National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Geomorphology of the Bacon Creek Watershed

Landform Mapping at North Cascades National Park Service Complex, Washington

Natural Resource Technical Report NPS/ NCCN/NRTR—2012/564

ON THE COVER
Clockwise from top left: Bacon creek Valley, Bacon Creek Headwaters, Triumph Peak and Triumph Creek tributary with Mount Triumph in the background.
Photograph by: Michael Larrabee

Geomorphology of the Bacon Creek Watershed

Landform Mapping at North Cascades National Park Service Complex, Washington

Natural Resource Technical Report NPS/ NCCN/NRTR—2012/564

Jon Riedel

Michael Larrabee

Jeanna Wenger

Stephen Dorsch

National Park Service
North Cascades National Park
7280 Ranger Station Road
Marblemount, Washington 98267

April 2012

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations.

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 website (http://science.nature.nps.gov/im/units/nccn/reportpubs.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

Please cite this publication as:

Riedel, J., M. Larrabee, J. Wenger, and S. Dorsch. 2012. Geomorphology of the Bacon Creek watershed: Landform mapping at North Cascades National Park Service Complex, Washington. Natural Resource Technical Report NPS/NCCN/NRTR—2012/564. National Park Service, Fort Collins, Colorado.

NPS 168/113497, April 2012

Contents

Page

Contents iii

Figures v

Tables vi

Abstract vii

1 - Introduction 1

1.1 Applications of Landform Mapping Data 1

1.2 Project History 2

2 - Study Area 3

2.1 Geographic Setting 3

2.2 Geologic Setting 3

2.2.1 Tectonics and Structure 5

2.2.2 Geologic Units 6

2.3 Glacial History 7

2.3.1 Neoglacial 9

2.4 Climate 10

2.5 Hydrologic Setting 12

2.6 Vegetation 14

2.7 Landform Age 14

2.7.1 Landforms and Soils 15

2.8 National Hierarchical Framework for Ecological Units 16

2.8.1 Subsection (1:250,000) 17

2.8.2 Landtype Association (1:62,500) 17

2.8.3 Landtype Phase (Landform) (1:24,000) 17

Contents (continued)

Page

3 - Methods 21

3.1 Preliminary Methods 21

3.2 Field Methods 21

3.3 Digitizing Methods 21

3.4 Areas Surveyed 22

4 - Results and Discussion 23

4.1 General Watershed Overview 23

4.1.1 High Elevation Landforms 23

4.2 Characteristics of Sub-watersheds 25

4.2.1 Lower Main Stem of Bacon Creek 25

4.2.2 Upper Main stem of Bacon Creek 27

4.2.3 East Fork 29

4.3 Bacon Creek Watershed Landslide Inventory 31

5 - Future Work 33

5.1 Progress Report 33

6 - Literature Cited 35

Appendix A. Landslide Inventory for the Bacon Creek Watershed 1

Figures

Page

Figure 1. Map showing the location of Bacon Creek and adjacent watersheds within North Cascades National Park Service Complex (NOCA).. 4

Figure 2. Landform map (1:24,000) showing the distribution of landforms in the Bacon Creek Watershed as well as the locations of the main tributary streams and other locations referred to in the text. 5

Figure 3. Bedrock map showing the Bacon Creek Watershed (river is in bold), fault locations and some of the adjoining watersheds 7

Figure 4. Map of the known extent of the Cordilleran Ice Sheet during the Fraser Glaciation.. 8

Figure 5. Reconstruction of the Bacon Glacier during the Sumas Stade (Riedel, 2007)............... 9

Figure 6. Permanent snowfields, glaciers and climate monitoring stations located in and around the Bacon Creek Watershed. 10

Figure 7. Mass balance chart of Noisy Glacier, located on Bacon Peak 14

Figure 8. Subsection map (1:250,000) of the North Cascade region showing the location of the Bacon Creek Watershed within the Crystalline Cascade Mountains Sub-Section and North Cascades National Park Service Complex (Davis 2004). 18

Figure 9. LTA map (1:62,500) of the Bacon Creek Watershed (Davis 2004)............................. 19

Figure 10. Lower main stem of Bacon Creek landform map (1:24,000) showing the distribution of landforms as well as the locations of the main tributary streams 26

Figure 11. Upper main stem of Bacon Creek landform map (1:24,000) showing the distribution of landforms as well as the locations of the main tributary streams 28

Figure 12. East Fork of Bacon Creek landform map (1:24,000) showing the distribution of landforms as well as the locations of the main tributary streams 30

Figure 13. Debris avalanche located in the East Fork of Bacon Creek Watershed 31

Tables

Page

Table 1. Summary of data from the Upper Baker Dam and Newhalem Cooperative Network sites located near the Bacon Creek Watershed 11

Table 2. Summary of data from the three snow survey sites located near the Bacon Creek Watershed... 11

Table 3. Maximum recorded discharges for water years 1943-2007, USGS Bacon Creek gauging station 12

Table 4. Approximate landform surface ages at North Cascades National Park. 15

Table 5. Map scale and polygon size in the National Hierarchical Framework for Ecological Units (Cleland et al. 1997)... 17

Table 6. Landform (1:24,000) legend for North Cascades National Park. 20

Table 7. Summary of area of each landform type within the Bacon Creek Watershed. 24

Table 8. Summary of the Bacon Creek Watershed landslide inventory data............................. 32

Abstract

This report describes the background information, methods and results of a surficial geology inventory within the North Cascades National Park Service Complex (NOCA). A suite of 29 landforms types were used to map NOCA at the 1:24,000 scale. The study area for this report is the Bacon Creek Watershed, which includes Bacon Creek, East Fork and their tributaries Triumph, Falls, Jumbo, and Oakes Creek. The Bacon Creek Watershed is located on the western slopes of the Skagit Crest and flows south into the Skagit River. This report focuses on the relationship between bedrock geology, glacial history, climate, hydrology and vegetation and landform development in the Bacon Creek Watershed.

The geology of Bacon Creek Watershed is largely controlled by the presence of the Straight Creek Fault, a 400 km long strike-slip extensional fault, and other smaller faults. The Straight Creek Fault separates low grade metamorphic greenschists and phyllites from higher grade schists with intrusive granitic plutons of the Eocene and Cretaceous. The topography of the Bacon Creek Watershed reflects multiple glaciations during the past 2 Ma, which carved deep U-shaped valleys, steep valley walls and jagged horns and arêtes. The North Cascades were inundated by the south flowing Cordilleran Ice Sheet during the Fraser Glaciation (Armstrong et al. 1965). Advance of alpine glaciers during the Little Ice Age deposited Neoglacial moraines.

The watershed climate is classified as maritime with relatively mild, wet winters and cool, dry summers. However, climatic conditions vary widely with large gradient in temperature and precipitation. Subalpine lowland and montane forests cover approximately 76 percent of the watershed and bare snow, rock and ice cover the remainder. Rivers and creeks typically reach flood stage during the spring and late fall.

The main stem of Bacon Creek is a narrow, glacially scoured valley with a straight profile and moderate gradient. The East Fork is a hanging valley above the main stem, and has a steep gradient in its lower 1 km. Within the watershed, 66% is valley wall and 13% is high elevation cirque; with only 2% as riparian (floodplain, valley bottom, and alluvial fan). High elevation landforms (cirque, Neoglacial moraines, ridges, arêtes, other mountains, horns and passes) account for 20 km^2, which is 15% of the total area in the watershed.

Aspect is a strong control on the development of cirque basins and valley walls, with north and east facing cirques deeper, broader and with lower elevation Neoglacial moraines than those on southerly aspects. Valley asymmetry, reflected by steep northeast-facing valleys walls and rock fall and more gentle forested southwest facing slopes, is a product of differential freeze-thaw cycles. The transition between floodplain and valley bottom in the watershed occurs at a notably lower elevation than elsewhere in NOCA, likely a result of CIS erosion along the Straight Creek Fault.

Debris aprons are composed of till, colluvium and a significant component of volcanic ash. Several Pleistocene moraines are located in the watershed, the largest is an end moraine of the Sumas Stade Bacon Glacier (Riedel 2007), located at the confluence with the East Fork. Terrace heights range from four to 36.5 meters. The higher terraces are likely late ice age outwash from valley glaciers. The lower terraces are likely alluvium deposited over the last few hundred years.

Seven large debris avalanches have occurred in the watershed, most in relatively weak Darrington Phyllite oversteepened by glaciation. Two of the debris avalanches have blocked the Bacon Creek entirely, delivering large amounts of sediment to the creek.

1 - Introduction

The purpose of this report is to describe the study area, methods, and results of a surficial geology inventory within the North Cascades National Park Service Complex (NOCA). This is one of the 12 basic resource inventories initiated by the National Park Service (NPS) Natural Resource Challenge in 1998. The study area for this report is the Bacon Creek Watershed (Fig. 1), which is presented in three sections: the main stem above the East Fork junction, the main stem below the East Fork junction, and the East Fork of Bacon Creek (Fig. 2).

Background information presented in this report focuses on key factors that influence the development of landforms in the Bacon Creek Watershed. These factors include bedrock geology and structure, glacial history, climate, hydrologic setting, and vegetation. A brief discussion on landform age is provided to put these factors in a temporal context. A detailed description of methods, results and interpretations of the landform inventory form the balance of this report.

Results and discussion 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. Geomorphic processes such as mass wasting, flooding, and glaciation directly impact the human use and management of rugged landscapes. The materials produced by these processes create distinct landforms and 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). The mapping of mass movements, active debris cones, alluvial fans, and more stable landforms can aid in the placement of new trails, campsites and other visitor use facilities. Detailed landform maps of this area can also be a valuable resource in the protection and recovery of endangered or threatened species.

Landform mapping data are being utilized in the creation of a soils map for NOCA. Due to rugged topography and relative inaccessibility of large parts of NOCA, and the estimated high cost of traditional mapping methodologies, extensive soil surveys have not been conducted. Parent material, time (stability/age), and relief are three of five soil-forming factors, so digital landform maps are a critical component in the developing new approaches to mapping soils in remote, rugged landscapes. Landforms provide a preliminary landscape delineation that simplifies the soil sampling strategy. Linking soils to landforms is a cooperative effort among NOCA, the Natural Resource Conservation Service (NRCS) state mapping program, the United States Forest Service (USFS), Washington State University, and the NPS Geologic Resource Division Soils Program. Currently a model known as The Remote Area Soil Proxy (RASP) uses

GIS, remote sensing technology, and a focused field effort to simulate the distribution of soils. 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 the NOCA Thunder Creek watershed has indicated 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. Additionally, soils maps provide useful information for modeling fuel loads, humidity recover, susceptibility to erosion, and possible restoration efforts related to wilderness fires and human impacts.

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 15 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. This included the development of a 23 landform scheme to support classification and assessment of aquatic habitat in Thunder Creek and Chilliwack River. There are now 37 distinct units in the landform scheme, 29 of which are found in NOCA. Landform units are created by active and relict geologic 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 12 basic inventories for all NPS areas, including surficial geology and soils. In 2001, NOCA landform mapping was linked with the United States Forest Service (USFS) multi-scaled "National Hierarchical Framework for Ecological Units" (Cleland et al. 1997) for public lands in the North Cascades. The approach uses a nested system of land classification at eight spatial scales. Together the USFS and NPS have mapped at three of these scales; Subsection (1:250,000), Landtype Association (LTA; 1:62,500), and Landform scales (1:24,000). The first product was a seamless coverage of public lands in the North Cascade region at the Subsection scale, where the focus is on climate, bedrock geology, and topography. The LTA scale is mapped by watershed and units are based on topography and process. The NPS is currently focused on mapping at the landform scale (1:24,000), the largest scale within the framework.

This report gives detailed results for the Bacon Creek Watershed, which includes a discussion of the unique geomorphology and history of the Bacon Creek 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 North Cascades Range is a geologically distinct unit of the Cascade Range, characterized by jagged glaciated peaks with high relief. The Bacon Creek Watershed is located along the western slopes of the North Cascades Range (Fig. 1). This report focuses on the entire watershed, which includes 99 km^2 in NOCA and 44 km^2 in the Mount Baker-Snoqualmie National Forest (Fig. 2). Bacon Creek Watershed is approximately 20 km long, flowing from its headwaters south into the Skagit River.

The eastern edge of the Bacon Creek Watershed contains a series of peaks and ridges collectively termed the 'Skagit Crest' (Riedel 2007). The Skagit Crest and the Pacific Crest, located further east, separate the maritime Puget lowland from the continental interior. Topographic relief in the Bacon Creek Watershed is 2100 m, ranging from 116 m at the Skagit River to 2223 m at Mount Despair. Prominent peaks surrounding the watershed include Diobsud Buttes (1796 m), Bacon Peak (2154 m), Hagan Mountain (2152 m), Mt. Despair (2223 m), Mt. Triumph (2216 m), and Damnation Peak (1717 m). The largest active glaciers in the watershed are located on Bacon Peak. Mt. Baker (3285 m), a highly recognized Quaternary stratovolcano, is located 25 km west of the Bacon Creek Watershed, and has likely deposited ash into Bacon Creek Watershed.

Bacon Creek and the East Fork of Bacon Creek are fed by countless small tributaries as well as named tributaries, including Triumph Creek, Falls Creek, Jumbo Creek, and Oakes Creek. Bacon Creek and its tributaries are recharged by rainfall, small glaciers, high alpine lakes and permanent snowfields. Two large alpine lakes are located in the watershed headwaters, Green (33.2 ha; 82 acres) and Berdeen Lakes (51.8 ha; 128 acres).

2.2 Geologic Setting

The bedrock geology of the North Cascades has been mapped at the 1:100,000 scale by Tabor et al. (2003). The regional geologic map is presented in this report for context (Fig. 3; Tabor and Haugerud 1999). Bedrock of the North Cascades was formed by a complex series of igneous, metamorphic and tectonic events beginning in the Cretaceous period (145 – 65 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 (Early Jurassic) and 50 million years ago (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 40-50 million years ago 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 million years ago 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.

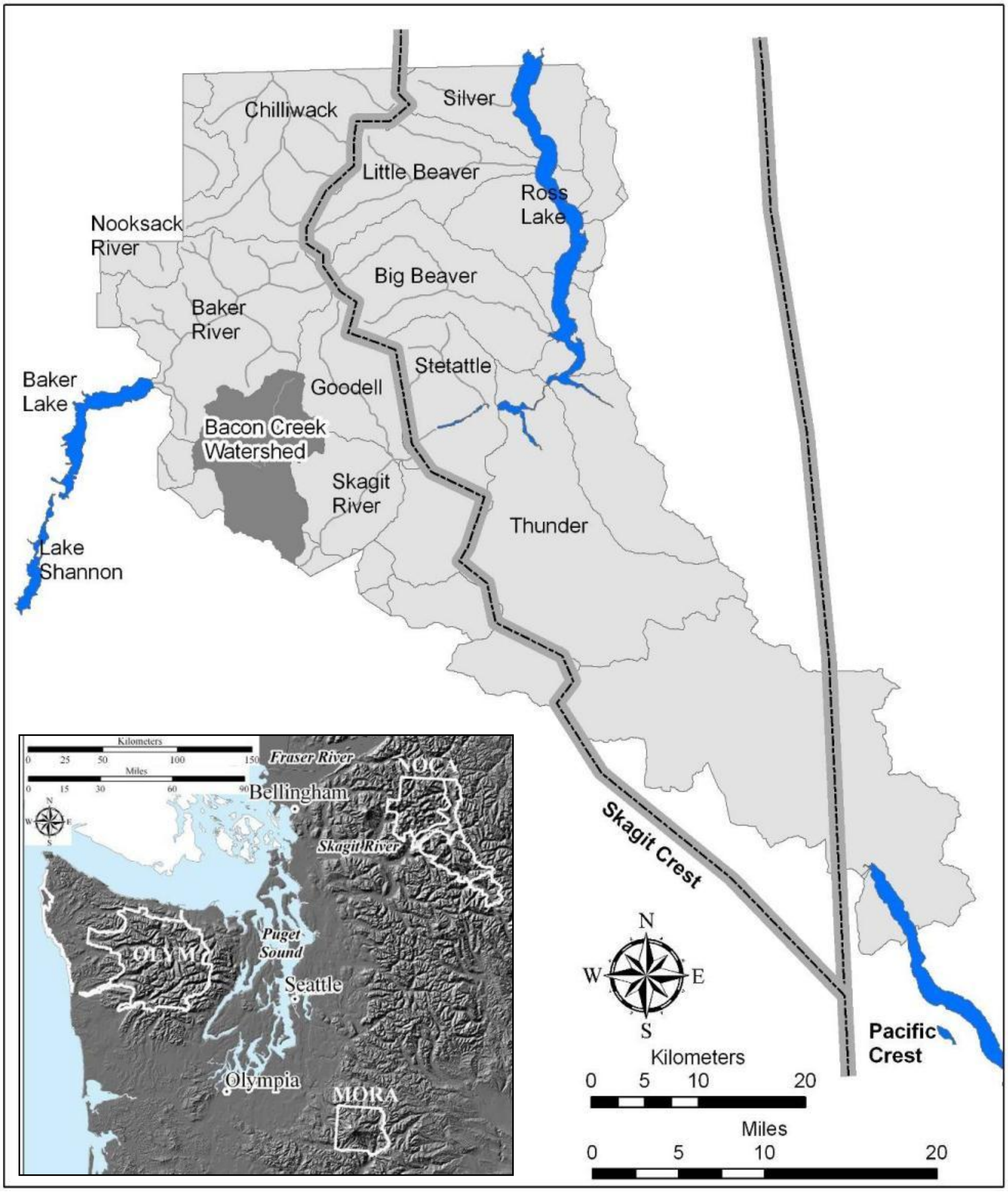

Figure 1. Map showing the location of Bacon Creek and adjacent watersheds within North Cascades National Park Service Complex (NOCA). Insert map shows the location of NOCA within Washington State, as well as Mount Rainer (MORA) and Olympic (OLYM) National Parks.

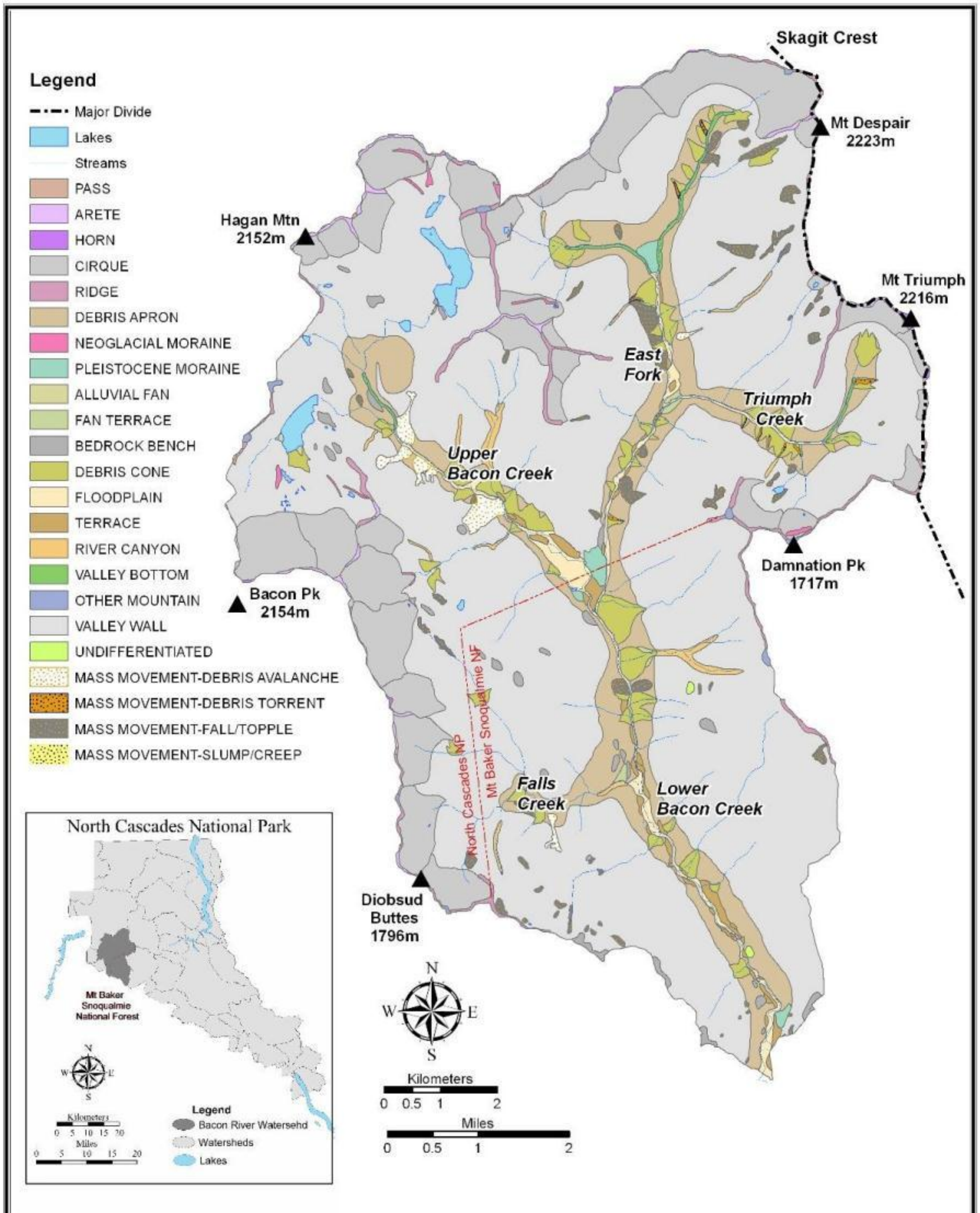

Figure 2. Landform map (1:24,000) showing the distribution of landforms in the Bacon Creek Watershed as well as the locations of the main tributary streams and other locations referred to in the text.

2.2.1 Tectonics and Structure

Geologic structure has played an important role in the development of drainage patterns in the area. The geology of the Bacon Creek Watershed is largely controlled by the presence of the

Straight Creek, Entiat and Triumph Faults (Fig. 3). The Straight Creek Fault is a strike-slip extensional fault that is a total of 400 km long. It begins in Central Washington and extends 210 km into Canada, where it is named the Fraser River Fault Zone (USGS 2003). The fault separates low-grade metamorphic rocks to the west from highly metamorphosed rocks of the North Cascades core to the east. The main stem of Bacon Creek follows the Straight Creek Fault. In the eastern part of the watershed, Triumph Fault begins near the summit of Mount Despair and runs due south for approximately 8 km. In the eastern part of watershed, the Entiat Fault Zone extends approximately 6 km into the watershed from the south and runs along the eastern side of the main stem of Bacon Creek. There are shallower thrust faults in the south east part of the watershed. These faults have been exploited by surface processes to form river canyons and ridge saddles. There appears to be no appreciable tectonic Holocene activity along any of these three faults systems within the Bacon Creek Watershed (USGS 2009). Most of the faults have been intruded by younger batholiths that do not show off-set.

2.2.2 Geologic Units

A generalized geologic map provides a regional perspective on the geology in the Bacon Creek Watershed and neighboring watersheds (Tabor and Haugerud 1999; Fig. 3). A detailed description of the geology is found in the Tabor et al. publication (2003) and is summarized in the paragraphs below.

Bedrock of the Bacon Creek Watershed was formed by a complex series of metamorphic and tectonic events beginning 120 million of years ago (Ma) during the Cretaceous and continuing today. In the last 2 Ma, during the Quaternary, dynamic surficial processes have sculpted the landscape through active hillslope, fluvial, glacial and nival processes.

Bedrock west of the Straight Creek Fault, including the Falls Creek area and the upper main stem of Bacon Creek, is composed of metabasalts of the Shuksan Greenschist. East of the fault, granodiorite of the Mount Despair Composite Batholith (Oligocene) dominates Triumph Creek and the East Fork of Bacon Creek. In the southwest section of the watershed and near Berdeen Lake, there are small outcrops of Darrington Phyllite (early Cretaceous). Along the SCF are small pockets of sandstone, and conglomerate deposits (age uncertain). In the southeast there is a north-south band of Napeequa Schist and Cascade River Schist of the middle Eocene to Late Cretaceous and metaplutonic rocks of the Marblemount Pluton (Late Cretaceous).

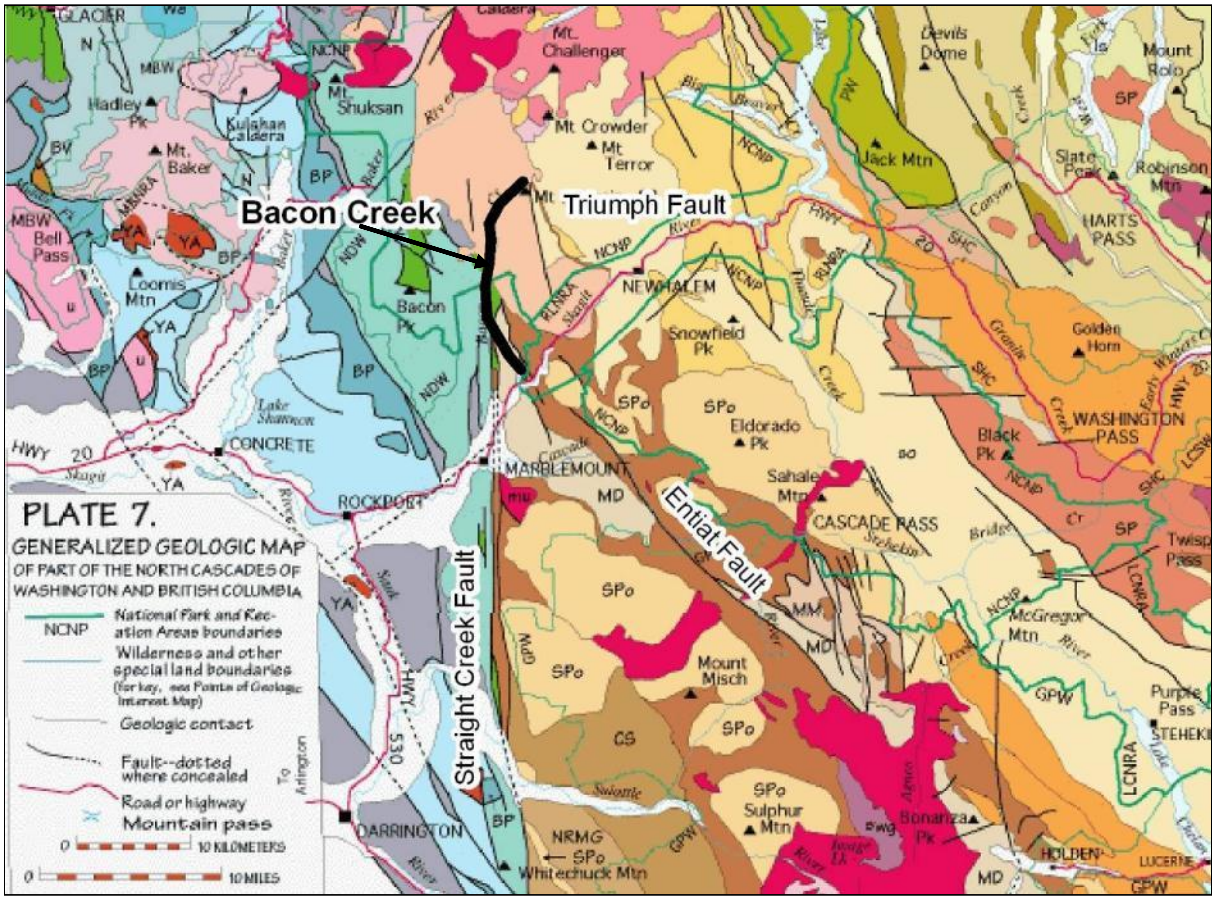

Figure 3. Bedrock map showing the Bacon Creek Watershed (river is in bold), fault locations and some of the adjoining watersheds (see Tabor and Haugerud 1999 for geologic map key).

2.3 Glacial History

Multiple Pleistocene alpine and ice sheet glaciations in the past 2 ma have carved deep U-shaped valleys, steep valley walls, and jagged horns and arêtes. Continental ice sheet glaciations have also altered both local and regional drainage patterns (Riedel 2007). During the last major incursion of the ice sheet (Vashon stade of the Frasier glaciation), approximately 17,000 years ago, the area was inundated by the south flowing Cordilleran Ice Sheet (CIS; Fig. 4; Armstrong et al. 1965). Impacts from the ice sheet are evident throughout the Bacon Creek Watershed and North Cascade range and include broad passes and ridges, enlarged valley cross-sections, and truncated valley spurs. Ice surface elevations of the CIS in the watershed were 1700-1900 m asl (Riedel 2007). CIS probably flowed into Bacon Creek from Baker Valley via the pass between Hagan Mountain and Bacon Peak, as well as into the lower valley from Skagit River.

Following the Cordilleran Ice Sheet maximum, valley glaciers flowed from cirques into the Bacon Creek valley forming a valley glacier system (Fig. 5, Riedel 2007). The Bacon valley glacier reached its maximum 12,000 years ago, forming moraines and terraces at junction of Bacon Creek with East Fork. Tributary systems were left as hanging valleys with bedrock canyons or narrow stepped waterfalls at their mouths. Where they join with the main river system, these streams have deposited alluvial fans or substantially widen the flood plain. Today, these old fans and flood plains have been incised leaving behind river terraces and alluvial fan terraces. Extensive valley glaciers left behind large amounts of glacial drift, including till and outwash at the toe of valley walls. This material has been reworked by subsequent surficial processes, or abandoned as terraces. This sediment fills most of the larger valleys to depths of several hundred meters.

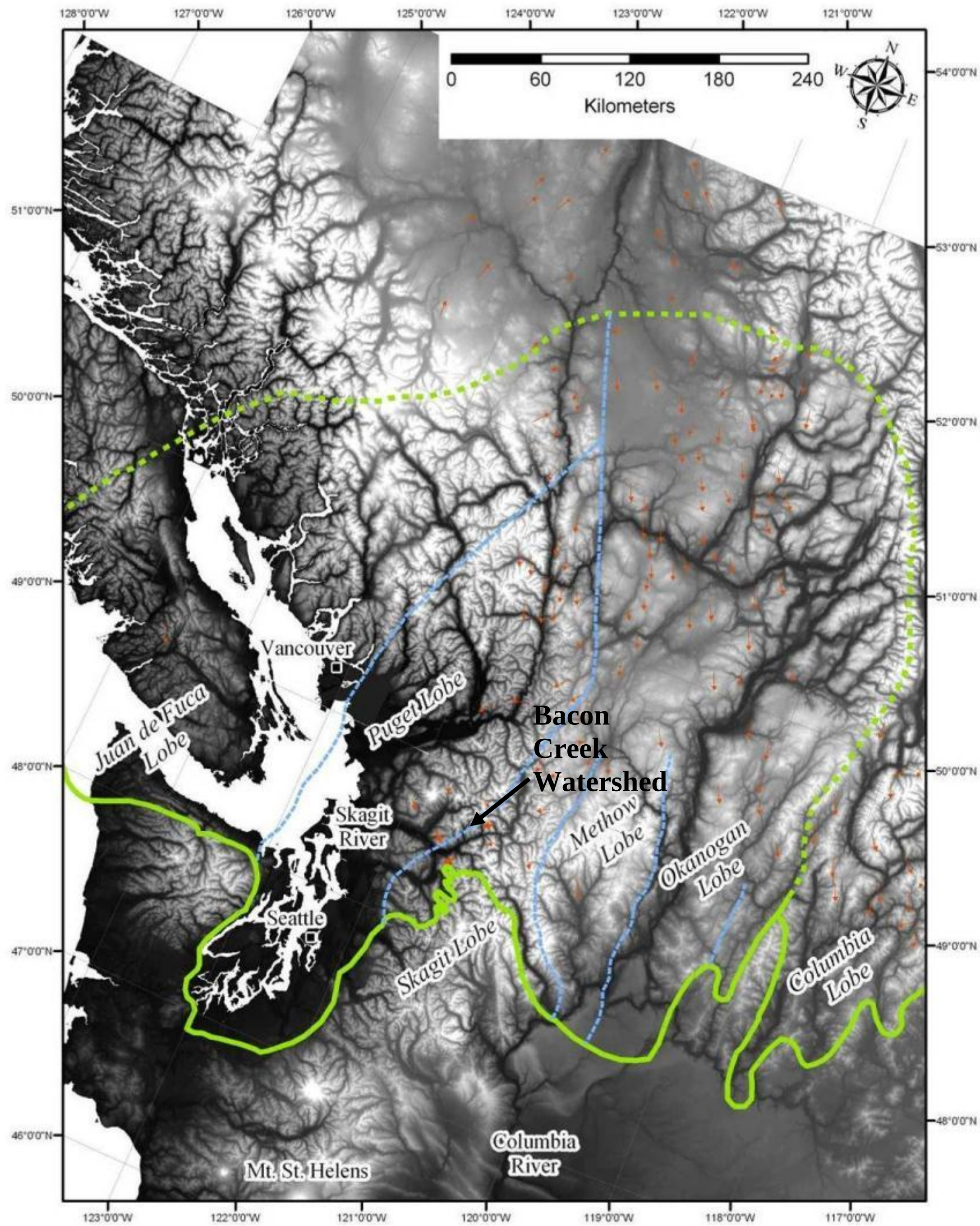

Figure 4. Map of the known extent of the Cordilleran Ice Sheet during the Fraser Glaciation. Note the various lobes of the ice sheet mapped, extending down into the United States.

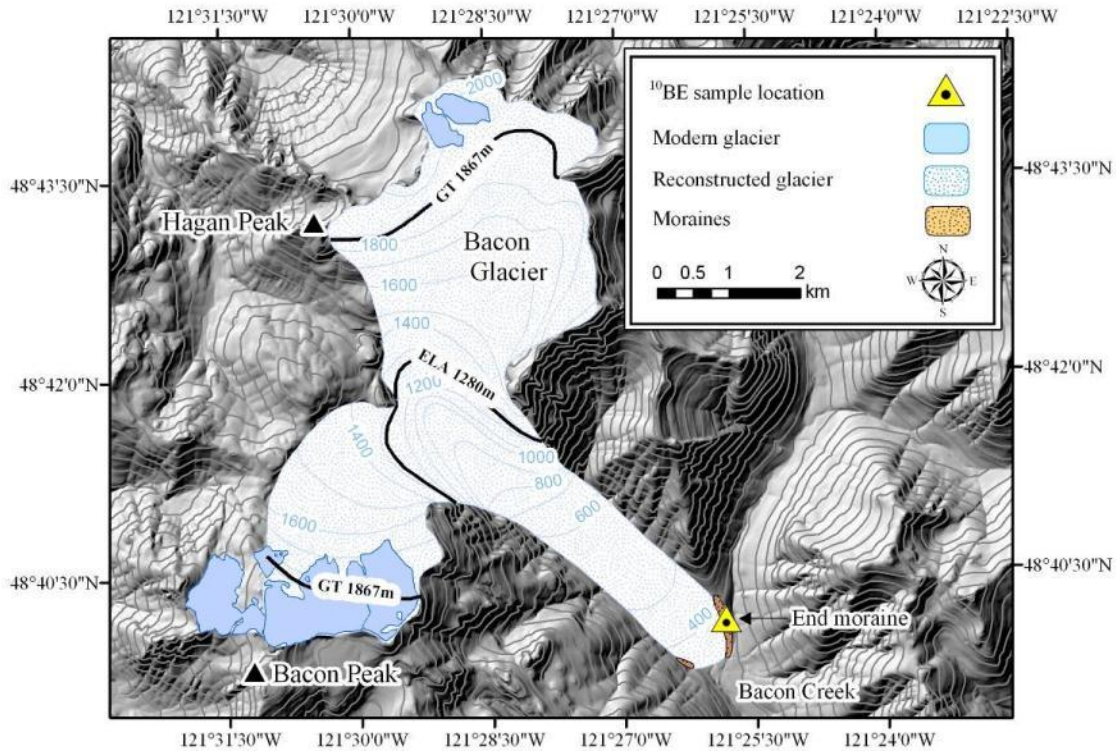

Figure 5. Reconstruction of the Bacon Glacier during the Sumas Stade (Riedel, 2007). Also shown are the Equilibrium Line Altitude (ELA) about 12,000 years ago and the modern glaciation threshold (GT), which is analogous to ELA.

2.3.1 Neoglacial

Most existing glaciers reached their maximum size since the last ice age ended 11,000 years ago. During the Little Ice Age, ca. 1350-1900 A.D., glacial advances built hundreds of small moraines in the upper reaches of the watershed. Small cirque glaciers and permanent snow fields of today are 45-50% less extensive than 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.

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 Bacon Creek valley to depths of several hundred meters.

There are 312 glaciers present within NOCA today. Permanent snowfields and glaciers cover an area of 2.85 km^2 in the Bacon Creek Watershed; they are most extensive on Bacon Peak (Fig. 6). Since 1993, the NPS has been collecting mass balance measurements to monitor four glaciers at NOCA; Noisy, North Klawatti, Sandalee, and Silver glaciers. No glaciers within the Bacon

Creek Watershed are currently being monitored. Noisy Glacier is the closest to Bacon Creek Watershed, located on the northwest side of Bacon Peak in the Baker River watershed. A summary of the results from the Noisy Glacier in the Baker River Watershed follow in the Hydrology section of this report.

2.4 Climate

Climate is the primary driver of surficial processes that have shaped the Bacon Creek Watershed. In general, the climate is classified as maritime with relatively mild, wet winters and cool, dry summers. However, climatic conditions vary widely with large gradients in temperature and precipitation. Bacon Creek Watershed lies on the western slopes of the North Cascades range, west of the Skagit Crest. The Skagit Crest has a strong influence on the local climate, forming a barrier to eastward flowing winds; orographic uplift cools and condenses the moisture laden air. This results in large precipitation gradients from west to east, with higher annual rainfall on the westside of the crest and lower rainfall on the east. The precipitation gradients are evident even within the watershed, with the main stem of Bacon Creek being wetter than the East Fork. Additionally, the Skagit and Pacific Crests divide the maritime and continental climate. Located near the divide, the Bacon Creek Watershed lies in a transitional zone, and is influenced by continental conditions at some times of the year.

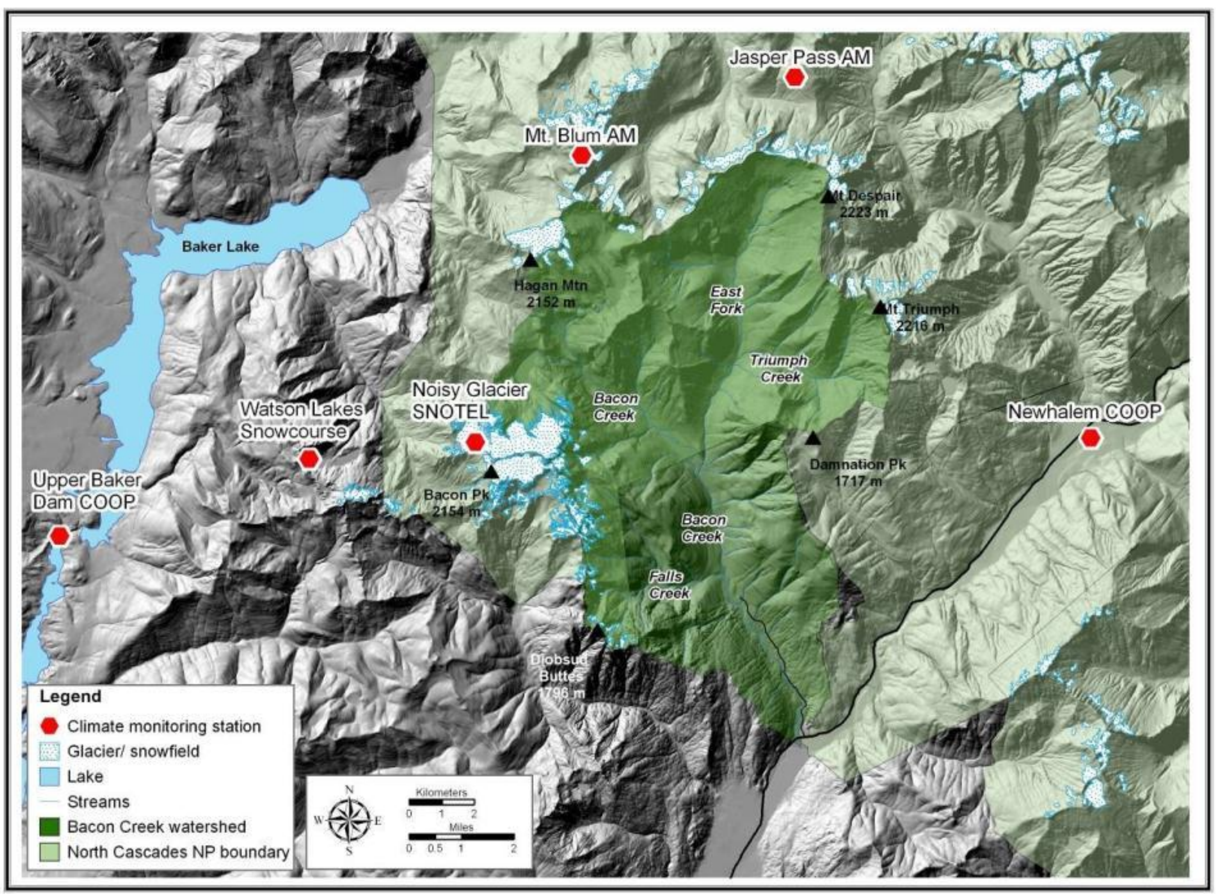

Figure 6. Permanent snowfields, glaciers and climate monitoring stations located in and around the Bacon Creek Watershed.

There are no current weather monitoring stations located within the Bacon Creek drainage. However there are numerous monitoring stations in adjacent watersheds, including Cooperative Network stations (COOP), Natural Resource Conservation Service (NRCS) snow course, aerial markers (AM) and snow telemetry (SNOTEL) sites and NPS glacier mass balance monitoring (Fig. 6). The two COOP weather stations near the Bacon Creek Watershed are the Upper Baker Dam station (210 m) located to the west in the Baker River watershed and the Newhalem station (160 m) located to the east in the Skagit River watershed. Climate data provided here are 30-year averages calculated from 1971-2000 data. Precipitation and temperature data for these two sites are listed in Table 1. Annual high temperatures tend to occur in August, and low temperatures occur between December and January. Lapse rates tend to vary by season, but are generally 0.5° C/100 m.

Precipitation rates are characterized as high frequency, low to medium intensity. Most precipitation occurs during the winter months of November through January, averaging 46-47% of the total accumulation. November is routinely the wettest month at both COOP sites. June through August tend to be the driest months, averaging only 8% of total precipitation. The driest month is August for Upper Baker Dam and July for Newhalem, averaging 5.6 cm and 4.4 cm, respectively.

Table 1. Summary of data from the Upper Baker Dam and Newhalem Cooperative Network sites located near the Bacon Creek Watershed. Data is provisional and subject to change (http://www.wrcc.dri.edu/summary/Climsmwa.html).

Station	Basin	Elev. (m)	Period of record	Average Temperature (° C)			Average Precipitation (cm)		
				Annual	Monthly Low	Monthly High	Annual	Monthly Low	Monthly High
Upper Baker Dam	Baker River	210	1965-current	8.7	3.8	23.7	253	5.6	40
Newhalem	Skagit	160	1959-current	9.4	1.0	24.6	202	4.4	34

Maximum snow depth and snow water equivalent for the three closest snow survey sites located near the Bacon Creek drainage are listed in Table 2. At higher elevations, the snowpack reaches its maximum in May. The spring snow depth on Noisy Glacier is typically between 3.5 and 5.5 m, with as much as 9.5 m in heavy snow years.

Table 2. Summary of data from the three snow survey sites located near the Bacon Creek Watershed. Data is provisional and subject to change (http://www.wcc.nrcs.usda.gov/cgibin/state-site.pl?state=WA&report=snowcourse).

	Mt. Blum AM	Jasper Pass AM	Watson Lakes
Elevation (m)	1768	1646	1372
Period of Record	1965-Present	1959-Present	1959-Present
Max. Snow Year	1965	1971	1971
Max. Depth/ SWE (cm)	528/ 213	762/ 335	625/ 262
Lowest Snow Year	1996	1996	1996
Min. Depth/ SWE (cm)	244/ 97	318/ 127	152/ 64

In 2008, a high elevation weather station was installed on the north slope of Bacon Peak near Noisy Glacier (data is unavailable at the timing of this publication). The Jasper Pass aerial marker was also removed and a snow telemetry station (SNOTEL) was installed at the Easy Pass snowcourse site.

2.5 Hydrologic Setting

The USGS operates a stream gauging station for Bacon Creek, located 2 km downstream from the confluence with Oakes Creek at an elevation of 125 m. The period of record for the gauging station is August 1943 to September 1950 and October 1998 to the current year. The average annual discharge for the period of record is 0.39 km^3. Monthly means indicate the lowest flows are in late summer, especially following hot and dry summers, and in winter when precipitation largely falls as snow (Table 3). The lowest recorded discharge is 1.6 m^3/s on October 14-15, 2006. Rivers and creeks can typically reach flood stage during both the spring and late fall. Large rain on snow events have been responsible for the highest flows, these generally occur in fall when warm moisture-laden air rains on early season snowpack. The maximum recorded discharge is 513 m^3/s on November 26, 1949.

Hydrologic processes have significant effects on development of floodplains, valley bottoms, terraces, debris cones, alluvial fans, and deltas. Large floods transport sand and gravel, erode river banks and mobilize large woody debris. During large magnitude events, channels and gravel bars shift positions and water occupies side channels and floodplains. Small, steep tributaries can contribute large amounts of sediment to streams via debris flows. Specific examples of the effect of the study area hydrology on landform development are addressed in the Discussion section of this report.

Table 3. Maximum recorded discharges for water years 1943-2007, USGS Bacon Creek gauging station. Period of record: August 1943 to September 1950 and October 1998 to current year. USGS records are poor for discharges above 5,000 ft^3/s. Units: cubic feet per second. (http://waterdata.usgs.gov/wa/nwis/uv/?site_no=12179900&PARAmeter_cd=00060,00065).

WY	Date	Gage Height (ft)	Discharge (cfs)
1944	Dec. 03, 1943	4.25	3,050
1945	Feb. 07, 1945	5.62	5,510
1946	Oct. 25, 1945	6.2	7,000
1947	Oct. 24, 1946	5.88	6,480
1948	Oct. 19, 1947	5.67	5,670
1949	Oct. 07, 1948	4.65	3,300
1950	Nov. 26, 1949	7.13	18,100
1999	Dec. 13, 1998	6.83	1,940
2000	Nov. 11, 1999	6.89	2,000[1]
2001	Oct. 20, 2000	6.47	1,630
2002	Jan. 07, 2002	10.74	7,850
2003	Jan. 26, 2003	9.07	4,840
2004	Oct. 20, 2003	19.97	[9]
2005	Jan. 19, 2005	9.8[2]	8,120
2006	Dec. 24, 2005	7.58	3,890
2007	Mar. 11, 2007	11.93	14,000

[1] – Discharge is an estimate

[2] – Gage height not the maximum for the year
[9] – Discharge not available, values due to debris dam break-up

Glaciers are an important component to hydrology of the North Cascades, glacially fed streams help to produce a continual flow of water throughout the year. Meltwater contributions from glacial ice and snowfields are critically important for sustaining local endangered salmon and trout species

Permanent snowfields and glaciers are located on the western slopes of peaks in the watershed (Fig. 6). Glacial surveys based on 1950-1960 and 1998 air photos (Post et al. 1971) indicate a 14 percent reduction in glaciated area with the Bacon Creek Watershed (Granshaw 2001). Glacial inventories based on 1950 – 1960 air photos reported 3.1 km^2 of ice within the Bacon Creek Watershed (Post et al. 1971). Research done in 1998 placed that number at 2.8 km^2, an approximately 14% loss of ice (Granshaw 2001).

The glacier monitoring program at NOCA provides significant insight into the contribution glaciers are making to the overall watershed total run-off. NOCA has been monitoring Noisy Glacier on the north face of Bacon Peak since 1993. Noisy Glacier is one of four glaciers monitored by the NPS (Riedel et al. 2008) and the mass balance data from Noisy are presented below (Fig. 7). The Noisy Glacier is the lowest in elevation and furthest west of the four glaciers monitored at NOCA (1670 – 1930 m), so it tends to have the most winter accumulation and summer ablation of the glaciers monitored. Since monitoring began, Noisy Glacier has been retreating; with a negative mass balance in 10 of the last 15 years (Fig. 7). While Noisy Glacier does not drain into the Bacon Creek Watershed, it gives a proxy to the conditions of other glaciers within it. More detail regarding the status of glaciers, photographs of those monitored and the methods of glacier monitoring within NOCA can be found in several locations (Riedel et al., *in press,* NOCA NPS 2009, Riedel et al. 2008).

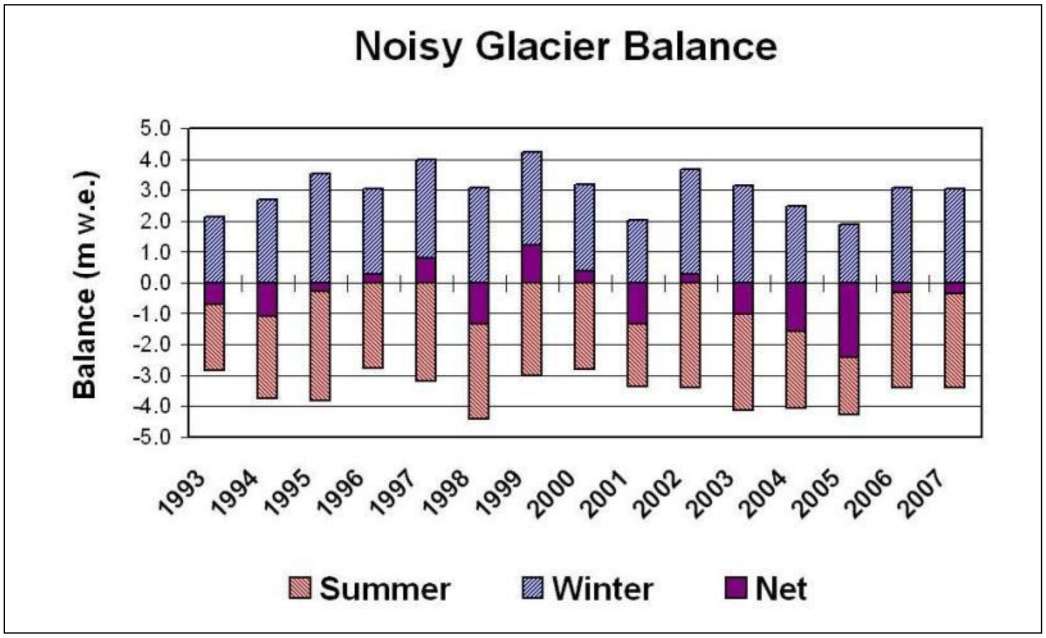

Figure 7. Mass balance chart of Noisy Glacier, located on Bacon Peak. The vertical axis is the amount of water gained (winter balance), lost (summer balance) and retained (net balance – solid bar) in meters of water equivalent (m w.e.) averaged across the glacier. (http://www.nps.gov/noca/naturescience/glacial-mass-balance1.htm)

2.6 Vegetation

Digital vegetation coverage within NPS land in the watershed is complete, with the remaining 11% National Forest Service land unmapped. Based on available data, subalpine lowland and montane forest cover about 76% of the watershed, and bare snow, rock, and ice cover approximately 23%. In most cases, dominant overstory vegetation provides an inference on landform age, surficial geology, hydrology, and disturbance. However, lowland forests of the lower watershed have been logged and now contain young secondary forests.

Wetland (sedges and rushes) and riparian (Oregon ash, black cottonwood, willows, sedges, alder) vegetation occupy approximately 2% of the watershed and is found at low elevation in floodplains. Lowland forest vegetation occurs below 900 m, it is comprised of Douglas-fir (*Pseudotsuga menziesii)*, Western hemlock (*Tsuga heterophylla)*, Western Red-cedar (*Thuja plicata)*, and Big-leaf maple (*Acer gigantum)*. Montane vegetation occurs from 1500 to 900 m, with treeline beginning at approximately 1400 m. Montane vegetation includes Pacific Silver fir (*Abies amabilis*), Western hemlock (*Tsuga heterophylla*), and Yellow cedar (*Chamaecyporis nootkatensis*). Heavy snow creates a wide subalpine zone between 2000 to 1500 m and includes Subalpine fir (*Abies lasiocarpa)*, Mountain hemlock (*Tsuga mertensiana*) and open herbaceous meadow communities. Alpine vegetation is comprised primarily lichens, mosses and sedges at elevations above approximately 2000 m.

2.7 Landform Age

Landforms can either be depositional such as moraines and alluvial fans; or they can be erosional such as bedrock benches, river canyons and glacial horns. Many depositional features, such as moraines and terraces, were formed during the last ice age. Other depositional landforms, such as floodplains, 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 available radiocarbon dates, associated process of formation, volcanic tephra, soil development, and vegetation type and age. The approximate ages of landforms at NOCA reflect their stability and are listed below in Table 4. Data were obtained from several sources and include radiocarbon dates on a variety of landforms within NOCA (Riedel et al. *in press*, Riedel 2007, Mierendorf, 1999, Mierendorf et al. 1998).

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

Landform	Age
Debris cone, floodplain, alluvial fan	<500 years
Most neo-glacial moraines	<300 years
Valley walls[1]	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[1]	12,000 years
Mass movements (landslides)	0-14,000 years

[1] *These features formed over long periods of time during multiple ice ages. Dates given are for the most recent ice age.*

2.7.1 Landforms and Soils

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

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

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

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

2.8 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 5). 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 5. 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

2.8.1 Subsection (1:250,000)

Landscape mapping units are defined on the basis of climate, bedrock geology and topography at a regional scale. Features of the landscape such as regional hydrologic divides, contacts between major bedrock terranes and glaciated topography are boundaries of Subsection mapping units. In the North Cascades, the draft Subsection map (Fig. 8) identifies 17 mapping units; including: Major Valley Bottoms, Crystalline Glaciated Cascade Mountains, Volcanic Cones and Flows, Sedimentary Cascade Hills, etc. These units were developed by Wenatchee National Forest (Davis 2004) and applied to the west slope of the Cascades by staff from Wenatchee National Forest and NOCA (Riedel and Probala, 2005).

The Bacon Creek Watershed is primarily within the Crystalline Cascade Mountains but the lower third of the watershed is within the Metamorphic Cascade Hills subsection. Rocks of the Metamorphic Cascade Hills are prone to mass failure and erosion by glaciers, whereas the Crystalline Cascade Mountain rocks are more stable.

2.8.2 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 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. For the Bacon Creek Watershed this scale of mapping has been completed only for NPS land in the upper watershed (Fig. 9).

2.8.3 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 detailed sedimentologic and 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 6. A detailed description of each landform, including location, associated landforms, process, material, mapping guidelines, and potential natural vegetation are available on request.

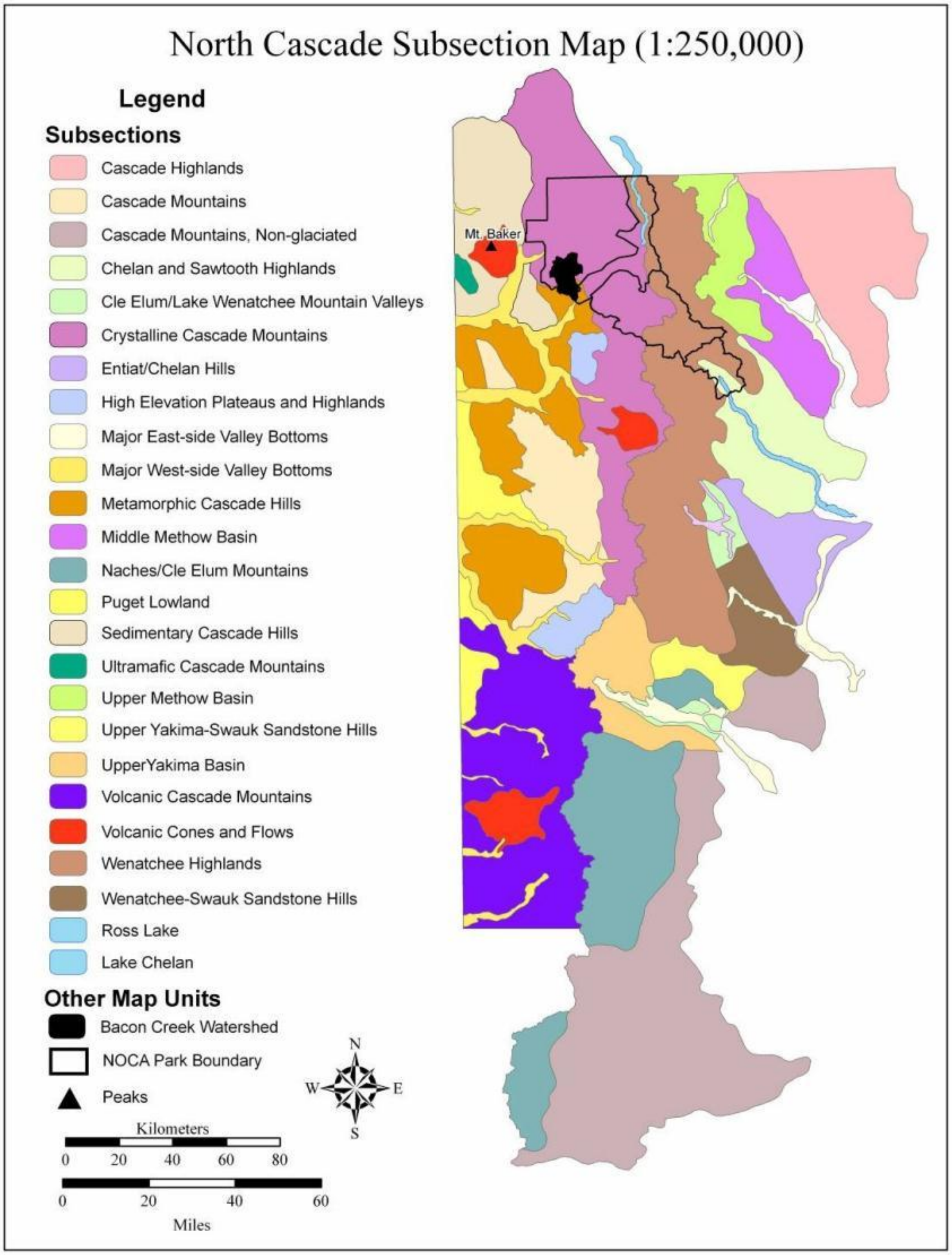

Figure 8. Subsection map (1:250,000) of the North Cascade region showing the location of the Bacon Creek Watershed within the Crystalline Cascade Mountains Sub-Section and North Cascades National Park Service Complex (Davis 2004).

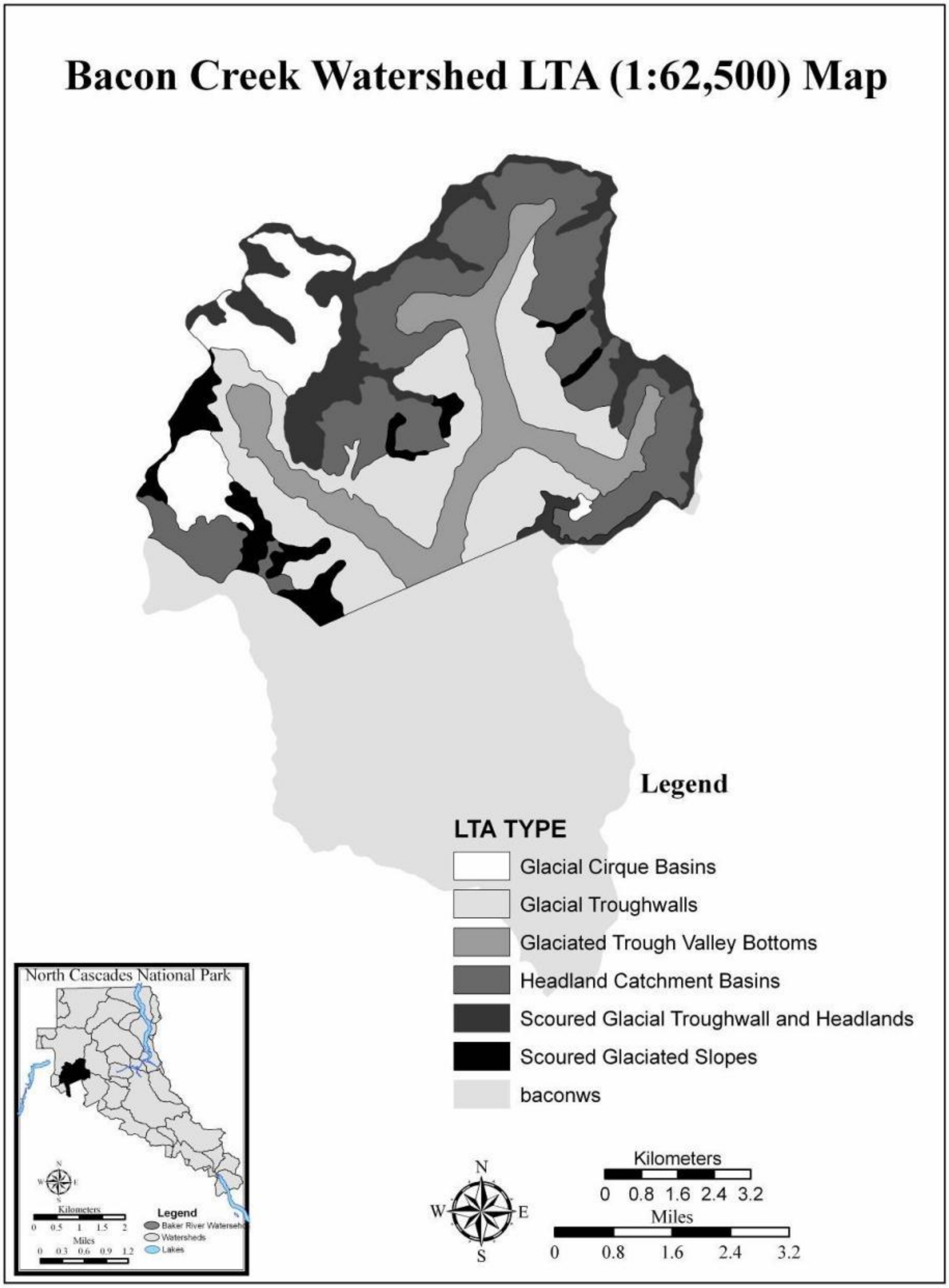

Figure 9. LTA map (1:62,500) of the Bacon Creek Watershed (Davis 2004).

Table 6. Landform (1:24,000) legend for North Cascades National Park.

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

3 - Methods

3.1 Preliminary Methods

At the beginning of the mapping process each national park was divided into watersheds that were 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 completed 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 100 m^2 with some exceptions for smaller units like Neoglacial moraines and slumps.

3.2 Field Methods

Each field trip typically focuses on a sub-watershed. Before entering the field, a task list of areas to visit is developed. As much ground as possible is surveyed, but efforts are concentrated 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, valley cross sections are made. 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.

3.3 Digitizing Methods

After identifying landforms and drawing the boundaries, each area is peer-reviewed for accuracy and mapping consistency. Landform line-work 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.

3.4 Areas Surveyed

All field investigations in the watershed were completed in the summer seasons of 2002 and 2003 by NOCA Resource Management staff both past and present: Jon Riedel, Robert Burrows, Michael Larrabee, Jeanna Probala (Wenger), Daniel McCrumb, Cathi Jones, Daniel Diedrich, and Steven Dorsch

Secondary forests growing in old logging stands made travel by foot difficult in the lower watershed and as a result access in the watershed followed mainly Forest Service roads, unmaintained trails, and wadable parts of streams. The main road is maintained by the Forest Service, it follows along the eastside of Bacon Creek for approximately 7.5 km (just south of the Bacon Creek and East Fork confluence) where it crosses a bridge and heads south on the west side of Bacon Creek. A few smaller unmaintained roads branch off from the main road.

The entire road network was walked and most of the main stem of the lower Bacon Creek was waded to check terrace heights and boundaries of floodplains and debris cones. Difficult travel impeded ground surveys on the main stem above ~427 m, and areas above 540 m altitude in the East Fork, Falls Creek, and Triumph Creek. No high elevation landforms were field checked. Aerial surveys were made via several helicopter flights while in transit to other NPS research projects

4 - Results and Discussion

4.1 General Watershed Overview

The main stem of Bacon Creek is a narrow, glacially scoured valley with a straight profile and moderate gradient. The East Fork is a hanging valley above the main stem, and has a steep gradient in its lower 1 km. Difference between these two main tributaries are due to the more intense glaciations of wetter Bacon Creek, which also served as a major conduit for the CIS. Other glacial characteristics of the valley include, steep vegetated valley walls, hanging tributary valleys, and truncated valley spurs. Within the watershed, 66% is categorized as valley wall and 13% is high elevation cirque; with only 1.8% riparian (floodplain, valley bottom, and alluvial fan, most occurring in lower Bacon Creek; Table 7). The steepness of the terrain is also reflected by the fact that 14.6% of the watershed is classified as debris deposits and mass movement. Surficial material in the watershed is dominated by glacial till and colluvium. The asymmetry of the valley is marked by the steep valley wall and rock fall on the creek's northeast-facing side compared to the more gentle forested slopes on the southwest-facing side.

The floodplain on Bacon Creek formed on the flat valley floor from the confluence with the Skagit River to an elevation of 670 m, above a Pleistocene moraine at the East Fork confluence. At NOCA, the valley bottom usually begins around 1200 m; the presence of valley bottom at lower elevations in Bacon Creek is likely a result of CIS erosion of brittle bedrock along the Straight Creek Fault. The debris apron zone (colluvial), adjacent to the valley bottom and flood plain, occupies an area between 366 to 1400 m. The debris aprons contain till and colluviums with a significant component of volcanic ash.

Terraces heights range from four to 36.5 meters with reoccurring terraces up the main stem at approximately 1, 1.5, 3.5 and 6 m. The higher terraces could be outwash from late ice age valley glaciers. Lower terraces are probably alluvium deposited in the past few hundred years.

The location of mass movements are often related to the underlying bedrock and structure (Fig. 2 and 3). Bedrock west of the Straight Creek Fault (SCF), including the Falls Creek area and the upper main stem of Bacon Creek, is composed of Shuksan Greenschist. Most large debris avalanches in the watershed have occurred in this relatively weak rock, particularly where it is oversteepened by glaciations on valley walls. In the southwest and near Berdeen Lake, there are small outcrops of Darrington Phyllite, which are also prone to mass failure.

4.1.1 High Elevation Landforms

High elevation landforms (cirques, Neoglacial moraines, ridges, arêtes, horns, passes and other mountains) account for 20.3 km^2, or 15.3% of the watershed (Table 7). The dominance of cirques in the watershed speaks to the importance of glaciations in the shape of the landscape and its history. Cirque floors can be useful in determining equilibrium line attitudes of Quaternary glaciers. Two large cirques contain large, deep Green and Berdeen lakes. Aspect strongly influences the development of cirque basins; south facing cirques tend to have the highest elevations and are generally not cut as deeply. North and east facing cirques have the lowest elevations in the watershed, extending to elevations of 1340 m. There are few cirques located on the eastern watershed boundary, likely a result of its western aspect and lower precipitation.

Glacial erosion of cirque headwalls is greatest on northern aspects, resulting in a southward divide migration.

Particularly well-developed horns and arêtes in the watershed were shaped by alpine glaciers in cirques, and generally stood above the level of the ice sheet. These solitary peaks include Mt. Triumph, Mt. Despair, Hagan Mountain. These landforms are visited frequently by climbers for their sheer cliffs, flying buttresses, and chimneys.

Recent glacial activity is recorded in Neoglacial moraines. These landforms were deposited by alpine glaciers in the last 7,000 years. Most of these features were deposited in the Little Ice Age, between 1350 and 1900 AD. This advance was the most extensive in the past 10,000 years in most cirques. There are 12 Neoglacial moraines in the Bacon Creek Watershed. The majority of these are located in upper main stem of Bacon Creek on the slopes of Bacon Peak. The elevation of Neoglacial moraines are influenced by aspect and hypsometry and tend to occur between 1340 to 1890 m.

Table 7. Summary of area of each landform type within the Bacon Creek Watershed.

Landform Type	Number observed	Area (km^2)	Percent of the watershed (%)
Valley wall	1	86.83	65.7
Cirque	47	17.50	13.2
Debris Apron	43	12.35	9.3
Debris Cone	58	4.11	3.1
Mass Movement – Fall/ Topple	64	1.94	1.5
Floodplain	3	1.81	1.4
Ridge	31	1.46	1.1
Terrace	46	0.95	0.7
Bedrock Bench	38	0.90	0.7
River Canyon	14	0.85	0.6
Mass Movement – Debris Avalanche	7	0.78	0.6
Arête	24	0.66	0.5
Valley Bottom	4	0.57	0.4
Pleistocene Moraine	4	0.42	0.3
Other Mountain	17	0.26	0.2
Neoglacial Moraine	12	0.23	0.2
Fan Terrace	5	0.14	0.1
Mass Movement – Debris Torrent	10	0.12	0.1
Horn	7	0.10	0.1
Pass	12	0.05	0
Undifferentiated	3	0.05	0
Alluvial Fan	2	0.03	0
Mass Movement – Slump/ Creep	3	0	0
Total	*455*	*132.10*	*100*

4.2 Characteristics of Sub-watersheds

4.2.1 Lower Main Stem of Bacon Creek

For this report, the lower main stem of Bacon Creek is defined as the reach from the mouth of Bacon Creek to the East Fork junction. The drainage pattern of the lower main stem is influenced by both Entiat and Straight Creek Fault Zones (Fig. 3 and 10). The lowest 5 km of Bacon Creek roughly parallels the northwest-southeast trending Entiat fault. At 5 km, Bacon Creek crosses the Straight Creek Fault realigning itself with the north-south trending fault. Sediment transported by Bacon Creek is deposited as an alluvial fan at its convergence with Skagit River. Along the lower reaches, the wide floodplain supports many low terraces with heights of 1, 1.5, 2, 3, and 3.5 m above the floodplain on both the east and west banks (Fig. 10). The largest terrace is located at the mouth of Bacon Creek; it is 4 m above the floodplain with an area of 0.5 km^2. A total of five high terraces with heights of 6, 9 and 13.5 were mapped in the lower reaches of the watershed. The high terraces were most likely formed by outwash from the Bacon Creek glacier about 12,000 years ago (Fig. 5). Above where Bacon Creek crosses the Straight Creek Fault, the floodplain width constricts from ~200 m to ~70 m and is void of river terraces, the floodplain widens significantly and terraces are present above the East Fork junction.

The Straight Creek Fault separates low-grade metamorphic rocks to the west from granitic and high-grade metamorphic rocks to the east. The fault had been intruded by numerous granitic plutons in the past 35 million years. Mass movements in the lower main stem are mostly rockfalls, located primarily on northwest facing slopes on the west side of the valley in Shuksan Greenschist. The bedrock on the eastern slopes of the lower main stem is largely orthogneiss and granodiorite, and judging by the relative scarcity of mass movements, is less prone to failure.

Several small low elevation bedrock benches and bedrock cored terraces, beginning ~ 130 m in elevation above the floodplain, line the valley from the mouth of the valley, up river for about 1.6 km. These bedrock features were likely formed by valley glaciers and ice sheets. They are often capped by glacial till and in the lower valley outwash. They are among the oldest surfaces in the watershed. Two large Pleistocene end moraines are located in this reach, one near the mouth of Bacon Creek (213 m) and one at the main and East Fork junction (400 m). Using cosmogenic dating on surface boulder exposures, the East Fork moraine was dated to the Sumas stade, 11,805+/- 1300 (Be^{10}, cal) yr BP (Fig. 5 and 10; Riedel 2007).

There are several east facing cirques with small glaciers and permanent snowfields on the west side of the lower valley, these mainly drain into Falls Creek. The steep and incised Falls Creek is a hanging tributary to Bacon Creek. Neoglacial moraines are non-existent in upper Falls Creek but there are a few small protalus rampart features built by a combination of snow avalanching and rock fall within the cirques. Both Falls and Jumbo Creek are river canyons, which are likely associated with nearby faulting. Jumbo Creek has a fan terrace located at the outlet of the river canyon. The fan terraces are likely associated with the end of the last ice age, when all of the streams produced massive quantities of sediment.

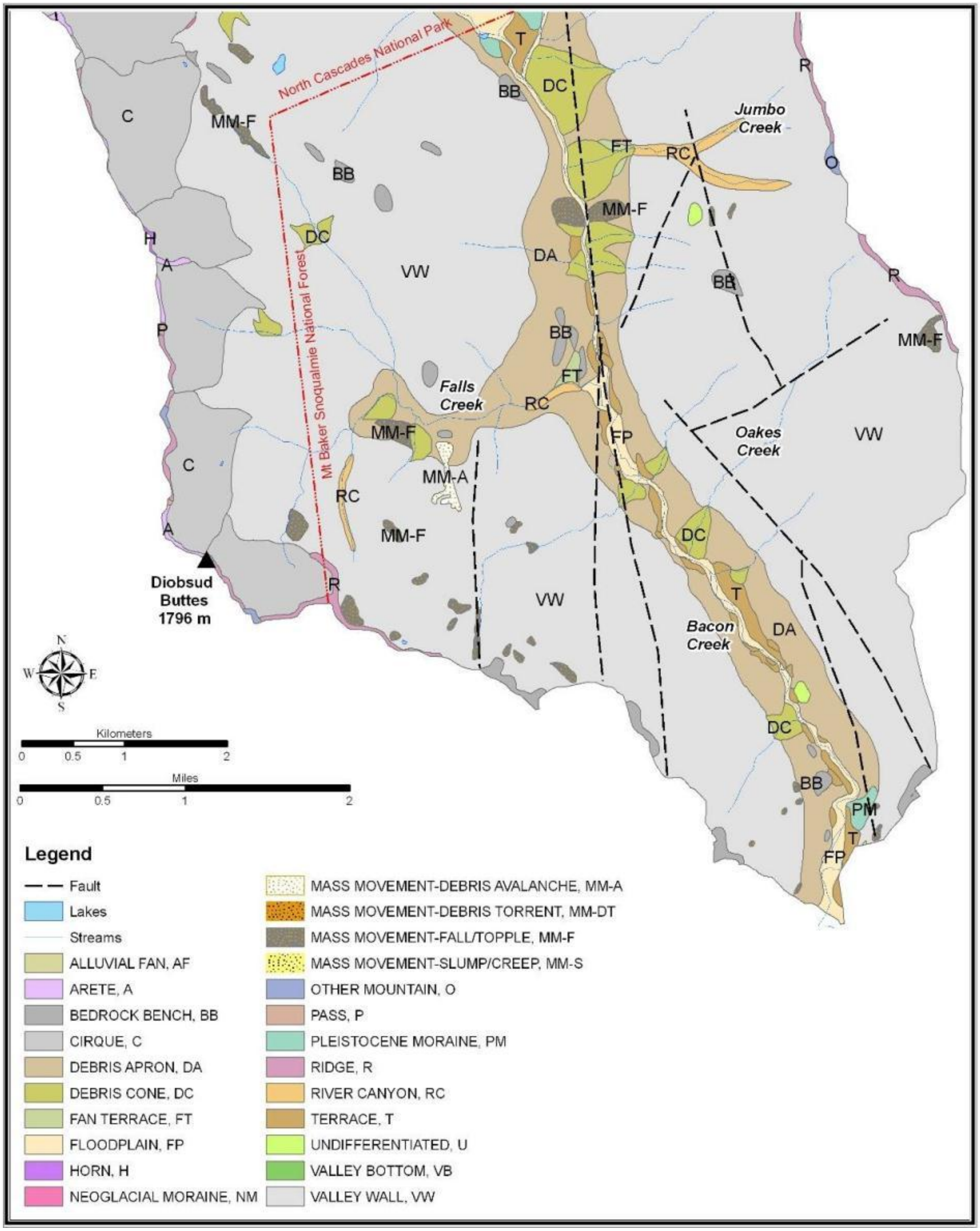

Figure 10. Lower main stem of Bacon Creek landform map (1:24,000) showing the distribution of landforms as well as the locations of the main tributary streams, bedrock faults and other locations referred to in the text.

4.2.2 Upper Main stem of Bacon Creek

For this report, the upper main stem of Bacon Creek is defined as the reach above the junction of Bacon Creek and the East Fork. The upper Bacon Creek floodplain is nine kilometers long and trends northwest-southeast (Fig. 11). Nearby faults with similar orientation indicate continued structural control on the drainage pattern of upper Bacon Creek. Evidence of past glaciations includes glacially scoured valley walls and bedrock benches, and Pleistocene and Neoglacial moraines. Alley walls in the upper Bacon Creek are spectacular vertical walls with waterfalls that tumble thousands of feet from the outlets of Green and Berdeen lakes. Multiple advances of alpine glaciers have left the valley heads as a series stepped valleys with extensive areas of scoured perched bedrock. Tributaries truncated by valley glaciers in the East Fork and Bacon Creek have formed river canyons.

Cirques floors extend down to 1645 m altitude, face all aspects, and are large and well-defined. The largest cirques are located on the western slopes of the valley, on Bacon and Hagan Peaks, where precipitation is higher. The headwaters of the upper main stem have the most extensive modern glacier cover within the watershed.

Upstream from a Pleistocene moraine at the East Fork confluence, the valley floor widens from less than a quarter kilometer to approximately 0.6 km, with large terraces and the widest floodplain in the entire watershed. Features within the floodplain include gravel bars, log jams, side channels, and low terraces. Terrace heights are 1, 1.5, 3.5, 6, and 7 m above floodplain level, the taller terraces are outwash features from the last excursion of glaciers to the valley floor 12,000 years ago (Fig. 5).

The valley narrows in the uppermost part of Bacon Creek, terraces are absent above 365 m and the floodplain is replaced by valley bottom above 670 m. Glacially over-steepened and unstable valley walls composed of Shuksan Greenschist result in the heaviest concentrations of debris avalanches in the watershed. Five debris avalanches contribute a significant amount of sediment to the river and at least one of these probably blocked or rerouted the river at some point in time.

Green and Berdeen lakes owe their spectacular color to glaciers and glacial sediments. Both large lakes have bedrock control at the outlets. Berdeen Lake is recharged by several small glaciers. Green Lake is recharged by several large glaciers resting on the northern flanks of Bacon Peak. Both lakes are surrounded by exposed bedrock with little vegetation, and a significant amount of reworked glacial till. The east side of the valley, below Berdeen Lake, is dominated by glacial till, whereas bedrock benches and stepped valley wall features dominate the west side of the valley.

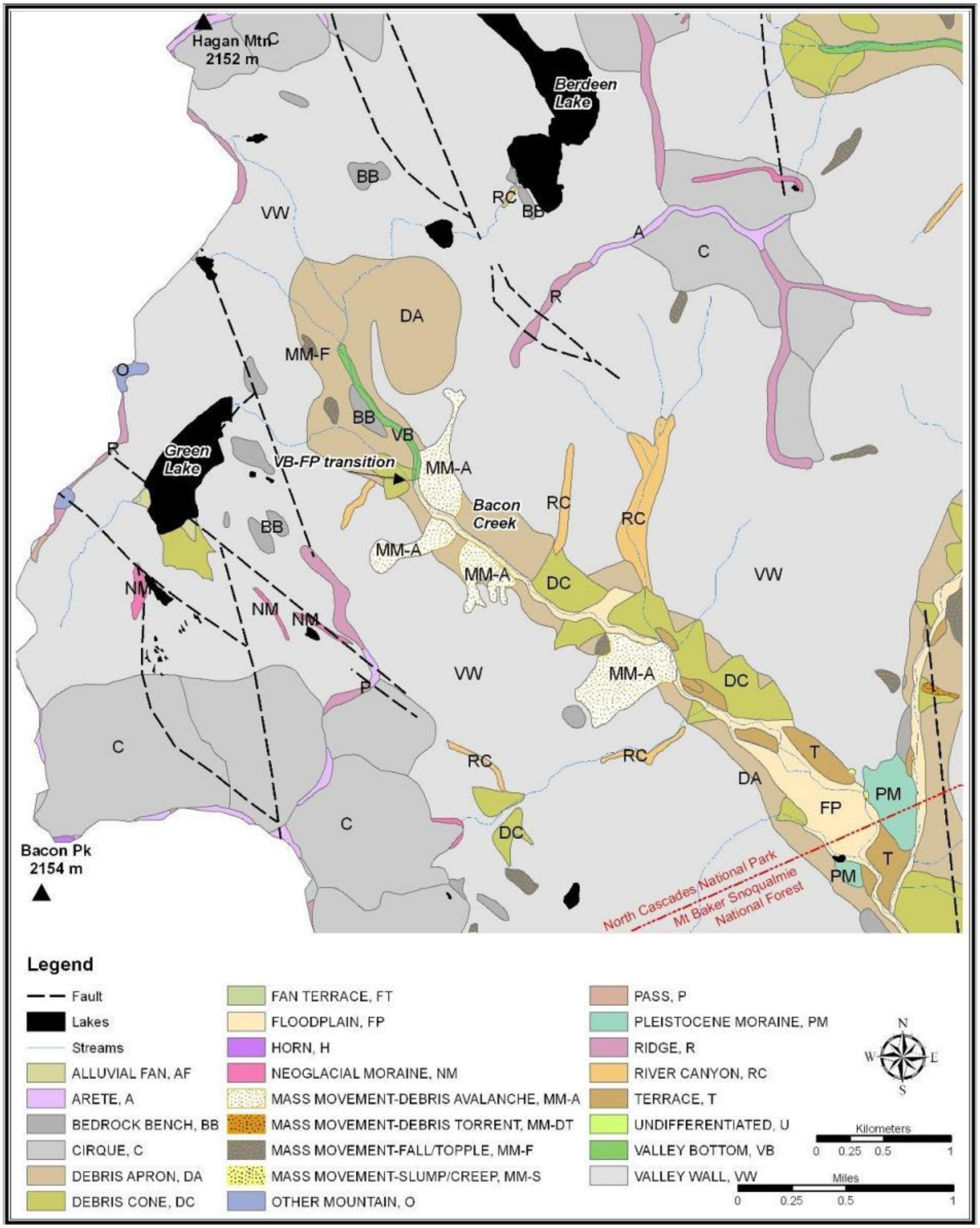

Figure 11. Upper main stem of Bacon Creek landform map (1:24,000) showing the distribution of landforms as well as the locations of the main tributary streams, bedrock faults and other locations referred to in the text.

4.2.3 East Fork

The East Fork is a seven kilometer long, north-south trending valley with steep scoured valley walls and a narrow valley floor (Fig. 12). Lower East Fork follows the Straight Creek Fault, and the upper valley trends parallel, but between, the SCF and the Triumph Fault. The East Fork is a hanging valley, with a steep drop to its juncture with Bacon Creek. Directly up river from the canyon there is a narrow floodplain supporting terraces between 1 and 2.5 m above the main river channel, with a high terrace at 36.5m. The floodplain momentarily widens upstream of Triumph Creek for 1 km before narrowing again. The transition from floodplain to valley bottom occurs around 550 m, which then extends up to 850 m at the valley head. In this area, sediment supply exceeds the hydrologic capacity to transport it downstream, so the channel is choked with sediment, is aggrading, and no terraces are observed (Jarrett, 1990).

The East Fork is positioned further east than the main stem of Bacon Creek, resulting in generally drier and colder climatic conditions. Cirque characteristics reflect the drier conditions, they are distinctly smaller than cirques further west and they have poorly defined cirque floors. One small northeast facing glacier remains in the East Fork drainage, sheltered from the sun by steep rock walls. There is one large Pleistocene moraine located at an elevation of 580 m at the divide between distinct east and west headwalls, which probably formed as a medial moraine between coalescing glaciers. There are only two small Neoglacial end moraines in the East Fork with elevation of 1465 m, which corresponds to the lower elevation limits of cirques.

Mass movements in the East Fork are distinctly different from Bacon Creek main stem, likely a result of bedrock type. The majority of mass movements in the East Fork are rock falls and debris torrents originating in granodiorite. Unlike the upper main stem, only one small debris avalanche was mapped in the East Fork (Fig. 12 and 13). The most impressive rock fall mapped in the watershed is located ~5 km above Bacon Creek and contains house sized blocks.

Triumph Creek is a two kilometer long narrow hanging tributary to the East Fork. Three-meter high alluvial fan terraces are located on either side of the East Fork and Triumph confluence. No floodplain is mapped in Triumph Creek, only valley bottom. There are several debris cones with active north facing debris torrents.

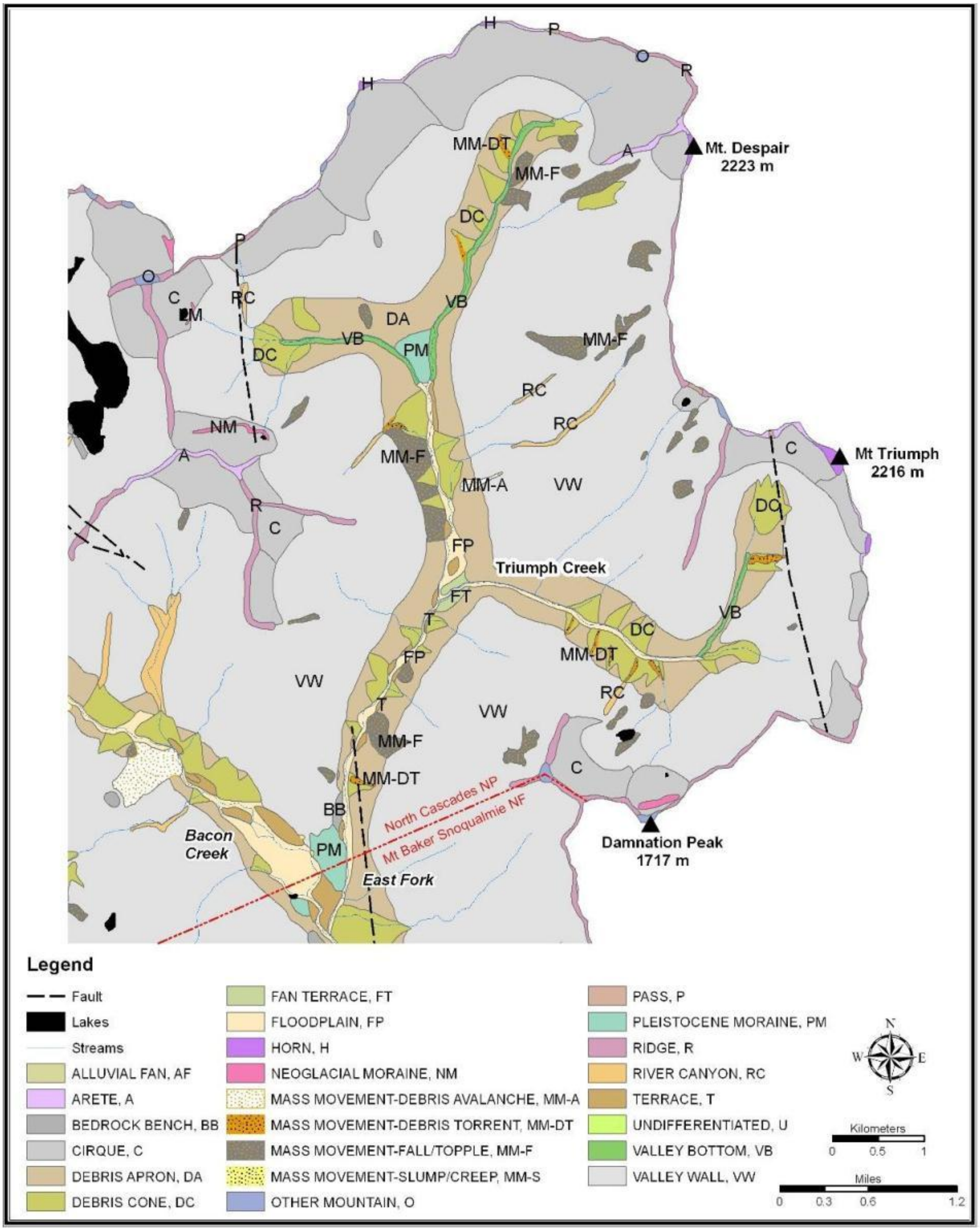

Figure 12. East Fork of Bacon Creek landform map (1:24,000) showing the distribution of landforms as well as the locations of the main tributary streams, bedrock faults and other locations referred to in the text.

Figure 13. Debris avalanche located in the East Fork of Bacon Creek Watershed

4.3 Bacon Creek Watershed Landslide Inventory

Information on landslides can guide the selection of NPS long-term monitoring reference sites or locations of public facilities such as trails, campgrounds, and bridges. A landslide database was created with data collected on 18 characteristics of each landslide, including age, activity, bedrock geology, material type, and area. For large mass movement avalanches, depth of cavity and the volume of sediment delivered to rivers/ creeks 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.

Large landslides in steep terrain are an important event in the valley's natural history. They can block streams, and create lakes, wetlands, and fish migration barriers. They also provide large woody debris to streams that help establish log jams and influence river patterns and habitat downstream of the landslide.

There were 84 mass movements mapped within the Bacon Creek Watershed that encompassed ~2.2% of the watershed area (Table 8). The seven largest debris avalanches encompass 0.6% of the watershed area. Debris avalanches in the watershed displaced an estimated volume of 3,800,000 m^3, mostly bedrock. A total of 23 of the mapped landslides delivered sediment and debris to the stream system; and two of the debris avalanches located in Upper Bacon Creek blocked the stream entirely. Evidence of blockages on the river includes massive debris piles emanating from valley walls across valleys floors that displace streams to the opposite side of the valley.

The location of mass movements is often related to the underlying bedrock type and faulting. Most large debris avalanches in the watershed have occurred in Shuksan Greenschist. Additionally, Darrington Phyllite is also prone to mass failure. Landslides occurred on all aspects, but 51% are on northeast facing slopes and 10% are on northwest facing slopes. Most of the rock falls tend to be on slopes with northeast aspects because the effects of freeze-thaw are most pronounced. The mass movements released from a range of slope gradients, with only 16% of slides originating on slopes greater than 76%.

Table 8. Summary of the Bacon Creek Watershed landslide inventory data.

Mass movement type	Quantity of MM type	Surface area (km^2)	Volume (km^3)	Percent of watershed
Fall/Topple	64	1.94	NA	1.5
Debris torrent	10	0.12	NA	0.1
Debris avalanche	7	0.78	0.0038	0.6
Slump/Creep	3	0	NA	0
Total	*84*	*2.84*		*2.2*

5 - Future Work

5.1 Progress Report

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

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

6 - Literature Cited

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.

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

Briggs, C. 2004. GIS-based mapping of soil distribution in Thunder Creek watershed, North Cascades National Park, Washington, Master's Thesis. Washington State University.

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

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.

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

Jarrett, R. 1990. Paleohydrologic techniques used to define the spatial occurrence of floods, Geomorphology 3:181-195.

Johnson, S. 1984. Stratigraphy, age, and paleogeography of the Eocene Chuckanut Formation, northwest Washington, Canadian Journal of Earth Science, 21:92-106.

National Weather Service Cooperative Network Station (NWS COOP). 2009. COOP data from the Upper Baker Dam and Newhalem sites. Accessed from the www on August 1, 2009 at http://www.wrcc.dri.edu/summary/Climsmwa.html.

Natural Resource Conservation Service (NRCS). 2009. Snow data for Mt. Blum, Japer Pass, and Watson Lakes aerial marker sites. Accessed from the www on August 1, 2009 at http://www.wcc.nrcs.usda.gov/cgibin/state-site.pl?state=WA&report=snowcourse

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

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.V., and Rosselot, F.L. 1971. Inventory of Glaciers in the North Cascades Washington, US Geological Survey, Professional Paper 705-A.

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

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

Schaetzl, R.J., Anderson, S.N. 2005. Soils: Genesis and Geomorphology. Cambridge University Press, New York, p. 803.

Staatz, M., Tabor, R, Weis, P. and Robertson, J. 1972. Geology and mineral resources of the northern part of North Cascades National Park, Washington. U.S. Geological Survey Bulletin 1359.

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

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.

United States Geological Survey (USGS). 2003. Fault number 553, Straight Creek Fault, in Quaternary fault and fold database of the United States. Accessed from the www on November 2007 at http://earthquakes.usgs.gov/regional/qfaults.

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

United States Geological Survey (USGS), 2009b. Water data for Bacon Creek from the USGS National Water Information System database. Accessed from the www on August 1, 2009 at http://waterdata.usgs.gov/wa/nwis/uv/?site_no=12179900&PARAmeter_cd=00060,00065

Appendix A. Landslide Inventory for the Bacon Creek 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.

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

Bacon River WS Landslide Inventory 2002-2003

MM Type	*Material Type*	*Sediment deposited to stream*	*Forms*	*Positions*	*State Type*
1: Fall/ Topple 2: Creep/ Slump 3: Deb. Av/ Flow 4: Deb. Torrent	R: Rock S: Soil T: Till D: Debris	Y: Yes N: No BLKD:	CV: Convex CC: Concave FL: Flat COMP: Complex	D: Divide VW: Valley Wall VB: Valley Bottom CH: Channelized	SR: Shallow-rapid L.S LD: Lg. persitant, deep seated SD: Small-sporatic, deep seated DT: Debris Torrent

MM #	Sub-Drainage	ID # (see *)	MM Type (1-4)	Material Type	Age	Sediment deposited to stream	Bedrock Type	Length (m)	Width (m)	Area (m^2)	Slope Aspect (deg.)	% slope	Form	Position	Top Elev. (m)	Top Elev. (m)	State Type
1	Lower Bacon	1-1-1	1	R		N	Kcs	76	100	6497	168	67	FL	VW	249.9	170.7	SD
2	Lower Bacon	1-2-1	1	R		N	Kcs	121	191	20861	230	80	FL	VW	298.7	158.5	SD
3	Lower Bacon	1-3-1	1	R		N	Kcs	76	132	9191	257	80	FL	VW	298.7	201.2	SD
4	Lower Bacon	1-4-1	1	R		N	Kcs	79	59	3839	272	93	FL	VW	317.0	146.3	SD
5	Lower Bacon	1-5-1	1	R		N	Kmd	42	111	3749	112	80	FL	VW	243.8	219.5	SD
6	Lower Bacon	1-6-1	1	R		N	Kmd	52	55	2392	96	40	FL	VW	566.9	536.4	SD
7	Lower Bacon	1-7-1	1	R		N	Kmd	63	47	2754	80	40	FL	VW	402.3	365.8	SD
8	Lower Bacon	1-8-1	1	R		N	Kmd	68	48	3252	90	67	FL	VW	286.5	249.9	SD
9	Lower Bacon	1-9-1	1	R		N	Kmd	78	101	6002	81	53	FL	VW	262.1	231.6	SD
10	Lower Bacon	1-10-1	1	R		N	Kes	83	267	15043	26	40	FL	VW	975.4	932.7	SD
11	Lower Bacon	1-11-1	1	R		N	Kes	69	90	4693	70	32	FL	VW	1036.3	1024.1	SD
12	Lower Bacon		1	R		N	Kes	72	132	7803	94	50	FL	VW	1109.5	1036.3	SD
13	Lower Bacon		1	R		N	Kes	111	58	6398	44	40	FL	VW	1170.4	1091.2	SD
14	Lower Bacon		1	R		N	Kes	489	63	26364	5	40	FL	VW	1158.2	951.0	SD
15	Lower Bacon		1	R		N	Kes	129	65	6921	25	67	FL	VW	1127.8	1042.4	SD
16	Lower Bacon		1	R		N	Kes	98	197	18295	78	33	FL	VW	1024.1	969.3	SD

MM #	Sub-Drainage	ID # (see *)	MM Type (1-4)	Material Type	Age	Sediment deposited to stream	Bedrock Type	Length (m)	Width (m)	Area (m^2)	Slope Aspect (deg.)	% slope	Form	Position	Top Elev. (m)	Top Elev. (m)	State Type
17	Lower Bacon		1	R		N	Kes	145	78	10972	104	50	FL	VW	1207.0	1170.4	SD
18	Lower Bacon		1	R		N	Kes	85	99	7387	108	40	FL	VW	1463.0	1426.5	SD
19	Lower Bacon		1	R		N	Kes	151	312	40683	82	30	FL	VW	1578.9	1524.0	SD
20	Lower Bacon		1	R		N	Kes	73	245	19869	44	50	FL	VW	1438.7	1389.9	SD
21	Lower Bacon		1	R		N	Kes	74	105	8299	86	50	FL	VW	731.5	682.8	SD
22	Lower Bacon		1	R		N	Kes	122	48	7131	118	53	FL	VW	853.4	816.9	SD
23	Lower Bacon	2-23-1	1	R		Y	Tos	358	177	60835	270	40	FL	VW	390.1	219.5	SD
24	Lower Bacon	2-24-1	1	R		Y	Qag	280	290	72477	89	28	FL	VW	317.0	225.6	SD
25	Lower Bacon	2-25-1	1	R		N	Kns	53	176	9230	269	80	FL	VW	865.6	865.6	SD
26	Lower Bacon	2-26-1	1	R		N	TKns	45	130	6589	94	80	FL	VW	1030.2	1005.8	SD
27	East Fork	2-27-1	1	R		N	Tos	190	106	16945	98	57	FL	D	658.4	438.9	SD
28	East Fork	2-28-1	1	R		N	Tcdg	321	58	16485	4	55	FL	VW	1328.9	1146.0	SD
29	East Fork	2-29-1	1	R		Y	Tcdg	395	81	25805	238	43	COMP	VW	1706.9	1536.2	SD
30	East Fork	2-30-1	1	R		N	Tcdg	100	432	38261	278	56	FL	VW	1731.3	1597.2	SD
31	East Fork	2-31-1	1	R		N	Tcdg	208	382	80965	26	63	FL	VW	1554.5	1408.2	SD
32	East Fork	2-32-3	3	R		N	Tcdg	480	130	32926	70	63	COMP	D	755.9	512.1	SD
33	East Fork	2-33-1	1	R		N	Tcdg	222	178	37860	86	50	FL	VW	536.4	524.3	SD
34	East Fork	2-34-1	1	R		N	Tcdg	313	619	154595	87	60	FL	VW	542.5	530.4	SD
35	East Fork		4	D		Y	Tcdg	71	198	13177	41	43	CC	VW	670.6	579.1	DT
36	East Fork		1	R		N	Qag	197	76	10478	196	67	FL		847.3	719.3	SD
37	East Fork		1	R		N	Tcdg	116	425	30151	360	33	FL	VW	1286.3	1133.9	SD
38	East Fork		1	R		N	Tcdg	425	401	86260	0	47	FL	VW	1524.0	1304.5	SD
39	East Fork		1	R		N	Tcdg	68	171	8630	296	80	FL	VW	1633.7	1609.3	SD
40	East Fork		1	R		N	Qag	316	75	21556	220	50	FL	VW	1005.8	920.5	SD
41	East Fork		1	R		N	Qag	265	81	19431	256	67	FL	VW	1036.3	877.8	SD
42	Upper Bacon		1	R		N	Kes	46	248	13041	210	20	FL	VW	1304.5	1219.2	SD
43	Upper Bacon		1	R		N	Tcdg	225	92	17638	195	67	FL	VW	1463.0	1280.2	SD
44	Triumph Creek		1	R		N	Tcdg	351	71	22538	353	60	FL	VW	1194.8	1127.8	SD
45	Triumph Creek		1	R		N	Tcdg	209	65	12302	89	67	FL	VW	1280.2	1158.2	SD
46	Triumph Creek		1	R		N	Tcdg	32	98	3959	182	50	FL	VW	1487.4	1426.5	SD

MM #	Sub-Drainage	ID # (see *)	MM Type (1-4)	Material Type	Age	Sediment deposited to stream	Bedrock Type	Length (m)	Width (m)	Area (m^2)	Slope Aspect (deg.)	% slope	Form	Position	Top Elev. (m)	Top Elev. (m)	State Type
47	Triumph Creek		1	R		N	Tcdg	260	78	15927	292		FL	VW	1621.5	1499.6	SD
48	Triumph Creek		1	R		N	Tcdg	278	55	18254	227		FL	VW	1731.3	1621.5	SD
49	Triumph Creek		1	R		N	Tcdg	49	131	19708	234		FL	VW	1706.9	1621.5	SD
50	Triumph Creek		1	R		N	Tcdg	214	201	34062	259	57	FL	VW	1621.5	1475.2	SD
51	Triumph Creek		4	D		Y	Tcdg	205	20	4993	21	50	CC	D	816.9	676.7	DT
52	Triumph Creek		4	D		Y	Tcdg	299	23	8991	20	40	CC	D	890.0	719.3	DT
53	Triumph Creek		4	D		Y	Tcdg	199	20	5705	4	53	CC	D	914.4	768.1	DT
54	Triumph Creek		4	D		Y	Tcdg	150	24	5681	29	67	CC	D	914.4	816.9	DT
55	Triumph Creek		1	R		N	Tcdg	183	124	19939	31	67	FL	VW	1036.3	926.6	SD
56	Upper Bacon		2	T		Y	Qyal	37	72	2054	45	60	CC	VW	304.8	292.6	SD
57	Upper Bacon		1	R		N	Qag	140	111	319299	25	40	FL	VW	487.7	426.7	SD
58	Upper Bacon		3	D		BLKD	Qag	645	545	242848	25	75	COMP	VW	670.6	304.8	SD
59	Upper Bacon		3	D		BLKD	Qag	845	270	156895	180	50	COMP	VW	1280.2	609.6	SD
60	Upper Bacon		1	R		N	Qag	74	119	9211	180	20	FL	VW	951.0	914.4	SD
61	East Fork		1	R		N	Tcdg	76	366	40566	285	67	FL	VW	1463.0	1341.1	SD
62	East Fork		2	T		Y	Qf	19	37	557	270	22	CC	VW	359.7	347.5	SD
63	East Fork		4	D		Y	Tcdg	283	64	12798	280	60	FL	VW	512.1	378.0	DT
64	East Fork		1	R		Y	Tcdg	547	342	144193	280	88	FL	VW	914.4	390.1	SD
65	East Fork		1	R		N	Qf	157	207	27408	280	40	FL	VW	487.7	426.7	SD
66	Upper Bacon		1	R		N	Qag	90	172	11165	60	50	FL	VW	1036.3	999.7	SD
67	Upper Bacon		2	T		N	Qyal	35	49	1525	40	80	CC	VW	317.0	304.8	SD
68	Triumph Creek		4	D		Y		260	50					D			
69	Triumph Creek		1	R		N											
70	Triumph Creek		4	D		Y											
71	East Fork		1	R		Y											
72	East Fork		1	R													

MM #	Sub-Drainage	ID # (see *)	MM Type (1-4)	Material Type	Age	Sediment deposited to stream	Bedrock Type	Length (m)	Width (m)	Area (m^2)	Slope Aspect (deg.)	% slope	Form	Position	Top Elev. (m)	Top Elev. (m)	State Type
73	East Fork		1	R													
74	East Fork		4	D		Y											
75	East Fork		4	D		Y											
76	Upper Bacon		3	D		Y	Qag	270	130								
77	Upper Bacon		3	D		Y	Qag	500	170								
78	Upper Bacon		3	D		Y	Qag	660	120								
79	Upper Bacon		1	R		N	Qag										
80	Upper Bacon		2	R		N	Qag										
81	Falls Creek		1	R		N											
82	Falls Creek		1	R		N											
83	Falls Creek		4	D		Y		640	90								
84	Lower Bacon		1	R		N											

NPS 168/113497, April 2012

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov