of Dry Creek.

Geologic units of localized interest in the Upper Skagit Watershed include the Skymo Complex which consists of metamorphosed troctolite, gabbronorite and anorthosite. This unit is small and trends northwest along the fault zone, composing the headwaters of Skymo, upper No Name and a minor amount of the Arctic Creek drainage. Parts of Skymo, Arctic, No Name, Roland and May Creeks are also composed of the Little Jack Mountain terrane, which contains quartz-mica phyllite and biotite schist with local staurolite, garnet, andalusite and sillimanite. The outlets of Panther and Roland Creeks are mapped as the Ruby Creek Heterogeneous Plutonic Belt of Misch which includes granitic to gabbroic plutonic masses in the phyllite and schist of Little Jack Mountain. Little Jack Mountain schist is considered as part of the Ross Lake Fault Zone and composes the east side of Ross Lake between Ruby Creek and the outlet of May Creek at Roland Point.

2.3 Glacial History

The topography of the Upper Skagit 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. Glaciations have 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 35 to 11.5 thousand years ago (Ka) (Armstrong et al. 1965) (Fig. 5).

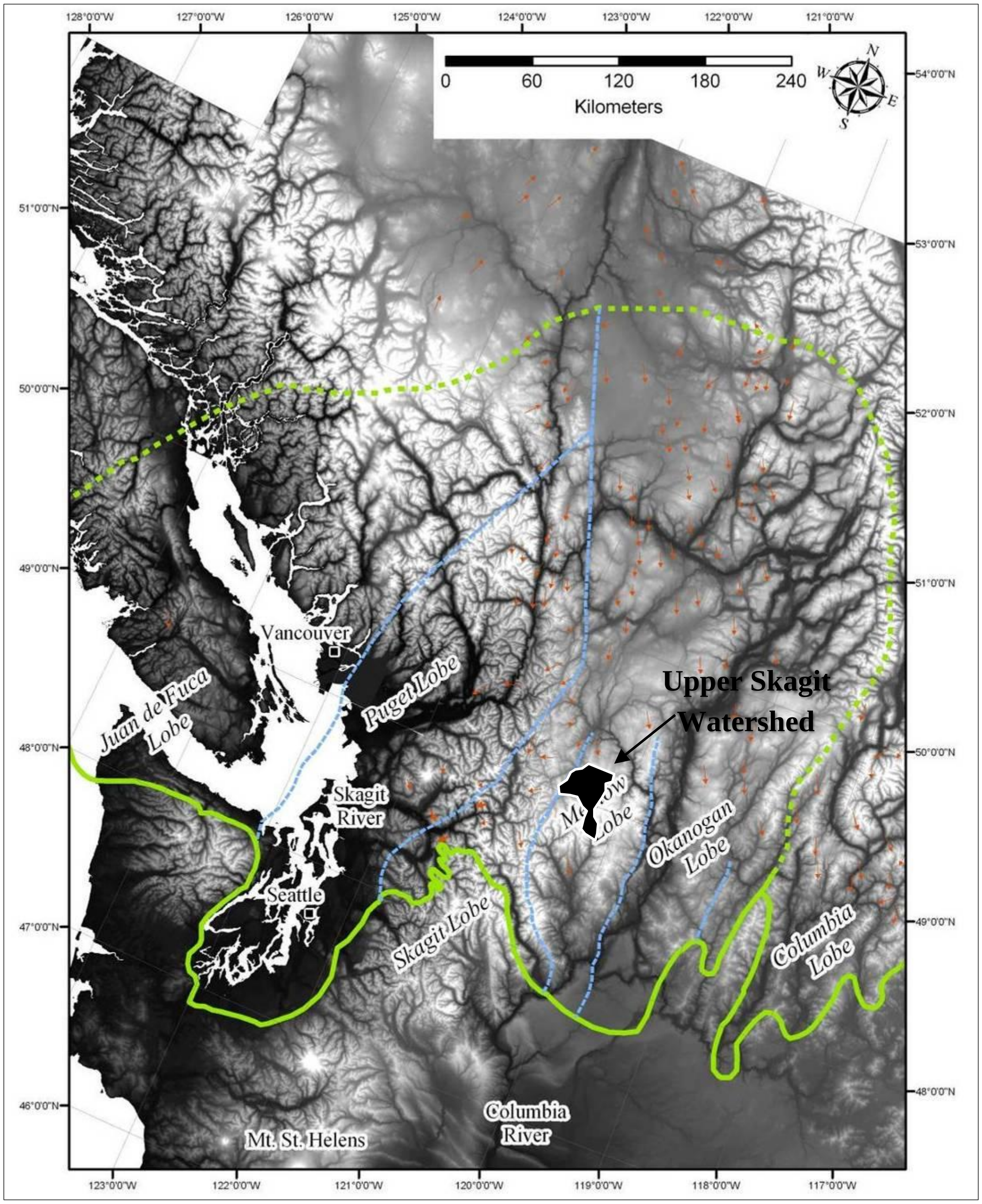

Figure 5. Map of the known extent of the Cordilleran Ice Sheet during the Fraser Glaciation. Note the various lobes of the ice sheet mapped, extending down into the United States.

Three major periods of intensive glacier growth are recorded in deposits in the Upper Skagit Watershed. The Evans Creek stade marks the beginning of the Fraser Glaciation and has been dated in the Skagit Valley at ~ 30 Ka calendar years before present (cal. years B.P.) (Riedel 2007). Alpine glaciers advanced and filled the main valleys of Little Beaver and Big Beaver creeks and associated tributaries to depths of several hundred meters. Impacts from the glaciers are evident throughout the Little and Big Beaver valleys, and the greater North Cascade range, and include glacier-carved U-shaped valleys and truncated valley spurs. Tributary systems were left as hanging valleys with bedrock canyons or narrow stepped waterfalls at their mouths.

During the Evans Creek stade the Big Beaver Glacier dammed the Skagit River at Roland Point at ~ 28.8 Ka cal. years B.P. (Fig. 6), creating Glacial Lake Skymo (Riedel 2007). These early Fraser Glaciation deposits are visible in an outcrop 3 km south of the Skymo Creek outlet. Wood from these deposits constrains the timing of glaciolacustrine deposition of Glacial Lake Skymo between 28.7 Ka to 21.4 Ka cal. years B.P. Continuous lake sedimentation from Glacial Lake Skymo indicates that the alpine glaciers in the upper Skagit Valley remained in advanced positions for 8,000 years.

Evans Creek stade moraines and ice-marginal landforms were subsequently eroded away by the ice sheet during the Vashon stade. Deposits were only preserved in small pockets on the down-ice side of bedrock obstructions. Work in adjacent areas indicates that the most recent period of ice sheet glaciations of the Upper Skagit Valley occurred between ~19.5 and 11 Ka cal. years B.P. (Porter and Swanson 1998). Little research has been done on the Vashon stade in the North Cascades, but some has been done on the later Sumas stade, which marks the end of the Fraser Glaciation. The Sumas stade has been dated in the Skagit Valley as extending from 14.1 to 10.8 Ka cal. years B.P. (Riedel 2007).

Equilibrium line altitudes (ELAs) have been estimated for former glaciers within the Skagit Valley. The ELA is the elevation on a glacier where ablation balances the accumulation for one full year. This research shows that the Evans Creek stade alpine glaciers were larger and extended to lower elevations than their counterparts in the Sumas stade (Riedel 2007). Few moraines remain in the Upper Skagit Watershed as evidence of Pleistocene glaciation. These deposits are present in International, Silver and Little Beaver sub-watersheds.

2.3.1 Neoglacial

Glaciers in the Upper Skagit Watershed probably reached their minimum extent since the last ice age 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 occurred between 1350 and 1900 AD, in what is called the Little Ice Age.

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 valleys on the west side of Ross Lake to depths of several hundred meters.

There are three hundred and twelve glaciers present within NOCA today. The NPS staff members at NOCA are currently monitoring four glaciers: Noisy and North Klawatti glaciers are on the west side of NOCA, Sandalee Glacier on the east side and Silver Glacier which is at the headwaters of Silver Creek. Silver Glacier is the only glacier that NOCA monitors that drains into Ross Lake. A summary of the results from the Silver Glacier follows in the Hydrology section of this report.

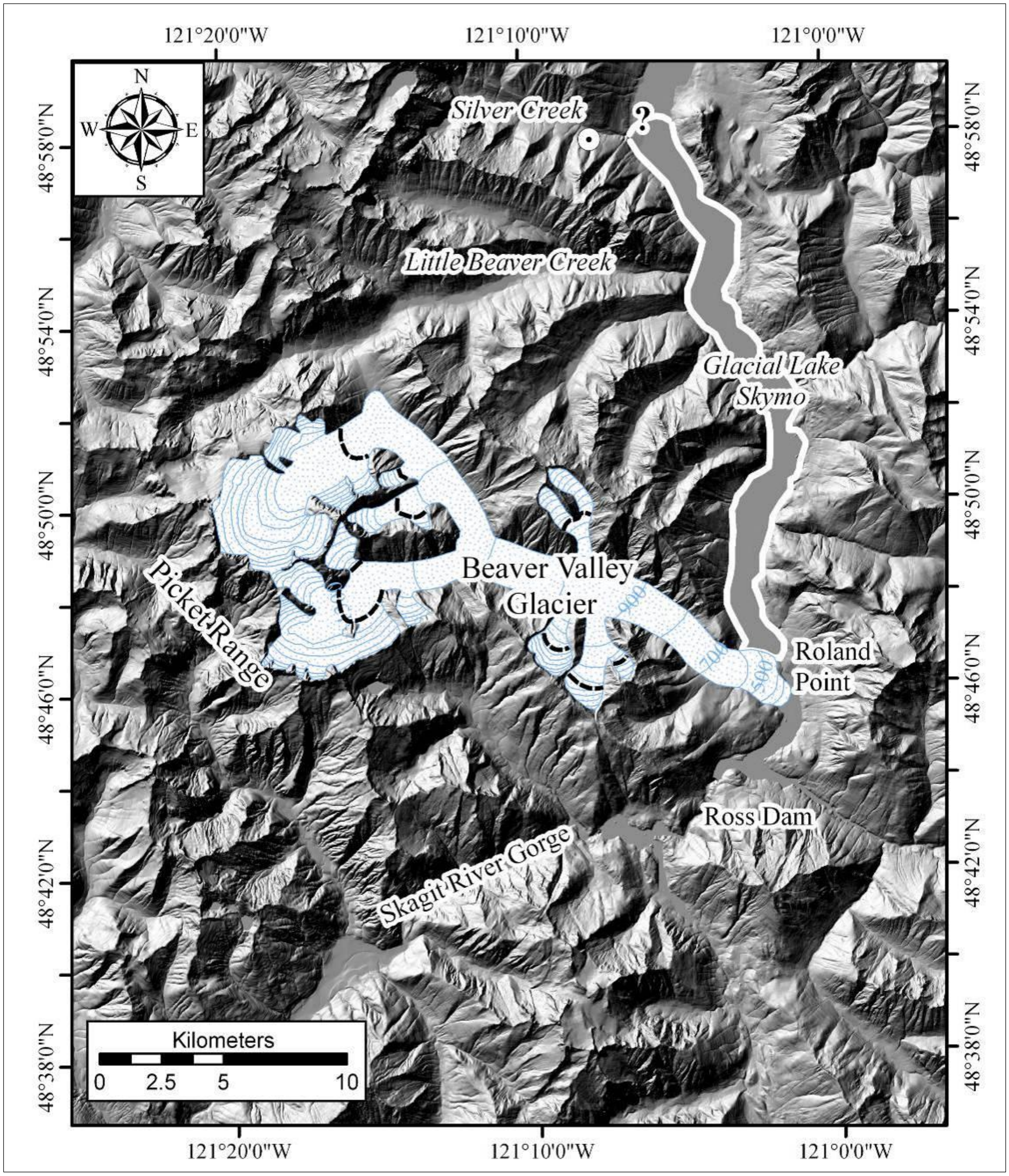

Figure 6. Reconstruction of Big Beaver Glacier during about 25 Ka , showing the approximate extent of Glacial Lake Skymo. Ice surface contour interval is 100 m with dashed lines showing approximate ELA

(Riedel 2007). Valley glaciers in adjacent valleys are not shown and were likely extensive, but did not enter Skagit Valley.

2.4 Climate

Climate is the primary driver of surficial processes that have shaped the Upper Skagit Watershed, including glaciers, rivers and mass wasting. Climatic conditions vary widely in the Upper Skagit Watershed with large gradients in temperature and precipitation. The most pronounced difference is between watersheds on the wetter and cooler west side and drier and hotter east side of Ross Lake. The effect of this climatic asymmetry, played out through the immense erosion that occurred during the great ice ages, has resulted in distinctly different topography on either side of Ross Lake which will be discussed later.

Steep climate gradients are observed in data from weather monitoring stations within the Upper Skagit Watershed. Monitoring sites include: four Natural Resource Conservation Service (NRCS) snow course sites, two NRSC snowpack telemetry (SNOTEL) stations and a National Weather Service (NWS) Cooperative Network (COOP) station at Ross Dam (Fig. 7). The snow course stations are located at Beaver Pass, Beaver Creek Trail, Browntop Ridge (between the Silver and Little Beaver valleys) and Lake Hozomeen. The SNOTEL stations are located at Beaver Pass and at Hozomeen. A Cooperative Network station was also located at Beaver Pass, but data only extends from 1941 to 1971. Therefore monitoring sites are present on both sides of Ross Lake to qualify climate variability.

Snow course data reveals that the snow pack generally reaches its maximum depth at the higher elevation sites (Beaver Pass and Brown Top Ridge) by late April while the lower elevation sites (Beaver Creek and Lake Hozomeen) generally reach their maximum in March. Maximum snow depth and snow water equivalent (SWE) for the four snow courses are listed in Table 1. While Lake Hozomeen and Beaver Creek Trail have fairly similar depth and SWE, Lake Hozomeen on the east side receives less snowfall.

Table 1. Summary of data from the four snow course sites located in the Upper Skagit Watershed (NRCS 2009a). All measurements were taken as of May 1st except for the last two rows or if stated otherwise. Data is provisional and subject to revision.

	Beaver Creek Trail	Beaver Pass	Brown Top Ridge	Lake Hozomeen
Elevation (m)	671	1122	1829	853
Period of Record	1944-In Service	1944-In Service	1970-In Service	1971-In Service
Record Snow Year	1999	1954	1972	1971
Max. Depth (cm)	117	338	577	137
Max. SWE (cm)	62 (1971)	146	265	62
Lowest Snow Year	1981	1981 & 2005	2005	2005
Min. Depth (cm)	13 (total for year)	33	160	3 (total for year)
Min SWE (cm)	2 (February)	8	66	0.3 (January)
Max. Depth recorded (date/cm)	April, 1956/218	April, 1956/460	March, 1999/638	March, 1974/170
Max. SWE recorded (date/cm)	March, 1954/71	April, 1956/185	April, 1999/268	April 1971/65.5

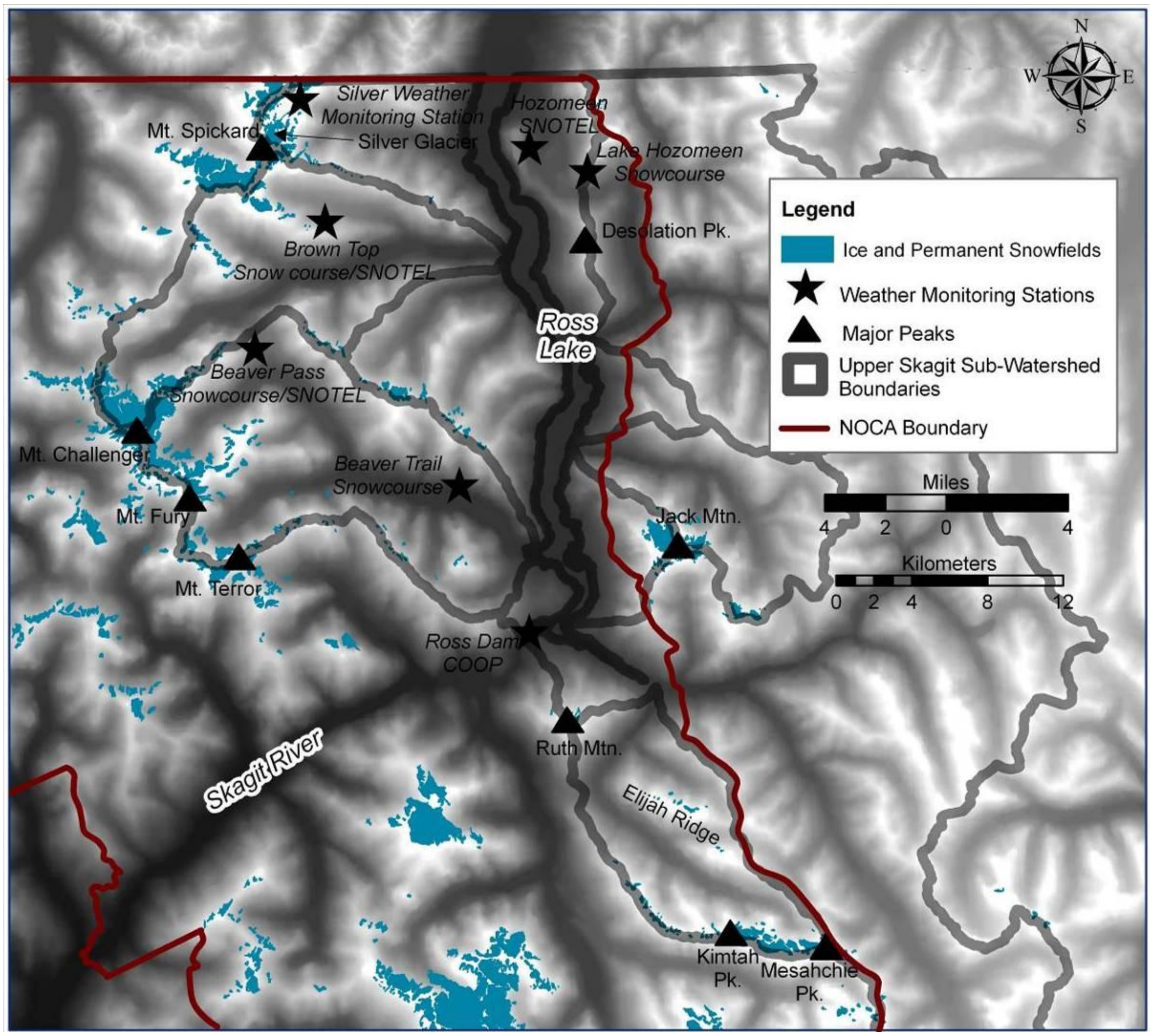

Figure 7. Digital elevation model showing permanent snowfields and glaciers in and around the Upper Skagit Watershed, as well as weather monitoring stations mentioned in the text.

Rainfall and air temperature data was collected from NRCS SNOTEL sites and a NWS COOP site (Table 2). November is routinely the wettest month, averaging 36 cm at Beaver Pass, 17 cm at Hozomeen and 23.8 cm at Ross Dam. Most precipitation occurs during the winter months of November through January, averaging 54% of the annual total. Conversely, the summer months of June through August tend to be the driest, averaging only 6-7% of total annual accumulation. While the two sites are quite different in elevation, Hozomeen is drier and warmer overall. The NWS COOP station at Ross Dam has been collecting precipitation, temperature, snowfall and snow depth data since 1960. At 700 m above sea level, data from this site reflects conditions on western Ross Lake, with a mean annual precipitation of 147 cm.

A new SNOTEL site is was installed in the fall of 2009 on Browntop Ridge. A climate monitoring station was also installed on Silver Glacier, which would collect real-time meteorological data, including temperature, wind speed and direction, relative humidity, snow depth and solar radiation. The Silver Glacier climate station will be the highest near-real time station in the North Cascades at 2316 m (NOCA NPS 2009).

Table 2. Summary of two SNOTEL sites (NRCS 2009b) and one NWS COOP site (NWS COOP 2009). Data is provisional and subject to revision.

	Beaver Pass	Hozomeen	Ross Dam
Watershed	Skagit	Skagit	Skagit
Elevation (m)	1106	503	700
Beginning Year of Data Collection	2001	2001	1960
End Year of Data Collection	In Service	In Service	In Service
Mean Annual Temperature (° C)	4.7	8.0	9.3
Average Low Temperature (° C)/Month	-4.8/Jan.	-3.7/Jan	0.6/Jan
Average High Temperature (° C)/Month	22.5/July	29.0/July	19/August
Mean Annual Precipitation (cm)	178.5	95.3	147
Average High Precipitation (cm)/Month	49.3/Nov.	28.7/Nov.	25.7/Nov.
Average Low Precipitation (cm)/Month	1.3/Aug.	0.5/Aug.	3.0/July

2.5 Hydrologic Setting

Hydrologic processes have significant effects on landform development, specifically 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 effect of the study area hydrology on landform development are addressed in the Discussion section of this report.

In general, the discharge of streams and rivers in the Upper Skagit Watershed often decreases drastically in late summer and winter, when glacial melt water dissipates and rainfall is minimal. These times of low flow can expose sand and gravel bars and dried up side channels. Rivers and creeks can typically reach flood stages during both the spring and late fall. Large rain on snow events, which can occur during the early spring or late fall can reinitiate first order stream flow, flood rivers, transport debris, erode river banks and mobilize large woody debris. During large magnitude events water levels rise, shifting channel and gravel bar positions and reintroducing water to old side channels. Typically a large amount of sediment and woody debris can be provided from smaller side channels to larger main creeks, as well as to Ross Lake itself.

Hydrologic data has been collected on the Skagit River at Newhalem site since 1909 (USGSb 2009) (Fig. 8). This data is likely affected to a certain extent by activities on the three Seattle City Light dams on the Skagit River: Gorge Dam (completed in 1921), Diablo Dam (completed in 1930) and Ross Dam (completed in 1953). This data reveals that spring floods dominated the upper Skagit hydrologic system until the 1970’s when fall floods became higher peak flow events. Peak streamflow data is also available for Big Beaver Creek (1941-1969) and Ruby Creek (1949-1969) (USGSb 2009). This data reveals that Big Beaver Creek primarily had higher discharge in the fall (highest flow recorded in October of 1963 at 125 m^3/second) while Ruby Creek was spring flood dominated, although the highest flow recorded was also in the fall (245 m^3/second in November of 1949).

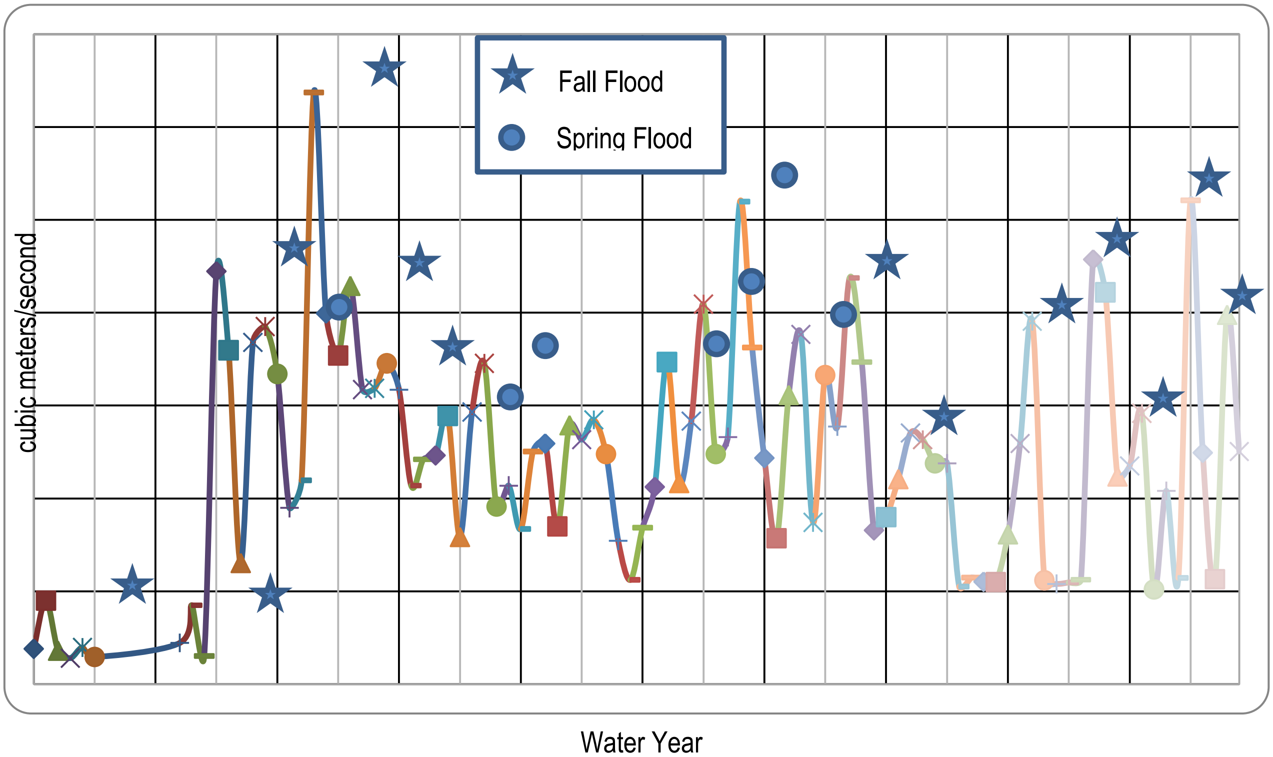

Figure 8. Peak annual flow for the Skagit River, from 1909 to 2008, from the gauging station in Newhalem.

Glacially fed streams dominate the hydrologic regime of the Upper Skagit Watershed and help to produce a continual flow of water throughout the year. Glaciers contribute 2 – 15% of the summer runoff to Ross Lake (NOCA 2009). This contribution from glacial ice and snowfields is critically important for sustaining local hydroelectric industries. Also, the cooler run-off provided by glacial melt water is essential to ensuring the survival of endangered salmon and trout species. Permanent snowfields and glaciers that feed the Upper Skagit Watershed are most extensive in the Big Beaver, Little Beaver and Silver sub-watersheds (Fig. 7). The largest glacier on the west side of Ross Lake is Challenger Glacier (3.3 km^2) at the headwaters of Little Beaver Creek. Little permanent snow or glacial ice is present on the east side of Ross Lake, although Jack Mountain hosts the Nohokomeen Glacier on its northeast face, (1.8 km^2) which is fed by storms funneled up the Skagit Valley. Panther Creek holds the majority of glaciers, including Katsuk, Kimtah and Mesahchie Glaciers, on the east side of Ross Lake, totaling 3.0 km^2 of ice.

Glacial inventories based on 1950-1960 air photos (Post et al. 1971) are compared to a 1998 inventory (Granshaw 2001) in Table 3. Regionally the 1998 study concluded that 8.3 km^2 of ice was lost in the NOCA complex. The Nohokomeen Glacier feeds May Creek and is outside of NOCA, therefore it was not re-surveyed in 1998 since that study only focused on glaciers within the park.

Table 3. Comparing glacial ice area from 1958 to 1998 in the Upper Skagit Watershed

Watershed	1958-Area of Glaciers (km^2)	1998-Area of Glaciers (km^2)
May	3.0	No Data
Ruby Mountain	0.1	0.1
Panther	3.8	3.0
Big Beaver	6.4	6.2
Little Beaver	6.6	6.7
Silver	3.2	3.2
Arctic	0.8	0.7

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 conducting a mass balance study on Silver Glacier since 1993. Silver Glacier, located on the north face of Mt. Spickard, is one of the four glaciers monitored by the NPS (Fig. 7).

Mass balance results for Silver Glacier are provided in Figure 9. The Silver Glacier is the highest in elevation of the four glaciers monitored (2090 – 2710 m), so it tends to have net positive balances in years when the other glaciers do not, however Silver has been losing mass since 1905 (Fig. 10). Silver Glacier contributes an average of 6% run-off into Ross Lake. More detail regarding the status of glaciers, historical photographs of North Cascades glaciers and the methods of glacier monitoring within NOCA and MORA can be found in several locations (Riedel et al. 2008, NOCA NPS 2009, Riedel et al. *in review*).

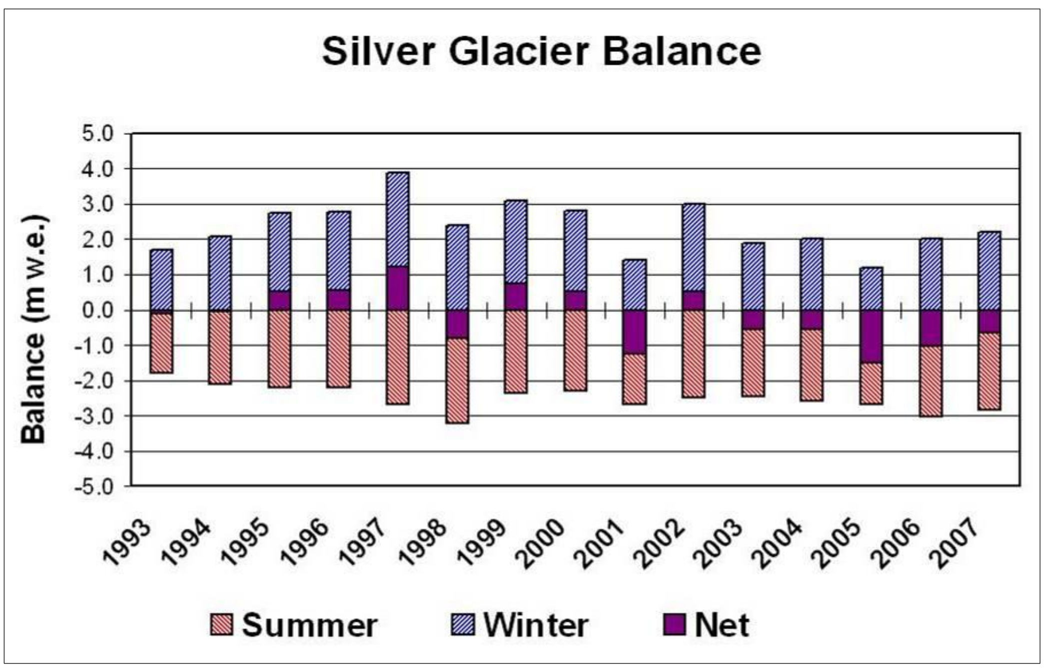

Figure 9. Mass balance chart of Silver Glacier, located on Mount Spickard. The vertical axis is the amount of water gained (winter balance), lost (summer balance) and retained (net balance; solid bar) in meters of water equivalent averaged across the glacier.

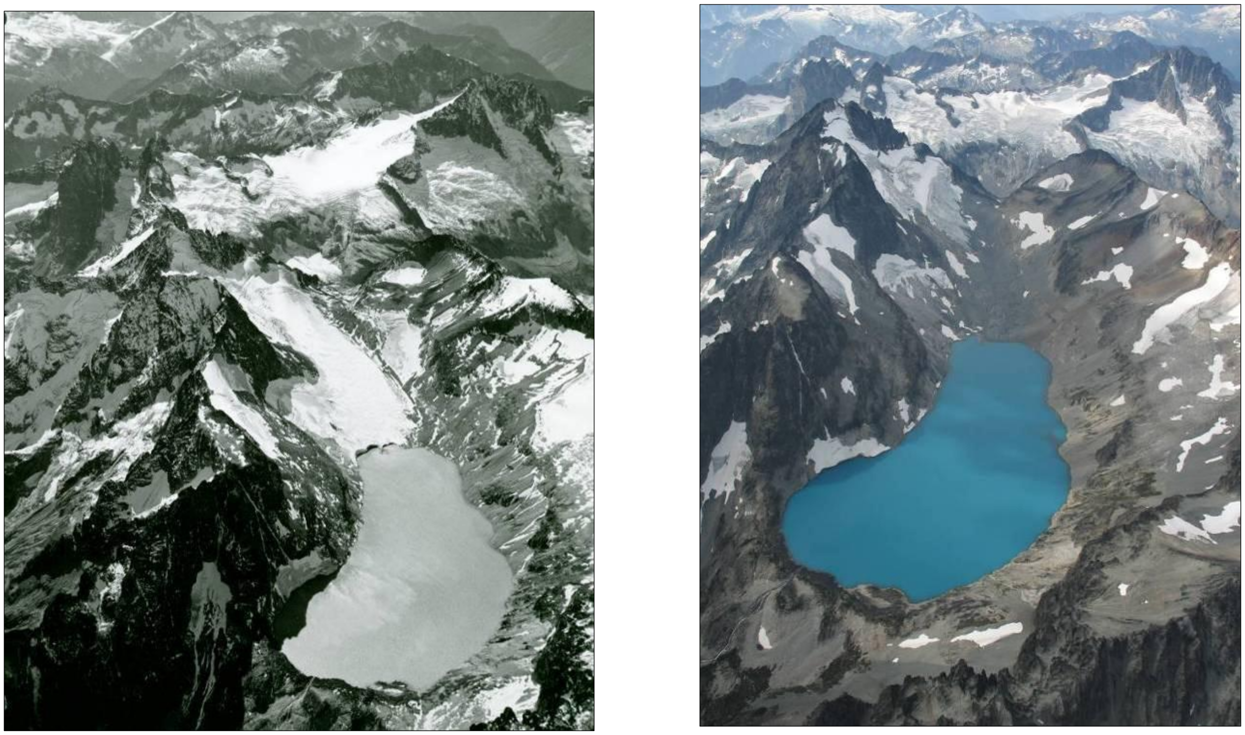

Figure 10. Silver Glacier in 1958 on left (Post 1971) and 2006 on right (Photograph courtesy of John Scurlock). A map made in 1905 shows the glacier covering all of Silver Lake (Tittman and Walcott 1913).

2.6 Vegetation

Vegetation variation between the west and east sides of the lake dramatically illustrate the difference between climate and hydrologic regimes discussed in the above sections. On the west side of the lake, sub-watersheds are dominated by coniferous trees. 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 1700 m on Ross Lake. Above this, scattered trees and subalpine vegetation form subalpine parkland which transition into subalpine meadow and the upper limit of vegetation is the sparsely vegetated alpine zone. The alpine vegetation dominates at elevations above ~ 2000 m. Alpine vegetation is comprised primarily of lichens, mosses and sedges. Heavy snow creates a wide zone between 1750 m and 2000 m of subalpine fir (*Abies lasiocarpa)*/mountain hemlock (*Tsuga mertensiana*) and open meadow communities dominated by heather shrubs (Phyllodoce spp., Vaccinium spp. and Cassiope spp.) or moist meadow communities. Wildflowers such as Indian paintbrush, mountain bistort, mountain harebell, tiger lily and red columbine occur in subalpine meadows.

Below the subalpine forested communities is the montane forest from 1700 to 400 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)* make up the lowland forest on the wetter west side of Ross Lake. Ponderosa pine (*Pinus ponderosa*), Douglas fir and lodgepole pine (*Pinus contorta*) dominate on drier sites found on the east side of Ross Lake. On both sides of the lake, lodgepole pine tends to dominate on exposed bedrock benches. 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 larger valleys of the Big and Little Beaver Creeks. In areas of oxbows, isolated river channels and slow water along the river help wetlands develop. These wetlands are dominated by obligate wetlands species such as sedges and rushes. Lower Big Beaver has one of the most extensive wetlands in the North Cascades.

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 4). 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 4. 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. 11) 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 Upper Skagit Watershed is part of the Crystalline Cascade Mountains and Wenatchee Highlands subsections.

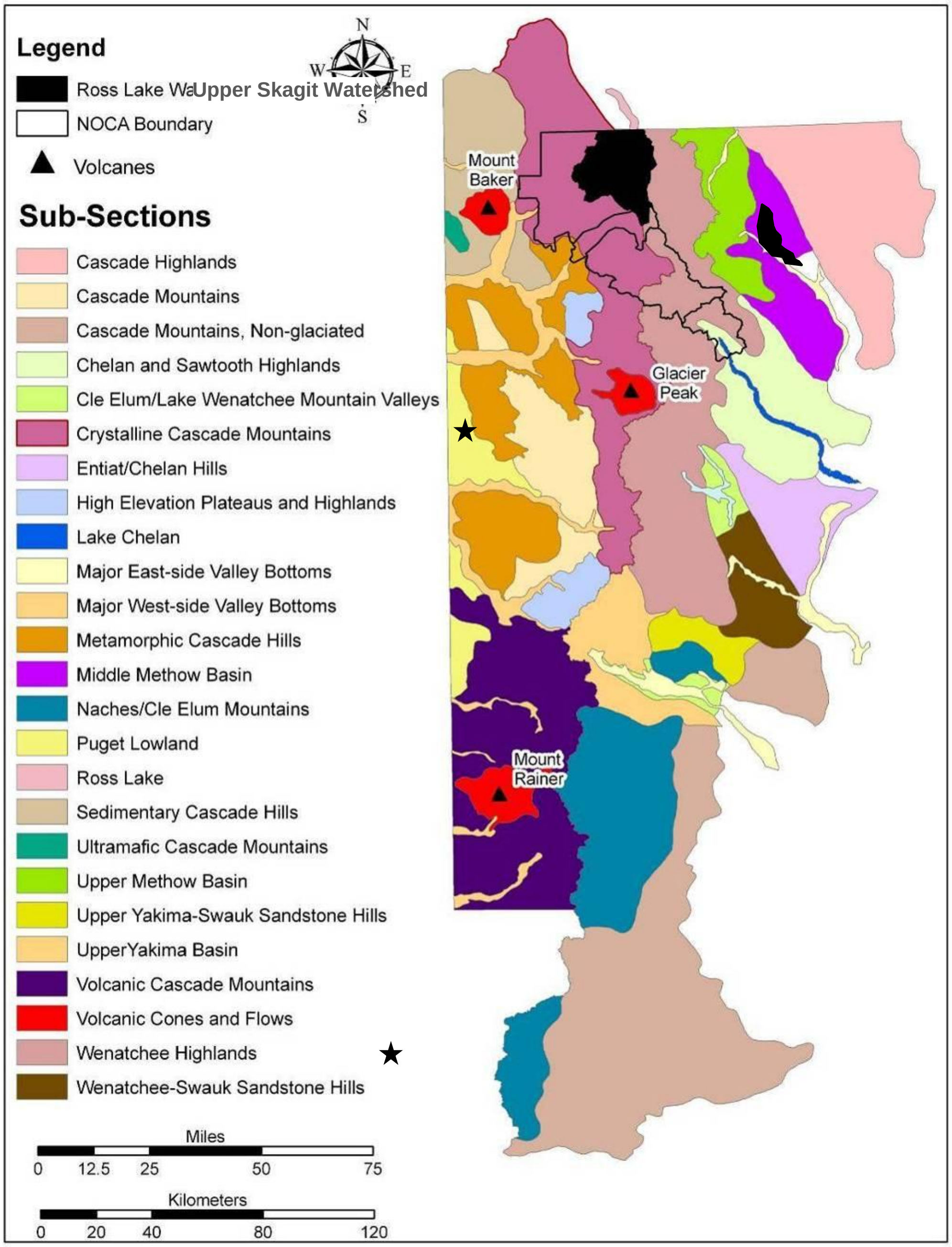

Figure 11. Subsection map (1:250,000) of the North Cascade region showing the location of the Ross Lake watersheds and North Cascades National Park.

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. At this time, no LTA mapping has been completed for the Upper Skagit Watershed.

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

These are the smallest functional units of the landscape that are created by discreet geologic processes, most 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 often require field-verification when they are located beneath closed canopy forest on valley floors. A suite of 29 different landforms is currently being mapped at NOCA and are listed below in Table 5. 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 5. 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

Table 5. Landform (1:24,000) legend for North Cascades National Park (continued).

Unit	Description
-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 6. 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).

Table 6. 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 Linking Landform Age to Soil Genesis

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 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 forth 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 m^2 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 that access the west side of the Upper Skagit Watershed. Maintained trails exist along the entire main stems of both Big Beaver and Little Beaver creeks from Ross Lake. Old trails can be followed in parts of lower Silver and No Name Creeks. There are unmaintained climbing and game trails that were followed throughout the sub-watersheds when available. All field investigations for the west side of Ross Lake were completed in the summer seasons of 2005 and 2006 by NOCA Resource Management staff both past and present: Jon Riedel, Stephen Dorsch, Jeannie Wenger, Mike Larrabee and Nicole Bowerman. The area beneath Ross Lake was originally surveyed by Mierendorf et al. (1998). The main stem of the Big Beaver Creek was field checked from the outlet at Ross Lake up river to the confluence of Luna Creek. The main stem of the Little Beaver Creek was field checked from the outlet at Ross Lake up river to its headwaters below Whatcom Pass and the Challenger Glacier. These areas were accessed by trail and also by traveling in the riverbed via wading. Field visits to each major tributary were attempted from the main stem of the Big Beaver Creek and Little Beaver Creek. However, due to difficult travel (e.g. canyons, thick vegetation and cliffs) some areas were not field checked. The tributaries that were field checked include the lower portion of McMillan Creek, most of Luna Creek, upper Skymo, the lower half of Perry Creek and the mouth of Redoubt Creek. Silver Creek was field checked as well by Riedel (2007). The remaining smaller drainages that empty into Ross Lake from the west side (Arctic, No Name and International) were not field checked and only mapped from air photos and 10 m DEMs.

The east side of Ross Lake is easily accessible by the East Bank trail, which runs the entire length of the lake. Once the trail reaches the mouth of Lightning Creek, it heads northwest into this drainage and then west to Lake Hozomeen, thus access for mapping these two sub-watersheds was good. Mapping along the East Bank trail was done in 1988 by Jon Riedel with additional mapping around Hozomeen and Lightning Creek in 2006 and 2007 by Stephen Dorsch and Nicole Bowerman. Panther Creek was field mapped by Stephen Dorsch, Nicole Bowerman and Mike Larrabee in the summer seasons of 2007 and 2008 from State Route 20 to 1220 m elevation.

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. 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

The results and discussion of the Upper Skagit Watershed landform mapping will be divided into west side sub-watersheds (Big Beaver, Little Beaver, Arctic, No Name, Skymo and Silver Creeks) and east side sub-watersheds (Hozomeen, Lightning, Dry, Devils, May, Roland, Ruby and Panther). The sub-watersheds valley morphology on the west side of Ross Lake is distinct from the east side valleys because of the enhanced effects of alpine glaciation (Waitt 1977). The west side valleys are U-shaped troughs that extend all the way to Ross Lake, that enter Skagit Valley as hanging valleys. The east side valleys, experiencing alpine glaciation restricted to upper valleys, enter the Skagit Valley as winding narrow river canyons.

Drainage of glacially dammed lakes caused divide lowering and migration northwards, as well as modification of dendritic, trellis and other drainage patterns. At the beginning of the great ice ages 2 Ma, a divide near present day Skagit Gorge separated flow to Puget Sound from flow to the Fraser River. This pass became the major outlet for drainage of a large area in the interior of the North Cascades. At that time, the Skagit River flowed north into British Columbia, with the headwaters draining Thunder Creek. Erosion of this divide created the Skagit River Gorge, just below Ross Dam, and led to the capture of the upper Skagit drainage system. The divide now separating the Fraser from the Skagit is Klesilkwa Pass in British Columbia, which is flooded by a series of swamps. Lightning Creek is another example of glacial rearrangement of drainage due to the advance/retreat of the Cordilleran Ice Sheet. A glacier-dammed lake in the Similkameen valley of British Columbia drained down Lightning Creek to the Skagit. Along its way, this torrent bisected Freezeout Creek, and built a huge alluvial fan at the mouth of Lightning Creek. As a result, Lightning Creek captured the headwaters of Freezeout Creek, and the lower part of Freezeout valley, now occupied by Willow and Hozomeen lakes, is beheaded (Riedel 2007).

On the west side of Ross Lake, the main stem of both the Big and Little Beaver Creek are classic U-shaped glacial valleys with a flat valley bottom, straight profile and low gradient. Other glacial characteristics of the valleys include, oversteepened valley walls, hanging tributary valleys and truncated valley spurs. Throughout the watershed, near-vertical walls of 600 to 1200 m rise directly up from the valley floor, hosting many mass movements. Valley walls in the upper reaches contain vegetation with sparse soil cover. Within the entire west Ross Lake sub-watersheds, 56.7% is valley wall and 12.7% is high elevation cirque; with only 0.91% as riparian (floodplain, valley bottom and alluvial fan) (Table 7). An extensive former floodplain of the Skagit River accounts for a large percentage of floodplain and this feature has been separated out from the overall floodplain total. The glacially over-steepened valley walls, aspect influenced erosion on the north -facing slopes and structural weakness associated with faults and hydrothermal alternation are likely responsible for the majority mass movement avalanches and rock falls throughout the sub-watersheds.

The eastern side Ross landforms also reflect climatic influences (Table 8). In the east Ross Lake sub-watersheds, it is important to note that the entire drainages were not mapped, with the exceptions of Hozomeen and Panther, since they were not within the NOCA complex. Therefore cirques and other high elevation landforms are thus under-represented in comparison to the west

Ross Lake sub-watersheds. Within the east Ross Lake sub-watersheds, 58.2% is valley wall and 2.3% is river canyon, reflecting the steep and narrow nature of the V-shaped east side tributaries. Two large post-glacial landslides and extensive outwash terraces are also mapped on the seasonally flooded valley floor. Otherwise, riparian habitat is limited, mainly present at the flats mapped as debris apron located at Hozomeen and in parts of Big and Little Beaver Creeks.

Table 7. Summary of area of each landform type within the west Ross Lake sub-watersheds.

Landform Type	Number Observed	Area km^2	% of West Ross Lake Sub-Watersheds
Valley Wall	24	294.183	56.656
Cirque	152	65.947	12.701
Debris Apron	270	43.051	8.291
Debris Cone	242	22.932	4.416
*Skagit Floodplain under Ross Lake	1	27.344	5.266
Mass Movement - Debris Avalanche	42	7.803	1.503
Ridge	45	6.911	1.326
River Canyon	113	6.886	1.400
Mass Movement - Fall/Topple	188	5.329	1.026
Arete	54	4.555	0.877
Alluvial Fan	5	2.816	0.542
Neoglacial Moraine	108	2.777	0.535
Terrace	71	2.650	0.510
Bedrock Bench	57	1.968	0.379
Valley Bottom	13	1.828	0.352
Horn	24	1.771	0.341
Pass	27	0.699	0.135
Other Mountain	15	0.633	0.122
Mass Movement - Debris Torrent	29	0.476	0.092
Pleistocene Moraine	12	0.470	0.091
Undifferentiated	4	0.183	0.035
Floodplain	11	0.115	0.022
Fan Terrace	11	0.047	0.009
Mass Movement - Slump/Creep	13	0.025	0.005
Delta	2	0.012	0.002
Mass Movement - Sackung	1	0.012	0.002
Mass Movement - SAIL	2	0.008	0.002
Totals	1525	519.243	100.0

Table 8. Summary of area of each landform type within the east Ross Lake sub-watersheds.

Landform Type	Number Observed	Area km^2	% of East Ross Lake Sub-Watersheds
Valley Wall	21	149.149	58.164
Debris Apron	80	34.395	13.413
Cirque	40	13.900	5.420
Debris Cone	98	6.902	2.692
Mass Movement - Debris Avalanche	17	6.896	2.689
River Canyon	31	6.012	2.344
Bedrock Bench	51	3.798	1.481
Alluvial Fan	4	3.721	1.451
Ridge	19	3.410	1.330
Terrace	49	2.731	1.070
Floodplain	6	1.840	0.718
Mass Movement - Fall/Topple	77	1.814	0.461
Arete	23	1.176	0.459
Valley Bottom	6	1.109	0.433
Horn	13	0.537	0.209
Pleistocene Moraine	2	0.326	0.127
Pass	11	0.268	0.127
Neoglacial Moraine	31	0.306	0.120
Mass Movement - Debris Torrent	4	0.141	0.055
Other Mountain	2	0.087	0.034
Mass Movement - Slump/Creep	3	0.016	0.006
Undifferentiated	0	0	0
Delta	0	0	0
Mass Movement - Sackung	0	0	0
Mass Movement - SAIL	0	0	0
Totals	590	256.429	100.0

5.1.1 High Elevation Landforms

High elevation landforms (cirques, Neoglacial moraines, ridges, horns, arêtes, lower mountains and passes) account for 62.5 km^2, which is 28.7% of the total area on the west Ross Lake sub-watersheds. As stated in Table 7, most of this area is cirque basins, which are primarily rock, snow and ice. Lower mountains, passes and ridges have extensive alpine and subalpine vegetation. Particularly well-developed cirque basins are located on north face of Mt. Spickard, the northeast face of Mox Peaks, the north face of Mt. Challenger and the northwest face of Luna Peak. Aspect has particularly strong control on the development of cirque basins, with those north and east facing cirques able to hold their ice longer since they receive less sunlight. Snow and ice in the west Ross Lake sub-watersheds totals 16.9 km^2, with the Challenger Glacier accounting for 20% of that area. Most of the lakes in the west Ross Lake sub-watersheds are high alpine lakes, totaling 140 ha in area, with the largest lake being Silver Lake (65 ha). The increasing number of alpine lakes is a direct reflection of the shrinking glaciers and permanent snowfields at NOCA.

The number of high elevation landforms is under-represented in the east Ross Lake sub-watersheds since the headwaters of most creeks are not within NOCA. High elevation landforms account for 20 km^2, only 7.8%, with a majority of them within Panther Creek. The craggy summit horn of Mt. Hozomeen is impressive in its distinctive profile (see cover photo). Its cirque is less developed than those on the west side of Ross Lake. Jack Mountain contains a very well-developed cirque basin on its north side that contains Nohokomeen Glacier, the most significant body of ice on the east side of Ross Lake. While Jack and Crater Mountain are outside the NOCA boundary, they feed the waters of May, Dry, Roland and Devil's Creeks. Ruby Mountain also has a cirque basin on its north face and upper Panther Creek contains several well-developed cirque basins. The only permanent snow and ice in the east Ross Lake sub-watersheds within the NOCA boundary are contained these two sub-watersheds. Snow and ice in the east Ross Lake watersheds totals 3.2 km^2, with the glaciers on Ragged Ridge along upper Panther Creek (Kimtah, Katsuk and Mesahchie Glaciers) accounting for 64% of that area. Most of the lakes in the east Ross Lake watersheds are located in the Hozomeen valley, with a few alpine lakes in Panther Creek sub-watershed. Lakes total on area of 58 ha in the east Ross Lake sub-watersheds, the largest being Hozomeen and Willow Lakes.

Impacts from the ice sheet are evident throughout the Upper Skagit 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 Upper Skagit Watershed, only the magnificent horns along the Pickets Range, North Cascades Crest, Ragged Ridge, Elija Ridge and Ruby Mountain were high enough to stand above the ice sheet as nunataks. Since it is estimated the level of the Cordilleran Ice Sheet was approximately 2000 m near Hozomeen, peaks such as Sourdough and Desolation were over-run by the ice sheet and thus are broadened, rounded and contain glacial striae and polished bedrock. Advance rates of the ice sheet are estimated at 130m/yr in Puget lowland, while ice funneled into the Skagit River valley probably reached speeds 5-6 times this rate (Evans 1990). Valleys like the Skagit, Chilliwack and Thunder, which all trend north/south, are particularly broad since they were parallel to ice sheet flow (Riedel 2007).

Recent glacier activity is recorded in Neoglacial moraines. These landforms where deposited by alpine glaciers in the last 700 years. There are one hundred and eight Neoglacial moraines on the west side of Ross Lake and they are present within each individual sub-watershed. Terminus elevations for these moraines tend to be lower on north-facing slopes due to the influence of aspect producing more extensive glaciers on these slopes. The east side of Ross Lake was not extensively mapped in the alpine; therefore only thirty-one Neoglacial moraines were mapped. They are located on Ruby Mountain, Red Mountain, Elija Ridge and Ragged Ridge. Air photos do reveal several Neoglacial moraines on and around Jack Mountain as well, but they are not within the NOCA boundary.

5.2 Valley Characteristics of West Ross Lake Sub-Watersheds

In this section the west Ross Lake sub-watersheds will be discussed in detail while the following section will focus on the east side of Ross Lake. Both Big and Little Beaver contain several tributaries within their sub-watersheds that will be described individually.

5.2.1 Main Stem of Big Beaver Creek

The master stream in Big Beaver Creek is Luna Creek based on the size of the glacial trough. Beaver Pass (elevation of ~1100 m), which was dramatically broadened by the Cordilleran Ice Sheet, separates the valley from Little Beaver Creek to the north (Fig. 12). The Big Beaver valley may follow the Ross Lake Fault northwest-southeast structural fabric established in the Cretaceous (Fig. 3). The Mt. Prophet ridgeline confines the valley to the northeast marking the boundary between Big Beaver and Little Beaver, Arctic, No Name and Skymo Creeks. The Picket Range is the local drainage divide on the west side of Big Beaver, splitting it from the north-flowing Chilliwack River, southwest-flowing Baker River and south-flowing Goodel Creek.

Big Beaver Creek begins at elevation 750 m in a valley ~0.1 km wide, bordered by small debris cones and river terraces (1.5 m in height). There are recent debris torrent on debris cones and rock falls which lie on a contact between biotite granite and biotite-hornblende tonalite and granodiorite, both of the Chilliwack Composite Batholith. Several of the debris cones enter the debris apron from steeply incised river canyons. An unnamed tributary enters Big Beaver from the east slopes of Luna Creek within this first 5 km. This tributary contains three debris avalanches composed of biotite-hornblende tonalite that are likely fault-influenced (Fig. 12). It is estimated that they delivered a combined load of 11,000,000 m^3 of sediment to the creek bed. In this tributary there are also three rock falls and several debris torrents.

Continuing on the main stem of Big Beaver, the bedrock changes from the granite, tonalite and granodiorite of the Chilliwack Composite Batholith to the older orthogneiss and banded gneiss of the Skagit Gneiss Complex. The creek continues southeast for 3 km, where McMillan Creek then merges with Big Beaver Creek. Six terraces are present near the junction, 1.5 to 3.0 m in height. The higher terraces could be outwash from late ice age valley glaciers. Lower terraces are probably alluvium deposited in the past few hundred years. One small debris avalanche is mapped on the northern valley wall right as Big Beaver turns to the east-southeast. Here, the floodplain increases in size to ~0.2 km and the valley is now almost entirely void of river terraces and dominated by the floodplain. This is likely due to the nature of the resistant bedrock walls steeply descending to the valley floor, the continued alluviation of the Big Beaver Creek and the low valley gradient created by ice age over-deepening.

Downstream of the junction with McMillan Creek, the Big Beaver valley is constricted by two debris avalanches (delivering an estimated 16,300,000 m^3 of sediment) before entering a bedrock river canyon. Valley width increases to 0.7 km below the canyon and in this section there are numerous ponds. The especially wide flat floor of the lower Big Beaver valley is maintained by the ongoing accumulation of sediments introduced in the valley by the various tributary streams feeding Big Beaver Creek. Four debris avalanches are within this reach of Big Beaver Creek, which delivered an estimated 7,900,000 m^3 of sediment to the valley wall composed of Skagit Gneiss Complex. Numerous rock falls dots the valley walls on both the north and south side and debris torrents are intermittently present on debris cones. In the cirques of side tributaries in this section of Big Beaver Creek, two Neoglacial moraines are mapped, one in Thirtynine Mile and one in an unnamed north-flowing side tributary. These are the only Neoglacial moraines mapped in the Big Beaver sub-watershed, terminating at 2090 m (up Thirty-nine Mile Creek) and 1425 m (up the unnamed tributary). As shown on Figure 12, Thirtynine Mile Creek and other nearby tributaries appear to be following the fabric of the Thunder Lake Fault. Thirtynine Mile Creek is a small 4.5 km long south-flowing tributary that enters Big Beaver 8 km upstream of the outlet on Ross Lake. Numerous rock falls dot the valley walls of the Thirtynine Mile valley and many of the straight steep drainages parallel to the Thunder Lake Fault are active debris torrent systems. Deposition out of the Thirtynine Mile tributary occurs frequently in this area, which has affected the trail and camp area.

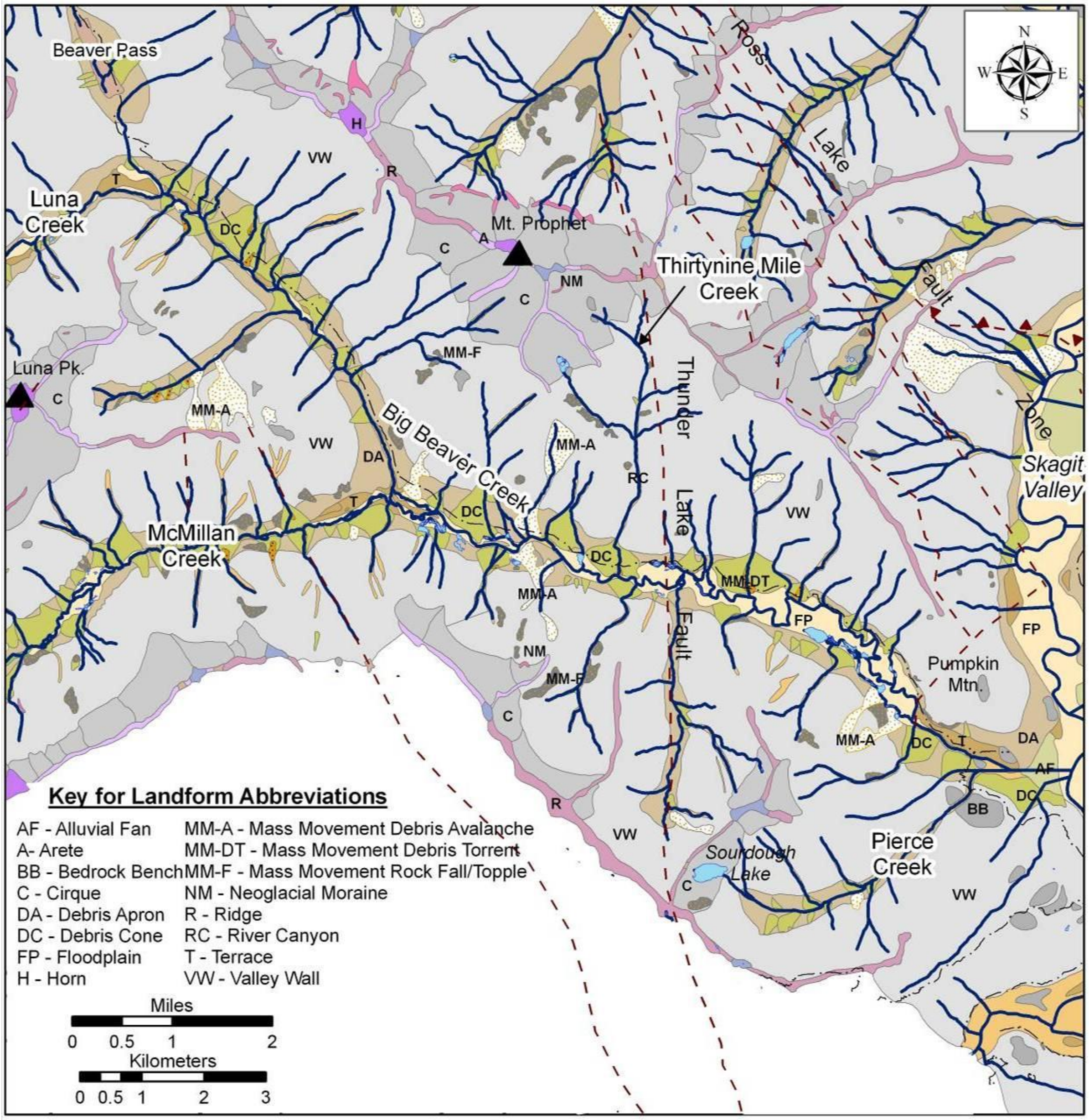

Figure 12. Landform map of Big Beaver Creek. The black dot-dashed lines are trails and red dashed lines are faults.

The floodplain of the lowermost Big Beaver Creek narrows significantly (0.08 km wide), constrained from the north by a large glacial outwash terrace (Fig. 12) and from the south by a pair of large debris cones. Before inundation by the water behind Ross Dam, Big Beaver plunged more than 25 m over a series of waterfalls before constructing a large fan on the Skagit River floodplain. Pierce Creek also enters Ross Lake near the mouth of Big Beaver Creek. The waters of Pierce Creek originate from Sourdough Lake, which is 0.11 km^2 in size and sits in a small poorly-developed cirque basin just northwest of Sourdough Mountain. Sourdough ridge itself bears signs of being overridden by the thick, fast moving ice sheet. Pumpkin Mountain, at the valley mouth of Big Beaver Creek, is a distinct bedrock bench carved by alpine and continental glaciers.

5.2.2 Luna Creek

Luna Creek is a 7.5 km long, southwest-northeast trending U-shaped valley with steep valley walls (Fig. 13). The headwaters of Luna Creek begin in the Picket Range where the steep arêtes and horns reach elevations greater than 2500 m. Resistant rocks of the Skagit Gneiss Complex orthogneiss and the Chilliwack Composite Batholith biotite-hornblende tonalite and granodiorite compose the headwater's peaks in what is known as the crystalline core of the North Cascades. Luna Creek flows northeast, following the late Tertiary compressional faults of the Cascade Arc. Cirques ring the entirety of the headwall of Luna Creek, with cirque floors at elevations as low as 1650 m. They contain both Neoglacial moraines (four in total) and abundant deposits of glacial drift. Luna (7 ha) and Lousy (5 ha) Lakes are two tarns just below the cirque walls of upper Luna Creek. Both are surrounded by large Neoglacial moraines, the lowest of which terminates at 1000 m. There are a total of seven moraines that extend below the cirque boundaries in the upper drainage.

The first 2 km of Luna Creek flow in a valley bottom below Luna and Lousy Lakes, then transition into floodplain at elevation 960 m. On the northern valley wall rock falls and talus are present. The floodplain remains relatively wide at 0.3 km until it reaches a large debris avalanche. It is likely that this debris avalanche composed of biotite-hornblende tonalite and granodiorite of the Chilliwack Composite Batholith blocked the creek at one time with an estimated volume of 2,000,000 m^3. The valley for the remaining 4.5 km is generally dominated by small debris cones, debris apron and steep valley walls. Several tributaries entering from the south side of the Luna valley are river canyons, some with recent debris torrents. On the south side of the valley there is another Neoglacial moraine that terminates at 1844 m within a cirque on the northeast side of Luna. The lower reaches of the creek's floodplain contain three prominent terraces, all ~1.5 m in height, the largest of which is located where Luna Creek joins with the water draining from Beaver Pass into Big Beaver Creek.

In the lower Luna valley there is a somewhat rare landform known as a SAIL (snow avalanche impact landform). It is located in front of Luna Creek Pond and is marked in Figure 13. SAILs are depressions and ridge-like deposits created by a snow avalanche impact hitting saturated and unconsolidated sediments. There is only one other SAIL mapped in the Ross Lake Watershed and it is located in upper Arctic Creek.

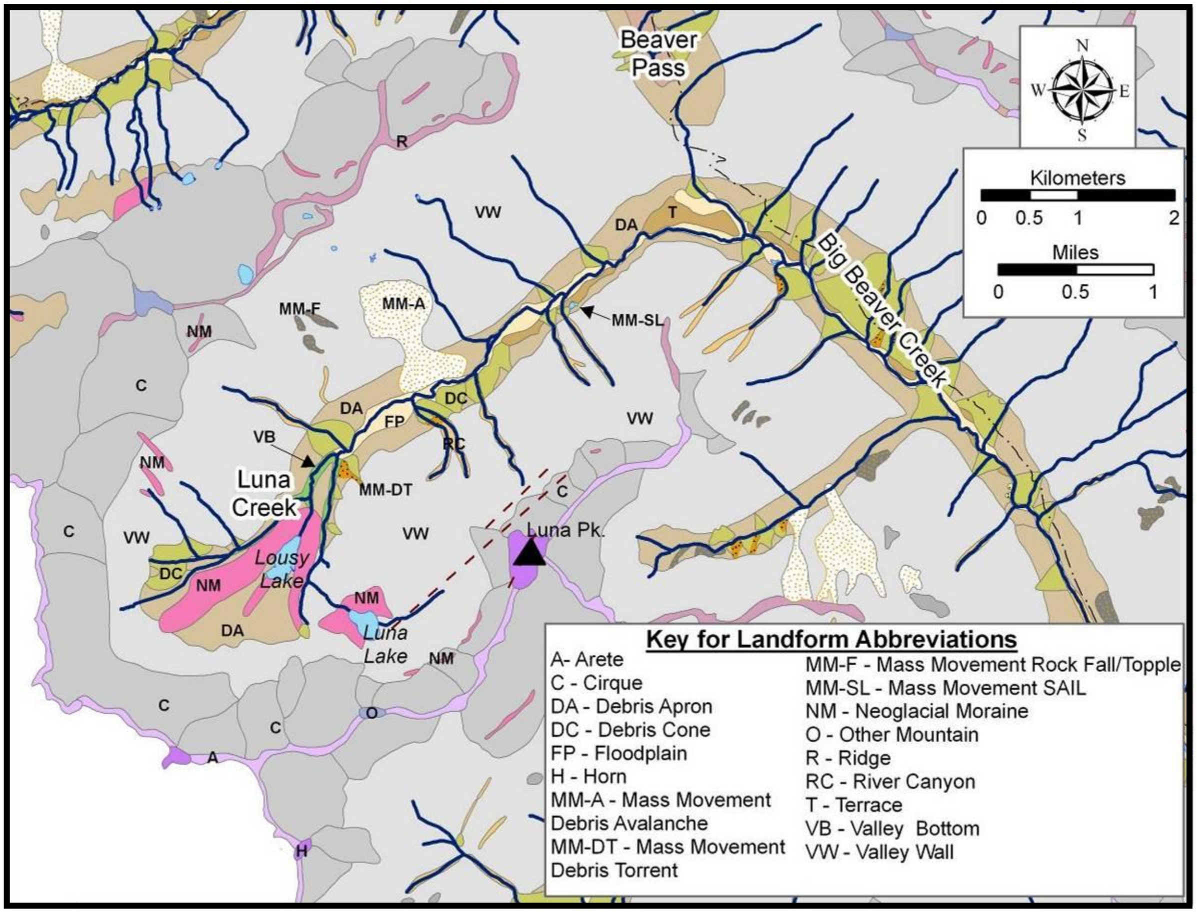

Figure 13. Landform map of Luna Creek. See Figure 2 for legend, black dot-dashed lines are trails and red dashed lines are faults.

5.2.3 McMillan Creek

The McMillan Creek sub-watershed houses some of the most inaccessible and spectacular terrain in the entire NOCA complex. In fact, the park's webcam in Newhalem captures the east and west McMillan Spires, a breathtaking and inspirational view (Fig. 14). The creek is ~9 km long and is generally northeast trending, and like Luna Creek, it appears to have preferentially exploited northeast-southwest trending faults (Fig. 15). The headwaters of McMillan Creek begin in the Picket Range, where steep horns and arêtes, composed solely of orthogneiss, reach beyond 2500 m in elevation. The headwall of the creek is encircled with cirques reaching down to 1460 m in elevation. Within the cirques of the valley head there is only one Neoglacial moraine. There are six Neoglacial moraines below the cirques, the lowest moraine terminating at 1097 m. The first kilometer of the creek drops steeply from an unnamed lake (0.01 km^2) before entering valley bottom. A short narrow stretch of floodplain confined by debris cones follows before the creek abruptly opens into a wide (up to 0.4 km) boggy floodplain. Several small ponds that are collectively known as the McMillan Creek Ponds are mapped in this floodplain along with the active channels of McMillan Creek.

Figure 14. A picture from the NOCA webcam in Newhalem, taken March 11, 2009. McMillan Spires are to the right side of the picture. Pinnacle Peak or 'The Chopping Block" is on the far left, which is within the Goodel Creek sub-watershed.

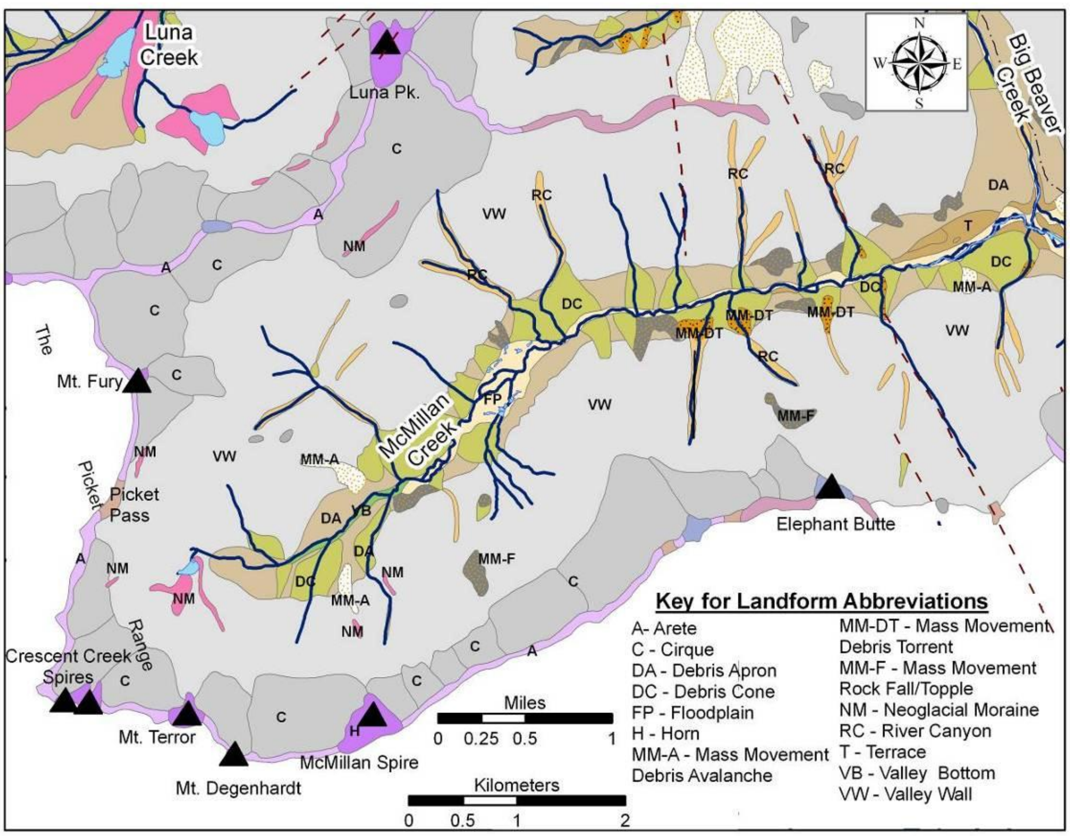

Figure 15. Landform map of McMillan Creek, black dot-dashed lines are trails and red dashed lines are faults.

The head of the valley is dominated by debris apron, several large debris cones, two small debris avalanches and four rock falls on the valley wall. Snow avalanches from either side of McMillan Creek are known to overlap on the valley floor. In addition, multiple tributary river canyons are mapped within the steep valley wall, which may run along the Thunder Lake Fault. Following the floodplain stretch, the lower reaches of the creek return to a narrower floodplain (0.6 km wide) containing several terraces at heights of ~1.5, 2.5 and 3 m. The extent of these terraces generally increases as McMillan Creek approaches the junction with the main stem of Big Beaver Creek. Within this lower reach, debris cones, seven rock falls, one small debris avalanche and abundant river canyons are mapped in the valley wall and along the creek channel. There are six fairly recent debris torrent deposits on debris cones that all originate from steep river canyons. It is possible that the increase of rock fall in this part of the drainage is due to the fractured rock in these fault zones. Fault-bound banded gneiss and biotite gneiss of the Skagit Gneiss Complex making up most of the rock falls. An unnamed broad pass, just east of Elephant Butte, was likely a prominent ridge that was overrun by the Cordilleran Ice Sheet as it flowed south from British Columbia.

5.2.4 Main Stem of Little Beaver Creek
The valley head of Little Beaver Creek is ringed by cirques of substantial size that extend down to an elevation of 1460 m from the towering arêtes near Mt. Challenger (Fig. 16). Challenger Glacier and Whatcom Glacier both drain into Little Beaver Creek as do other small unnamed glaciers. Challenger Glacier on the north side of Mt. Challenger is the largest glacier within the west Ross Lake watersheds at 3.3 km^2. Whatcom Glacier (0.3 km^2) sits within a smaller cirque basin on the northeast face of Whatcom Peak. Significant Neoglacial deposits (including moraines) are found within these cirques, particularly below the Challenger Glacier.

The southern drainage divide of upper Little Beaver Creek is known as Wiley-Eiley Ridge which descends east to Beaver Pass. Well-developed cirques holding small unnamed tarns, Wiley Lake (2 ha), Eiley Lake (0.04 ha) and six Neoglacial moraines. The northern drainage divide of Little Beaver Creek is the North Cascades Crest, which separates it from the north-flowing Chilliwack River. Little Beaver is divided from Silver Creek to the north by a ridge line that trends east-southeast towards Ross Lake. Tributaries such as Perry and Redoubt Creeks appear influenced by northwest-southeast fabric of the Ross Lake Fault Zone, while Pass and Mist Creeks follow the north-south trend of the Straight Creek Fault (Fig. 16). Little Beaver itself only trends slightly northeast-southwest, perhaps part of a relict radial drainage from volcanoes over the Chilliwack Composite Batholith.

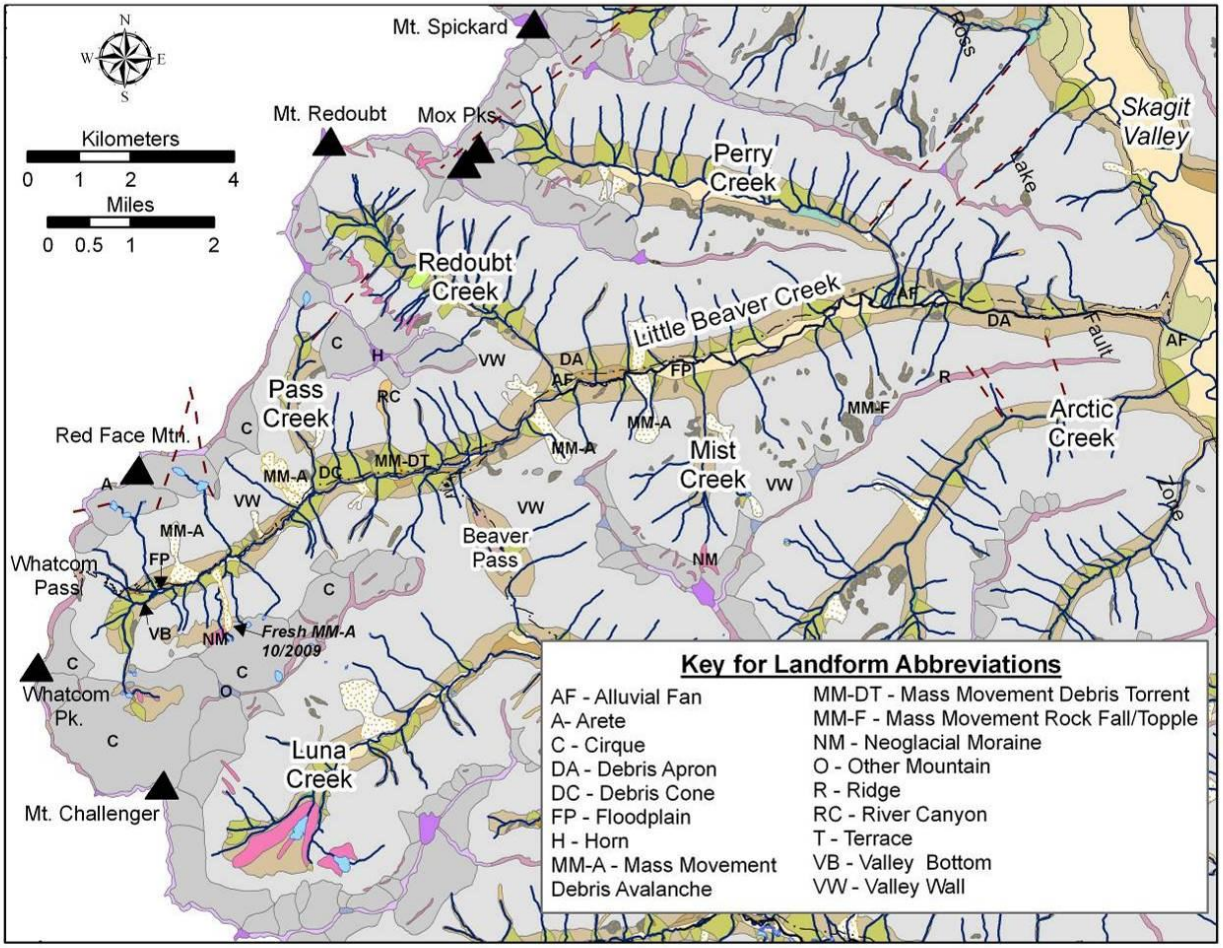

Figure 16. Landform map of Little Beaver Creek, black dot-dashed lines are trails and red dashed lines are faults.

The upper reaches of Little Beaver Creek flow in a narrow valley bottom below the Challenger Glacier, quickly transitioning into floodplain at elevation 930 m. The relatively narrow floodplain continues for ~11 km and is bounded by terraces 2.5 m in height. Ten of the 16 mass movement debris avalanches in the entire Little Beaver Creek drainage are located along this stretch, composed of Skagit Gneiss Complex banded gneiss and orthogneiss as well as Chilliwack Composite Batholith biotite granodiorite and biotite-hornblende tonalite. A recent release of glacial till from a cirque below Mt. Challenger resulted in a new debris avalanche on September 6, 2009 (Fig. 17) that is marked in Figure 16. It appeared that unconsolidated till within the cirque released due to a flash flood event, scouring the valley wall upon descent. It is possible that the other debris avalanches that appear to have originated at the edge of cirque basins released in a similar manner.

Both Pass Creek and Redoubt creeks join Little Beaver Creek as hanging valleys. The headwaters of Pass Creek originate from the cirque that holds Pass Lake (3 ha). This cirque floor is at 1996 m and contains one Neoglacial moraine. A small stream follows a northeast-southwest mapped fault trace in gabbros and diorites of the Chilliwack Composite Batholith.

The western valley walls of Pass Creek are steeper than the eastern valley walls, likely due to increased freeze/thaw processes on this aspect.

Figure 17. Recent debris avalanche in upper Little Beaver. NPS Photo.

Just downstream of Redoubt Creek, Little Beaver passes through a large 2.5 m high terrace and is constricted between two large mass movement debris avalanches that delivered combined 12,000,000 m^3 of sediment to the valley. Below the two debris avalanches, the channel opens up abruptly into a wide floodplain (~0.3 km) entirely void of terraces and dominated by wetlands. Mist Creek flows north into Little Beaver in this stretch. A small tributary, 3.5 km in length, Mist Creek drains directly north from its cirque-lined headwall. The creek is defined by a horn on the northwestern ridge of Mt. Prophet and subsequent ridges and arêtes to the east and west. Several small snow fields compose the headwaters and are within cirques that contain a total of seven Neoglacial moraines.

On the valley walls of the main Little Beaver valley, numerous rock falls are present below the lesser developed cirques located on the ridge between Little Beaver and Arctic Creek (Fig. 16).

The wide floodplain reach continues for ~5 km where it is then constricted by the large alluvial fan of Perry Creek. The constricted river channel continues for ~3 km through primarily valley wall and debris apron deposits then enters a 1.5 km long river canyon to Ross Lake. An alluvial fan was deposited at the mouth of the creek that is now below the waters of Ross Lake. Little Beaver campground is located on the bedrock bench on the left bank of the creek. This bench has several perched boulders left by the ice sheet more than 14 Ka.

5.2.5 Redoubt Creek

The head of Redoubt Creek begins below a steep arête and prominent horn of Mt. Redoubt (Fig. 18). The headwaters of Redoubt Creek contain five northeast facing cirques (~1770 m lower elevation limit) and one southwest facing cirque (~1830 m lower elevation limit) carved out of quartz monzodiorite of the Chilliwack Composite Batholith. All of these cirques contain well-defined Neoglacial moraines and remnant ice and snowfields that feed the creek. Redoubt Creek stretches for nearly 5 km, trending southeast, where it joins Little Beaver Creek. It is likely that both Redoubt and Perry Creeks exploited the southeast-northwest trending geologic fabric of the Ross Lake Fault Zone.

The Redoubt Creek valley is dominated by very steep glaciated valley walls, river canyons and rock falls. The upper reaches of the channel are mapped as valley bottom, but transition to floodplain after ~ 2 km. The floodplain is only 2 km long and is ringed by a number of debris cones and six mass movements on the northeast facing valley wall. The ridge between Perry and Redoubt Creek contains the only sackung in the entire Upper Skagit Watershed. Sackungs form when over-steepened and under-cut valley slopes create a gravitational spreading or when deep-seated and slow gravitational slope deformation occurs away from a ridge top (see Tabor 1971 for numerous references). Lower Redoubt Creek flows off of a hanging valley through a steep river canyon (Fig.19) that spreads out into an alluvial fan at the mouth of the creek. No terraces were mapped in this drainage, mostly likely because the creek is choked with sediment.

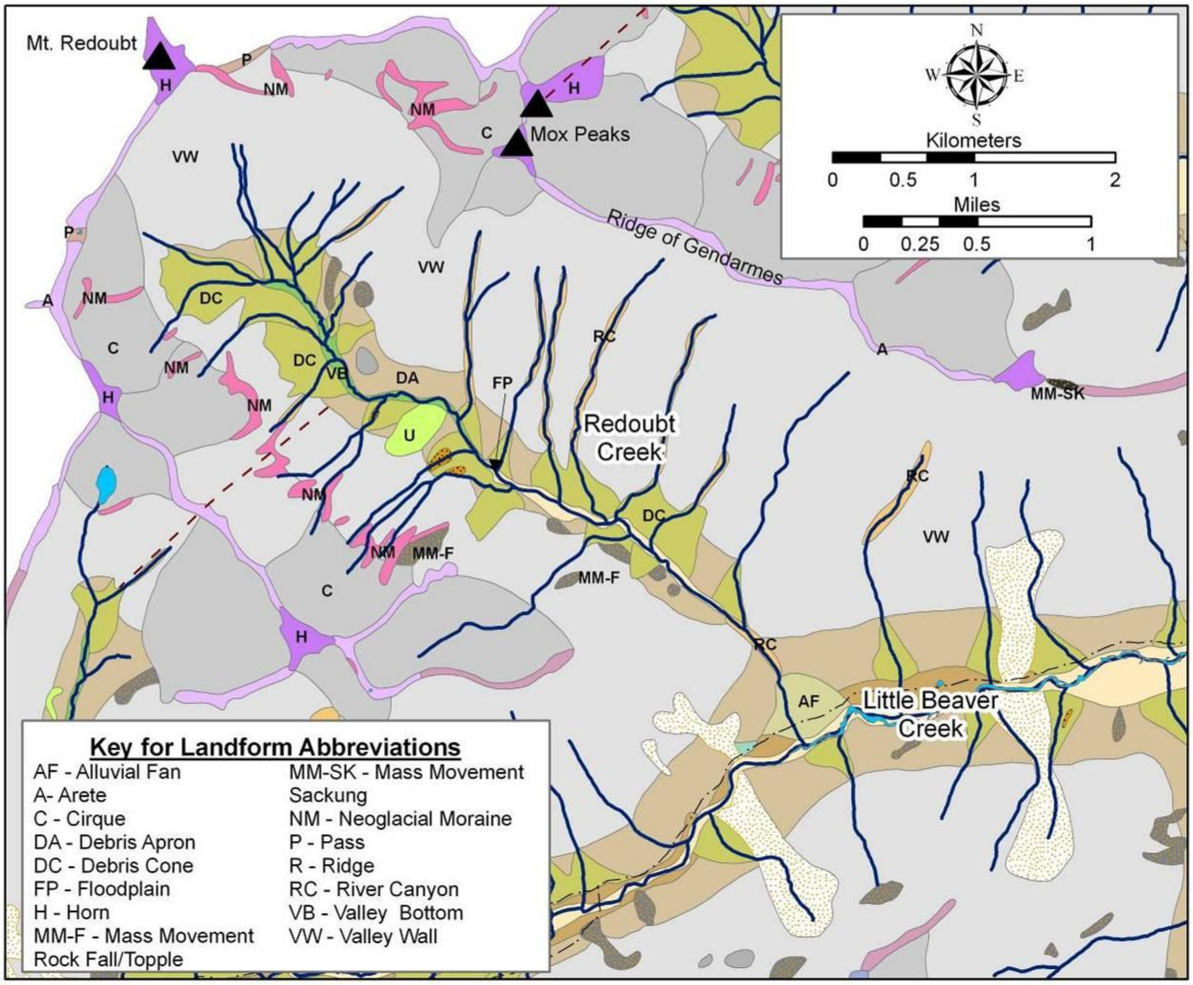

Figure 18. Landform map of Redoubt Creek, black dot-dashed lines are trails and red dashed lines are faults.

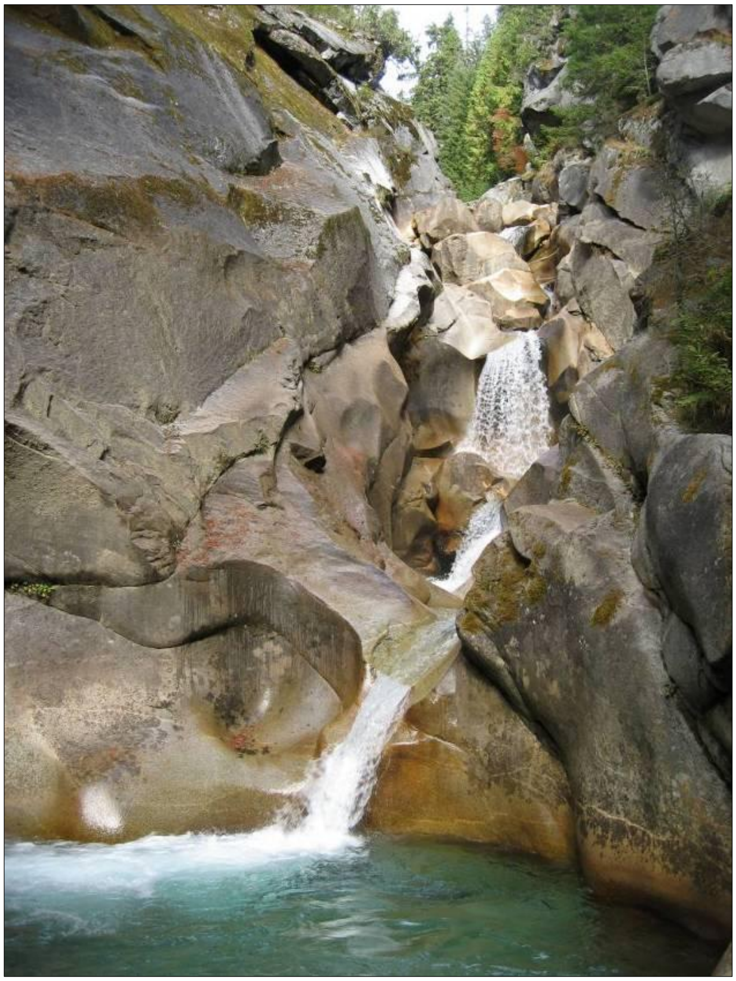

Figure 19. Redoubt Creek within the river canyon located just up-creek of its outlet.

5.2.6 Perry Creek

Perry Creek is an eight km long, east-southeast trending creek whose valley morphology varies widely along its length (Fig. 20). Steep arête ridges, including the Ridge of Gendarmes, connect unnamed horns, Mox Peaks and Mt. Spickard at the headwall of Perry Creek. The southerly-facing cirques have distinct cirque walls but less defined cirque floors, whereas north-facing cirques are deeper and have flat-floors. Small remnant glaciers and snowfields still remain in these cirques feeding Perry Creek and eleven Neoglacial moraines have been mapped. The uppermost kilometer of the valley is valley bottom. The character of the creek changes drastically in the heavily vegetated floodplain, reaching a width of ~0.5 km. At this transition between valley bottom and floodplain, two large debris avalanches are present from the south-facing valley wall. It is likely that the debris avalanches blocked the creek for a brief time. On the south-facing valley walls above the floodplain, rock fall and abundant talus is present.

The wide floodplain continues for ~3.5 km and ends where constricted by a Pleistocene moraine along the right bank. Two small (2,000 and 1,000 m^2) slump deposits are mapped along the base of this moraine. This narrowed floodplain continues for ~2 km, passing through a large debris avalanche deposit that presumably blocked the creek at one time and delivered an estimated volume of ~ 2,500,000 m^3 of sediment to the creek. A northeast-southwest trending fault is mapped directly through this debris avalanche and likely influenced its development. Perry Creek then enters a steep river canyon (hanging valley) before emptying out into a wide alluvial fan that forces Little Beaver Creek to the opposite side of the valley (Fig. 21).

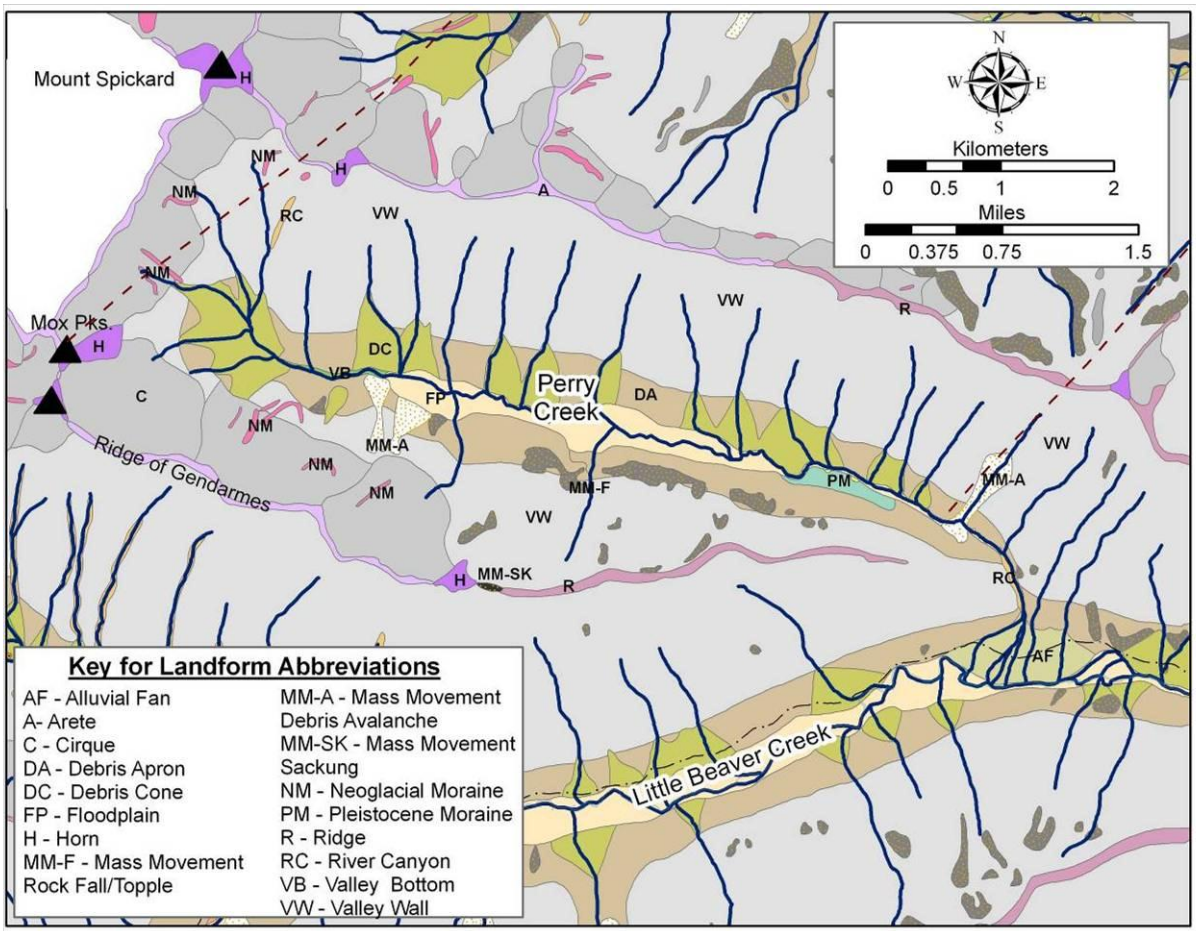

Figure 20. Landform map of Perry Creek, black dot-dashed lines are trails and red dashed lines are faults.

Figure 21. Near the apex of the Perry Creek alluvial fan, looking south.

5.2.7 Silver Creek

Silver Creek drains east-southeast into Ross Lake just south of the Canadian border (Fig. 22). The headwaters begin from a series of well defined cirques, the largest of which contains Silver Glacier on northwest face of Mount Spickard. Cirques reach down to ~1770 m in elevation and contain several Neoglacial moraines, small remnant glaciers and snowfields. The main source of water for Silver Creek is the Silver Creek Glacier, one of the four glaciers that are monitored by the NPS. This glacier has shrunk vastly since the Little Ice Age and as recently as 1913 covered Silver Lake (Tittman and Wolcott, 1913). The Silver Glacier cirque contains several large Neoglacial moraines, the most notable being the apparent left lateral moraine that trends linearly north-northeast for a nearly 1 km. Silver Lake, the largest in the Upper Skagit Watershed at 65 ha, is ~ 200 m deep (Fig. 23). Presence of fault-weakened rock and the actions of Silver Glacier over many hundreds of thousands of years created the remarkable deep lake basin. It has been proposed that Silver Creek's drainage pattern was defined as a radial stream off a volcanic topographic high that is no longer present (Riedel et al. 2007). Evidence of volcanic activity in the area is preserved in the volcanic rocks at the headwaters and northern half of the drainage.

At the base of the cirque walls, the creek drops steeply to the main Silver Creek valley where it joins water from additional cirques. Near this location, two Pleistocene moraines are mapped as are four rock falls. These rock falls are composed of dacites of Mount Rahm on the left bank and biotite-hornblende tonalite and granodiorite of the Chilliwack Composite Batholith on the right bank. This is also where the creek transitions from valley bottom into floodplain (elevation 1052

m) which continues for the remainder of the reach with the exception of two short (~0.5 km) stretches of river canyon. Two additional smaller Pleistocene moraines are located just east of this junction of valley bottom and floodplain.

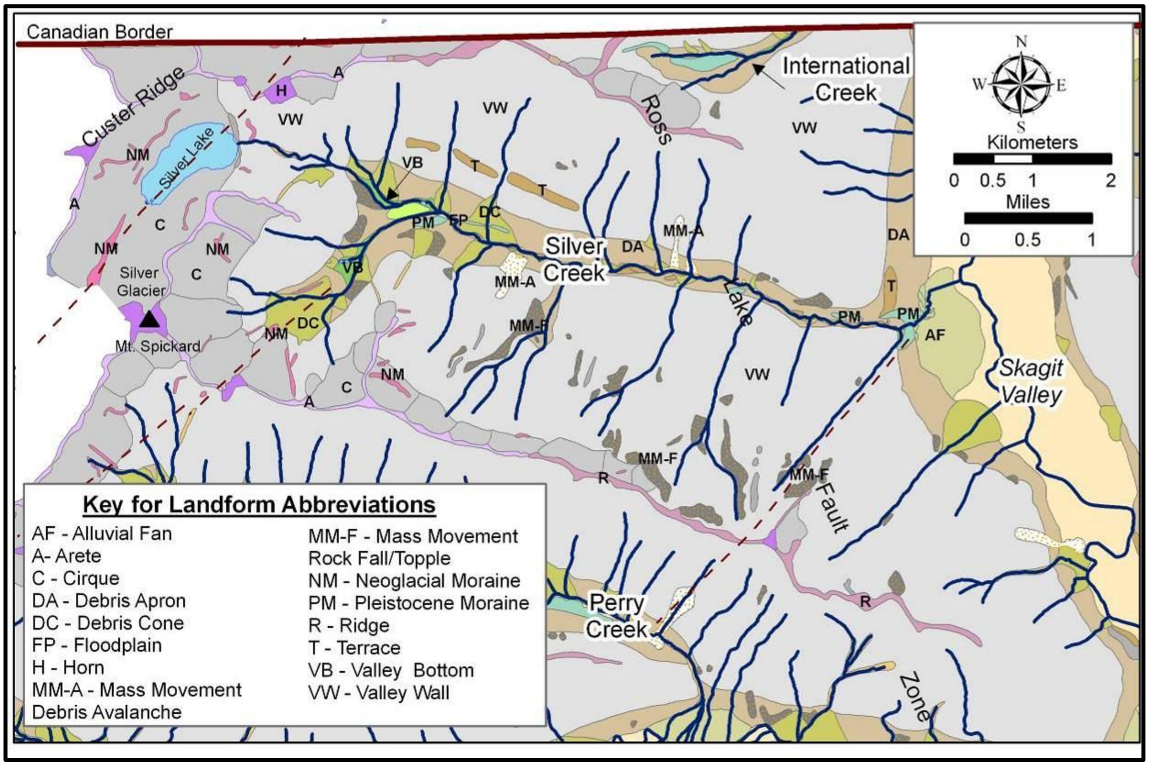

Figure 22. Landform map of Silver Creek, red dashed lines are faults.

Figure 23. Silver Lake from the base of Silver Glacier, located on the north face of Mt. Spickard. Custer Ridge is in the background.

The Silver Creek valley is dominated by valley wall and debris apron for most of its length except for three debris avalanches and numerous small rock falls and some slumps. Rock falls dominate the south-facing valley wall of the lower valley and are composed primarily of biotite-hornblende tonalite and granodiorite. Northeast-southwest fault traces are mapped within the valley, both near the mouth of the creek and beneath Silver Lake.

The upper reaches of the floodplain are bound by several small terraces varying in height from 1 m to nearly 25 m in one location. A series of lateral-moraine/kame terraces have also been mapped in the upper reaches, north of the creek, marking the margin of the glacier that filled the upper valley about 12 Ka (Riedel 2007). The lower valley has several 1.5 – 2 m terraces in addition to Pleistocene glacial deposits. At the mouth of Silver Creek is an extensive alluvial fan on the edge of Ross Lake. Numerous fan terraces are mapped near the apex of the fan, one large Pleistocene moraine is present just west of the mouth of Silver Creek. This drainage has several Pleistocene moraines, the most mapped in any of the sub-watershed in the Upper Skagit Watershed because of the extensive research on the valley and preservation.

5.2.8 Arctic Creek

The headwaters of Arctic Creek consist of six glacial cirques, one of which is occupied by a small glacier along the northeast face of Mt. Prophet (Fig. 24). Four of these cirques contain prominent Neoglacial moraines. Cirque floors extend down to ~1520 m, but are overall poorly defined in this drainage. Six rock falls and one debris avalanche are present near the junction of the west and east forks of Arctic Creek. All of these mass movements are within biotite-hornblende tonalite and granodiorite. A potential factor explaining the occurrence of these mass movements is that the valley cuts across the Ross Lake Fault Zone. As Figure 22 shows, many northwest-southeast trending faults have been mapped in this drainage. The Thunder Lake Fault probably controls the trend of the east fork of Arctic Creek.

The entire 10.5 km length of Arctic Creek is mapped as valley bottom with the exception of the short 0.5 km stretch of river canyon just above the mouth, where the hanging valley abruptly ends. A small debris cone has been deposited at the mouth of the creek. Overall, the Arctic Creek watershed is dominated by valley wall and debris apron morphologies. Although not field verified, no terraces or floodplain were identified within Arctic Creek.

In the upper valley there is a SAIL that has been identified on NAIP imagery (Fig. 25). It includes an unnamed lake and is marked in Figure 24. The difference between the Luna Creek SAIL and this one is that the one in Luna Creek was deposited by snow avalanches that travelled all the way to the valley floor, while the SAIL in Arctic Creek was deposited on a small level spot on the valley wall.

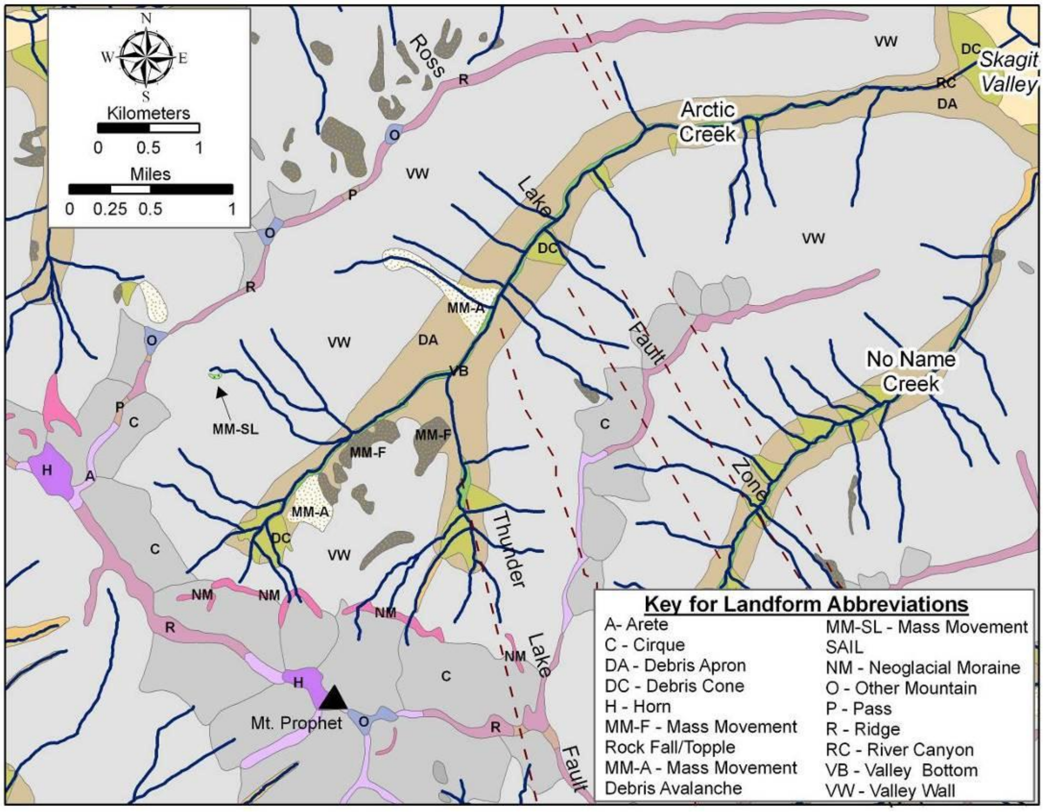

Figure 24. Landform map of Arctic Creek, red dashed lines are faults.

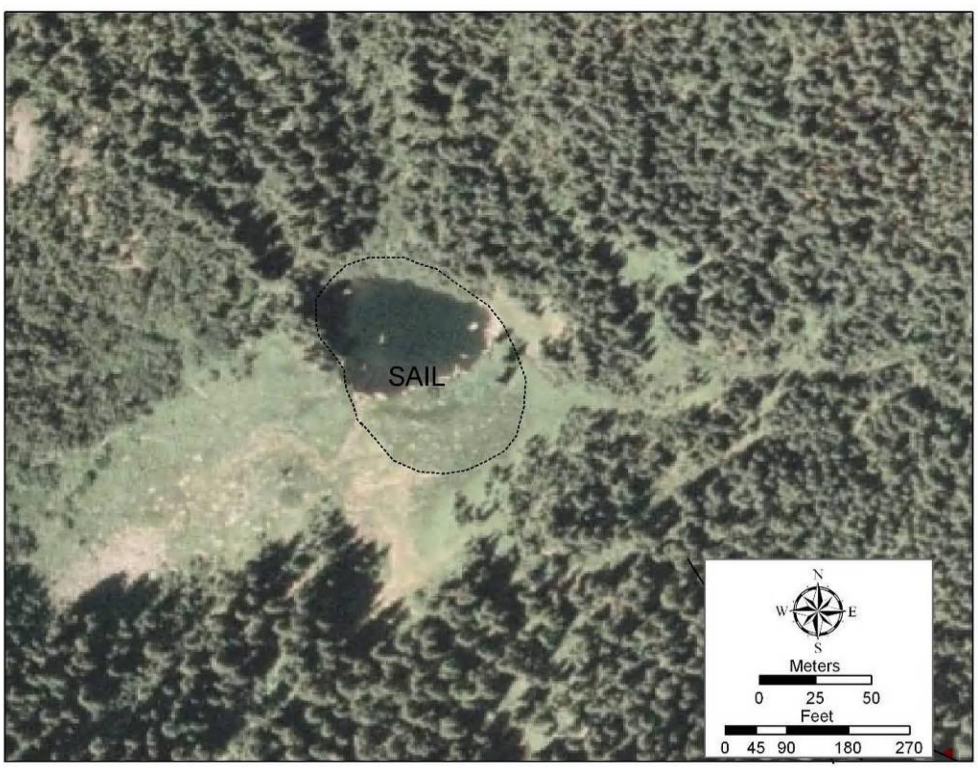

Figure 25. SAIL (snow avalanche impact landform) upper Arctic Creek. The SAIL is outlined in a dashed line, note the elliptical shape of the deposition area south of the lake.

5.2.9 No Name Creek

No Name Creek valley trends northeast and is 6 km long (Fig. 26). The head of the drainage has a series of small glacial cirques, two of which each contain a Neoglacial moraine. Three more Neoglacial moraines are present below the cirque walls, the lowest terminating at 1372 m. Cirque basins are poorly defined overall, with mostly ridges connecting cirques as opposed to steep arêtes. Several unnamed high alpine lakes are also present below the ridges and cirques of the headwaters. Alpine lakes have only been increasing in abundance over the last several decades due to the rapid shrinking of North Cascade glaciers and once permanent snowfields.

The ice and snowfields of the upper cirques drain into No Name Lake (3 ha) at the head of the valley. The entire valley channel is mapped as valley bottom with the exception of the final kilometer, which is a steep river canyon emptying into Ross Lake via a small waterfall. Development of landforms in the upper drainage has been influenced by the Ross Lake Fault Zone. Many of No Name's tributaries follow the northwest-southeast trending faults.

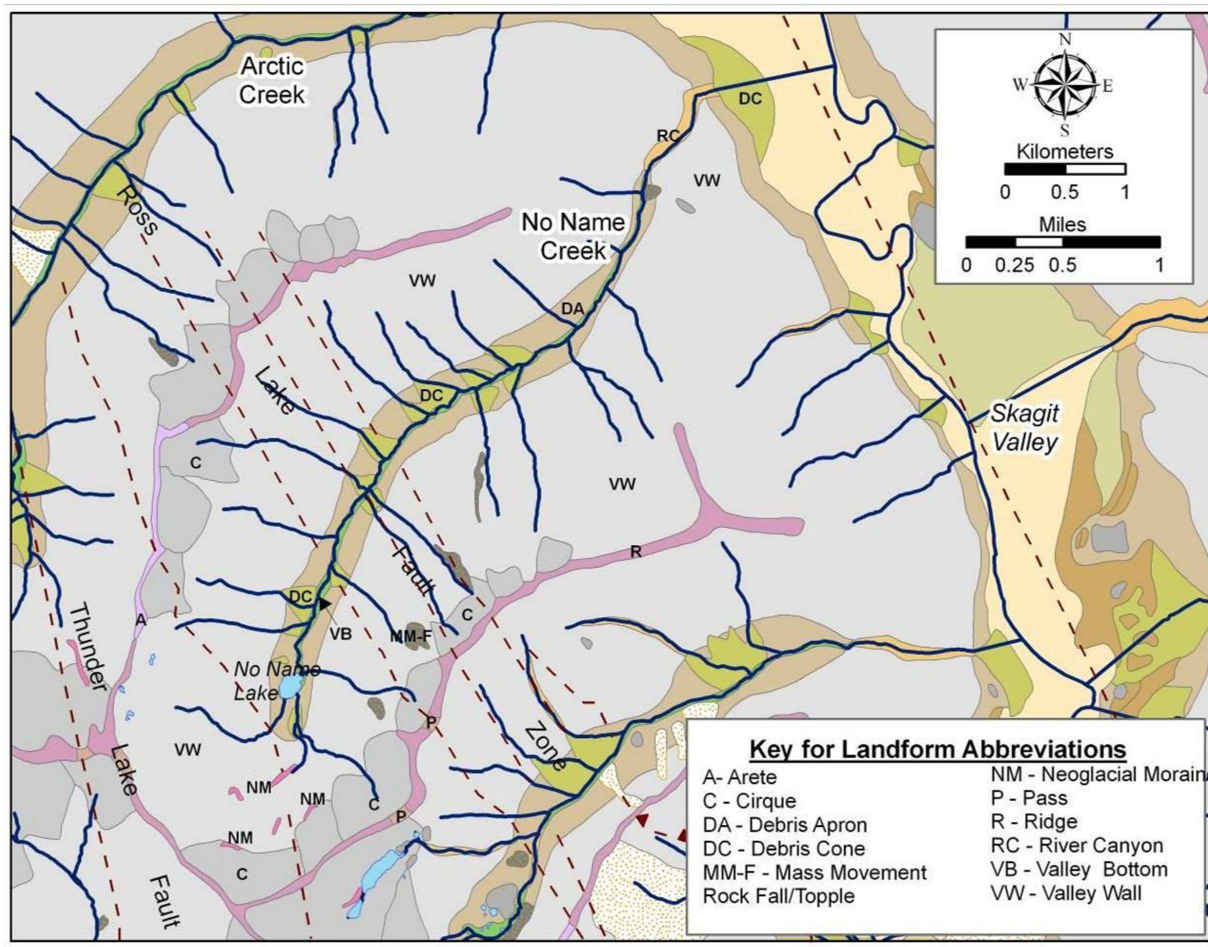

Figure 26. Landform map of No Name Creek, red dashed lines are faults.

5.2.10 Skymo Creek

Skymo Creek drains northeast from the Mt. Prophet massif to Ross Lake (Fig. 27). The headwaters rise from three cirques with the larger two containing small remnant glaciers or permanent snowfields. Cirque floors extend down to ~1580 m and contain three Neoglacial moraines. The largest cirque holds Skymo Lakes (1 and 4 ha), both tarns at elevation 1610 m. Three bedrock benches are near the mouth of these lakes. Valley bottom begins at elevation 1402 m in a series of small ponds. This upper part of the valley is composed of the metamorphosed troctolite, gabbronorite and anorthosite that locally contain pockets of fine-grained granulites. Two rock falls are located within these geologic units.

The Skymo Creek channel is mapped as valley bottom until the final ~1 km where the creek turns due east into a steep sided river canyon and descends to Ross Lake. Skymo Creek forms a spectacular waterfall as it tumbles over the edge of a hanging valley into Ross Lake. The valley contains four debris avalanches in Hozomeen Group rocks mapped on the south side of the valley. Several river canyons are mapped within the valley wall along the north side of the valley.

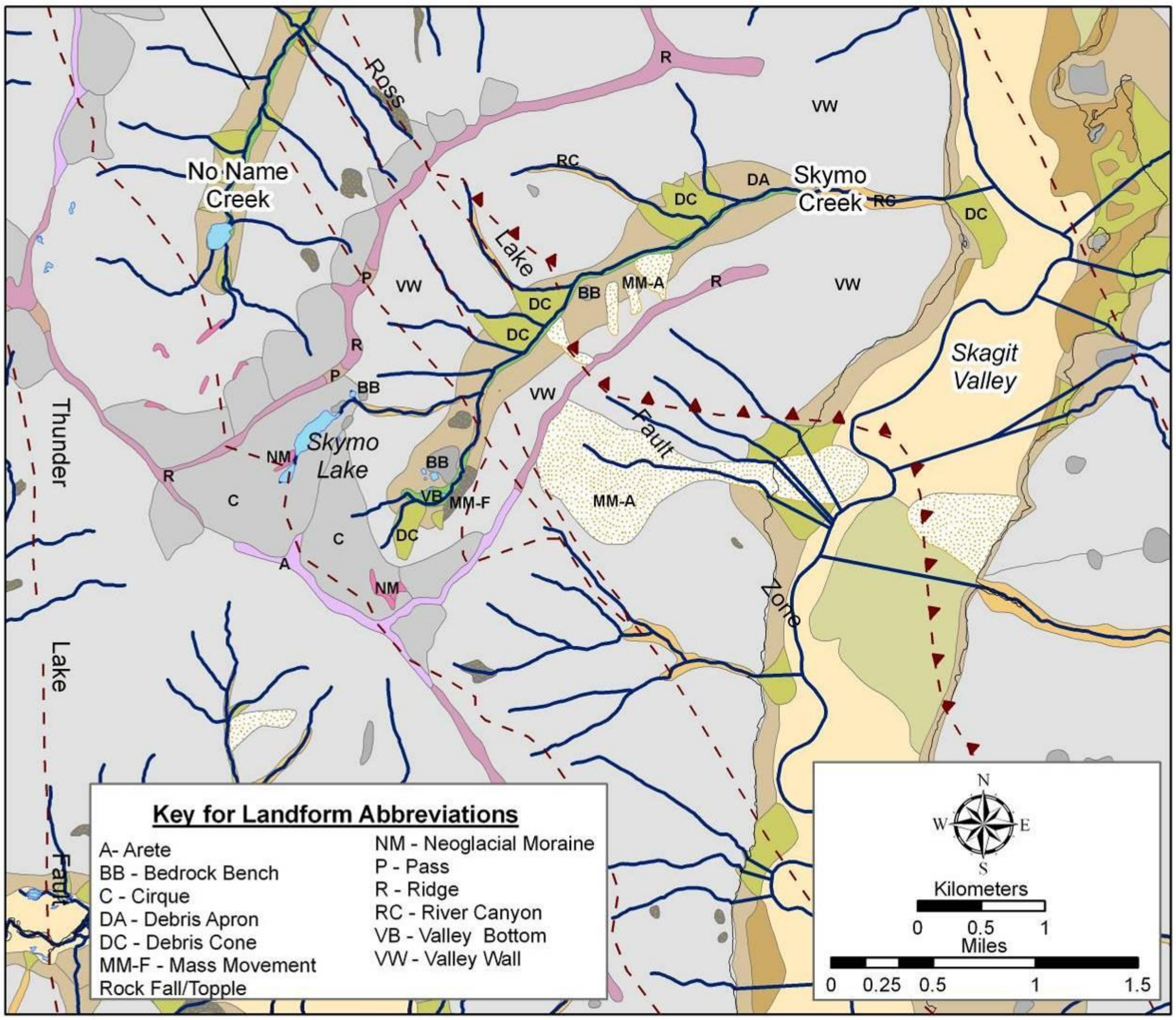

Figure 27. Landform map of Skymo Creek, red dashed lines are faults.

5.3 Valley Characteristics of East Ross Lake Sub-Watersheds

Landform development on the east side of Ross Lake has been strongly influenced by the warmer and drier climate regime (Waitt 1977). Valleys on the east side of Ross Lake tend to be longer, narrower and steeper than those on the west side.

Sub-watersheds will be discussed north to south, beginning with Hozomeen and ending with Panther Creek. Since the headwaters of many of Lightning, Roland May, Dry and Devils Creeks are not within NOCA; high elevation landforms are under-represented (Table 8). In the case of these drainages, the headwaters will be briefly described, but no landform information is currently available.

5.3.1 Hozomeen Creek

Hozomeen Creek is the northern-most tributary of Ross Lake in the United States. The headwaters begin from the breached divide between Hozomeen and Lightning Creeks, which is also bisected by the Hozomeen fault (Fig. 28). The waters of Hozomeen Creek used to include Freezeout Creek to the east. However, ice age floods flowing down Lightning Creek beheaded Hozomeen Creek east of Willow Lake, cutting off the headwaters of Freezeout Creek (Riedel et al. 2007). Willow Lake (7 ha) and Hozomeen Lake (40 ha) sit on the floor of the beheaded valley. Hozomeen Creek is considered an underfit stream by being so small in comparison to its valley width. Ridley Lake (4 ha) sits at the toe of the valley wall on drift deposited by the ice sheet.

Hozomeen Creek flows within valley bottom all the way to its outlet on Ross Lake. Several small rock falls/topples are present on the valley wall on both side of the creek, all composed of the Hozomeen terrane (mainly pillow basalt, with minor argillite, volcanic lithic sandstone, ribbon chert and limestone). Bedrock benches around Hozomeen Lake represent former divides and valley spurs eroded by the south-flowing ice sheets. At its lower end Hozomeen Creek crosses a large (kame) terrace deposited along the edge of the retreating Cordilleran Ice Sheet. The surface of the terrace has several ponds and unusually wet conditions compared to surrounding lodgepole pine and Douglas fir forests. Terraces are mapped at the mouth of the creek as well.

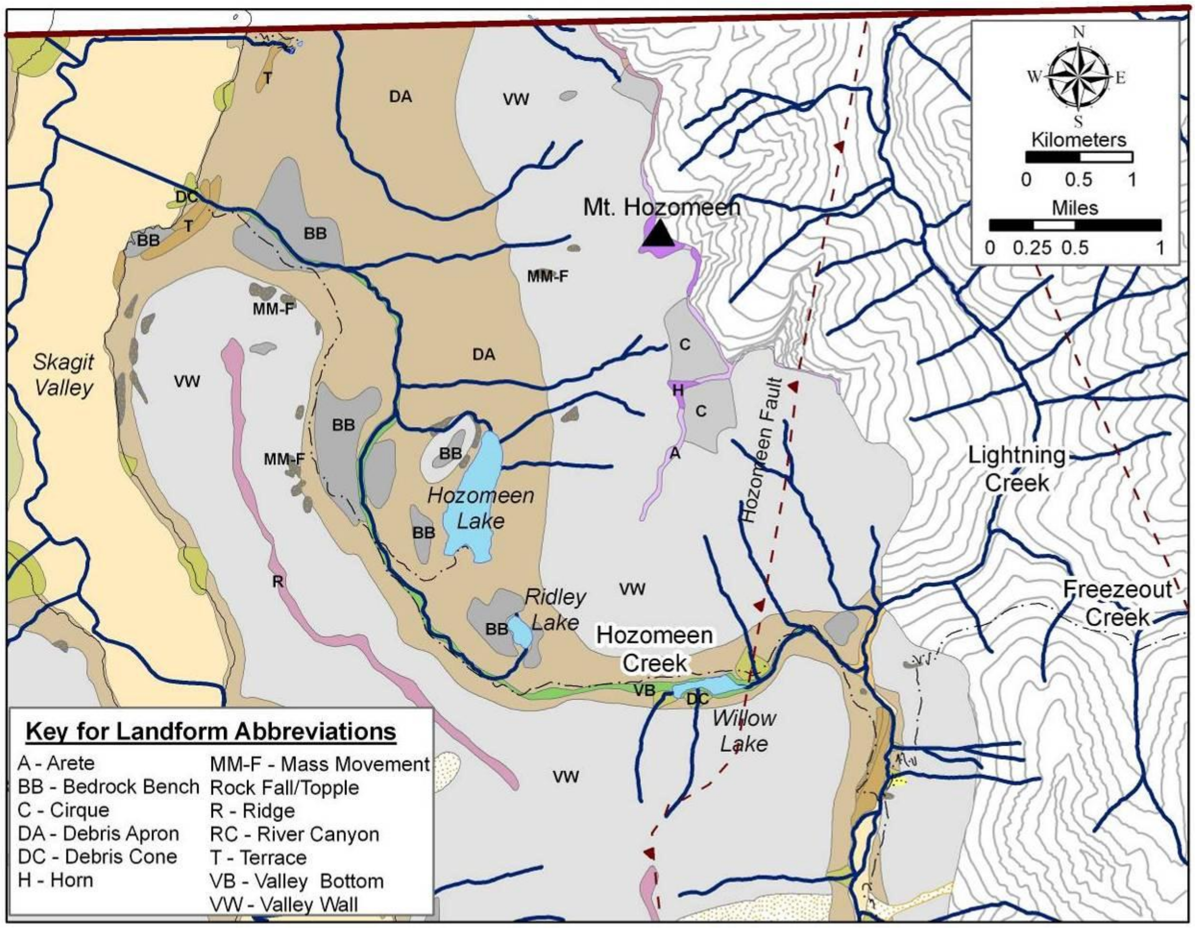

Figure 28. Landform map of Hozomeen Creek, black dot-dashed lines are trails and red dashed lines are faults.

5.3.1 Lightning Creek

The headwaters of Lightning Creek are 4 km north of the border in British Columbia at Thunder Lake. This watershed was extremely accessible to map since the East Bank Trail runs the entire length of the drainage in NOCA. The trend of the upper Lightning Creek follows the boundary of the Hozomeen Fault (Fig. 29). The creek enters the United States via a river canyon cut across the Pacific Crest by meltwater from ice age lakes trapped in Similkameen valley, British Columbia (Matthew 1968, Riedel 2007). A series of three terraces, at 30, 15 and 1.5 m are located along the right bank and confine the creek. The higher two terraces were probably deposited by the last of the ice age floods as was most of the Lightning Creek alluvial fan.

At the Nightmare Camp (Fig. 29) the valley opens up slightly from a 200 m to a 1 km wide floodplain. The valley then narrows as it traverses the large Desolation Peak debris avalanche. There is another debris avalanches, with terraces of 15, 12 and 1.5 m on the left bank. These terraces, like those further up-valley, represent deposition from the last ice age floods. Near the junction of Lightning and Three Fools Creek, the Lightning Creek turns west and enters a river canyon.

Beneath the waters of Ross Lake is a large (23 m thick) alluvial fan composed of large cobbles and small boulders deposited by Lightning Creek. This alluvial fan was created when a glacier-dammed lake in the Similkameen valley rushed down Lightning Creek to the Skagit River (Riedel 2007, Matthews 1969). There is a small pond (informally known as Lost Lake) on the surface of the subsequently abandoned fan terrace which is a kettle lake formed by the melting of a giant iceberg buried in outburst flood gravels. It can only be seen when Ross Lake is drawn down in the spring. The rapid deposition of this alluvial fan forced the Skagit River to the west side of the valley (Fig. 29).

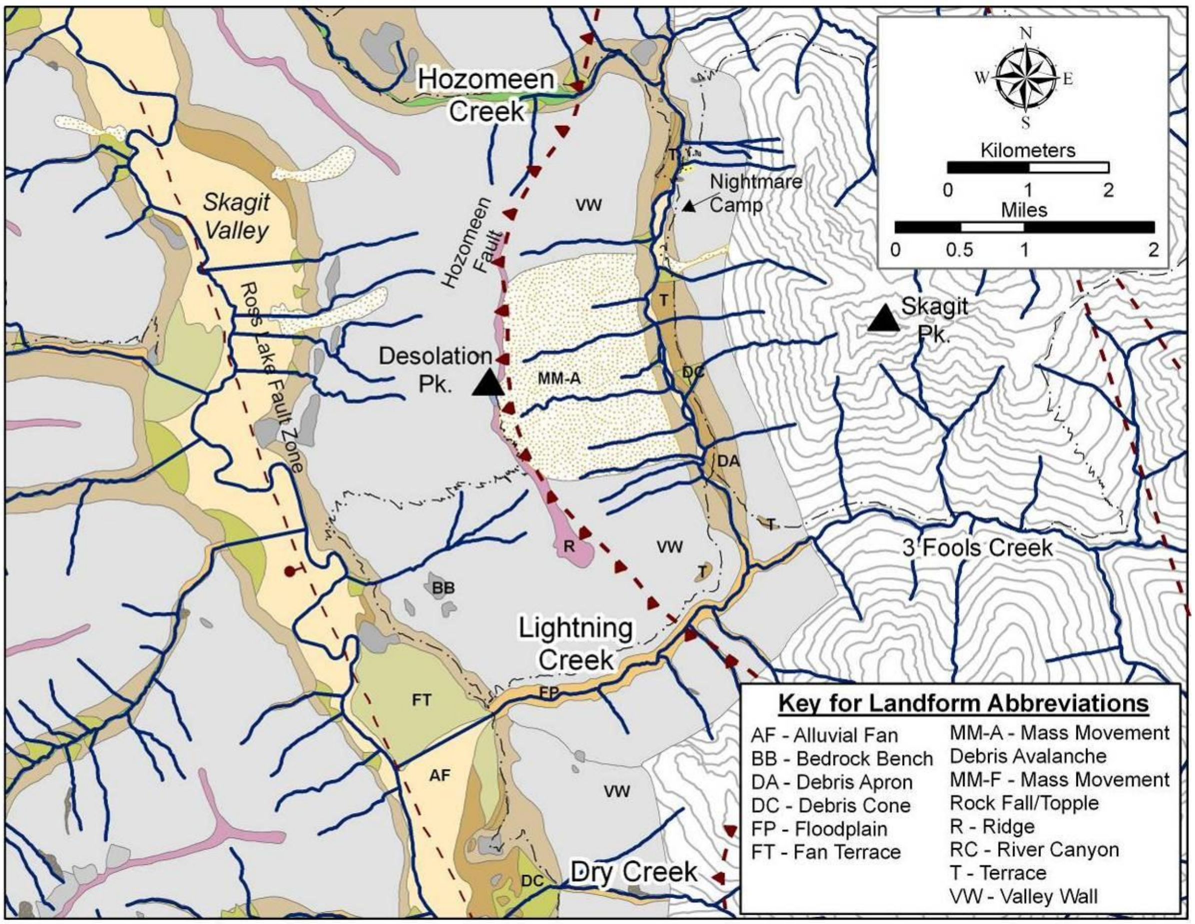

Figure 29. Landform map of Lightning Creek, black dot-dashed lines are trails and red dashed lines are faults.

5.3.3 Dry Creek

While only 1.3 km of Dry Creek is within the Park and mapped, the headwaters of the creek begin to the south-east below Dry Creek Pass (Fig. 30). As the creek travels northwest along a prominent thrust fault, it collects water draining the south and west face of Spratt Mountain. NAIP imagery reveals that the 4.2 km stretch of Dry Creek outside of the NOCA boundary contains a narrow valley bottom surrounded by steep sided valley walls, particularly on the creek's left (north-east facing) bank.

The creek takes a sharp turn to the west just prior to reaching the NOCA boundary. The creek is mapped entirely in river canyon until it reaches Ross Lake and deposits a debris cone that is confined to the north by a bedrock knob. Along the river canyon one small rock fall is mapped. A series of terraces is at the mouth of the creek, ranging from 6 to 3 m in height. Small bedrock benches are also present, intermixed with the terraces and debris cone.

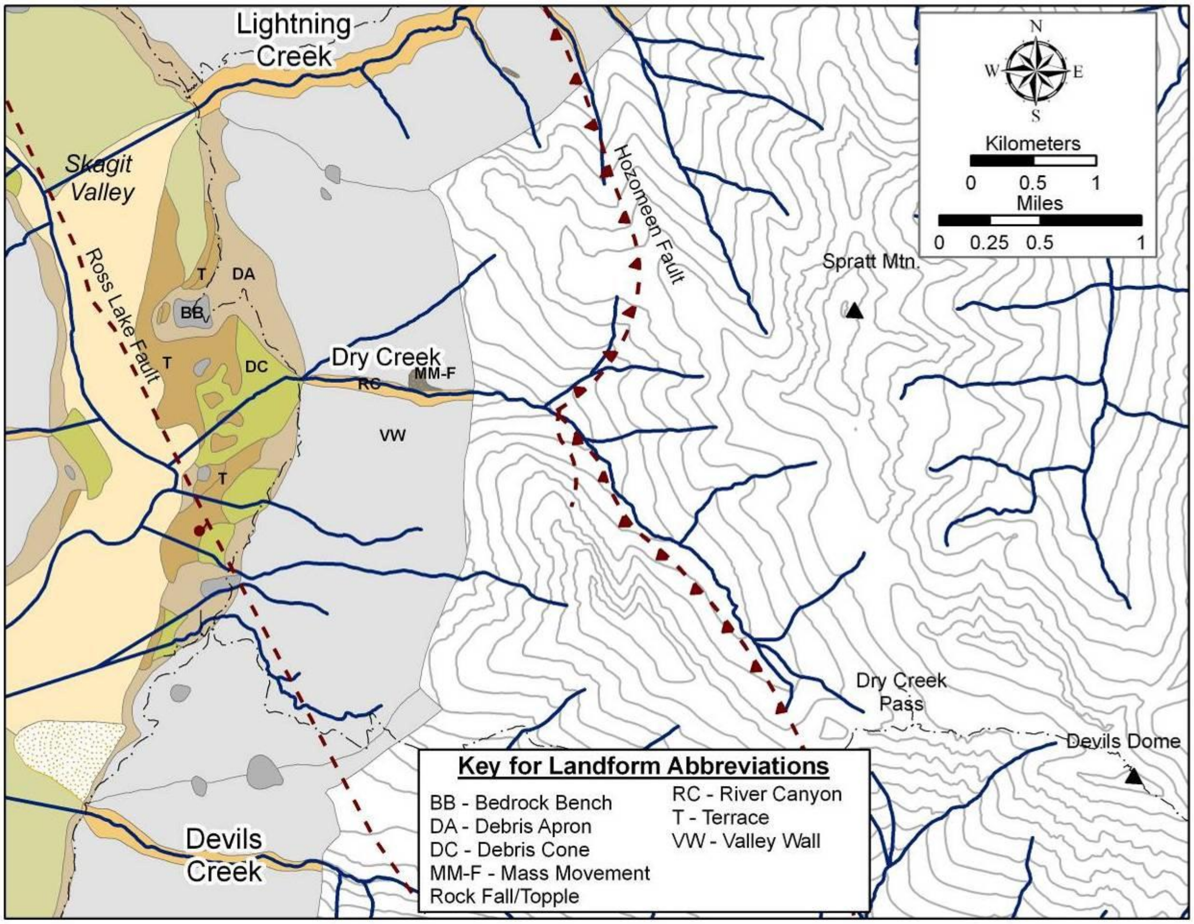

Figure 30. Landform map of Dry Creek, black dot-dashed lines are trails and red dashed lines are faults. Contour interval is 100 m.

5.3.4 Devils Creek

The Devils Creek headwaters are east of the NOCA boundary, in the cirque of Crater Mountain (Fig. 29). From here, the creek flows north and then west through a narrow floodplain. There appears to be numerous debris avalanches and debris cone/debris apron units before the stream reaches the NOCA boundary. Water from the glacier on Crater Mountain (0.5 km^2) and Jerry Lakes (11, 1, 0.8, 0.5 and 0.08 ha) enter the creek in its headwater area. The amount of glacial ice and permanent snowfields feeding Devils Creek from Jack Mountain (0.58 km^2) is slightly greater than the contributions from Crater Mountain (0.55 km^2). The northwest-southeast trend of the upper creek is directly along the edge of the Hozomeen fault. The unnamed tributary that collects water from the north face of Jack Mountain may also be influenced by these faults.

Devils Creek enters NOCA in a 2 km long, deep and narrow river canyon with steep valley walls, marking a transition from a U-shaped to a V-shaped valley. A large alluvial fan is present at the mouth of the creek, which is under the waters of Ross Lake. A debris avalanche deposit confines the northern extent of the alluvial fan.

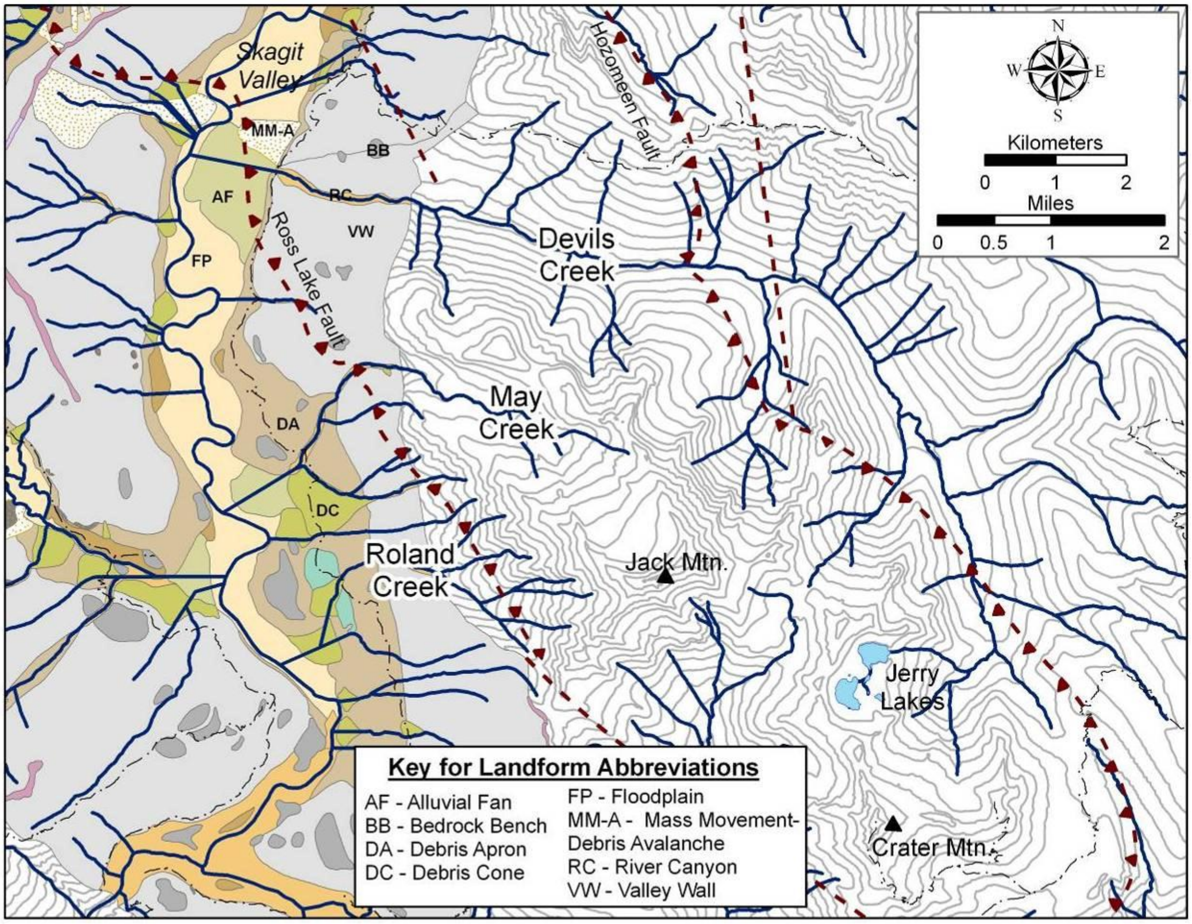

Figure 31. Landform map of Devils Creek, black dot-dashed lines are trails and red dashed lines are faults. Contour interval is 100 m.

5.3.5 May and Roland Creek

Both May and Roland Creek begin on the slopes of Jack Mountain and are composed mainly of the Hozomeen terrane and near their outlets cross the Ross Lake thrust fault to the Little Jack terrane (Fig. 32). Due to different valley head aspects, the creeks have very different geomorphology. May Creek directly sources run-off from the Nohokomeen Glacier, the largest glacier on the east side of Ross Lake. This impressive glacier is 1.8 km^2 in size and sits in a well-developed cirque basin (see cover photo). NAIP imagery reveals numerous Neoglacial moraines in the upper reaches of May Creek. The valley bottom is especially wide in the upper 2 km, due to the advances of the Nohokomeen Glacier. The valley does constrict 0.3 km before the NOCA boundary and the creek enters the park via a river canyon. Along either side of the 1 km long river canyon, there is steep valley wall mapped. The creek then enters a second 1 km long river canyon with broad debris apron with several bedrock benches on either side.

Roland Creek is a small sub-watershed, draining off the southwest-facing flank of Jack Mountain. Small snow fields feed the creek, but there is no glacial ice in the poorly formed cirques. The headwaters drain west off the steep ridge and valley wall then run northwest along the creek's valley bottom. Like most creeks in the Ross Lake area, the upper reaches of Roland Creek appear to follow the northwest-southeast trend of the Ross Lake Fault. Roland Creek enters NOCA after 1.8 km, flowing across the boundary in a river canyon. This river canyon is only 0.5 km long and the creek passes across debris apron to enter Ross Lake. A debris cone is deposited at the creek's outlet, with the East Bank trail crossing at the cone's apex. On either side of this debris cone are Pleistocene moraines, deposited beneath the ice sheet ~ 17Ka. Another debris cone is present further southwest of the creek's current outlet, a relic of the depositional environment before the creation of Ross Lake.

A large bedrock bench, known as Roland Point, is a distinctive landmark of Ross Lake near the mouth of Roland Creek. The Big Beaver valley glacier during the Evans Creek stade likely advanced against the bedrock bench, forming the dam that created glacial lake Skymo (Riedel 2007). Roland Point was also streamlined and scoured by repeated excursions of the Cordilleran Ice Sheet down Skagit Valley. Many bedrock benches in the Upper Skagit Valley have this north to south streamlined shape.

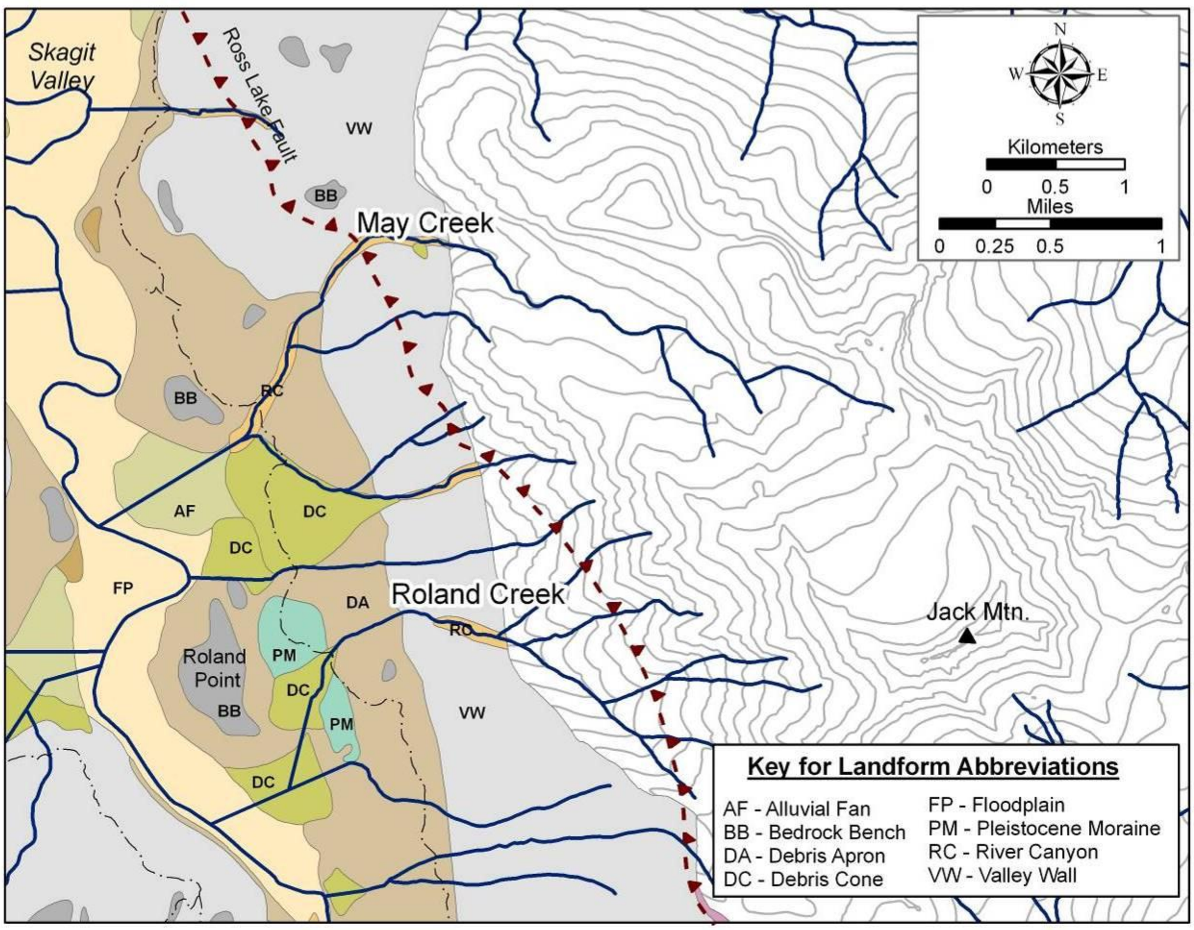

Figure 32. Landform map of May and Roland Creek, black dot-dashed lines are trails and red dashed lines are faults. Contour interval is 100 m.

5.3.6 Ruby Creek

The majority of Ruby Creek is not within the NOCA boundary. Many creeks (Canyon, Slate and Granite Creek) feed Ruby Creek from Harts Pass to McAlester Pass. The only major tributary of Ruby Creek that is within the Park is the sub-watershed of Panther Creek, which will be discussed in detail below. While the size of the Ruby Creek sub-watershed is greater than other large creeks like Big and Little Beaver, only the area within the park will be discussed in regards to landforms.

Ruby Creek enters Ross Lake along Ruby Arm (Fig. 33). Ruby Arm and Ruby Creek within NOCA are in a deep river canyon that is traceable to the Pacific Crest at Holman Pass (Riedel 2007). During the ice ages, water from the Pasayten River was forced down Canyon and Ruby Creeks by the south advancing ice sheet (Riedel et al. 2007). Bedrock benches are mapped on valley spurs top of the canyon, all glacially scoured by the Cordilleran Ice Sheet during the last major glaciation. Small unnamed tributaries on the left bank drop steeply, at times via river canyons, to meet Ruby Creek.

Lillian Creek enters Ruby Arm from the south (Fig. 33). Two rock falls/topples are present along Lillian Creek, with its headwaters at the lip of a cirque at elevation 1935 m. The cirque contains two Neoglacial moraines, the lowest of which terminates at 1940 m. Most of the creek is mapped as valley wall, which drops steeply to Ruby Arm. Happy Creek is just west of Lillian Creek, draining the same glacial cirque on Ruby Mountain. This creek has six debris avalanches and two rock falls along its banks, several of which likely blocked the creek at one time. The outlet of the creek has been artificially directed to drain into Ross Lake, just east of Ross Dam. Both Happy and Lillian Creek are mainly composed of bedrock of orthogneiss of the Skagit Gneiss Complex, which is found mainly in the Big Beaver drainage. Therefore although this sub-watershed is on the east side of Ross Lake, its geology matches those sub-watersheds on the west side of the Ross Lake Fault Zone.

Extensive bedrock benches between Diablo and Ross Dams, such as Happy Flats (Fig. 33), represent the base of the U-shaped trough carved through Skagit Gorge by the Cordilleran Ice Sheet. The ice sheet diverged to flow in three directions from the area near Ross Dam, including down the Skagit Gorge and up Thunder and Ruby Creeks (Riedel et al. 2007).

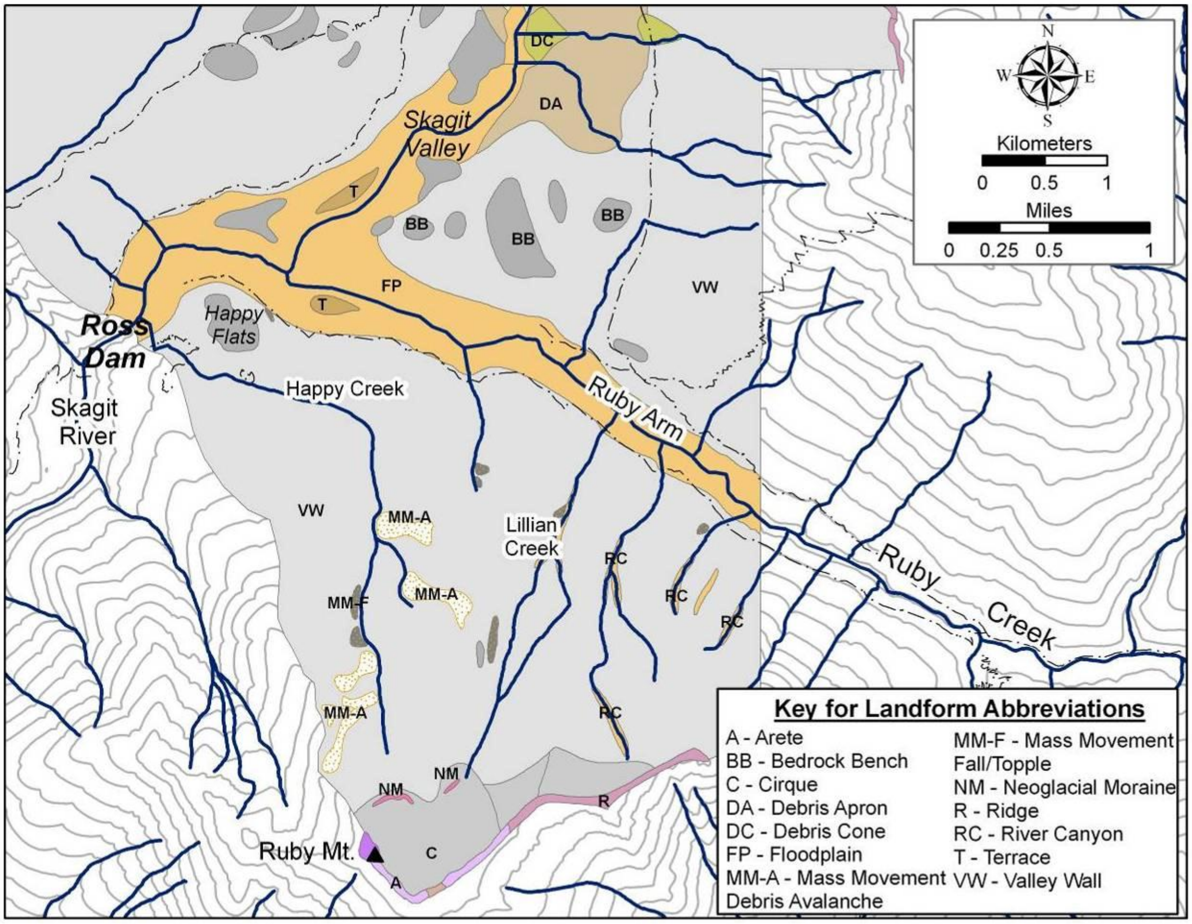

Figure 33. Landform map of Ruby Creek. See Figure 2 for legend, black dot-dashed lines are trails and red dashed lines are faults. Contour interval is 100 m.

5.3.7 Panther Creek

Entering Ruby Creek east of Ross Lake, Panther Creek is 22 km long with its headwaters on the north face of Ragged Ridge (the collective peaks of Cosho, Katsuk, Kimtah, and Mesahchie; Fig. 34). This creek drains a wide variety of rock types as it travels northwest to northeast (see Geologic Units). Panther Creek begins by travelling north from the Mesahchie Glacier on Mesahchie Peak. Approximately 0.5 km^2 in size, this glacier is within a well-defined north-northwest facing cirque with a floor at 1865 m but contains no Neoglacial moraines. The valley bottom starts at 1524 m and is surrounded by debris apron composed of glacial till. The waters from the Katsuk Glacier (0.8 km^2), and several other unnamed glaciers on the north face of Mesahchie and the northeast face of Kimtah Peak, enter Panther Creek in the upper reaches. While there are no Neoglacial moraines within the Katsuk cirque, two are present on a lesser cirque on the northeast face of Kimtah Peak. The lowest of these moraines terminates at 1841 m.

Continuing down the valley bottom, debris cones from steep side tributaries interrupt the continuous debris apron at the toe of the valley wall. Valley bottom transition to floodplain at about elevation 1340 m and the creek begins to trend more northwesterly, paralleling Ragged Ridge. In the first 2 km of floodplain, debris cones enter mainly from the south side of the valley. One rock fall and the waters from the Kimtah Glacier enter Panther Creek after it passes through these debris cones. Draining two cirque basins on the north to northwest face of Kimtah Peak (as well as the northeast face of Cosho Peak), the debris apron of this tributary is composed of glacial till. One Neoglacial moraine is mapped in each cirque, the lowest terminating at 1841 m.

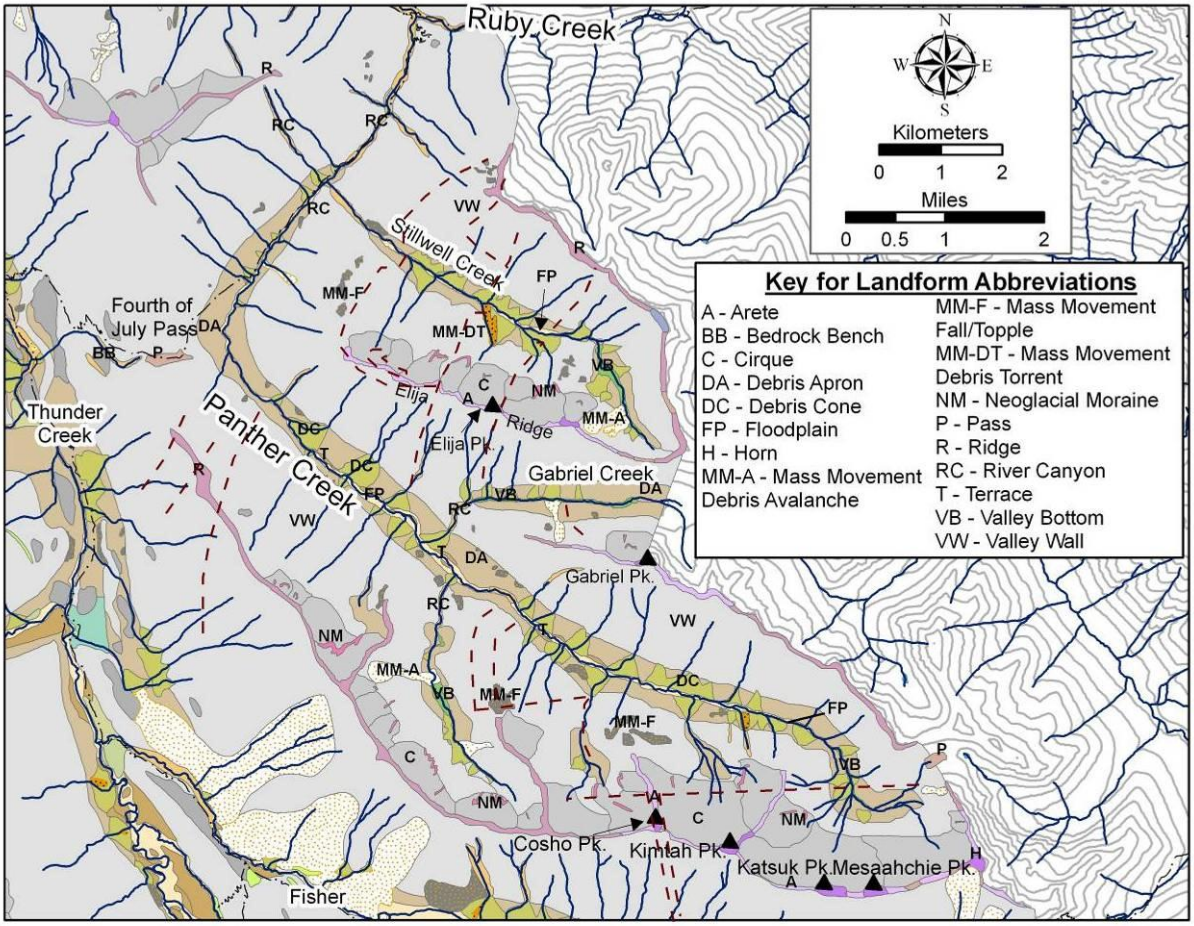

Figure 34. Landform map of Panther Creek, black dot-dashed lines are trails and red dashed lines are faults. Contour interval is 100 m.

As Panther Creek continues to drain northwest it passes three rock falls on the southern valley wall. An unnamed tributary drains the northwest face of Cosho Peak, a well-defined cirque basin with a total of three Neoglacial moraines and several small glaciers. The last tributary to enter Panther Creek along this stretch is another unnamed one that drains the northwest face of Red Mountain. This 4.5 km long tributary runs parallel to several cirques that contain a total of nine Neoglacial moraines. The valley bottom of the creek itself passes through mainly debris cones and debris apron landforms. A debris avalanche on the left bank may have temporarily blocked the stream at the time of deposition.

Gabriel Creek is a small tributary, collecting water from the south face of Elija Ridge and the north face of Gabriel Peak, which contains a small cirque with two Neoglacial moraines. Composed of valley bottom for almost its entire 5.5 km length, this steep-sided valley significantly broadens in the upper reaches, and shares a broad pass with Cabinet Creek.

Gabriel Creek drops steeply in a river canyon to its outlet on Panther Creek. It is likely that a large amount of sediment has been contributed to Panther by Gabriel Creek, since a large debris cone has built up and forced Panther Creek to the southwest side of the valley. Downstream of the Gabriel Creek outlet Panther Creek continues northwest 4.5 km through more terraces, debris cones and small rock falls before abruptly turning north-northeast around Elija Ridge just below Fourth of July Pass to the west. Fourth of July Pass was likely broadened by erosion from the ice sheet, which appears to have moved from east to west through the pass (Riedel 2009).

One debris avalanche enters Panther Creek on the right bank, originating from the valley wall of Elija Ridge. Small rock falls dot the valley walls as well. Stillwell Creek enters 1.5 km below the debris avalanche. Stillwell Creek parallels the entire northeastern face of Elija Ridge. The headwaters of 7 km long Stillwell Creek gather in valley bottom. Two debris avalanches that originate from Elija Ridge are mapped on the left bank of Stillwell Creek. It is likely that a majority of these mass movements along Elija Ridge are fault controlled since the area is intricately faulted. The creek enters a small river canyon and then transitions to floodplain. Numerous debris cones confine the floodplain as the creek parallels the ridge. Elija Ridge itself contains six cirques with a total of six Neoglacial moraines (terminating at 1829 m to 1585 m). Several rock falls are present at the northwesterly tip of the ridge. The creek has 4 km of floodplain, but enters Panther Creek via a 1 km long river canyon.

The remainder of Panther Creek consists of a steeply bound river canyon with rock falls on the upper valley walls. Bedrock cliffs are exposed along the river canyon and the trail adheres closely to the creek until the last 2 km. Panther Creek enters Ruby Creek in a river canyon and where the two meet is an impressive collection of large boulders deposited by steep mountain streams.

5.4 Upper Skagit 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).

Large landslides in the steep terrain of the Upper Skagit 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. Data from both sides of Ross Lake is summarized in the tables below (Table 9 and 10). This data clearly shows that rock falls/topples are the most common type of mass movement, with debris avalanches making up most of the mass movements by volume and area.

Table 9. Mass movements by sub-watershed on the west side of Ross Lake.

	Debris Avalanches		Rock Fall/Topple		Debris Torrent		Slump/Creep		SAIL or Sackung	
	#	Surface Area (m^2)	#	Surface Area (m^2)	#	Surface Area (m^2)	#	Surface Area (m^2)	#	Surface Area (m^2)
Big Beaver	15	2,861,290	44	1,408,840	20	385,990	2	5,395	1	2,960-SA
Little Beaver	16	2,385,714	78	1,716,826	8	94,788	4	4,409	1	11,676- SK
Silver	3	203,105	34	1,210,395	-	-	5	8,880	-	-
Arctic	2	415,680	7	404,633	-	-	-	-	1	4,873-SA
No Name	-	-	5	123,800	-	-	-	-	-	-
Skymo	4	171,184	2	56,644	-	-	-	-	-	-
Additional on West Side	2	1,350,674	11	158,057	-	-	2	5,882	-	-

Table 10. Mass movements by sub-watershed on the east side of Ross Lake.

	Debris Avalanches		Rock Fall/Topple		Debris Torrent		Slump/Creep		SAIL or Sackung	
	#	Surface Area (m^2)	#	Surface Area (m^2)	#	Surface Area (m^2)	#	Surface Area (m^2)	#	Surface Area (m^2)
Hozomeen	-	-	13	165,865	1	3,391	-	-		-
Lightning	2	4,999,428	4	18,144	-	-	1	14137	-	-
Dry	-	-	1	23,773	-	-	-	-	-	-
Devils	-	-	-	-	-	-	-	-	-	-
May	-	-	-	-	-	-	-	-	-	-
Roland	-	-	-	-	-	-	-	-	-	-
Ruby	6	293,327	8	77,057	-	-	-	-	-	-
Panther	7	665,179	45	799,178	3	137,886	2	1393	-	-
Additional on East Side	2	544,190	6	97,470	-	-	-	-	-	-

On the west side of Ross, mass movements constitute 2.8% of the landforms. The forty-two debris avalanches on the west side total an area of 7,387,600 m^2. Of these debris avalanches, thirty-one delivered an estimated total of 178,283,400 m^3 of sediment to streams, while eight of them likely blocked a creek entirely for a short time. 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. The majority of debris avalanches (52%) were composed of rocks of the Skagit Gneiss Complex, typically banded gneiss. The most common aspect for debris avalanches was north to northwest (43%). The debris avalanches under the "Additional West Side" (Table 9) consisted of two large debris avalanches that occurred from the valley wall into the main Skagit Valley. The more significant of the two debris avalanches is located between Big Beaver and Skymo Creeks, within rocks of the phyllite and schist of Little Jack Mountain. It was estimated that this debris avalanche delivered ~99,000,000 m^2 of sediment into the Skagit, which is 55% of the total amount of sediment added to the Skagit Valley from the west of the lake. Deposits from this debris avalanche travelled from west to east across the valley.

For rock falls, 41% occurred in Chilliwack Composite Batholith rock types (orthogneiss and biotite-hornblende tonalite) and 30% in Skagit Gneiss Complex (banded gneiss). While only 8% were found in the volcanic rock of Mount Rahm, it is significant to mention since very little of the watershed actually contains this geologic unit. Rock falls, like debris avalanches, are typically found on north to northwest facing slopes (51%). There were only a total of thirteen slump/creep mass movements on the west side of Ross Lake.

On the east side of Ross, mass movements constitute 3.2% of the landforms. On the east side of Ross, where only lower parts of most valleys were mapped, a total of seventeen debris avalanches were mapped. Of these debris avalanches, fifteen delivered a total of ~ 57,450,000 m^3 of sediment to streams total and six of them likely blocked a creek entirely. The majority of debris avalanches (35%) were composed of rocks of the Skagit Gneiss Complex, typically orthogneiss. The most common aspect for debris avalanches was split evenly between northeast and northwest aspects. The most significant debris avalanche on the east side of Ross Lake is located on the east face of Desolation Peak, directly on the Hozomeen fault. It delivered an estimated 51,200,000 m^3 of sediment to Lightning Creek. This deposit was mapped by the USGS as being an older landslide, Holocene to Pleistocene in age (Tabor et al. 2003).

Rock falls are also typically found on north to northeast/northwest facing slopes. Skagit Gneiss Complex orthogneiss and greenstone of the Hozomeen terrane composed the majority of rock falls (43%). There were only a total of three slump/creep mass movements on the east side of Ross Lake and only four debris torrents.

By reviewing the location, size and composition of these mass movements, some general observations can be made. The glacially over-steepened valley walls, aspect influenced erosion on the north -facing slopes and structural weakness associated with faults and hydrothermal alternation are likely responsible for the majority mass movement avalanches and rock falls throughout the sub-watersheds. The Upper Skagit Watershed is heavily faulted, lying directly in the Ross Lake Fault Zone and cut by the Thunder Lake and Hozomeen Faults as well. Rock falls/topples and debris avalanches in Arctic, No Name, Skymo and Lightning Creeks appeared to have been influenced by these northwest-southeast trending fault traces and originate from rocks weakened by this structure. The largest debris avalanche on the west side of Ross Lake, the one between Big Beaver and Skymo Creeks is located directly on the Ross Lake Fault, while on the east side the largest debris avalanche, located on the east face of Desolation Peak, is located on the Hozomeen Fault. Another dominant fault trace was of northeast-southwest extension faults. Some mass movements in Silver and Perry followed this trend.

Some rock types seemed more prone to developing mass movements, especially if they were heavily bisected by faults. Chilliwack Composite Batholith orthogneiss, biotite-hornblende tonalite and granodiorite and Skagit Gneiss Complex banded gneiss composed most of the mass movements on the west side of Ross Lake. The phylite and schist of Little Jack Mountain also seemed prone to mass movements, likely due to preferential foliation and its location in the Ross Lake Fault Zone.

The low number of slumps and creeps throughout the Upper Skagit Watershed may be reflecting the high amount of bedrock, the overall stability of vegetated valley walls and the lack of large exposed deposits of glacial drift/till in the floodplain. Such small deposits are difficult to identify in the field and in aerial photographs and thus may be under-represented. Most debris torrents were mapped in Big and Little Beaver Creeks, which 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. However it is also likely that since Big and Little Beaver Creek are the most accessible valleys, it is quite possible that debris torrent deposits were simply not revealed from aerial photograph mapping.

6 - Future Work

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.

7 - Literature Cited

Almack, J., Gaines, W., Morrison, P., Eby, J., Naney, R., Wooten G., Fitkin, S. and Garcia, E. 1993. North Cascades grizzly bear ecosystem evaluation; final report. Interagency Grizzly Bear Committee, Denver, Colorado.

Armstrong, J., Crandell, D., Easterbrook, D. and Noble, J. 1965. Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington. Geological Society of America Bulletin 76:321–330.

Baukun, W., Haugerud, R., Hopper, M., and Ludwin, R. 2002. The December 1872 Washington State Earthquake, Bulletin of the Seismological Society of America 92-8:3239-3258.

Bloom, A., 1978. Geomorphology. Prentice Hall, New Jersey, USA.

Briggs, C., Busacca, A. and McDaniel, P. 2006. Pedogenic processes and soil-landscape relationships in North Cascades National Park, Washington. Geoderma 137:192-204.

Briggs, C. 2004. GIS-Based Mapping of Soil Distribution in Thunder Creek Watershed, North Cascades National Park, Washington. Thesis. Washington State University, Pullman, Washington, USA.

Clague, J. 1981a. Late Quaternary Geology and Geochronology of British Columbia. Part I: Radiocarbon Dates. Geological Survey of Canada Paper 80-13.

Clague, J. 1981b. Late Quaternary Geology and Geochronology of British Columbia. Part II: Summary and Discussion of Radiocarbon-dated Quaternary History. Geological Survey of Canada Paper 80-35.

Cleland, D., Avers, P., McNab, W., Jensen, M., Bailey, R., King, T. and Russell, W. 1997. National hierarchical framework of ecological units. Pages 181-200 *in* M. Boyce and A. Haney, editors. Ecosystem management applications for sustainable forest and wildlife resources. Yale University Press, New Haven, CT.

Davis, C. 2004. Landtype Associations of North-Central Washington. USDA Forest Service, Wenatchee, Washington, USA.

Franklin, J. and Dyrness, C. 1973. Natural Vegetation of Oregon and Washington, Oregon State University Press, USA.

Frazier, B., Rodgers, T., Briggs, C. and Rupp, R. 2009. Remote area soil proxy modeling technique. Soil Survey Horizons 50:62-67.

Granshaw, F. 2001. Glacier Change in the North Cascades National Park Complex, Washington State, USA, 1958-1998. Thesis. Portland State University, Portland, USA.

Haugerud, R., van der Heyden, P, Tabor, R., Stacey, J., Zartman, R. 1991. Late Cretaceous and early Tertiary plutonism and deformation in the Skagit Gneiss Complex, North Cascade Range, Washington and British Columbia. Geological Society of America Bulletin 103: 1297 – 1307.

Malone, S. and Bor, S. 1979. Attenuation patterns in the Pacific Northwest based on intensity data and location of the 1872 North Cascades earthquake, Bulletin of the Seismic Society of America 69:531–546.

Matthews, W. 1968. Geomorphology of Lightning Creek valley, Manning Park, southwest B.C. Syesis 1:65-78.

Mierendorf, R. 1999. Precontact Use of Tundra Zones of the Northern Cascades Range of Washington and British Columbia. Archaeology in Washington 7:3-23.

Mierendorf, R., David, H. and Sullivan, G.1998. An Archaeological Site Survey and Evaluation in the Upper Skagit River Valley, Whatcom County, Washington. Technical Report NPS/CCCNOCA/CRTR-98/01. National Park Service. Fort Collins, Colorado.

National Weather Service Cooperative Network Station (NWS COOP). 2009. COOP data from the Ross Dam site. Online. (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wa7185). Accessed on 9 May 2009.

Natural Resource Conservation Service (NRCS). 2009a. Snow course data for Beaver Creek Trail, Beaver Pass, Brown Top Ridge, and Lake Hozomeen snow course sites. Online. (http://www.wcc.nrcs.usda.gov/snowcourse/sc-data.html). Accessed on 6 May 2009.

Natural Resource Conservation Service (NRCS). 2009b. SNOTEL data for Beaver Pass and Hozomeen SNOTEL sites. Online. (http://www.wcc.nrcs.usda.gov/snotel/Washington/washington.html). Accessed on 6 May 2009.

North Cascades National Park Service Complex (NOCA NPS 2009). Glacier Monitoring program. Online. (http://www.nps.gov/noca/naturescience/glacial-mass-balance1.htm). Accessed on 22 July 2009.

Porter, S. and Swanson, T. 1998. Radiocarbon age constraints on rates of advance and retreat of the Puget Lobe of the Cordilleran Ice Sheet during the last glaciation, Quaternary Research 50:205-213.

Post, A., Richardson, D., Tangborn, W. and Rosselot, F. 1971. Inventory of Glaciers in the North Cascades Washington, US Geological Survey, Professional Paper 705-A.

Reiners, P., Ehlers, T., Garner, J., Mitchell, S., Montgomery, D., Vance, J. and Nicolescu, S. 2002. Late Miocene erosion and uplift of Washington Cascade Range. Geological Society of America Bulletin 31:767-770.

Riedel, J. 2009. Cordilleran Ice Sheet in Skagit Valley, Washington and British Columbia. Talk presented to the Annual Canadian Quaternary Association Meeting in Vancouver, 2009.

Riedel, J. 2007. Late Pleistocene glacial and environmental history of Skagit valley, Washington and British Columbia. Dissertation. Simon Fraser University, Canada.

Riedel, J. 1987. Chronology of Late Holocene glacier recessions in the Cascade Range and deposition of a recent esker in a cirque basin, North Cascades Range, Washington. Thesis. University of Wisconsin-Madison, USA.

Riedel, J., Burrows, R. and Wenger, J. 2008. Long term monitoring of small glaciers at North Cascades National Park: A prototype park model for the North Coast and Cascades Network, Natural Resource Report NPS/NCCN/NRR—2008/000. National Park Service, Fort Collins, Colorado.

Riedel, J., Haugerud, R. and Clague, J. 2007. Geomorphology of a Cordilleran ice sheet drainage network through breached divides in the North Cascades Mountains of Washington and British Columbia, Geomorphology.

Riedel, J. and Probala, J. 2005. Mapping ecosystems at the landform scale in Washington state, Park Science 23-2: 37-42.

Riedel, J., Wenger, J. and Bowerman, N. *in review*. Long term monitoring of glaciers at Mount Rainier National Park. Natural Resource Technical Report NPS/PWR/NCCN/NRTR – National Park Service, Oakland, CA.

Rodgers, T. 2000. Modeling soils of the Sawtooth and Paysayten wilderness areas with a GIS. Thesis. Washington State University, Pullman, Washington, USA.

Schaetzl, R., Anderson, S. 2005. Soils: Genesis and Geomorphology. Cambridge University Press, New York, USA.

Soil Survey Staff. 1999. Soil Taxonomy, 2nd edition. USDA-Natural Resources Conservation Service, Washington, DC, USA.

Tabor, R. 1971. Origin of ridge-top depressions by large-scale creep in the Olympic Mountains, Washington. Geological Society of America Bulletin 82:1811-1822.

Tabor, R. and Haugerud, R. 1999. Geology of the North Cascades: A mountain mosaic. The Mountaineers, Seattle, Washington, USA.

Tabor, R., Haugerud, R., Brown, E. and Hildreth, W. 2003. Geologic Map of the Mount Baker 30- by 60-minute quadrangle, Washington. U.S. Geological Survey, Miscellaneous Investigations Map, I-2660.

Tittman, O. and Walcott, C. 1913. Topographic map of the U.S. – Canadian International Boundary, Sheet 5. United States Geological Survey (USGS).

United States Geological Survey (USGS)a, 2009, Earthquake Database. Online. (http://neic.usgs.gov/neis/epic/epic.html). Accessed on 5 March 2009.

United States Geological Survey (USGS)b. 2009. Peak annual flow for streams in Washington, by county. Online. (http://nwis.waterdata.usgs.gov/nwis/peak?state_cd=wa&format=station_list&sort_key=station_nm&group_key=county_cd&set_logscale_y=1&date_format=YYYY-MM-DD&rdb_compression=file&hn2_compression=file&list_of_search_criteria=state_cd.). Accessed on 8 October 2009.

Waitt, R Jr. 1977. Evolution of glaciated topography of upper Skagit drainage basin, Washington. Arctic and Alpine Research 9:183-192.

Zdanowicz, C., Zielinski, G., Germani, M. 1999. Mount Mazama eruption: calendrical age verified and atmospheric impact assessed. Geology 27: 621–624.

Appendix A: Landslide Inventories for the Upper Skagit Watershed

List of landslide characteristics documented for each landslide is reviewed in this appendix. There are 18 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 m^2 and km^2. 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.

There are several different landslide inventories for the Upper Skagit Watershed. They are broken into 5 different sets: Big Beaver Creek, Little Beaver Creek, West side Ross Sub-watersheds (Silver, Arctic, International, Skymo, NoName and Unnamed), East side Ross Sub-watersheds (Hozomeen, Lightning, Dry, Devils, May, Roland, Ruby and Unnamed) and Panther Creek. The information will be presented in this order.

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
12	1	Pierce	12-1-3	3	D		Y	TKsbg
12	2	Big Beaver	12-2-1	1	R		Y	Tkso
12	3	Big Beaver	12-3-3	3	D		N	Tkso
12	4	Big Beaver	12-4-1	1	R		N	Tkso
12	5	Big Beaver	12-5-3	3	D		N	Tkso
12	6	Big Beaver	12-6-1	1	R		N	TKsbg
12	7	Big Beaver	12-7-1	1	R		Y	TKso
12	8	Big Beaver	12-8-3	3	D		Y	TKso
12	9	Big Beaver	12-9-1	1	R		N	TKso
12	10	Big Beaver	12-10-1	1	R		N	TKso
12	11	Big Beaver	12-11-1	1	R		N	TKso
12/11	12	Big Beaver	11-12-1	1	R		N	TKsbg
12/11	13	Big Beaver	11-13-3	3	D		N	TKsbg
11	14	Big Beaver	11-14-1	1	R		N	TKsbg
11	15	Big Beaver	11-15-1	1	R		Y	TKsbg
11	16	Big Beaver	11-16-1	1	R		Y	TKsbg
11	17	Big Beaver	11-17-3	3	D		Y	TKsbg
11	18	Big Beaver	11-18-1	1	R		N	TKsbg
11	19	Big Beaver	11-19-1	1	R		N	Tksbga
11	20	Thirtynine Mile	11-20-1	1	R		N	Tksbga
11	21	Thirtynine Mile	11-21-1	1	R		N	Qb
11	22	Thirtynine Mile	11-22-1	1	R		N	Tksbga
11	23	Thirtynine Mile	11-23-1	1	R		N	Tksbga
11	24	Thirtynine Mile	11-24-1	1	R		N	Tksbga
11	25	Thirtynine Mile	11-25-1	1	R		N	Tksbga
11	26	Big Beaver	11-26-3	3	D		Y	Tksbga
11	27	Big Beaver	11-27-1	1	R		N	Tksbga
11	28	Big Beaver	11-28-1	1	R		N	TKsbg
11	29	Big Beaver	11-29-3	3	D		N	TKsbga
11	30	McMillan	11-30-3	3	D		N	TKsbga
11	31	McMillan	11-31-1	1	R		N	TKso
11	32	McMillan	11-32-1	1	R		N	TKsbga

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
11	33	McMillan	11-33-1	1	R		N	TKsbg
11	34	McMillan	11-34-1	1	R		N	TKsbg
11	35	McMillan	11-35-1	1	R		N	TKsbg
11	36	McMillan	11-36-1	1	R		N	TKso
11	37	McMillan	11-37-1	1	R		Y	Qag
11	38	Big Beaver	11-38-1	1	R		N	TKsbg
11	39	Big Beaver	11-39-1	1	R		N	TKsbga
11	40	Big Beaver	11-40-1	1	R		Y	TKsbga
11	41	Big Beaver	11-41-1	1	R		Y	Tcpc
11	42	Big Beaver	11-42-3	3	D		BLKD?	TKsbg/TKsbga
11	43	Big Beaver	11-43-1	1	R		Y	Qt
11	44	Big Beaver	11-44-1	1	R		N	Tcpc
11	45	Big Beaver	11-45-1	1	R		N	Tcpc
10	46	McMillan	10-46-1	1	R		N	Tcpc
10	47	McMillan	10-47-1	1	R		N	TKso
10	48	McMillan	10-48-1	1	R		N	TKso
10	49	McMillan	10-49-1	1	R		N	TKso
10	50	McMillan	10-50-3	3	D		N	TKso
10	51	McMillan	10-51-3	3	D		N	TKso
10	52	Big Beaver	10-52-1	1	R		Y	TKsbg
10	53	Luna	10-53-5	5	S		N	Qag
10	54	Luna	10-54-3	3	D		BLKD	Tcpc
10	55	Luna	10-55-1	1	R		N	Tcpc
10	56	Luna	10-56-1	1	R		N	Tcpc
10	57	Luna	10-57-1	1	R		N	Tcpc
12	58	Big Beaver	12-58-4	4	D		Y	Qf
12	59	Big Beaver	12-59-4	4	D		Y	Qag
11	60	Big Beaver	11-60-1	1	R		Y	Tksbg
11	61	Big Beaver	11-61-4	4	D		Y	Qag
11	62	Big Beaver	11-62-4	4	D		Y	Qf

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
11	63	Big Beaver	11-63-4	4	D		Y	Qf
11	64	McMillan	11-64-4	4	D		Y	Qf
11	65	McMillan	11-65-4	4	D		Y	Qf
11	66	McMillan	11-66-4	4	D		Y	Qf
11	67	McMillan	11-67-4	4	D		Y	Qf
11	68	McMillan	11-68-4	4	D		Y	Qyal
11	69	Big Beaver	11-69-2	2	T		Y	Qag
11	70	Big Beaver	11-70-2	2	T		Y	Qag
11	71	Big Beaver	11-71-3	3	D		N	TKso
11	72	Big Beaver	11-72-3	3	D		Y	TKsbg
11	73	Big Beaver	11-73-4	4	D		Y	Qas
11	74	Big Beaver	11-74-4	4	D		Y	Qas
11	75	Big Beaver	11-75-4	4	D		Y	Qas
11	76	Big Beaver	11-76-4	4	D		Y	Qyal
11	77	Big Beaver	11-77-4	4	D		Y	Qyal
11	78	Big Beaver	11-78-4	4	D		Y	Qf
11	79	Big Beaver	11-79-4	4	D		Y	Qyal
10	80	Luna	3-80-4	4	D		Y	Qag
10	81	Luna	3-81-4	4	D		Y	Qag
10	82	Luna	3-82-4	4	D		Y	Tcpc

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	256	191	42453	0.042453	50	109	9.144	26080.212
2	83	236	23086	0.023086				
3	943	157	189328	0.189328	433	200	57.912	2624610.448
4	225	305	80252	0.080252				
5	1000	187	181828	0.181828	538	200	73.152	4119237.888
6	149	281	44635	0.044635				
7	119	282	38675	0.038675				
8	526	148	81578	0.081578	168	162	48.768	694604.5747
9	58	185	10265	0.010265				
10	65	126	12981	0.012981				
11	87	256	24747	0.024747				
12	401	149	52471	0.052471				
13	765	133	93799	0.093799	189	151	27.432	409708.1671
14	571	102	104293	0.104293				
15	144	280	51798	0.051798				
16	141	215	27388	0.027388				
17	1516	239	316019	0.316019	272	180	67.056	1718135.654
18	189	186	38991	0.038991				
19	66	162	11792	0.011792				
20	113	112	12185	0.012185				
21	136	64	8814	0.008814				
22	133	83	13884	0.013884				
23	158	119	33363	0.033363				
24	155	120	40396	0.040396				
25	131	75	16486	0.016486				
26	1836	332	504875	0.504875	679	463	88.392	14542602.17
27	105	116	11566	0.011566				
28	45	82	4698	0.004698				
29	617	219	153185	0.153185	172	101	24.384	221683.3971
30	226	123	30337	0.030337	75	129	6.096	30865.572
31	156	224	33044	0.033044				
32	219	119	34305	0.034305				
33	181	114	28445	0.028445				
34	132	222	39450	0.03945				
35	144	258	56229	0.056229				

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	144	258	56229	0.056229				
36	173	157	61761	0.061761				
37	182	407	89302	0.089302				
38	158	385	59482	0.059482				
39	161	199	37779	0.037779				
40	96	195	37057	0.037057				
41	166	347	63190	0.06319				
42	1192	397	411867	0.411867	527	443	67.1	8198138.656
43	58	147	22825	0.022825				
44	59	107	7699	0.007699				
45	58	200	12840	0.01284				
46	145	111	26232	0.026232				
47	125	118	15245	0.015245				
48	110	397	47791	0.047791				
49	226	98	21365	0.021365				
50	321	87	28086	0.028086	72	60	24.384	55127.3472
51	614	132	78872	0.078872	190	98	36.576	356413.6128
52	255	58	14538	0.014538				
53	35	54	2960	0.00296				
54	1055	450	537036	0.537036	492	543	134.112	18750418.66
55	216	62	13886	0.013886				
56	163	71	15881	0.015881				
57	161	73	15015	0.015015				
58	593	116	54272	0.054272				
59	271	48	12902	0.012902				
60	62	164	9199	0.009199				
61	108	64	7719	0.007719				
62	119	48	5605	0.005605				
63	208	64	12958	0.012958				
64	406	59	18978	0.018978				
65	364	100	35190	0.03519				
66	249	126	34535	0.034535				
67	171	208	47962	0.047962				
68	159	53	7907	0.007907				
69	42	49	2522	0.002522				
70	45	57	2873	0.002873				

MM#	For all Types				Values for Volume Calculations: For MM-As Only			
	Length m.	Width m.	Surface Area m^2	Surface Area km^2	Width m.	Width m.	Depth m.	Volume m^3
71	237	183	45798	0.045798	87	162	33.524	247268.3306
72	954	181	166229	0.166229	362	278	48.768	2568423.941
73	95	58	7187	0.007187				
74	210	50	11142	0.011142				
75	156	65	15609	0.015609				
76	276	51	16002	0.016002				
77	228	58	16059	0.016059				
78	160	36	8506	0.008506				
79	62	142	14318	0.014318				
80	261	35	11582	0.011582				
81	155	103	21965	0.021965				
82	315	70	25592	0.025592				

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
1	COMP	5	54	VW	1036	877.824
2	FL	110	142	VW	939	694.944
3	COMP	70	71	VW	1256	499.872
4	FL	60	50	VB	671	499.872
5	COMP	40	73	VW	1231	499.872
6	FL	350	79	VW	1402	1219.2
7	FL	60	59	VB	610	512.064
8	COMP	255	108	VW	1487	938.784
9	FL	240	52	VW	585	536.448
10	FL	280	68	VW	585	524.256
11	FL	190	50	VW	610	524.256
12	FL	60	68	VW	1768	1511.808
13	COMP	120	88	VW	1646	1011.936
14	FL	70	74	VW	1524	1097.28
15	FL	110	122	VW	1085	877.824
16	FL	120	82	VW	975	829.056
17	COMP	340	58	VW	1369	548.64
18	FL	310	108	VW	1244	950.976
19	FL	170	48	VW	683	633.984
20	FL	100	68	VW	1097	1011.936
21	FL	250	81	VW	1341	1219.2
22	FL	250	44	VW	1500	1432.56
23	FL	90	62	VW	1670	1487.424
24	FL	110	38	VW	1536	1341.12
25	FL	80	68	VW	1390	1243.584
26	COMP	200	60	VW	1622	548.64
27	FL	170	70	VW	914	829.056
28	FL	10	53	VB	597	569.976
29	COMP	210	58	VW	1036	569.976
30	COMP	360	87	VB	853	633.984
31	FL	160	57	VW	683	597.408
32	FL	130	73	VW	853	658.368
33	FL	160	52	VB	768	655.32
34	FL	5	27	VB	732	670.56
35	FL	180	83	VW	890	682.752
36	FL	330	62	VW	1524	1280.16

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
37	FL	10	64	VB	1036	743.712
38	FL	240	75	VB	792	694.944
39	FL	270	82	VW	1341	1194.816
40	FL	300	56	VW	1402	1274.064
41	FL	330	61	VB	1134	975.36
42	COMP	340	61	VW	0	0
43	FL	60	62	VB	1329	1219.2
44	FL	30	135	VW	1573	1463.04
45	FL	50	139	VW	1548	1438.656
46	FL	120	46	VB	878	768.096
47	FL	40	69	VW	1085	975.36
48	FL	330	31	VB	853	804.672
49	FL	10	56	VW	1524	1377.696
50	COMP	330	102	VW	1402	1048.512
51	COMP	110	90	VW	1402	853.44
52	FL	30	37	VB	1402	1280.16
53	CV	10	11	VB	829	822.96
54	COMP	140	52	VW	1524	914.4
55	FL	120	59	VW	1756	1609.344
56	FL	170	51	VW	1768	1645.92
57	FL	140	63	VW	1609	1475.232
58	CV	200	16	VB	610	512.064
59	CV	230	17	VB	549	499.872
60	FL	300	90	VB	768	694.944
61	CV	170	7	VB	521	512.064
62	CV	80	26	VB	634	597.408
63	CV	40	33	VB	695	609.6
64	CV	360	25	VB	744	640.08
65	CV	350	46	VB	853	670.56
66	CV	330	31	VB	841	743.712
67	CV	350	39	VB	829	743.712
68	CV	150	21	VB	732	694.944
69	CC	90	36	VB	750	731.52
70	CC	100	27	VB	747	731.52
71	COMP	350	63	VW	1585	1402.08
72	COMP	5	65	VB	1768	1085.088

MM#	Form	Aspect (^{o})	Percent Slope (%)	Position	Top (m)	Toe (m)
73	CV	67	5	VB	1195	1109.472
74	CV	54	15	VB	1280	1158.24
75	CV	49	10	VB	1280	1182.624
76	CV	12	200	VB	805	768.096
77	CV	14	220	VB	792	755.904
78	CV	25	210	VB	878	822.96
79	CV	98	20	VB	890	780.288
80	CV	44	350	VB	1024	902.208
81	CV	42	290	VB	1049	944.88
82	CV	15	300	VB	1146	1091.184

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
5	1	Little Beaver	5-1-4	4	D		Y	Qag
5	2	Little Beaver	5-2-1	1	R		N	Qag
5	3	Little Beaver	5-3-1	1	R		N	Qf
4	4	Little Beaver	4-4-4	4	D		Y	Qf
4	5	Little Beaver	4-5-1	1	R		N	Qf
4	6	Little Beaver	4-6-1	1	R		N	Qf
4	7	Little Beaver	4-7-1	1	R		N	Qf
4	8	Perry	4-8-1	1	R		N	Tcpc
4	9	Little Beaver	4-9-1	1	R		N	Qf
4	10	Perry	4-10-1	1	R		N	Qag
4	11	Perry	4-11-2	2	S		Y	Qag
4	12	Perry	4-12-2	2	S		Y	Qag
4	13	Perry	4-13-3	3	D		BLKD	Tcpc
4	14	Perry	4-14-2	2	T		N	Qag
4	15	Perry	4-15-1	1	R		N	Qag
4	16	Perry	4-16-1	1	R		N	Qag
4	17	Perry	4-17-1	1	R		N	Qag
4	18	Perry	4-18-1	1	R		N	Qag
4	19	Perry	4-19-1	1	R		N	Tcbg
4	20	Perry	4-20-1	1	R		N	Qag
4	21	Perry	4-21-1	1	R		N	Tcbg
4	22	Perry	4-22-1	1	R		N	Tcbg
4	23	Perry	4-23-1	1	R		N	Tcbg
4	24	Perry	4-24-1	1	R		N	Qag
4	25	Perry	4-25-6	6	R		N	TKsbga
4	26	Perry	4-26-1	1	R		N	TKsbga
4	27	Perry	4-27-1	1	R		N	Qag
4	28	Perry	4-28-3	3	D		Y	TKsbga
4	29	Perry	4-29-3	3	D		Y	TKsbga
4	30	Perry	4-30-1	1	R		N	Qam
4	31	Little Beaver	4-31-1	1	R		N	Tcbg
4	32	Little Beaver	4-32-1	1	R		N	Tcpc

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
4	33	Little Beaver	4-33-1	1	R		N	Tcpc
4	34	Little Beaver	4-34-1	1	R		N	Tcpc
4	35	Little Beaver	4-35-1	1	R		N	Tcpc
4	36	Little Beaver	4-36-1	1	R		N	Tcpc
4	37	Little Beaver	4-37-1	1	R		N	Tcpc
4	38	Little Beaver	4-38-1	1	R		N	Tcpc
4	39	Little Beaver	4-39-1	1	R		N	Tcpc
4	40	Little Beaver	4-40-1	1	R		N	Tcpc
4	41	Little Beaver	4-41-1	1	R		N	Tcpc
4	42	Little Beaver	4-42-1	1	R		N	Tcpc
4	43	Little Beaver	4-43-1	1	R		N	TKsbga
4	44	Little Beaver	4-44-1	1	R		N	TKsbga
4	45	Little Beaver	4-45-1	1	R		N	Tcpc
4	46	Little Beaver	4-46-1	1	R		N	Tcpc
4	47	Little Beaver	4-47-1	1	R		N	Tcbg
4	48	Little Beaver	4-48-1	1	R		N	TKsbga
4	49	Little Beaver	4-49-1	1	R		N	TKsbga
4	50	Little Beaver	4-50-1	1	R		N	TKsbga
4	51	Little Beaver	4-51-1	1	R		N	Tcbg
4	52	Little Beaver	4-52-1	1	R		N	Tcbg
4	53	Little Beaver	4-53-1	1	R		N	TKsbga
4	54	Little Beaver	4-54-1	1	R		N	Tcpc
4	55	Little Beaver	4-55-1	1	R		N	Tcpc
4	56	Mist	4-56-3	3	D		Y	TKsbga
4	57	Mist	4-57-1	1	R		N	TKsbga
4	58	Mist	4-58-3	3	D		Y	Tcpc
4	59	Mist	4-59-1	1	R		N?	Qag
4	60	Mist	4-60-1	1	R		N	Qag
4	61	Mist	4-61-1	1	R		N	Tcbg
4	62	Mist	4-62-1	1	R		N	Tcbg

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
4	63	Mist	4-63-1	1	R		N	Tcbg
4	64	Mist	4-64-1	1	R		N	Tcbg
4	65	Little Beaver	4-65-1	1	R		N	Tcbg
4	66	Little Beaver	4-66-1	1	R		N	Qag
4	67	Little Beaver	4-67-3	3	D		Y	TKsbga
4	68	Little Beaver	4-68-4	4	DT		Y	Qf
4	69	Perry	4-69-1	1	R		Y	Tcpc
4	70	Perry	4-70-2	2	T		N	Qag
4	71	Little Beaver	4-71-3	3	D		Y	Tcbg
4	72	Little Beaver	4-72-1	1	R		N	TKsbga
4	73	Little Beaver	4-73-3	3	D		Y	Tcbg
4	74	Little Beaver	4-74-1	1	R		N	Tcbg
4	75	Little Beaver	4-75-1	1	R		N	Qas
4	76	Little Beaver	4-76-3	3	D		Y	Tcbg
4	77	Little Beaver	4-77-3	3	D		N	Tcbg
4	78	Redoubt	4-78-1	1	R		N	Tcbg
4	79	Redoubt	4-79-1	1	R		N	Tcbg
4	80	Little Beaver	4-80-1	1	R		Y	Qag
3	81	Redoubt	3-81-1	1	R		N	Tksu
3	82	Redoubt	3-82-1	1	R		N	Tksu
3	83	Redoubt	3-83-1	1	R		N	TKsbga
3	84	Redoubt	3-84-1	1	R		N	TKsbga
3	85	Redoubt	3-85-4	4	DT		Y	TKsbga
3	86	Redoubt	3-86-4	4	DT		Y	TKsbga
3	87	Redoubt	3-87-4	4	DT		Y	Qag
3	88	Redoubt	3-88-1	1	R		N	Tcpc
3	89	Redoubt	3-89-1	1	R		N	Tcpc
3	90	Little Beaver	3-90-1	1	R		N	Tcpc
3	91	Little Beaver	3-91-1	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	92	Little Beaver	3-92-4	4	DT		Y	Qf
3	93	Little Beaver	3-93-4	4	DT		Y	Qf
3	94	Little Beaver	3-94-1	1	R		N	TKsbg
3	95	Little Beaver	3-95-3	3	D		Y	TKsbg
3	96	Pass	3-96-3	3	D		Y-BLKD?	TKsbg
3	97	Pass	3-97-1	1	R		N	TKsbg
3	98	Pass	3-98-1	1	R		N	TKsbg
3	99	Little Beaver	3-99-1	1	R		N	TKsbg
3	100	Little Beaver	3-100-3	3	D		Y	TKsbg
3	101	Little Beaver	3-101-3	3	D		Y	TKsbg
3	102	Little Beaver	3-102-3	3	D		Y	Tcpc
3	103	Little Beaver	3-103-1	1	R		N	Qag
3	104	Little Beaver	3-104-3	3	D		Y-BLKD?	Tcbg
10	105	Little Beaver	10-105-1	1	R		N	Tcpc
10	106	Little Beaver	10-106-4	4	D/T		Y	Qf
10	107	Little Beaver	10-107-1	1	R		N	TKsbg
10	108	Little Beaver	10-108-1	1	R		N	Tcbg
3	109	Little Beaver	3-109-3	3	D/T	9/6/2009	N	Tcbg

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	28	40	1506	0.001506				
2	180	130	22045	0.022045				
3	111	135	20728	0.020728				
4	91	48	4687	0.004687				
5	104	197	44994	0.044994				
6	138	198	31940	0.03194				
7	338	101	31350	0.03135				
8	181	57	9399	0.009399				
9	59	132	7810	0.00781				
10	75	67	6573	0.006573				
11	15	23	493	0.000493				
12	19	32	705	0.000705				
13	864	215	159338	0.159338	159.000	225	128	2396448
14	16	47	1024	0.001024				
15	65	45	3334	0.003334				
16	43	68	3230	0.00323				
17	89	247	29296	0.029296				
18	79	90	11906	0.011906				
19	84	799	84277	0.084277				
20	109	49	17661	0.017661				
21	51	133	7803	0.007803				
22	46	66	4894	0.004894				
23	172	67	11865	0.011865				
24	131	283	55367	0.055367				
25	52	198	11676	0.011676				
26	71	310	36291	0.036291				
27	140	94	18940	0.01894				
28	464	149	85774	0.085774	85.000	103	11	50399.61667
29	655	116	79147	0.079147	105.000	192	12	126604.8
30	135	75	14035	0.014035				
31	59	45	4676	0.004676				
32	103	64	10334	0.010334				
33	79	56	4776	0.004776				
34	211	164	53409	0.053409				
35	56	93	9443	0.009443				

MM#	For all Types				Values for Volume Calculations: For MM-As Only			
	Length m.	Width m.	Surface Area m^2	Surface Area m^2	Length m.	Width m.	Depth m.	Volume m^3
35	56	93	9443	0.009443				
36	334	61	24344	0.024344				
37	51	97	7924	0.007924				
38	130	181	37788	0.037788				
39	601	68	49266	0.049266				
40	255	110	35315	0.035315				
41	455	227	144589	0.144589				
42	130	42	8467	0.008467				
43	137	186	28141	0.028141				
44	170	62	12621	0.012621				
45	70	62	5503	0.005503				
46	72	64	5599	0.005599				
47	67	65	5240	0.00524				
48	185	82	17012	0.017012				
49	83	239	29741	0.029741				
50	135	84	15308	0.015308				
51	63	43	3289	0.003289				
52	59	93	7367	0.007367				
53	70	42	5172	0.005172				
54	67	95	11684	0.011684				
55	88	91	14772	0.014772				
56	449	132	66685	0.066685	114	180.000	15	161082
57	110	71	11116	0.011116				
58	570	219	135054	0.135054	128	272.000	49	892798.2933
59	75	136	21680	0.02168				
60	155	79	18782	0.018782				
61	67	52	5829	0.005829				
62	52	251	13748	0.013748				
63	237	76	24621	0.024621				
64	227	100	24620	0.02462				
65	74	62	6886	0.006886				
66	149	73	14741	0.014741				
67	1329	258	410291	0.410291	420	354.000	122	9492722.4
68	138	27	3591	0.003591				
69	47	78	5191	0.005191				
70	23	65	2187	0.002187				

MM#	For all Types Length m.	Width m.	Surface Area m^2	Surface Area km^2	Values for Volume Calculations: For MM-As Only Length m.	Width m.	Depth m.	Volume m^3
71	1080	294	5293	0.005293	300	289.000	55	2495515
72	108	233	30195	0.030195				
73	1123	285	376761	0.376761	339	379.000	110	7396222.9
74	109	209	34731	0.034731				
75	182	106	19499	0.019499				
76	562	169	121998	0.121998	171	149.000	24	320016.24
77	281	67	19125	0.019125	67	76.000	9	23983.32
78	67	65	5318	0.005318				
79	146	42	8170	0.00817				
80	211	73	15863	0.015863				
81	64	192	17810	0.01781				
82	101	93	13201	0.013201				
83	68	131	11804	0.011804				
84	367	112	45768	0.045768				
85	92	67	7484	0.007484				
86	187	82	16305	0.016305				
87	93	43	4806	0.004806				
88	130	126	19703	0.019703				
89	355	78	26097	0.026097				
90	417	108	51968	0.051968				
91	460	80	40248	0.040248				
92	647	46	26536	0.026536				
93	227	47	12260	0.01226				
94	213	132	28284	0.028284				
95	498	147	84651	0.084651	147W/113E	81W/82E	24W/18E	236837.64
96	618	132	84505	0.084505	195.000	132	73	983353.8
97	76	325	24762	0.024762				
98	161	159	34514	0.034514				
99	152	150	27756	0.027756				
100	1128	227	284733	0.284733	354.000	212	55	2160131.6
101	1029	105	124806	0.124806	133.000	127	24	212150.96
102	508	95	55757	0.055757	97.000	139	21	148178.17
103	196	129	29715	0.029715				
104	1123	246	291796	0.291796	489.000	210	61	3278207.1
105	95	337	33525	0.033525				

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	314	50	17613	0.017613				
107	193	84	17248	0.017248				
108	183	46	7915	0.007915				
109	1215	98	138390	.138390	254	145	24	462585

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
1	CV	175	87	VB	561	524
2	FL	180	38	VB	671	594
3	FL	190	51	VB	768	677
4	CV	185	32	VB	652	616
5	FL	210	63	VB	756	610
6	FL	5	45	VB	713	634
7	FL	175	69	VW	866	622
8	FL	190	65	VW	1561	1426
9	FL	75	58	VB	707	634
10	FL	200	88	VW	975	866
11	CC	210	102	VB	872	853
12	CC	210	90	VB	939	914
13	COMP	220	45	VW	1341	930
14	CC	40	47	VB	1085	1073
15	FL	20	29	VW	1170	1146
16	FL	40	47	VW	1183	1158
17	FL	50	37	VB	1225	1170
18	FL	30	62	VW	1451	1366
19	FL	30	35	VB	1280	1219
20	FL	35	39	VW	1582	1463
21	FL	20	42	VW	1646	1622
22	FL	10	52	VW	1646	1597
23	FL	5	46	VW	1731	1646
24	FL	30	43	VB	1341	1231
25	COMP	95	79	D	1951	1890
26	FL	35	66	VW	1707	1512
27	FL	45	33	VB	1329	1262
28	COMP	50	79	VW	1646	1274
29	COMP	5	56	VW	1646	1280
30	FL	35	34	VB	1390	1329
31	FL	200	48	VB	658	619
32	FL	10	73	VW	1463	1341
33	FL	15	60	VW	1402	1341
34	FL	25	61	VW	1585	1353
35	FL	330	0	VW	1646	1609
36	FL	345	59	VW	1561	1341

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
37	FL	340	60	VW	1524	1481
38	FL	350	66	VW	1719	1548
39	FL	8	50	VW	1548	1219
40	FL	338	49	VW	1134	988
41	FL	320	49	VW	1646	1335
42	FL	355	69	VW	1561	1439
43	FL	15	41	VW	1634	1558
44	FL	20	42	VW	1548	1451
45	FL	350	52	VW	963	914
46	FL	355	57	VW	963	914
47	FL	170	67	VW	890	829
48	FL	340	33	VW	1719	1634
49	FL	350	22	VW	1768	1731
50	FL	310	59	VW	1524	1390
51	FL	340	98	VW	939	866
52	FL	350	67	VW	951	866
53	FL	0	48	VW	1646	1594
54	FL	10	60	VW	1609	1530
55	FL	15	57	VW	1573	1475
56	COMP	335	68	VW	1707	1402
57	FL	115	119	VW	1585	1408
58	COMP	310	68	VW	1280	860
59	FL	340	71	VB	1036	951
60	FL	30	15	VB	1030	997
61	FL	155	44	VW	1439	1402
62	FL	150	75	VW	1402	1341
63	FL	55	81	VW	1170	927
64	FL	35	69	VW	1122	902
65	FL	165	83	VW	1414	1329
66	FL	10	34	VB	725	640
67	COMP	355	58	VW	1402	640
68	CV	20	31	VB	695	652
69	FL	220	53	VB	841	805
70	CC	55	36	VB	1061	1049
71	COMP	175	51	VW	1244	658
72	FL	340	87	VW	1585	1463

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
73	COMP	330	63	VW	1402	677
74	FL	0	71	VW	1585	1475
75	FL	355	49	VB	853	732
76	COMP	120	72	VW	1158	680
77	COMP	130	71	VW	1036	817
78	FL	50	57	VB	988	945
79	FL	50	39	VB	1024	957
80	FL	25	27	VB	732	664
81	FL	40	39	VB	1036	994
82	FL	20	43	VW	1292	1222
83	FL	35	65	VW	1097	1030
84	FL	10	68	VW	1707	1402
85	CV	65	4	VB	1280	1274
86	CV	60	49	VB	1280	1183
87	CV	30	30	VB	1414	1378
88	FL	205	61	VW	1561	1475
89	FL	180	46	VW	1573	1411
90	FL	330	83	VW	1085	725
91	FL	25	54	VW	1490	1231
92	CV	165	35	VB	975	747
93	CV	0	45	VB	951	841
94	FL	210	53	VB	927	799
95	COMP	30	69	VW	1219	780
96	COMP	210	88	VW	1585	1097
97	FL	230	80	VW	1524	1457
98	FL	240	103	VW	1768	1597
99	FL	130	58	VW	951	829
100	COMP	120	74	VW	1646	805
101	COMP	130	70	VW	1524	805
102	COMP	160	69	VW	1219	835
103	FL	150	44	VB	945	841
104	COMP	175	58	VW	1609	902
105	FL	330	168	VB	1219	1073
106	CV	110	42	VB	1097	975
107	FL	50	28	D	1707	1646
108	FL	175	42	VB	1036	951
109	COMP	355	63	VW	1646	884

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
5	1	Silver	5-1-2	2	T		N	Tvr
5	2	Silver	5-2-1	1	R		N	Tvr
5	3	Silver	5-3-1	1	R		N	Tvr
5	4	Silver	5-4-1	1	R		N	Tvr
5	5	Silver	5-5-1	1	R		N	Tvr
5	6	Silver	5-6-1	1	R		N	Tvr
5	7	Un-named	5-7-1	1	R		N	Tcpc
5	8	Un-named	5-8-1	1	R		N	Tcpc
5	9	Un-named	5-9-1	1	R		N	Tcpc
5	10	Un-named	5-10-1	1	R		N	JTrhgs
5	11	Un-named	5-11-1	1	R		N	JTrhgs
5	12	Un-named	5-12-3	3	D		Y	Trhc
4	13	Silver	4-13-1	1	R		N	Tvr
4	14	Silver	4-14-1	1	R		N	Tvr
4	15	Silver	4-15-1	1	R		N	Tvr
4	16	Silver	4-16-1	1	R		N	Tcpc
4	17	Silver	4-17-1	1	R		N	Tcpc
4	18	Silver	4-18-1	1	R		N	Tcpc
4	19	Silver	4-19-1	1	R		N	Tcpc
4	20	Silver	4-20-1	1	R		N	Tcbg
4	21	Silver	4-21-1	1	R		N	Tcbg
4	22	Silver	4-22-1	1	R		N	Tvr
4	23	Silver	4-23-1	1	R		N	Tvr
4	24	International	4-24-1	1	R		N	Tvr
4	25	International	4-25-2	2	T		Y	Tvr
4	26	International	4-26-2	2	T		Y	Tcpc
4	27	Silver	4-27-3	3	D		Y	Tcpc
4	28	Silver	4-28-3	3	D		Y	Tvr
4	29	Silver	4-29-1	1	R		N	Tcpc
4	30	Silver	4-30-1	1	R		N	Tcpc
4	31	Silver	4-31-1	1	R		N	Tcpc
4	32	Silver	4-32-1	1	R		N	Tcpc

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
4	33	Silver	4-33-1	1	R		N	Tcpc
4	34	Silver	4-34-1	1	R		N	Tcpc
4	35	Silver	4-35-1	1	R		N	Tcpc
4	36	Silver	4-36-1	1	R		N	Tcpc
4	37	Silver	4-37-1	1	R		N	Tcpc
4	38	Silver	4-38-1	1	R		N	Tvr
4	39	Silver	4-39-1	1	R		N	Tvr
4	40	Silver	4-40-2	2	S		Y	Qag
4	41	Silver	4-41-2	2	S		N	Qag
4	42	Silver	4-42-3	3	D		Y	Tcpc
4	43	Silver	4-43-1	1	R		N	Tcpc
4	44	Silver	4-44-1	1	R		Y	Tcpc
4	45	Silver	4-45-1	1	R		N	Tcpc
4	46	Silver	4-46-1	1	R		N	Tvr
4	47	Silver	4-47-1	1	R		N	Qt
4	48	Silver	4-48-1	1	R		N	Tvr
4	49	Silver	4-49-1	1	R		N	Tvr
4	50	Silver	4-50-2	2	S		N	Qag
4	51	Silver	4-51-2	2	S		Y	Tvr
4	52	Arctic	4-52-3	3	D		Y-BLKD	Tcpc
4	53	Arctic	4-53-5	5	R		N	TKsbga
11	54	Arctic	11-54-1	1	R		N	Tcpc
11	55	Arctic	11-55-1	1	R		N	Tcpc
11	56	Arctic	11-56-1	1	R		Y	Tcpc
11	57	Arctic	11-57-1	1	R		N	Tcpc
11	58	Arctic	11-58-1	1	R		N	Tcpc
11	59	Arctic	11-59-1	1	R		Y	Tcpc
11	60	Arctic	11-60-3	3	D		Y	Ql
5	61	No Name	5-61-1	1	R		Y	Pzhg
11	62	No Name	11-62-1	1	R		N	Tcpc

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
11	63	No Name	11-63-1	1	R		N	TKlp
11	64	No Name	11-64-1	1	R		N	TKlp
11	65	No Name	11-65-1	1	R		N	TKs
11	66	Skymo	11-66-3	3	D		Y-BLKD?	Pzhg
11	67	Skymo	11-67-3	3	D		N	Pzhg
11	68	Skymo	11-68-3	3	D		N	Pzhg
11	69	Skymo	11-69-3	3	D		Y	TKlp
11	70	Skymo	11-70-1	1	R		N	TKs
11	71	Skymo	11-71-1	1	R		Y	TKs
11	72	Un-named	11-72-3	3	D		Y-BLKD	Pzhg/TKlp
11	73	Un-named	11-73-1	1	R		N	TKs
11	74	Un-named	11-74-1	1	R		N	TKs
11	75	Un-named	11-75-1	1	R		N	TKs
11	76	Un-named	11-76-1	1	R		N	TKs
11	77	Un-named	11-77-1	1	R		N	Pzhg
4	78	Arctic	4-78-1	1	R		N	TKs

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	21	28	783	0.001				
2	117	345	51541	0.052				
3	79	54	5771	0.006				
4	71	93	17805	0.018				
5	253	90	27870	0.028				
6	140	195	57073	0.057				
7	119	91	15707	0.016				
8	73	151	12417	0.012				
9	63	115	9740	0.010				
10	67	58	7864	0.008				
11	256	151	43743	0.044				
12	897	109	115198	0.115	456.000	143.000	30.48	1040145.85
13	181	81	20416	0.020				
14	76	126	11064	0.011				
15	227	1176	146946	0.147				
16	108	105	15315	0.015				
17	129	426	81673	0.082				
18	61	116	9729	0.010				
19	102	348	42476	0.042				
20	165	39	9094	0.009				
21	144	498	85368	0.085				
22	32	76	2817	0.003				
23	89	121	13896	0.014				
24	177	89	18726	0.019				
25	46	14	907	0.001				
26	158	28	4975	0.005				
27	541	95	38303	0.038	127.000	58.000	24.384	93997.23136
28	647	90	55382	0.055	218.000	104.000	24.384	289316.4851
29	139	159	26077	0.026				
30	219	197	45955	0.046				
31	105	44	8696	0.009				
32	108	377	61459	0.061				
33	91	90	10262	0.010				
34	66	493	30093	0.030				
35	76	47	3434	0.003				

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	76	47	3434	0.003				
36	35	64	2539	0.003				
37	117	1233	163121	0.163				
38	81	40	3096	0.003				
39	63	150	8897	0.009				
40	19	51	1283	0.001				
41	28	96	3144	0.003				
42	597	232	109420	0.109	180.000	93.000	9.144	80106.9264
43	40	203	14896	0.015				
44	80	91	11973	0.012				
45	282	152	44516	0.045				
46	75	132	15186	0.015				
47	161	256	44476	0.044				
48	138	357	52043	0.052				
49	227	225	64822	0.065				
50	36	48	2205	0.002				
51	39	29	1465	0.001				
52	1154	237	263624	0.264	217.000	195.000	25.908	573728.7738
53	88	41	4873	0.005				
54	452	270	121352	0.121				
55	513	79	60444	0.060				
56	132	648	114810	0.115				
57	280	66	31773	0.032				
58	180	86	19215	0.019				
59	319	119	35507	0.036				
60	401	351	152056	0.152	74.000	199.000	18.288	140938.4227
61	112	92	13196	0.013				
62	499	34	24263	0.024				
63	303	82	36616	0.037				
64	151	208	33406	0.033				
65	166	93	16319	0.016				
66	339	192	67440	0.067	59.000	78.000	12.192	29362.96896
67	299	83	26557	0.027	68.000	75.000	24.384	65080.896
68	397	78	35018	0.035	92.000	75.000	27.432	99056.952
69	439	87	42169	0.042	150.000	87.000	36.576	249795.792
70	129	121	18690	0.019				

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	68	408	37954	0.038				68
72	2508	618	1235476	1.235	1141.000	906.000	182.88	2508
73	210	129	28788	0.029				210
74	55	81	5885	0.006				55
75	67	101	6898	0.007				67
76	68	58	4396	0.004				68
77	101	42	3893	0.004				101
78	253	82	21532	0.022				

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
1	CC	175	24	VB	677	610
2	FL	215	89	VW	902	732
3	FL	80	69	VW	896	841
4	FL	355	99	VW	1439	1292
5	FL	20	72	VW	1585	1366
6	FL	20	51	VW	1646	1475
7	FL	35	45	VW	719	646
8	FL	40	76	VB	671	610
9	FL	35	28	VW	610	561
10	FL	10	66	VW	1207	1073
11	FL	330	63	VW	1768	1585
12	COMP	120	56	VW	866	488
13	FL	40	54	VW	1524	1420
14	FL	60	85	VW	1524	1402
15	FL	320	31	VW	1707	1329
16	FL	330	60	VW	1292	1219
17	FL	20	86	VW	1841	1658
18	FL	35	42	R	1329	1289
19	FL	90	63	VW	1378	1268
20	FL	45	66	VW	1573	1439
21	FL	50	33	R	1658	1573
22	FL	185	122	VW	896	853
23	FL	210	66	VW	902	829
24	FL	20	60	VW	1646	1512
25	CC	100	46	VB	1390	1372
26	CC	110	51	VB	1329	1280
27	COMP	175	61	VW	1134	792
28	COMP	180	66	VW	1244	817
29	FL	35	53	VW	1743	1652
30	FL	20	71	VW	1731	1585
31	FL	330	31	VW	1280	1219
32	FL	100	81	VW	1475	1329
33	FL	290	98	VW	1548	1475
34	FL	320	54	VW	1597	1463
35	FL	330	63	VW	1353	1292
36	FL	40	54	VB	1195	1170

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
37	FL	90	5	VW	1219	1158
38	FL	170	60	VW	1542	1487
39	FL	165	70	VW	1506	1451
40	CC	175	19	VB	1000	994
41	CC	40	18	VB	1170	1164
42	COMP	25	40	VW	1402	1164
43	FL	355	47	VW	1719	1597
44	FL	65	63	VW	1292	1207
45	FL	20	60	VW	1219	1055
46	FL	20	16	VB	1158	1128
47	FL	15	33	VB	1280	1219
48	FL	120	73	VB	1268	1158
49	FL	40	43	VB	1268	1097
50	CC	10	14	VB	994	988
51	CC	20	38	VB	811	792
52	COMP	125	35	VW	1372	951
53	FL	65	11	VW	1536	1521
54	FL	35	24	VW	1402	1042
55	FL	85	48	VW	1631	1353
56	FL	325	74	VW	1292	1122
57	FL	310	63	VW	1585	1402
58	FL	340	67	VW	1317	1177
59	FL	340	66	VW	1390	1170
60	COMP	330	62	VW	1463	1170
61	FL	285	56	VW	829	756
62	FL	10	61	VW	1585	1237
63	FL	325	56	VW	1707	1426
64	FL	320	83	VW	1817	1597
65	FL	310	68	VW	1597	1484
66	COMP	0	80	VW	1280	975
67	COMP	355	90	VW	1280	1000
68	COMP	0	79	VW	1341	1000
69	COMP	340	91	VW	1475	1082
70	FL	10	60	VB	1292	1204
71	FL	310	34	VB	1426	1372
72	COMP	95	41	R	1487	427

MM#	Form	Aspect (^{o})	Percent Slope (%)	Position	Top (m)	Toe (m)
73	FL	95	40	VW	1561	1448
74	FL	80	66	VW	942	890
75	FL	95	65	VW	576	524
76	FL	90	55	VW	573	524
77	FL	90	64	VW	683	622
78	FL	330	50	VW	1524	1384

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
5	1	Hozomeen	5-1-1	1	R		N	Pzhg
5	2	Hozomeen	5-2-1	1	R		N	Pzhg
5	3	Hozomeen	5-3-1	1	R		N	Pzhg
5	4	Hozomeen	5-4-1	1	R		N	Pzhg
5	5	Hozomeen	5-5-1	1	R		N	Pzhg
5	6	Hozomeen	5-6-1	1	R		N	Pzhg
5	7	Hozomeen	5-7-1	1	R		N	Pzhg
5	8	Hozomeen	5-8-1	1	R		N	Pzhg
5	9	Hozomeen	5-9-1	1	R		N	Pzhg
5	10	Hozomeen	5-10-1	1	R		N	Pzhg
5	11	Hozomeen	5-11-1	1	R		N	Pzhg
5	12	Hozomeen	5-12-1	1	R		N	Pzhg
5	13	Hozomeen	5-13-4	4	D		Y	Qga
5	14	Un-named	5-14-1	1	R		N	Tcpc
5	15	Un-named	5-15-1	1	R		N	Tcpc
5	16	Un-named	5-16-1	1	R		N	Tcpc
5	17	Un-named	5-17-1	1	R		N	Tcpc
5	18	Un-named	5-18-1	1	R		N	Tcpc
5	19	Un-named	5-19-3	3	D		Y	Pzhg
5	20	Un-named	5-20-3	3	D		Y	Pzhg
5	21	Lightning	5-21-3	3	D		Y-BLKD	Ql
6	22	Lightning	6-22-1	1	R		N	Js
6	23	Lightning	6-23-2	2	D		Y	Js
6	24	Lightning	6-24-3	3	D		Y	Js
6	25	Lightning	6-25-1	1	R		N	Js
6	26	Hozomeen	6-26-1	1	R		N	Pzhg
5	27	Un-named	5-27-1	1	R		N	Pzhg
6	28	Lightning	6-28-1	1	R		N	Js
6	29	Lightning	6-29-1	1	R		N	Js
13	30	Devils	13-30-1	1	R		N	Pzhg

MM#	For all Types				Values for Volume Calculations: For MM-As Only			
	Length m.	Width m.	Surface Area m^2	Surface Area m^2	Length m.	Width m.	Depth m.	Volume m^3
1	110	47	5740	0.006				
2	154	75	16159	0.016				
3	128	65	14157	0.014				
4	59	128	7372	0.007				
5	71	205	17722	0.018				
6	90	234	25736	0.026				
7	68	134	12106	0.012				
8	55	69	5118	0.005				
9	66	112	7410	0.007				
10	84	112	18247	0.018				
11	144	50	11143	0.011				
12	87	90	10417	0.010				
13	48	40	3391	0.003				
14	51	180	12398	0.012				
15	75	164	13918	0.014				
16	60	208	15553	0.016				
17	295	52	14914	0.015				
18	79	317	37306	0.037				
19	1071	163	209399	0.209	469.000	250.000	30.48	1870278.2
20	1445	219	334791	0.335	410.000	219.000	12.192	572903.2992
21	1771	2731	4922280	4.922	714.000	2247.000	60.96	51182870.66
22	46	45	2457	0.002				
23	149	80	14137	0.014				
24	832	114	77148	0.077	211.000	57.000	9.144	57553.52472
25	150	31	4869	0.005				
26	46	295	14538	0.015				
27	106	32	3381	0.003				
28	154	39	6589	0.007				
29	76	45	4229	0.004				
30	123	140	23773	0.024				

MM#	Form	Aspect (^{o})	Percent Slope (%)	Position	Top (m)	Toe (m)
1	FL	270	36	VW	780	744
2	FL	265	56	VW	1225	1097
3	FL	245	57	VW	1170	1061
4	FL	140	64	VB	914	878
5	FL	340	73	VB	853	792
6	FL	5	74	VW	963	732
7	FL	15	68	VW	792	732
8	FL	40	79	VW	780	732
9	FL	95	64	VW	878	841
10	FL	90	61	VW	927	829
11	FL	60	56	VW	927	829
12	FL	70	50	VW	914	844
13	CV	175	25	VB	890	872
14	FL	280	55	VB	549	494
15	FL	300	85	VW	683	600
16	FL	270	69	VW	634	573
17	FL	320	90	VW	719	573
18	FL	270	50	VB	549	488
19	COMP	260	63	VW	1097	472
20	COMP	255	36	VW	927	460
21	COMP	85	58	VW	1768	597
22	FL	65	76	VB	719	683
23	CC	280	52	VW	768	658
24	COMP	250	48	VW	1036	646
25	FL	300	73	VW	902	780
26	FL	95	72	VB	914	866
27	FL	280	42	VW	1658	1603
28	FL	260	64	VW	988	881
29	FL	270	48	VW	719	668
30	FL	250	24	VW	902	835

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
19	1	Panther	19-1-1	1	R		N	TKrb
19	2	Panther	19-2-1	1	R		N	TKrb
19	3	Panther	19-3-1	1	R		N	TKrb
19	4	Panther	19-4-1	1	R		N	TKrb
19	5	Panther	19-5-1	1	R		N	Tkso/TKns
19	6	Panther	19-6-1	1	R		N	Tkso/TKns
19	7	Panther	19-7-1	1	R		N	Tkso/TKns
19	8	Panther	19-8-1	1	R		N	Tkso/TKns
19	9	Panther	19-9-2	2	S		Y	TKns
19	10	Panther	19-10-4	4	D		Y	TKns
19	11	Stillwell	19-11-1	1	R		Y	Tkso
19	12	Stillwell	19-12-3	3	T		Y	Qt
19	13	Stillwell	19-13-3	3	T		Y-BLKD	Qt
19	14	Stillwell	19-14-1	1	R		N	TKm
19	15	Stillwell	19-15-1	1	R		N	TKm
19	16	Stillwell	19-16-1	1	R		N	TKm
19	17	Stillwell	19-17-4	4	D		N	TKm
19	18	Stillwell	19-18-1	1	R		N	Tkso
19	19	Stillwell	19-19-1	1	R		N	Tkso
19	20	Stillwell	19-20-1	1	R		N	Tkso
19	21	Panther	19-21-1	1	R		N	Tkso
19	22	Panther	19-22-1	1	R		N	Tkso
19	23	Panther	19-23-3	3	D		N	Tkso
19	24	Panther	19-24-1	1	R		N	Tkso
19	25	Panther	19-25-1	1	R		N	Tkso
19	26	Panther	19-26-1	1	R		N	Tkso
19	27	Panther	19-27-1	1	R		N	Tkso
19	28	Panther	19-28-1	1	R		N	Tkso
19	29	Panther	19-29-1	1	R		N	Tkso
19	30	Panther	19-30-1	1	R		N	Tkso
19	31	Panther	19-31-2	2	S		Y	Qga
19	32	Panther	19-32-1	1	R		N	Qga

QUAD #	MM #	SUB-drainage	I.D. #	MM TYPE (1-4)	MATERIAL TYPE	AGE (IF KNOWN)	SED. DEL. TO STREAM? (Y/N/BLKD)	BEDROCK TYPE
19	33	Panther	19-33-1	1	R		N	Qga
19	34	Gabriel	19-34-1	1	R		Y	Qga
19	35	Gabriel	19-35-1	1	R		N	Qga
19	36	Gabriel	19-36-3	3	D		Y	TKm
19	37	Gabriel	19-37-1	1	R		N	TKm
19	38	Panther	19-38-1	1	R		N	Tkto
19	39	Panther	19-39-1	1	R		N	TKto
19	40	Panther	19-40-1	1	R		N	Qga
19	41	Panther	19-41-1	1	R		N	TKto
19	42	Panther	19-42-1	1	R		N	TKto
25	43	Panther	25-43-1	1	R		N	TKto
25	44	Panther	25-44-3	3	D		Y-BLKD	TKto
25	45	Panther	25-45-3	3	D		Y	TKto
25	46	Panther	25-46-1	1	R		N	Qga
25	47	Panther	25-47-1	1	R		N	Qga
25	48	Panther	25-48-1	1	R		N	Qga
25	49	Panther	25-49-1	1	R		N	Tkto/TKns
25	50	Panther	25-50-1	1	R		N	Tkto/TKns
25	51	Panther	25-51-1	1	R		N	Qga
25	52	Panther	25-52-1	1	R		N	TKns/Tkto
25	53	Panther	25-53-1	1	R		N	TKns/Tkto
25	54	Panther	25-54-1	1	R		N	TKns/Tkto
25	55	Panther	25-55-1	1	R		Y	Qga
25	56	Panther	25-56-4	4	D		Y	Qga
26	57	Panther	26-57-3	3	D		N	TKm

MM#	For all Types				Values for Volume Calculations: For MM-As Only			
	Length m.	Width m.	Surface Area m^2	Surface Area m^2	Length m.	Width m.	Depth m.	Volume m^3
1	96	70	9816	0.009816				
2	38	80	3520	0.00352				
3	40	32	2816	0.002816				
4	29	111	4037	0.004037				
5	69	95	6361	0.006361				
6	52	90	10081	0.010081				
7	101	76	10368	0.010368				
8	88	30	7351	0.007351				
9	13	30	688	0.000688				
10	134	29	3836	0.003836				
11	90	337	43237	0.043237				
12	456	128	70981	0.070981	128/182	70/80	12/ 24	239142.4
13	731	201	127993	0.127993	257	243	30	980480.7
14	110	95	10015	0.010015				
15	186	114	21244	0.021244				
16	140	102	17349	0.017349				
17	588	64	98460	0.09846				
18	68	198	14045	0.014045				
19	411	108	54344	0.054344				
20	191	95	22128	0.022128				
21	86	65	10335	0.010335				
22	93	140	13984	0.013984				
23	558	92	60376	0.060376	200	141	30	442740
24	66	76	4470	0.00447				
25	40	52	1654	0.001654				
26	56	61	3588	0.003588				
27	38	56	2009	0.002009				
28	120	85	6972	0.006972				
29	95	90	6915	0.006915				
30	70	126	11480	0.01148				
31	29	40	705	0.000705				
32	49	42	1618	0.001618				
33	58	45	1883	0.001883				
34	35	149	5279	0.005279				
35	119	87	8925	0.008925				

MM#	For all Types				Values for Volume Calculations: For MM-As Only			
	Length m.	Width m.	Surface Area m^2	Surface Area m^2	Length m.	Width m.	Depth m.	Volume m^3
36	674	114	98526	0.098526	252	159	24	503254.08
37	111	98	10889	0.010889				
38	82	61	4553	0.004553				
39	50	42	3292	0.003292				
40	93	112	12584	0.012584				
41	385	79	28658	0.028658				
42	132	140	19835	0.019835				
43	214	160	25367	0.025367				
44	1164	174	237162	0.237162	288	302	30	1365523.2
45	421	98	65616	0.065616	150	65	24	122460
46	71	69	3935	0.003935				
47	105	126	17183	0.017183				
48	59	101	8883	0.008883				
49	129	83	26544	0.026544				
50	202	235	84376	0.084376				
51	96	317	49247	0.049247				
52	88	424	61314	0.061314				
53	175	168	31079	0.031079				
54	104	589	76495	0.076495				
55	63	189	19120	0.01912				
56	257	120	35590	0.03559				
57	388	85	4525	0.004525	142	124	12	110578.24

MM#	Form	Aspect (°)	Percent Slope (%)	Position	Top (m)	Toe (m)
1	FL	30	54	VW	975	846
2	FL	45	98	VW	1036	975
3	FL	95	68	VW	1044	991
4	FL	100	88	VW	975	930
5	FL	345	97	VW	1676	1585
6	FL	345	167	VW	1768	1615
7	FL	340	68	VW	1783	1676
8	FL	340	37	VW	1652	1562
9	CC	150	286	VB	792	724
10	CV	170	10	VB	744	732
11	FL	220	76	VB	1006	899
12	COMP	40	71	VW	1935	1612
13	COMP	50	65	VW	2073	1599
14	FL	60	69	VW	1783	1676
15	FL	300	88	VW	1737	1562
16	FL	310	73	VW	1676	1524
17	CV	355	43	VB	1417	1143
18	FL	20	60	VW	1303	1173
19	FL	20	61	VW	1676	1387
20	FL	15	53	VW	1814	1684
21	FL	350	75	VW	899	792
22	FL	120	74	VW	1125	1018
23	COMP	300	63	VW	1189	786
24	FL	135	63	VW	1408	1349
25	FL	130	49	VW	1044	1009
26	FL	45	248	VW	1250	1052
27	FL	40	58	VW	1128	1097
28	FL	35	57	VW	991	914
29	FL	200	48	VB	960	902
30	FL	210	63	VB	991	930
31	CC	35	44	VB	927	911
32	FL	30	57	VB	988	948
33	FL	30	77	VB	1003	948
34	FL	180	146	VB	1539	1433
35	FL	355	543	VW	1692	1013
36	COMP	360	53	VW	1905	1524

MM#	Form	Aspect (^{o})	Percent Slope (%)	Position	Top (m)	Toe (m)
37	FL	360	62	VW	1753	1673
38	FL	220	98	VW	1311	1222
39	FL	240	63	VW	1158	1113
40	FL	40	62	VB	1059	975
41	FL	25	45	VW	1707	1527
42	FL	45	58	VW	1113	1006
43	FL	345	61	VW	1189	1036
44	COMP	100	52	VW	2012	1448
45	COMP	255	69	VW	1966	1603
46	FL	220	67	VB	1189	1128
47	FL	210	63	VB	1219	1109
48	FL	215	41	VB	1189	1128
49	FL	30	59	VW	1844	1730
50	FL	35	57	VW	2012	1737
51	FL	20	53	VB	1250	1135
52	FL	330	39	VW	1762	1585
53	FL	355	45	VW	1943	1829
54	FL	20	80	VW	1859	1615
55	FL	5	50	VB	1341	1250
56	CV	0	65	VB	1448	1265
57	COMP	275	73	VW	2057	1747

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