



# **Baker River Watershed Report**

## ***Landform Mapping at North Cascades National Park***

Natural Resource Report NPS/NCCN/NRTR—2008/127



**ON THE COVER**

The main stem of the Baker River near the junction with Bald Eagle Creek; looking south towards Mt. Blum.  
Photograph by: Jeanna Wenger; North Cascades National Park

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# Introduction

Understanding surficial processes and materials is critical for resource managers in mountainous terrain. Surficial processes such as landslides, floods, and glaciation directly impact the human use and management of rugged landscapes. The materials produced by these processes influence soil and vegetation patterns and provide information on geologic hazards, prehistoric landscape use, 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, and mapping of soils (Riedel and Probala 2005).

In 1988, staff at North Cascades National Park Service Complex (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 (LTEM) programs. This included the development of a 23 landform scheme to support classification and assessment of aquatic habitat in NOCA watersheds. The development of this program was supported by the goal of 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" (USDA Forest Service 1993, Cleland et al. 1997) for public lands in the North Cascades. The approach uses a nested system in which each scale (eight total) fit inside one another. Together the USFS and NPS have mapped at three of these scales; 1-Subsection, 2-Landtype Association (LTA), and 3-Landform scales. The first product was a seamless coverage in the North Cascade region at the Subsection scale (1:250,000). These units focus on climate, bedrock geology, and topography at a regional scale. The LTA scale (1:62,500) 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. There are now 37 distinct units in the landform scheme. Landform units are described as having discrete geologic processes that are active today and are relatively easy to identify. The landform scheme has now been applied to several watersheds within five of the seven NPS units in the North Coast and Cascade Network (NCCN), including NOCA, Mount Rainier National Park (MORA) and Olympic National Park (OLYM), Ebey's Landing National Historical Reserve (EBLA), and San Juan Island National Historical Park (SAJH) (Fig. 1).

The purpose of this report is to describe the study area, background information, and methods involved with mapping at the landform scale within the Baker River watershed (BRW) at NOCA. This report also gives detailed results for the BRW which includes a discussion of the unique characteristics of the Baker River valley and its tributaries, as well as a summary of landslide inventory data. The valley characteristics are presented in seven sections. Within these sections, a fine resolution of landform description, landslide activity, and any other pertinent information is included.



## Study Area

### Geographic Setting

The BRW is located approximately 15 km east of the composite volcano Mt. Baker (3285 m asl) in northwest Washington State (Figs. 1 and 2). This study focuses on the upper part of the watershed that resides within the northwest section of NOCA (Figs. 1 and 2). This portion of the watershed occupies approximately 246 km<sup>2</sup> of the 2,770 km<sup>2</sup> National Park. The Baker River drains southwest from the North Cascade crest into hydroelectric dammed Baker Lake and Lake Shannon (Fig. 2). It then merges with the Skagit River (Fig. 2) before flowing west to Puget Sound. The Skagit River basin is the largest drainage in Puget Sound, supplying more than 30% of its total freshwater input and draining more than 8,000 km<sup>2</sup>. The North Cascade range has impressive local relief of up to 2500 m in the BRW. Starting from an elevation of 220 m at Baker Lake and climbing to 2785 m at Mt. Shuksan, the BRW is ringed by peaks greater than 2000 m high (Fig. 3) such as; Seahpo Peak, Ruth Mountain, Mineral Mountain, Whatcom Peak, Mt. Challenger, Mt. Crowder, and Bacon Peak (Fig. 3). There are six main tributaries draining into the BRW: Sulphide, Crystal, Bald Eagle, Pass, Mineral, and Pickett Creeks (Fig. 3). These tributaries are all fed by meltwater from glaciers and/or snowfields.

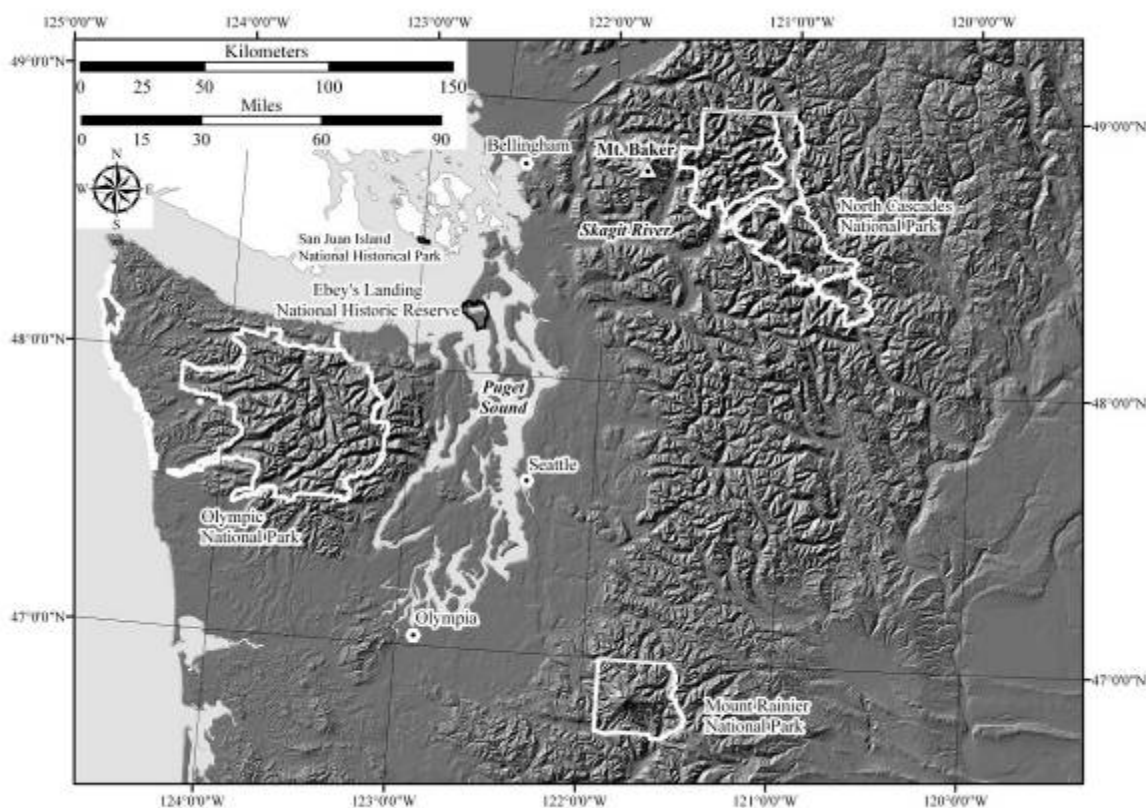


Figure 1. Map showing the location of North Cascades National Park in northwest Washington State along with the other major units in the North Coast and Cascade Network and localities mentioned in the text.

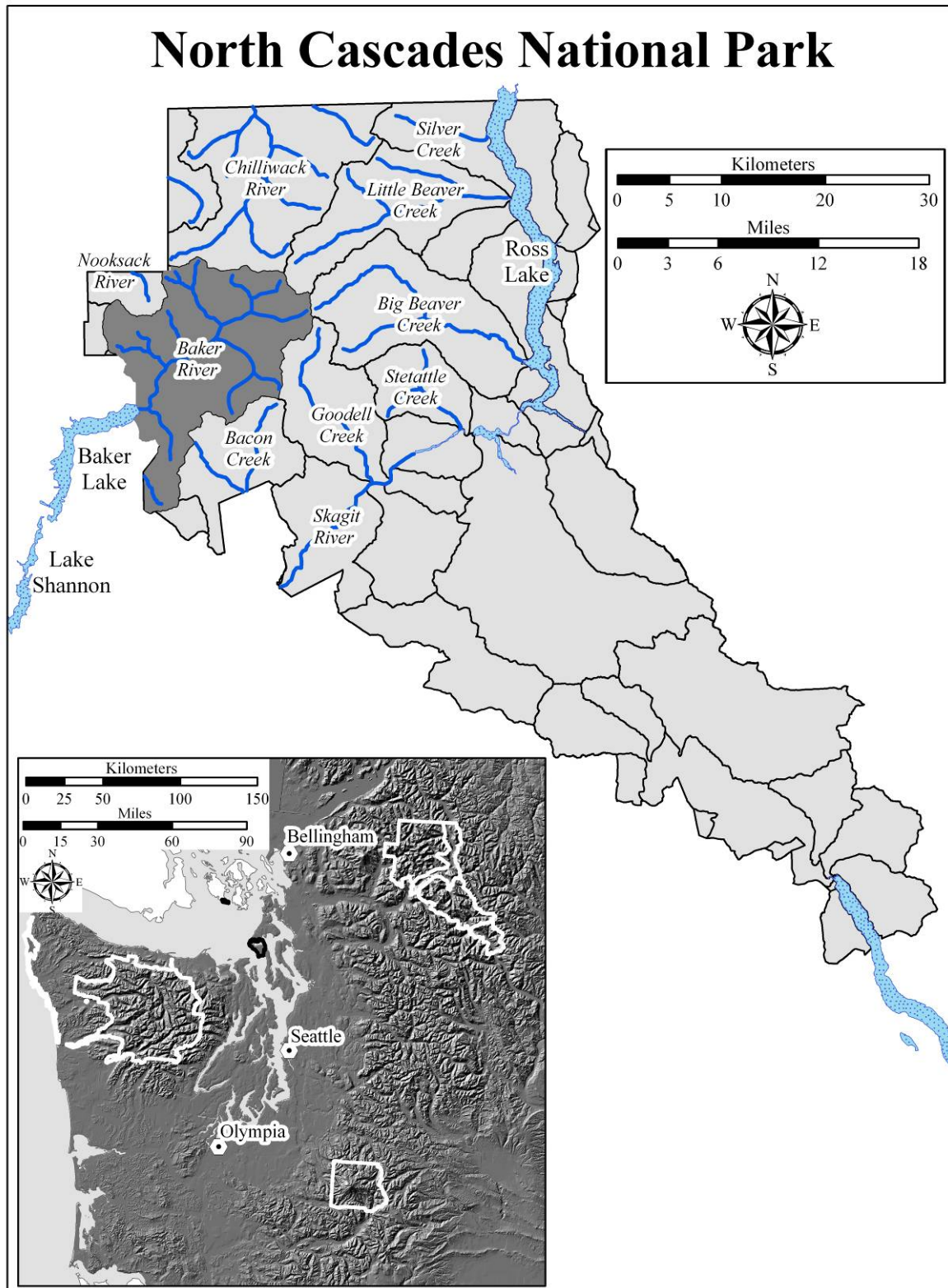


Figure 2. Map showing the location of the Baker River watershed within North Cascades National Park along with the location of other watersheds mentioned in the text.

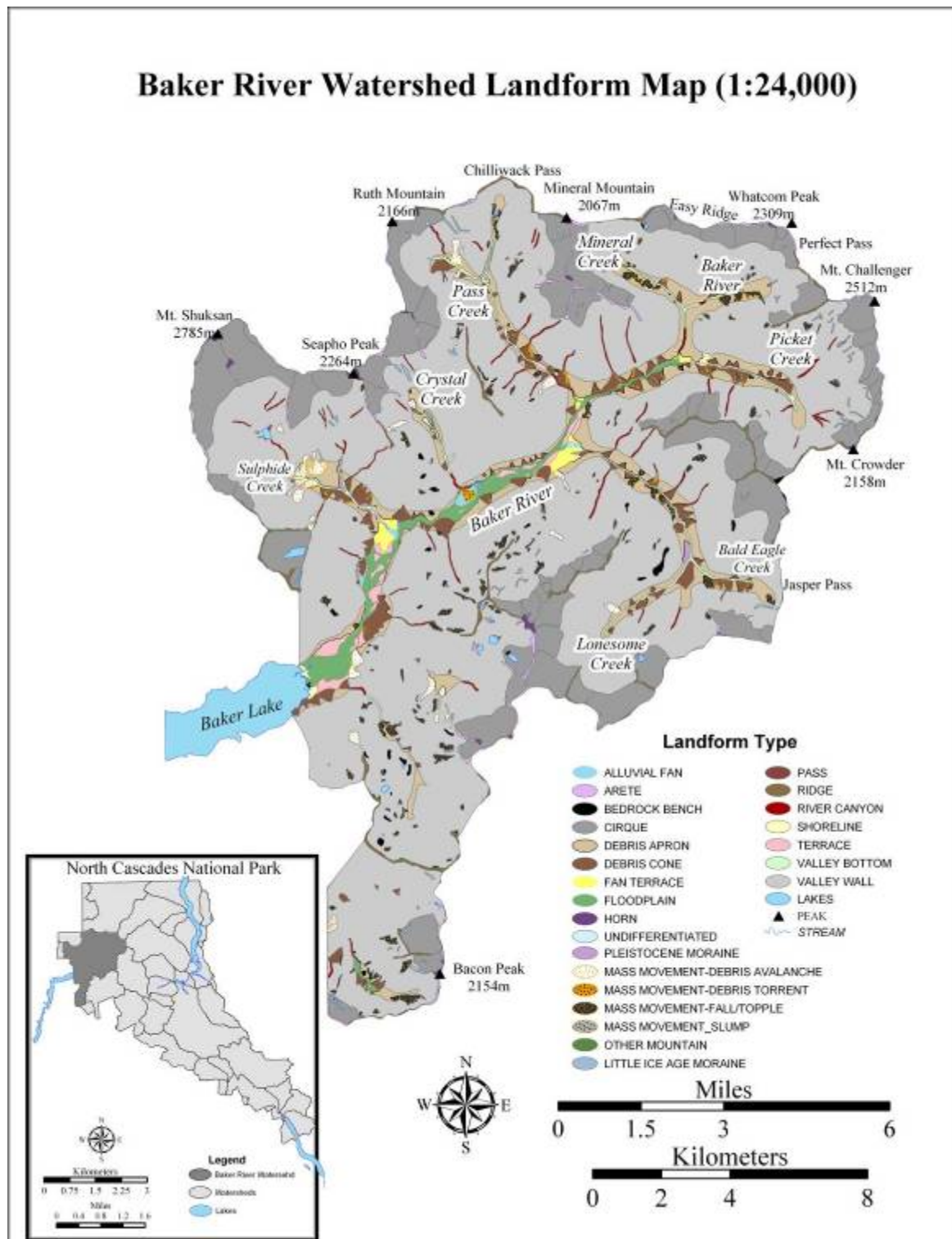


Figure 3. Landform map (1:24,000) showing the distribution of landforms in the Baker River watershed as well as the locations of the main tributary streams and locations referred to in the text.

## Geologic Setting

The bedrock geology of the North Cascades has been mapped at the 1:100,000 scale by Tabor et al. (2003). Bedrock of the BRW was formed by a complex series of igneous, metamorphic, and tectonic events beginning in the Cretaceous and continuing today. In the Quaternary, dynamic surficial processes continue to sculpt the landscape through active glacial, hillslope and fluvial processes. Generally, bedrock of the BRW includes metabasalts of the Shuksan Greenschist and metasediments of the Darrington Phyllite in the west. In the east, Skagit gneiss and granodiorite of the Chilliwack composite batholith are exposed (Tabor and Haugerud 1999). Several types of intrusive rock make up the batholith in this area and include granodiorite and quartz diorite, which were emplaced in the last 35 ma. There is a small band of sedimentary rock of the Eocene Chuckanut Formation in the southeast part of the watershed just north of Bacon Peak (Johnson 1984). There are also small pockets of Hannegan Volcanics (Tertiary) at the head of Pass and Picket Creeks and gneiss (possibly Cretaceous and older) at the head of Picket Creek.

There are several major faults in the area; the Shuksan Thrust Fault, Anderson Creek Fault, Winchester Fault, and a trace of the Fraser-Straight Creek Fault (Tabor et al. 2003). The Shuksan Thrust Fault is located approximately 2 km west of Mt. Shuksan and is one of a series of thrust faults in this area; Mt. Shuksan itself is a vestige of a once-continuous thrust plate that overlay the whole region to the west (Tabor and Haugerud 1999). The Anderson Creek Fault, which trends S40°W from near Mt. Blum towards Lake Shannon and Baker Lake for approximately 40 km (Figs. 2 and 3). The Winchester Fault begins near Mt. Sefrit and trends N20°W for approximately 10 km. The Fraser-Straight Creek Fault trace runs from near the Nooksack glacier on Mt. Shuksan northeast for approximately 75 km. Structure has played an important role in the development of drainage patterns in the area; the Baker River generally follows the trend of the Anderson Creek Fault and the Chilliwack River flows northeast along the trend of the Fraser-Straight Creek Fault.

Multiple Pleistocene alpine glaciations in the past 2 ma have carved deep U-shaped valleys, steep valley walls, and jagged horns and arêtes. Glaciations have also altered the fluvial morphology of both local and regional drainage patterns (Riedel et al. *in press*). The last major glaciation in the area occurred when the area was inundated by the south flowing Cordilleran Ice Sheet during the Vashon stade of the Frasier glaciation which reached its climax around 17,000 years ago (Porter and Swanson 1998). The Cordilleran Ice Sheet filled the main valley as well as the tributary systems to depths of approximately 1800 m and generally flowed into the Baker valley from the north. Impacts from the ice sheet are evident throughout the BRW and North Cascade range and include broad passes and ridges, enlarged valley cross-sections, and truncated valley spurs. Between multiple ice sheet glaciations, valley glaciers flowed from cirques into the Baker valley forming a large, complex valley glacier system that flowed south into the Skagit valley (Fig. 4, Riedel 2007). Tributary systems were left as hanging valleys with bedrock canyons or narrow stepped waterfalls at their mouths. Where they join with the main stem of the Baker River, these streams deposited large alluvial fans.

Glacial advance during the Little Ice Age, ca. 1400-1900 A.D., created small moraines and unconsolidated glacial till. Small cirque glaciers and permanent snow fields of today are approximately 40% less extensive than at the end of the Little Ice Age, 100 years ago. Presently, cirque alpine glaciers remain at high elevations (above ~1585 m in the BRW) and most have a

north or east aspect and are sheltered from the sun by steep cirque walls and arêtes. The Sulphide and Crystal glaciers of Mt. Shuksan are the exceptions; they are the largest glaciers within the BRW and have south facing aspects. 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.

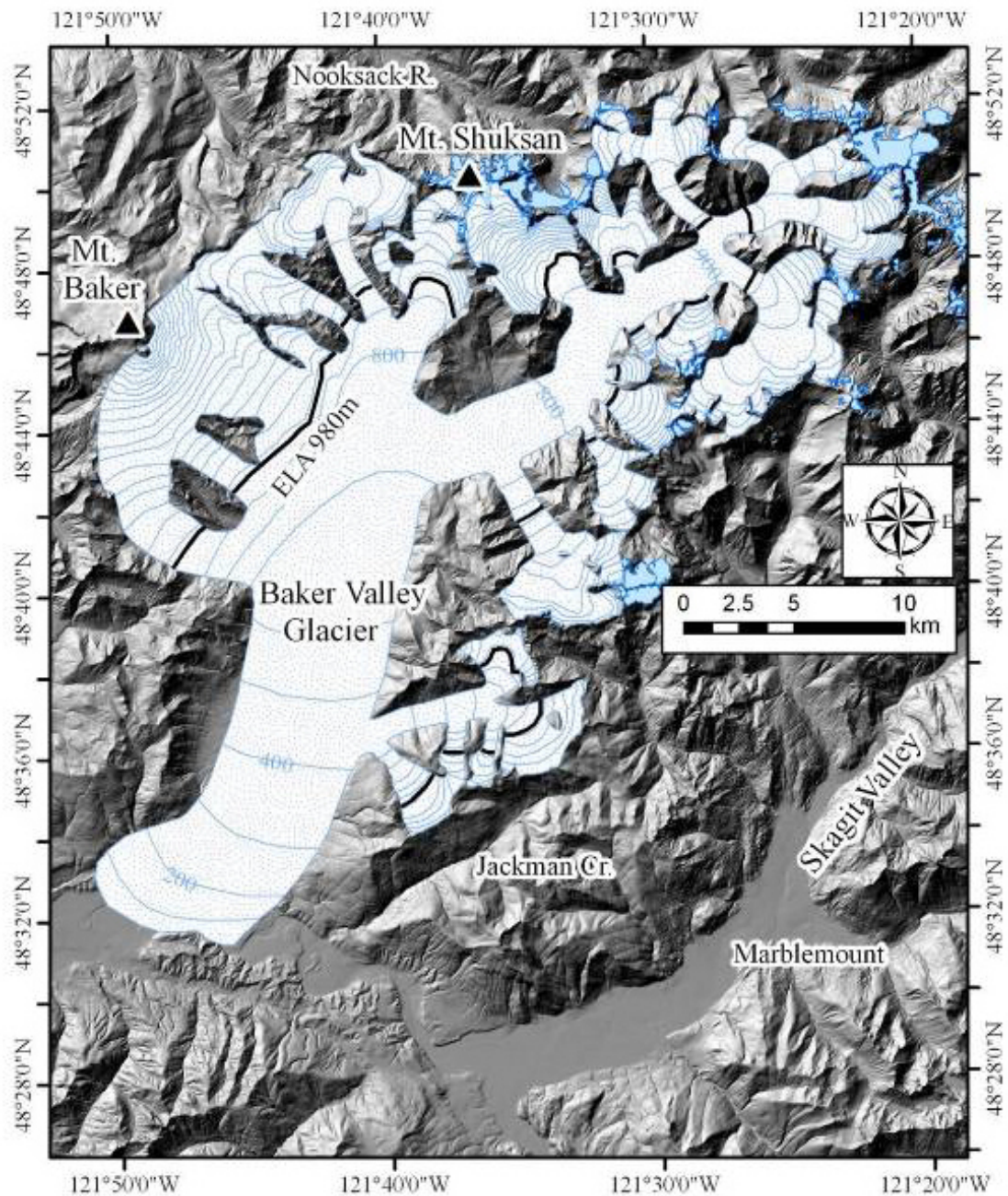


Figure 4. Reconstruction of the Baker Glacier during the Evans Creek stade (Riedel, 2007).

## Hydrologic Setting

Permanent snowfields and glaciers cover an area of 20 km<sup>2</sup> in the BRW. Glacially fed streams help to produce a continual flow of water throughout the year with glacial runoff contributing an average of 11% of the total watershed runoff annually (Fig. 5). This contribution from glacial ice and snowfields is critically important for sustaining local hydroelectric industries and endangered salmon and trout species. The discharge of streams and rivers often decreases drastically in late summer and early fall, especially following hot and dry summers. These times of low flow can expose sand and gravel bars, and dry up side channels. Rivers and creeks can typically reach flood stages during both the spring and late fall. Large rain on snow events, which can occur during the early spring or late fall can reinitiate first order stream flow, flood rivers, transport debris, erode river banks and mobilize large woody debris. During large magnitude events, water levels rise in the main stem of the Baker River shifting channel and gravel bar positions and reintroducing water to old side channels.

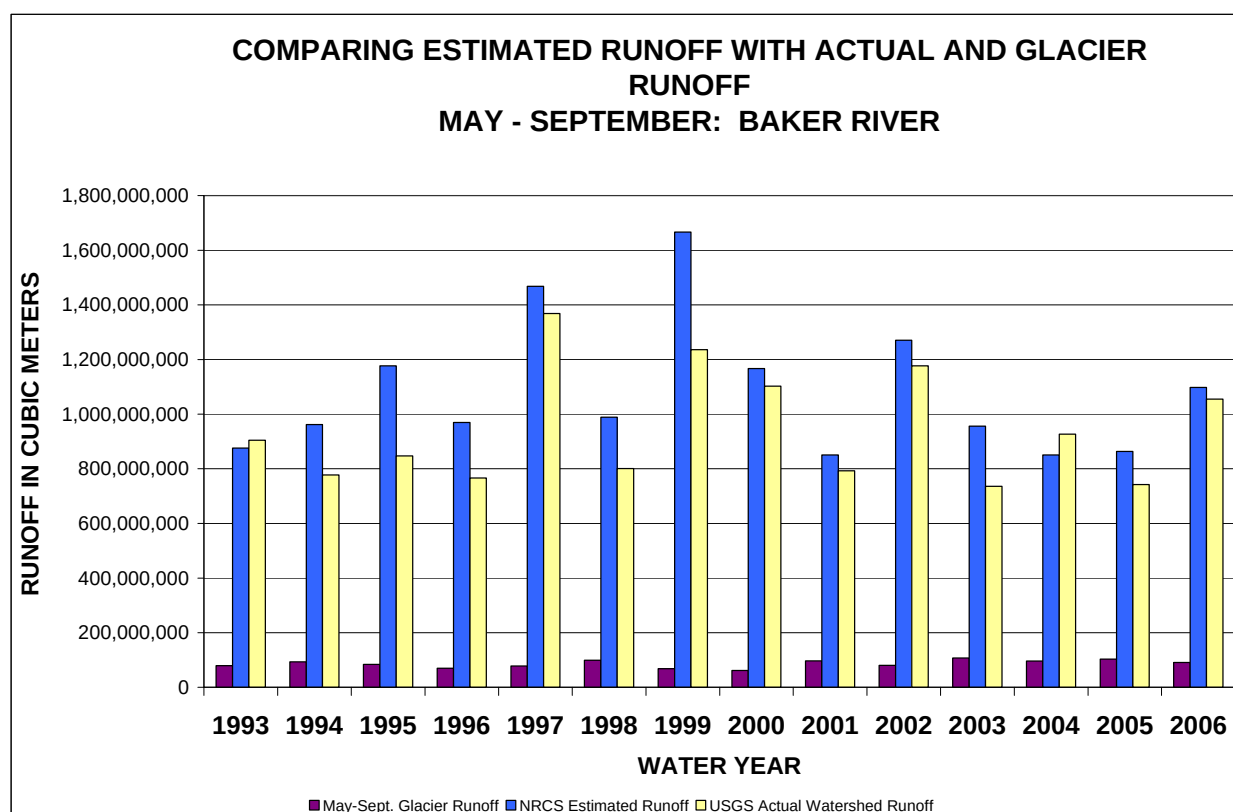


Figure 5. Graph showing the annual glacier contribution to runoff for the Baker River.

## Climate

The BRW lies on the western slopes of the North Cascade range. It is characterized by a maritime climate with relatively mild, wet winters and cool, dry summers. Climate and weather monitoring within the Baker River drainage consists of a Cooperative Network station, seven snow-courses, and glacier mass balance monitoring (Table 1). The Cooperative Network station is located on Upper Baker Dam at 210 m. The station has been operating since 1964. At this site, yearly temperature highs tend to occur in August, averaging 23.7° C. Winter low temperatures

tend to occur in December averaging 3.8° C. The mean annual temperature recorded at Upper Baker Dam is 8.7° C; lapse rates tend to vary by season, but are generally 0.5° C/100 m.

The annual precipitation at Upper Baker Dam totals 253 cm. November is routinely the wettest month, averaging 40 cm. Most precipitation occurs during the winter months of November through January, averaging 46% of the total accumulation. Conversely, the summer months of June through August tend to be the driest, averaging only 8% of total accumulation. At higher elevations, the snowpack reaches its maximum in May. At the Jasper Pass station, the average snow depth for the first of May is 493 cm, 232 cm snow water equivalent. Maximum snow depth and snow water equivalent for the six snowcourses in the drainage are listed in Table 1.

Table 1. Summary of data from the seven snowcourse sights located in the Baker River watershed.

| Station Name   | Elevation<br>(meters) | Month     | Max. Depth<br>(centimeters) | Max. SWE<br>(centimeters) |
|----------------|-----------------------|-----------|-----------------------------|---------------------------|
| Mt. Blum AM    | 1768                  | May       | 384                         | 181                       |
| Jasper Pass AM | 1646                  | May       | 493                         | 232                       |
| Easy Pass AM   | 1585                  | May       | 467                         | 222                       |
| Watson Lakes   | 1372                  | April/May | 373                         | 164                       |
| Marten Lake    | 1097                  | April/May | 424                         | 191                       |
| Schreibers Mdw | 1036                  | April/May | 310                         | 142                       |
| Rocky Creek    | 640                   | May       | 155                         | 66                        |

## Vegetation

Bare snow, rock, and ice cover approximately 60% of the BRW leaving 40% subalpine and forest vegetation. Alpine vegetation, which includes lichens and mosses, dominate elevations above approximately 2000 m. Subalpine vegetation occurs between 2000 to 1500 m, with treeline at approximately 1400 m, and includes Subalpine fir (*Abies lasiocarpa*), Mountain hemlock (*Tsuga mertensiana*) and open meadow communities. The BRW has a relatively wide subalpine zone due to the heavy winter snowfall amounts in the watershed. Montane vegetation occurs from 1500 to 900 m and includes Pacific Silver fir (*Abies amabilis*) Western hemlock (*Tsuga heterophylla*) and Yellow cedar (*Chamaecyparis nootkatensis*). Lowland vegetation, below 900 m, includes Douglas-fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*), Western Red-cedar (*Thuja plicata*), and Big-leaf maple (*Acer gigantum*). Wetland (sedges and rushes) and riparian (Oregon ash, black cottonwood, willows, sedges, alder) vegetation occupy approximately 2% of the watershed and is found at the lowest elevations. In most cases, dominant overstory vegetation provides an inference on landform age, surficial geology, hydrology, and disturbance.

## Landform Age

Landforms can either be depositional such as moraines and alluvial fans; or they can be erosional such as bedrock benches and horns. The landscape can be viewed as an assemblage of residual landforms, each in the process of being destroyed or transformed by erosion (Bloom 1978). Landform age can vary greatly within a watershed depending on the surficial process in which it was formed. Relative ages can be assigned to depositional landforms based on their available

radiocarbon dates, associated process of formation, soil development, and vegetation type and age. The approximate ages of landforms at NOCA are listed below in Table 2.

Table 2. Approximate landform surface ages at North Cascades National Park.

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

### **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 3). 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 3. 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                        |

### ***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. 6) identifies 17 mapping units; including: Major Valley Bottoms, Crystalline Glaciated Cascade Mountains, Volcanic Cones and Flows, Sedimentary Cascade Hills, etc.

### ***Landtype Association (1:62,500)***

Landscape scale ecological units or Landtype Associations (LTAs) are the smallest scale within the hierarchical framework that meets most NPS challenges and management needs. At this mapping scale, geomorphic process and topography become more important than climate and bedrock geology. The first step in mapping LTAs is to identify features of mountains and valleys

such as valley bottom, cirque basin, glaciated trough wall, and alluvial fan and toe slope at an intermediate scale (Davis 2004). Final map units incorporate data on vegetation, soils, 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. Mapping is conducted by interpretation of 1:62,500 scale stereo aerial photography and topographic maps. Dominant LTA units in the BRW (Fig. 7) include Headland Catchment Basins, Scoured Glacial Troughwall and Headlands, Scoured Glaciated Slopes, Glacial Cirque Basins, Glacial Troughwalls, and Glaciated Trough Valley Bottoms.

### ***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 today. These subdivisions of Landtypes or landforms, as they are here referred, are based on topographic criteria, hydrologic characteristics, associations of soil taxa and plant communities. They are readily identified on topographic maps and aerial photographs, but often require field-verification when they are located beneath closed canopy forest or valley floors. A suite of 29 different landforms is currently being mapped at NOCA and are listed below in Table 4 (Fig. 3). A detailed description of each landform which includes information on location, associated landforms, process, material, mapping guidelines, and potential natural vegetation will be published in a 2008 NPS Technical Report.

Table 4. Landform (1:24,000) legend for North Cascades National Park.

| Unit                                                                                 | Description                    |
|--------------------------------------------------------------------------------------|--------------------------------|
| -High elevation landforms (primarily erosional in genesis)                           |                                |
| H                                                                                    | Horn                           |
| A                                                                                    | Arete                          |
| C                                                                                    | Cirque                         |
| O                                                                                    | Other Mountain                 |
| R                                                                                    | Ridge                          |
| P                                                                                    | Pass                           |
| LM                                                                                   | Little Ice Age 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                   |

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

| Unit                                                         | Description         |
|--------------------------------------------------------------|---------------------|
| -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    |

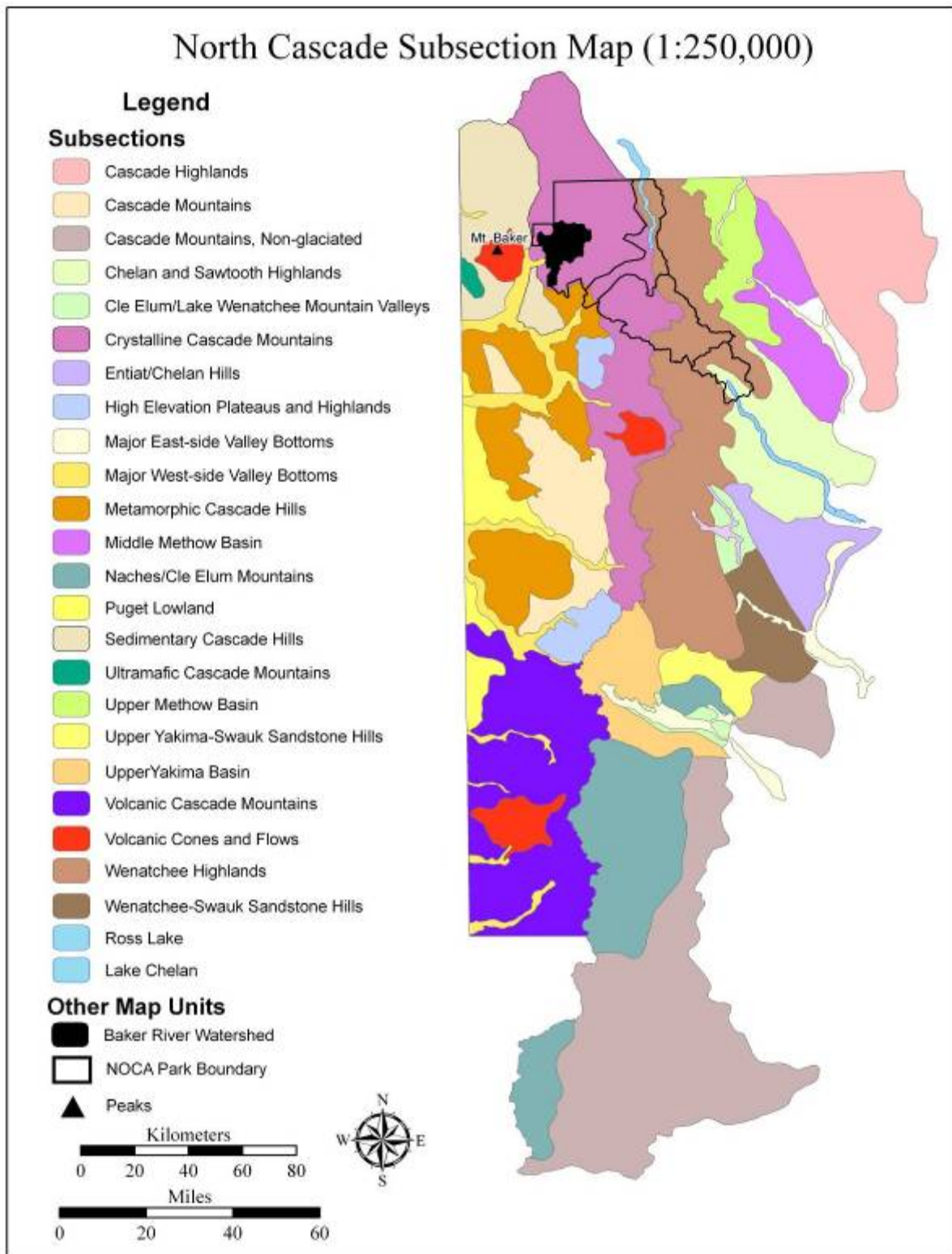


Figure 6. Subsection map (1:250,000) of the North Cascade region showing the location of the Baker River watershed and North Cascades National Park.

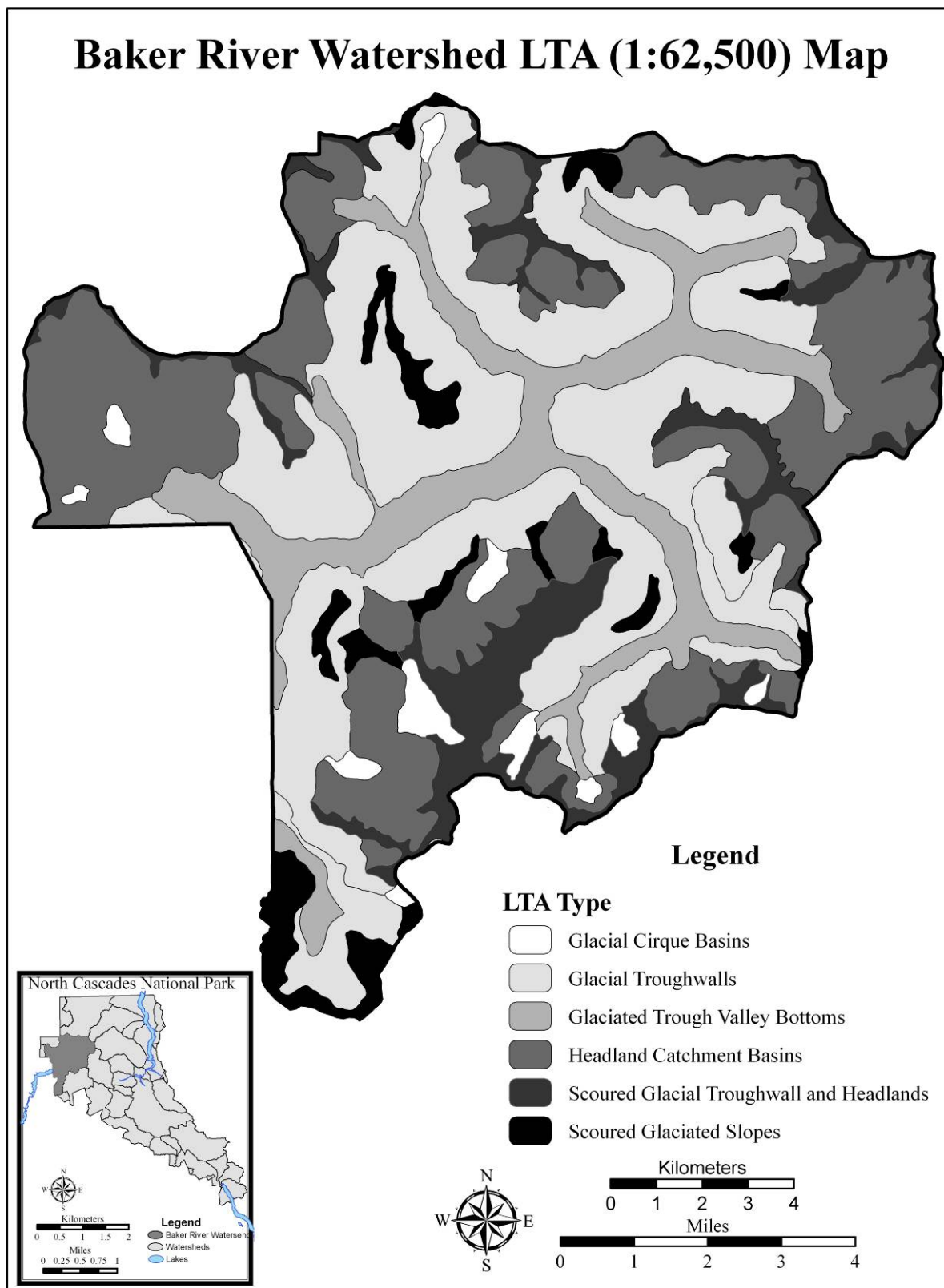


Figure 7. LTA map (1:62,500) of the Baker River watershed.

## Methods

### Preliminary Methods

At the beginning of the mapping process each Park is divided into watersheds and each is organized and mapped separately. This project recognizes a watershed as a major drainage system on a fourth order or larger stream. Each watershed is further broken down into smaller units referred to in the text as sub-watersheds. These units are then typically mapped by teams of two. A combination of mapping techniques used to conduct this inventory include the use of color stereo-pair 1998 air photos at the 1:12,000 scale, USFS LTA line work, bedrock geology maps and field investigations. Initially, the pattern of contour lines on United States Geological Survey (USGS) 7.5 minute topographic maps in conjunction with the 1:12,000 air photos are used to outline landforms. Though some landforms (e.g., debris avalanches, bedrock benches and debris cones) are easily identifiable using air photos and contour lines, other landforms (e.g., terraces, floodplain boundaries and small mass movements) require field identification. The minimum size for a mapping unit is approximately 1,000 m<sup>2</sup> with some exceptions for smaller units like Little Ice Age moraines and slumps.

### Field Methods

Teams of two are assigned a sub-watershed unit within a watershed. Each team develops a task list of areas to visit before entering the field. Teams survey as much ground as possible, but concentrate efforts within the valley bottom. Each drainage is unique with land barriers and essential viewpoints; therefore, each team selectively walks a particular sub-watershed. Generally, teams walk the banks of rivers enabling them to map terraces, slumps, and floodplain boundaries. Places where the valley bottom is wide or complex, teams make cross sections from one side of the valley to the other. Some landforms need further exploration and are investigated in more detail as needed. While in the field, staff transfers 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.

### Digitizing Methods

After identifying landforms and drawing the boundaries, each area is peer-reviewed for accuracy and mapping consistency. Landform linework is then transferred onto a new 7.5 minute paper map, which serves as the final map. All boundaries of landforms are then drawn onto Universal Transverse Mercator registered Mylar and a large format scanner transfers lines into digital format. Using GIS software, scans are edited and polygons, which represent landforms, are labeled resulting in a final digitized map (Fig. 3). As each polygon is labeled, the shape and location is checked for accuracy. 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.

### Areas Surveyed

There are no roads in BRW and trail access is limited to a short, approximately 3.5 km long, USFS maintained trail to Sulphide Creek (west bank of Baker River) and a washed out trail (Baker River east bank). There are unmaintained hunting, climbing, and game trails that were

followed throughout the watershed when available. All field investigations in the BRW were completed in the summer seasons of 2003 and 2004 by NOCA Resource Management staff both past and present: Daniel Dietrick, Stephen Dorsch, Preston Ellison, Mike Larrabee, Jeremy Miner, and Jeanna Probala (Wenger). The main stem of the Baker River was field checked from the head of Baker Lake up river to the confluence of Picket Creek. These areas were accessed by trail and also by traveling in the riverbed via wading. Field visits to each major tributary were attempted from the main stem of the Baker River. However, due to difficult travel (e.g. canyons, thick vegetation, cliffs, and minimal trail availability) some areas were not field checked. The tributaries that were field checked include the lower portion of Sulphide Creek, the outlet of Crystal Creek, the mouth of Pass Creek, and lower half of Bald Eagle Creek. Mineral Creek, Picket Creek, and the main stem of the Baker River above Picket Creek were not surveyed due to the extreme difficulty of access. Future surveys of valley heads may be conducted if opportunities arise. Minimal high elevation ground surveys were performed due to abundant air photo coverage and good visibility due to lack of vegetation on high elevation landforms. High elevation surveys completed include Bacon Peak north to Mt. Blum and a short traverse south of Mt. Shuksan. Aerial surveys were made via several helicopter flights while in transit to other NPS research projects.

## Results and Discussion

### General Watershed Overview

The main stem of the Baker River is a classic U-shaped glacial valley with a flat valley bottom, straight profile and low gradient. Other glacial characteristics of the valley include, oversteepened valley walls, hanging tributary valleys, and truncated valley spurs. Throughout the watershed, near-vertical walls of 600 to 1200 m rise directly up from the valley floor hosting many mass movements and scoured river canyons. Valley walls in the upper reaches contain sparse vegetation with little to no soil cover and are the steepest valley walls mapped at NOCA thus far. Within the BRW, 65% is valley wall and 15% is high elevation cirque; with only 2.3% as riparian (floodplain, valley bottom, and alluvial fan). The steepness of the terrain is also reflected by the fact that 11% of the watershed is classified as debris deposit and mass movement (Table 5). A more detailed description of valley characteristics for the main stem of the Baker River and each of its six main tributaries is presented below.

Table 6. Summary of area of each landform type within the Baker River watershed.

| Landform Type                  | Count       | Area m <sup>2</sup> | Area km <sup>2</sup> | % of WS    |
|--------------------------------|-------------|---------------------|----------------------|------------|
| VALLEY WALL                    | 17          | 161019304.6         | 161.0                | 65.4       |
| CIRQUE                         | 107         | 39240552.1          | 39.2                 | 15.9       |
| DEBRIS APRON                   | 129         | 14575221.6          | 14.6                 | 5.9        |
| DEBRIS CONE                    | 144         | 6463165.0           | 6.5                  | 2.6        |
| MASS MOVEMENT_FALL/TOPPLE      | 154         | 3868433.5           | 3.9                  | 1.6        |
| FLOODPLAIN                     | 3           | 3681580.5           | 3.7                  | 1.5        |
| ARETE                          | 75          | 2468258.3           | 2.5                  | 1.0        |
| RIDGE                          | 51          | 2417662.0           | 2.4                  | 1.0        |
| MASS MOVEMENT_DEBRIS AVALANCHE | 33          | 2082591.9           | 2.1                  | 0.8        |
| RIVER CANYON                   | 61          | 1900757.4           | 1.9                  | 0.8        |
| VALLEY BOTTOM                  | 9           | 1816034.9           | 1.8                  | 0.7        |
| TERRACE                        | 45          | 1802175.7           | 1.8                  | 0.7        |
| LITTLE ICE AGE MORaine         | 91          | 1004571.7           | 1.0                  | 0.4        |
| FAN TERRACE                    | 28          | 880955.6            | 0.9                  | 0.4        |
| BEDROCK BENCH                  | 75          | 728562.6            | 0.7                  | 0.3        |
| HORN                           | 19          | 495036.3            | 0.5                  | 0.2        |
| MASS MOVEMENT_DEBRIS TORRENT   | 29          | 486584.2            | 0.5                  | 0.2        |
| OTHER MOUNTAIN                 | 25          | 357832.8            | 0.4                  | 0.1        |
| ALLUVIAL FAN                   | 4           | 304153.9            | 0.3                  | 0.1        |
| PLEISTOCENE MORaine            | 8           | 223004.5            | 0.2                  | 0.1        |
| SHORELINE                      | 2           | 134273.6            | 0.1                  | 0.1        |
| PASS                           | 16          | 100630.3            | 0.1                  | 0.1        |
| UNDIFFERENTIATED               | 3           | 53439.9             | 0.1                  | 0.1        |
| MASS MOVEMENT_SLUMP/CREEP      | 6           | 8575.9              | 0.0                  | 0.1        |
| <b>Totals</b>                  | <b>1134</b> | <b>246113358.9</b>  | <b>246.1</b>         | <b>100</b> |

## Valley characteristics

### ***Main Stem of Baker River***

The Baker River begins at the summits of Whatcom Peak and Mt. Challenger (Fig. 3). Below these peaks, the valley head of the main stem of the Baker River is ringed with cirques that extend down to 1525 m. Easy Ridge confines the valley to the north and extends eastward to Whatcom Peak forming a portion of the North Cascade crest which is locally the drainage divide between the southeast flowing Baker/Skagit River system and the north-flowing Chilliwack River (Fig. 2). Jagged arêtes branching off of Whatcom Peak slice southward giving way to a more rounded ridge towards Perfect Pass (1890 m). Perfect Pass marks the divide between the Baker River and west Ross Lake tributaries (Big and Little Beaver Creeks). The Baker valley bottom begins at 1035 m and extends west for 2 km to merge with Mineral Creek. From here the valley bottom continues for 0.5 km before being confined to a river canyon. The canyon runs south for 0.75 km; when the Baker emerges from the canyon it joins with Picket Creek in a relatively small, but active alluvial fan. This is where the Baker floodplain begins and continues southwest until it reaches Baker Lake. The transition from valley bottom to floodplain occurs at 610 m; this is the lowest transition mapped thus far at NOCA. This transition can occur at up to 1220 m in other watersheds mapped at NOCA; guidelines for determining this transition are based on flood plain width, presence or absence of river terraces and gravel bars, lining of bedrock, and stream gradient (Jarrett, 1990).

The width of floodplain in the main stem has three distinct sections: the mouth area (~0.84 km), Blum Creek to Bald Eagle Creek (~0.5 km), and the upper section from Bald Eagle Creek to Picket Creek (0.08 km). The floodplain has a length of 11 km and ranges from an elevation of 220 m up to 548 m. The floodplain contains extensive sand and gravel bars (Fig. 8), side channels, and a marsh (below the junction of Sulphide Creek). There is one small section of confined floodplain just north of Sulphide Creek where the stream flows against bedrock. The largest terraces are near the mouth and have heights of 0.6, 2.4, and 3 m above the floodplain; terraces extend up to elevations of 548 m. The BRW has uniform, relatively low terraces compared to other watersheds within NOCA. This is likely due to the nature of the resistant bedrock walls steeply descending to the valley floor and the continued alluviation of the Baker River and its tributaries. Terraces of other watersheds typically have a range of elevations which can be used to link them with different time periods. Reoccurring terraces, noted by height, generally match in age throughout a watershed as described by similar type and age of vegetation and surface topography. Above the junction of Pass Creek, the valley narrows and terraces are less extensive and more infrequent. Terraces are mainly seen on the main stem where there are numerous bends in the river opposed to the tributary valleys which are narrow and lack the necessary terrace forming components. Major flooding following a fall 2003 rain on snow event caused significant channel reorganization, created new log jams (temporarily or permanently blocking side channels) which backed up sediment creating new 0.5 to 1.2 m gravel bar terraces. The flooding also undercut river banks and created new side channels (specifically 0.8 km west of Scramble Creek on south bank). The main stem has many mass movements- rockfalls, debris avalanches and debris torrents. With the exception of a few debris avalanches near Baker Lake, most of the landslides are located further upstream. There were relatively few slumps recorded on the banks of the main stem which is likely due to the presence of a relatively wide floodplain with gravel bars that buffer the river's contact with terraces cut banks.



Figure 8. Looking northeast up the main stem of the Baker River; large gravel bars in left foreground and right background (Photo courtesy of Jeanna Wenger, North Cascades National Park).

### ***Sulphide Creek***

The head of Sulphide drainage has two dominate glacial cirques occupied by the Sulphide and Crystal glaciers which are on the east flanks of Mt. Shuksan. There are an additional four smaller cirques to the north and south with cirque boundaries extending down to 1341 m. The head of Sulphide valley is the drainage divide between the Nooksack and Baker River systems (Figs. 2 and 3). Sulphide Creek splits into an east and west fork approximately 1.5 km upstream from the confluence with the Baker River. The west fork of Sulphide Creek emerges from the Sulphide glacier and into Sulphide Lake before steeply plunging through an impressive river canyon and a series of waterfalls. Below the canyon, the west fork contains 1.5 km of valley bottom, without terraces or other evidence of stream incision. The east fork of Sulphide Creek emerges from the Crystal glacier. It is initially confined to a river canyon until the gradient decreases to valley bottom which runs for 1 km. There is one prominent Pleistocene moraine that is positioned where the east and west forks join to form the main stem of Sulphide Creek. This moraine likely deposited at the end of the last ice age about 13, 000 years BP. Also at this junction, the valley bottom transitions to floodplain making Sulphide Creek the only tributary in the BRW with floodplain (Fig. 9). The floodplain extends for 1.5 km in a southeast direction from 268 to 366 m. There are a series of terraces in the Sulphide with terrace heights ranging from 3 to 5 m. There is no river canyon at the mouth of Sulphide, making it the only tributary in the BRW that does not have a canyon at its mouth. There is an active alluvial fan at the mouth below fan terraces ranging from 3 to 4.5 m which correspond to the terraces just upstream in the Sulphide. There is a band of disseminated sulfate deposits in the upper portion of the west fork of the valley. The

deposit starts just south of Sulphide Lake and continues down the northeast part of the valley (Staatz et al. 1972). These deposits stand out from the surrounding Shuksan Greenschist due to the brown iron oxide weathering. These relatively unstable deposits have produced several large mass movement-debris avalanches. There are also several slumps on the banks of Sulphide Creek exposing mainly till.

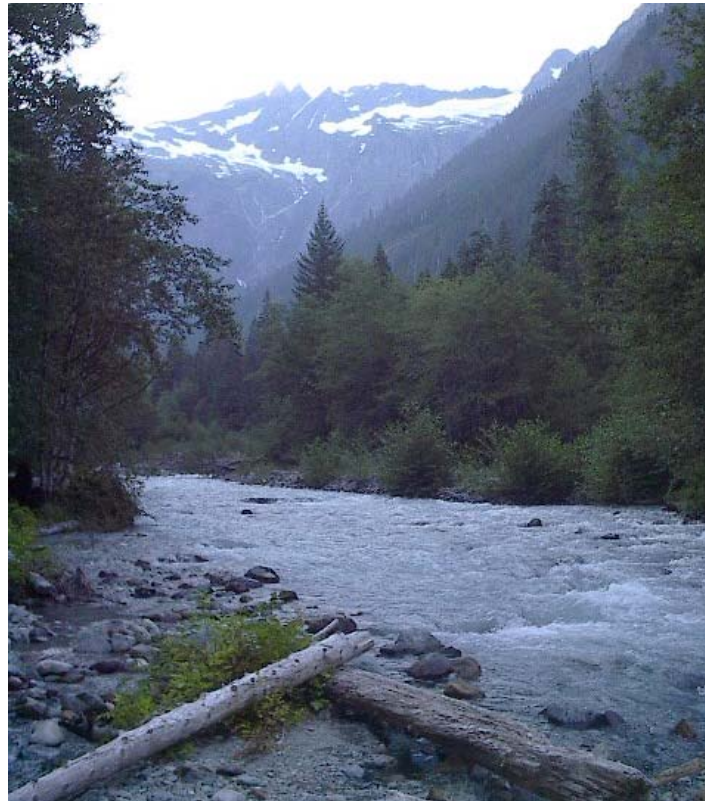


Figure 9. Looking northwest up the Sulphide Creek floodplain (Photo courtesy of Jeanna Wenger, North Cascades National Park).

### ***Crystal Creek***

Crystal Creek begins in three cirques that extend down to 1463 m (Fig.3); each has a small glacier or snow field. Slopes below the cirques are steep, contain several river canyons, and have only three Little Ice Age moraines preserved. The lowest Little Ice Age moraine is adjacent to two unidentified landforms that resemble Pleistocene moraines. The Little Ice Age moraines have a fresh appearance whereas the unidentified landforms are vegetated and older; these were not field checked for confirmation. The valley heads at Seapho Peak and, like Sulphide, is the drainage divide between the Nooksack and Baker River systems (Figs 2 and 3). The valley drains southeast with a confined valley bottom reaching from 427 to 744 m in elevation over a 2 km stretch. There are no terraces or floodplain and the debris apron is limited or non-existent throughout the drainage (Fig. 3). A river canyon is located at the mouth of the valley and has recently deposited a large and active debris torrent (Fig. 10). The debris torrent overrides an even larger part of an active alluvial fan. This deposit has forced the main stem of the Baker River against the opposite (east) side of the valley. The debris has also created several braided channels in this section of the Baker. Just upstream of the fan, the Baker River has eroded a relatively

wide swath of floodplain that is over 0.5 km wide. Crystal Creek has four relatively small mass movement-debris avalanches. The largest debris avalanche is located on the western valley wall and released from a relatively unstable outcrop of volcanic breccias of the Hannegan Volcanics.



Figure 10. Portions of a large debris torrent located at the mouth of Crystal Creek, person for scale (Photo courtesy of Jeanna Wenger, North Cascades National Park).

### ***Bald Eagle Creek***

Bald Eagle Creek is the largest tributary to the Baker River and drains northwest (Fig. 3). Five kilometers upstream from the confluence with the Baker River, Bald Eagle Creek splits into a west fork (Lonesome Creek) and an east fork. At the head of the east fork is Jasper Pass, which is the drainage divide between the Baker River and Goodell Creek (Fig 2.). Jasper Pass is a low point at the head of the valley that provides evidence of ice flow from northwest to southeast. The headwater cirques extend down to 1463 m and contain many Little Ice Age moraines. One large Pleistocene moraine was mapped just west of the fork of Bald Eagle and Lonesome Creek (Fig. 3). The Pleistocene moraine surface is hummocky, littered with large boulders, and lacks a sharp crest. No floodplain was mapped due to the constraining steep, approximately 900 m tall, valley walls. Valley bottom extends up to 1024 m and is confined for the total 8 km. There is a short river canyon at the mouth of Bald Eagle with an active alluvial fan and large fan terraces, ranging from 1.5 to 14 m. Low terraces from the main stem and fan terraces from Bald Eagle Creek merge on the down stream side of Bald Eagle confluence. There are many mass movement-rock falls in this sub-watershed which are mostly located at the base of steep cliffs, and two relatively small mass movement-debris avalanches. Landslide activity in Bald Eagle is low due to the relatively stable granodiorite of the Chilliwack Batholith.

### ***Pass Creek***

Pass Creek drains south-southeast over an 8 km stretch (Fig. 3). Approximately 5 km upstream from the confluence with the Baker River, Pass Creek splits into an east and west fork; the east

fork of the valley heads at Chilliwack Pass and the west fork heads at Ruth Mountain (Fig. 3). The west fork valley head is ringed with cirques that face both east and west and extend down to 1524 m with numerous Little Ice Age Moraines. Ruth Mountain forms a drainage divide between water flowing south into the Baker and water flowing northwest into the Nooksack (Fig. 2). The east fork valley head is defined by two passes, an unnamed pass and Chilliwack Pass, rather than a well-defined cirque. Here the valley head forms a portion of the North Cascade crest which is locally the drainage divide between the southeast flowing Baker/Skagit River system and the north-flowing Chilliwack River systems. Geomorphic evidence of proglacial lake drainage in Pass Creek includes a deep, narrow notch that cuts across Chilliwack Pass, which is 160 m lower than adjacent passes on the divide between Chilliwack and Baker valleys (Riedel et al. *in press*). Valley bottom is 2 km long on both the west and east forks before they merge to form the main stem of Pass Creek; there is another 4 km stretch of valley bottom downstream from the junction. There are no floodplains or terraces mapped in this drainage. Below the valley bottom, a one kilometer long river canyon is located at the mouth of Pass Creek (Fig. 11). Pass Creek flows out of the canyon and forms a large alluvial fan at its junction with the main stem of the Baker River. Where the two streams meet, the larger Baker River is forced to the opposite side of the valley and has a braided pattern. Also at the mouth of Pass Creek, there are 1.5 to 9 m high fan terraces. Pass Creek valley is V- shaped and confined by sparsely vegetated steep valley walls (Fig. 12). These steep walls form river canyons on first order streams with numerous debris cones and active debris torrents. There are three relatively large mass movement-debris avalanches in Pass Creek valley that all contributed sediment to the stream. The largest of these debris avalanches occurred near the headwaters of the west fork of Pass Creek in a fault zone of volcanic breccia of Hannegan Volcanics and granodiorite of the Chilliwack Batholith.



Figure 11. View looking northwest at the base of the river canyon near the mouth of Pass Creek (Photo courtesy of Jeanna Wenger, North Cascades National Park).



Figure 12. Oblique aerial view looking southeast down Pass Creek drainage (Photo courtesy of Patrick Buller, North Cascades National Park).

### ***Picket Creek***

Picket Creek drains west from a portion of the Picket Range (Fig 13). Mt. Challenger, Crooked Thumb Peak, Phantom Peak and Mt. Crowder rise to form the eastern sub-watershed boundary (Fig. 3). These jagged horns and arêtes form the head of Picket valley which is the drainage divide between the Baker River system, Goodell Creek and west Ross Lake tributaries (Big and Little Beaver Creeks). Picket Creek is ringed by many small cirques that extend down to 1402 m with many Little Ice Age moraines resting above 1524 m. Sparsely vegetated steep walls surround the drainage (Fig. 13). Valley bottom extends from 500 m at the confluence with main stem Baker up to 915 m in a 4 km stretch. No floodplain or terraces were mapped due to the steep, constraining valley walls. There are many mass movement-rock falls in the valley below steep cliffs, but no large mass movement-debris avalanches due to the relatively stable orthogneiss of the Skagit Gneiss and granodiorite bedrock of the Chilliwack Batholith.



Figure 13. Looking east from Copper Ridge to Whatcom Peak and Mt. Challenger (left) with Easy Peak in the foreground. The jagged peaks in the middle background are part of the Picket Range that rings the eastern boundary of the Picket Creek drainage (Photo courtesy of Jeanna Wenger, North Cascades National Park).

### ***Mineral Creek***

Mineral Creek drains southeast over the relatively short distance of 3.5 km, making it the shortest tributary in the BRW. Mineral Creek valley is ringed by cirques that extend down to 1402 m with five Little Ice Age moraines. Mineral Mountain is at the very head of the valley. To the east, there is a rounded pass at 1400 m which marks the drainage divide between the Baker and Chilliwack watersheds; east of the pass is Easy Peak and Easy Ridge (Fig. 13). The tributary has no floodplain or terrace mapped, but has a valley bottom that runs for 2.5 km ending at 1164 m. Though the valley walls are steep, they lack any substantial landslide activity due to the relatively stable biotite granite bedrock of the Mineral Mountain pluton that surrounds the sub-watershed.

### **Baker River Watershed Landslide Inventory**

Information on unstable and active landslides can guide the selection of LTEM reference sites or building/maintaining public facilities such as trails, campgrounds, and bridges. A landslide database was created to accompany landform maps with data collected on 18 characteristics of each landslide, including age, activity, bedrock geology, volume, material type, and impact to streams. A total of 222 landslides have been mapped within the BRW with 33 of these classified as debris avalanches (Table 6). The debris avalanche is the largest of four mass movements mapped. These landslides are of particular importance due to their large size, potential to block streams, and potential to deliver massive amounts of large woody debris and sediment to stream systems. Debris avalanches can displace millions of cubic meters of debris; a total volume of 1.86 km<sup>3</sup> was calculated for debris avalanches in the BRW. More than half of the avalanches mapped in the BRW either delivered sediment to a stream or blocked it entirely. These 222 mass movements encompass ~2.6% of the overall watershed area. The 33 debris avalanches in the BRW encompass 0.8% of the overall watershed and displaced an estimated 0.93 km<sup>3</sup> of debris.

There were 19 debris avalanches that delivered an estimated 0.74 km<sup>3</sup> of sediment and debris to the stream system; two of these debris avalanches blocked the stream entirely.

Table 7. Summary of the Baker River watershed landslide inventory data.

| Mass Movement Type | # of Each Type | Surface Area (km <sup>2</sup> ) | % of Total Watershed |
|--------------------|----------------|---------------------------------|----------------------|
| Fall/Topple        | 154            | 3.9                             | 1.6                  |
| Debris Torrent     | 29             | 0.5                             | 0.2                  |
| Debris Avalanche   | 33             | 2.1                             | 0.8                  |
| Slump/Creep        | 6              | 0.0                             | 0.0                  |
| <b>Totals</b>      | 222            | 6.4                             | 2.6                  |



## **Future Work**

### **Progress Report**

To date, NPS staff has completed mapping 80% of NOCA at the 1:24,000 landform scale. Landform mapping is also in progress at MORA, which is 75% complete, and OLYM, which is 24% 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 2009, 2010 for MORA, and 2011 for OLYM.

### **Soil Surveys**

A major gap in natural resource inventories for the NCCN is soils data. Traditional methodologies, relative inaccessibility and estimated high costs have not allowed for extensive soil surveys in the rugged wilderness areas of Washington State, which include NOCA. Because parent material, time (stability/age), and relief are three of five soil-forming factors, digital landform maps are a critical component in developing new approaches to mapping soils in remote, rugged landscapes. Landforms provide a preliminary landscape delineation that simplifies the soil sampling strategy. Linking soils to landforms is a cooperative effort among NOCA, the Natural Resources Conservation Service Soil Survey program, USFS, Washington State University, and the NPS Soil Resources program.

The Remote Area Soil Proxy (RASP) model uses GIS, remote sensing technology, and a focused effort to describe soils in the field in order to model and map 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 soil model using landform data from Thunder Creek watershed shows a strong correlation between landform type and soil order (Briggs 2004). Encouraged by these results, landform maps are being used to refine the soil model and produce a soil map for the remainder of NOCA. This approach will continue to be developed to obtain soil resource inventories for MORA and OLYM.



## Literature Cited

- Bloom, A., 1978. Geomorphology. Prentice Hall, New Jersey.
- Briggs, C., GIS-based mapping of soil distribution in Thunder Creek watershed, North Cascades National Park, Washington, Master's Thesis. Washington State Universtiy.
- 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.
- 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.
- 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.
- 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 Claque, J. *in press*. Geomorphology of a Cordilleran ice sheet drainage network through breached divides in the North Cascades Mountains of Washington and British Columbia, *Geomorphology*.
- Riedel, J. and Probala, J. 2005. Mapping ecosystems at the landform scale in Washington state, *Park Science* **23**, #2:37-42.
- 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.

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