



Geomorphology of the Stehekin River Watershed

Landform Mapping at North Cascades National Park Service Complex, Washington

Natural Resource Technical Report NPS/NCCN/NRTR—2012/566



ON THE COVER

Oblique air photograph looking northwest at the lower Stehekin valley; prominent landmarks in the photo include the Buckner Orchard and Rainbow Falls.

Photograph by: Stephen Dorsch, North Cascades National Park

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Abstract

The report describes the background information, methods and results of a surficial geology inventory within the North Cascades National Park Service Complex (NOCA). The study area for this report is the Stehekin River Watershed, which flows southeast from the Pacific Crest into Lake Chelan. Tributaries of the Stehekin River include Boulder, Bridge, Flat, Maple, McAlester, Park, and Rainbow Creeks. This report focuses on how factors such as bedrock geology, glacial history, climate, hydrology, and vegetation have affected landform development in the Stehekin River Watershed.

Bedrock in the Stehekin River Watershed is part of the crystalline core of the North Cascades. The Skagit Gneiss Complex and the Cascade Pass Family are the dominant rock units exposed in the watershed. The topography of the Stehekin Watershed reflects multiple glaciations during the past 2 Ma, which have carved deep U-shaped valleys, steep valley walls and jagged horns and arêtes. The North Cascades were inundated by the south flowing Cordilleran Ice Sheet during the Fraser Glaciation. The most extensive advances of alpine glaciers since the last ice age occurred in the Little Ice Age between 1350 and 1900 AD, depositing Neoglacial moraines.

The climate of the Stehekin River Watershed is classified as continental, but varies substantially by elevation and distance from the Pacific Crest. Yearly temperature average highs tend to occur in July and August with winter average low temperatures occur in December and January. The rainy season typically lasts from November through January.

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

Landforms in the Stehekin River Watershed are classified as 68.59% valley wall and 7.27% high elevation cirque; with only 3.25% as riparian (floodplain, valley bottom and alluvial fan). High elevation landforms (cirques, Neoglacial moraines, ridges, arêtes, other mountains, horns, and passes) account for 50 km², or 9.25% of the Stehekin River Watershed. The majority of this area is cirque basin. Aspect has particularly strong control on the development of cirque basins and valley walls, with north and east facing cirques are deeper and broader than those on southerly aspects and also containing lower elevation Neoglacial moraines. Steep cliffs on valley walls with north aspects are contrasted by gentler rises on those with south aspects. Landforms in the watershed, such as broad passes, extensive bedrock bench systems, Pleistocene moraines, Neoglacial moraines, and rounded ridges capture the history of ice sheet advances and retreats.

The main stem of Stehekin River is a broad U-shaped glacial valley with a flat valley bottom, straight profile and low gradient, created by both the southward excursions of the Cordilleran Ice Sheet and the multiple glaciations by alpine glaciers flowing down the major tributaries. Tributary systems were left as hanging valleys with bedrock canyons or narrow, stepped waterfalls at their mouths. Where they join with the main stem of Stehekin River, these streams

deposited alluvial fans. At the mouths of some tributaries, fan terraces were deposited at the end of the last ice age when slopes left bare by retreating glaciers fed massive quantities of sediment to streams. There are several large Pleistocene moraines along Stehekin River deposited by the ice sheet across the mouths of tributaries.

A total of 382 mass movement have been mapped within the watershed (2% of the total watershed area) with 13 being large debris avalanches total an area of 1.45 km². This is a relatively low number for a watershed at NOCA, which could be attributed to the competency of the Skagit Gneiss bedrock that is exposed extensively throughout the Stehekin River Watershed.

Debris torrents are fairly common with 41 mapped in the watershed, which is a relatively high number for a watershed at NOCA. This large number of debris torrents may be due to the dryer climate and associated vegetation that naturally occurs in the eastern portions of the watershed. Debris torrents are also important contributors to the total amount of sediment delivered to streams systems.

1 – Introduction

The primary purpose of this report is to describe the background information, methods, and results of a surficial geology inventory within the North Cascades National Park Service Complex (NOCA). This is one of twelve basic inventories called for in the National Park Service (NPS) National Resource Challenge. A secondary goal is to provide an overview of bedrock geology, climate, and hydrology as they affect landform processes. The study area for this report is the Stehekin River Watershed, which includes the main Stehekin River and its tributaries Boulder, Bridge, Flat, Maple, McAlester, Park, and Rainbow Creeks.

Background information presented in this report focuses on key factors that influence the development of landforms in Stehekin River Watershed. These factors include geology, glacial history, climate, hydrologic setting, and vegetation. A brief discussion on landform age follows the background information, to give geomorphic processes a temporal context. A detailed description of methods is then provided before discussing the results and interpretations of the landform inventory.

The results and discussion section of this report gives detailed analysis for the individual sub-watersheds mapped in this study within NOCA. Discussion of each sub-watershed includes the unique characteristics of the individual valleys and specific examples of landform genesis. Detailed information is gathered for each mass movement in order to reveal both historic and on-going mass wasting occurring in each sub-watershed.

1.1 Applications of Landform Mapping Data

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

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

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

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

The lower Stehekin valley contains numerous recreational facilities, public roads, administrative facilities and approximately 100 residences and seasonal cabins. The Stehekin Watershed is flood prone due to its climate, steep topography, and other watershed factors. In the past 14 years the three largest floods on record have wreaked havoc on public and private property and degraded scenic values along the river (Riedel 2008). Stehekin also has a long-history of wildland fire issues and is federally listed as a 'Community at risk from Wildfire' (Federal Register 2001). These flood and fire issues create numerous resource management challenges for the NPS in the Stehekin valley. Landform maps have proven to be valuable tools for resource managers in dealing with these and other management issues in the Stehekin River Watershed (NPS 1995).

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 (LTEM) programs. This included the development of a 23 landform scheme to support classification and assessment of aquatic habitat. There are now 37 distinct units in a regional landform scheme, of which 29 are found in NOCA. Landform units are created by discrete geologic processes, many of which are still active and relatively easy to identify. The landform scheme has now been applied to several watersheds within five of the seven NPS units in the North Coast and Cascade Network (NCCN), including NOCA, Mount Rainier National Park (MORA) and Olympic National Park (OLYM), Ebey's Landing National 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 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. These units focus on climate, bedrock geology, and topography at a regional scale. The LTA scale is mapped by watershed and units are based on topography and process.

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

2 - Study Area

2.1 Geographic Setting

The Stehekin River Watershed is located in north-central Washington State on the eastern slopes of the North Cascade mountains (Fig. 1). The Stehekin River drains an area of 890 km² of mostly public lands within the Okanogan-Wenatchee National Forest, Glacier Peak Wilderness Area, Lake Chelan National Recreation Area, and NOCA (Fig. 1). This study focuses on the portion of the watershed that resides within the southern unit of NOCA and Lake Chelan National Recreation Area (Fig. 2). The Stehekin valley occupies approximately 551 km² of the 2,770 km² National Park. The remaining 339 km² of the watershed is located in Glacier Peak Wilderness and Okanogan-Wenatchee National Forest (Fig. 1). The headwaters of the Stehekin drain southeast into Lake Chelan, which drains southeast into the Columbia River and into the Pacific Ocean.

The headwaters of the Stehekin River have a high average elevation and support relatively large glaciers. This area is surrounded by many high peaks, such as Buckner Mountain (2777 m), Boston Peak (2711 m) and Sahale Mountain (2646 m). The Stehekin River headwaters are part of the Pacific Crest, (Fig. 2) which is an important physiographic feature that influences the weather, climate, and ecology of this region and the watershed. The Stehekin River watershed has an elevation range of 3000 m, from 2899 m asl at Bonanza Peak to 107 m bsl at the bottom of Lake Chelan, making the valley one of the deepest gorges in North America. Glacier Peak volcano, a highly recognized landmark in the area, is 40 km southwest of the Stehekin watershed.

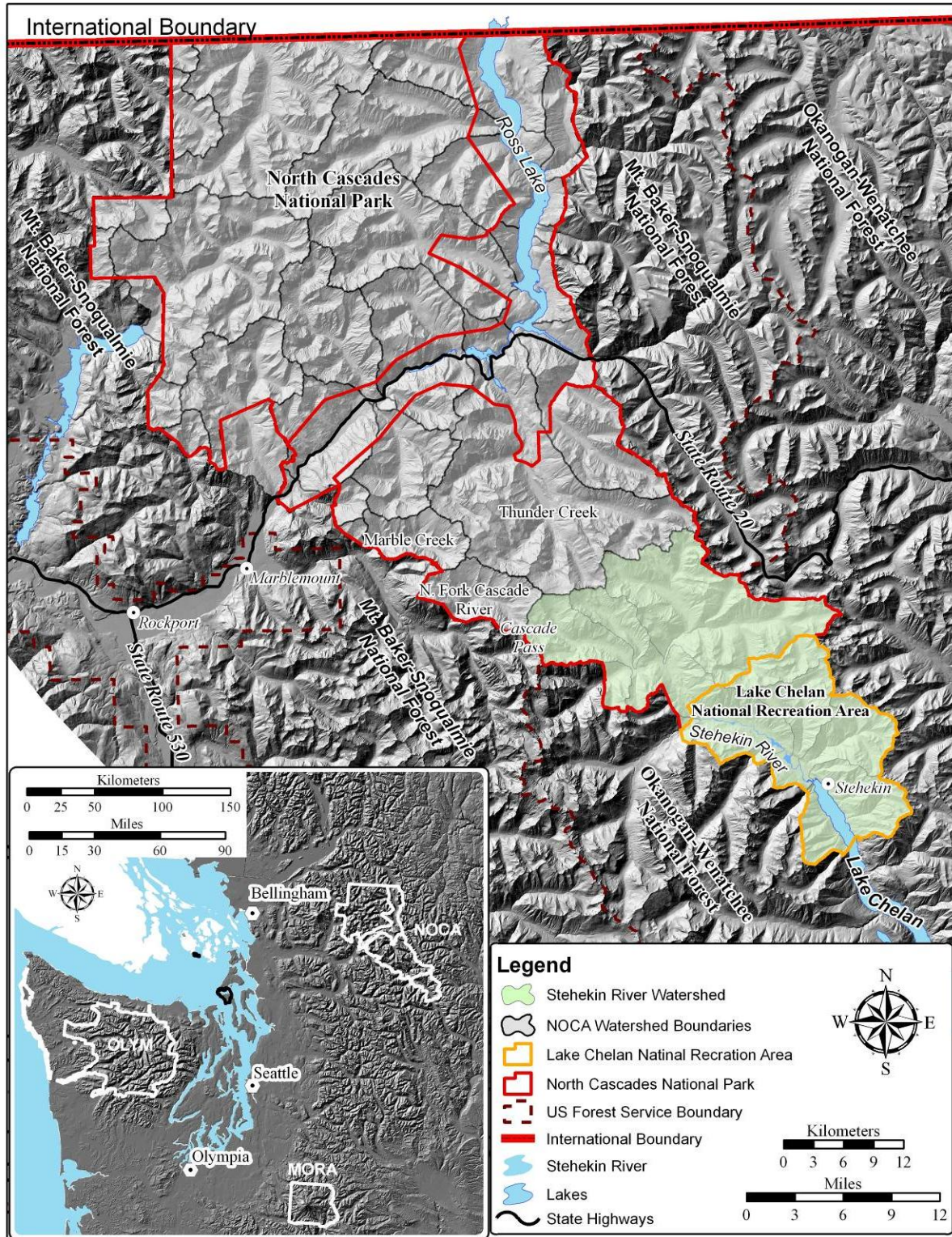


Figure 1. Map showing the location of Stehekin River and adjacent watersheds within North Cascades National Park Service Complex. Insert map shows the location of NOCA within Washington State, as well as Mount Rainer (MORA) and Olympic (OLYM) National Parks.

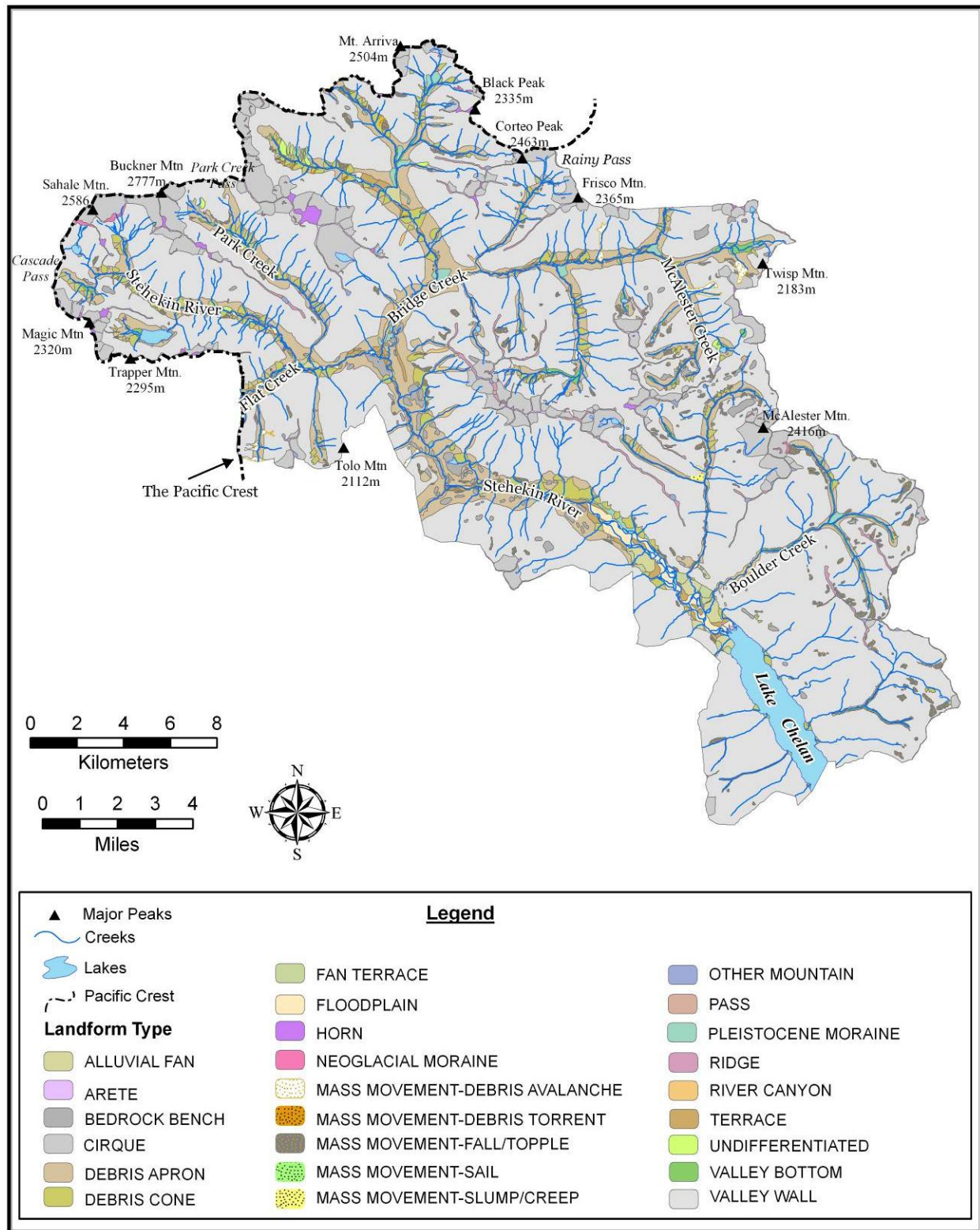


Figure 2. Landform map of the Stehekin River Watershed with the locations of the main tributary streams and other localities referred to in the text.

2.2 Geologic Setting

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

1. Accumulation of massive bodies of rock (terrane) to the west coast of North America between 200 (Early Jurassic) and 50 Ma (Late Cretaceous);
2. Uplift and erosion of these rocks to create a pre-North Cascades mountain range between 130 (Early Cretaceous) and 50 Ma (Eocene);
3. Intensive movement and faulting 50-40 Ma that fragmented the preexisting mountains;
4. Another phase of mountain uplift that created the modern North Cascades began 40 Ma and continues today; and
5. From about 2.6 Ma and continuing intermittently the great ice age glaciers created not only the jagged *arêtes* and horns, but also the broadened passes, rounded ridges and deepened valleys.

2.2.1 Tectonics and Structure

The trend of the Stehekin River follows the NW-SE alignment of the major faults in the region (Fig. 4). However, the Stehekin valley and Lake Chelan do not follow a major fault or other structural weakness. Rather, geologists believe that the Stehekin River was superimposed on the crystalline core of the range as it was uplifted and exposed by erosion (Tabor and Haugerud 1999). Individual landform maps with the structural features of each sub-watershed within the Stehekin Watershed are provided in this report under the Characteristics of Sub-Watersheds section.

2.2.2 Geologic Units

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

The Skagit Gneiss Complex, which was emplaced in the last 122 Ma (Tabor et al. 2003), was subsequently intruded by rocks of the 18 Ma old Cascade Pass Family. These two rock types make up the majority of the watershed and are part of the crystalline core of the North Cascades. Units of the Skagit Gneiss Complex found in the Stehekin Watershed include the Eldorado Orthogneiss, Napeequa Schist, Cascade River Schist, Magic Mountain Gneiss and the Black Peak Batholith. Igneous tonalite of the Cascade Pass Family is exposed west of Mixup Peak (Fig. 2) near the Stehekin River headwaters. These rocks are part of the Cascade Pass dike, which is over 14 km long, almost a mile wide and rose along a northeast-oriented crack in the Cascade River Schist (Tabor and Haugerud 1999). The upper Stehekin River valley is composed primarily of Eldorado Orthogneiss while the lower valley is primarily Skagit Gneiss (Fig. 3).

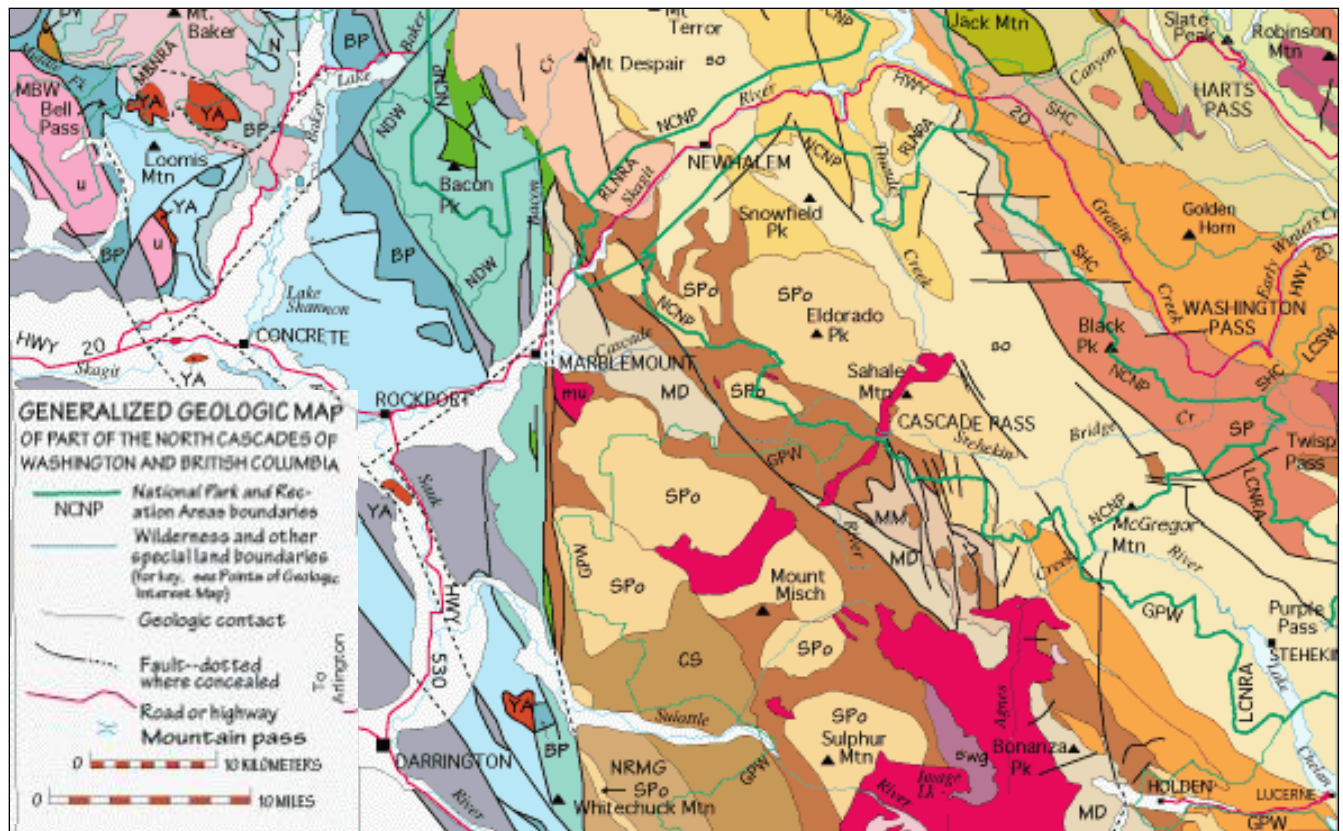


Figure 3. Bedrock map showing the Stehekin River Watershed and some of the adjoining watersheds (see Tabor and Haugerud 1999 for geologic map key).

2.3 Glacial History

The topography of the Stehekin River Watershed reflects multiple glaciations during the past 2.6 Ma, which have carved deep U-shaped valleys, steep valley walls and jagged horns and arêtes. The geomorphology of the North Cascades during this period has been shaped by both alpine and continental glaciations. Glaciation has altered the fluvial morphology of both local and regional drainage patterns (Riedel et al. 2007). The North Cascades were inundated by the south flowing Cordilleran Ice Sheet during the Fraser Glaciation (35 to 11.5 Ka) (Armstrong et al. 1965) (Fig. 4), marking the end of the Olympia nonglacial interval (60 to 30 Ka) (Clague 1981a and 1981b). At Stehekin, it is likely that the ice sheet was 1500 m thick (Riedel 2009). The upper surface of the Cordilleran Ice Sheet at 1800 m can be estimated by noting the change in ridge forms from wide-rounded to jagged arête.

As the Cordilleran Ice Sheet and alpine glaciers flowed down the Lake Chelan trough and encountered weaker bedrock, they eroded the floor of the valley to a depth more than 600 m below sea level. Substantial flow of the ice sheet from the Skagit into Lake Chelan in part explains the incredible depth of Lake Chelan. The modern floor of Lake Chelan is covered in a blanket of glacial sediment 520 m thick, which thins to a approximately 100 m where the Stehekin River meets the lake.

Impacts from the ice sheet are evident throughout the Stehekin River Watershed and North Cascade range. They include broad passes and beveled ridges, enlarged valley cross-sections,

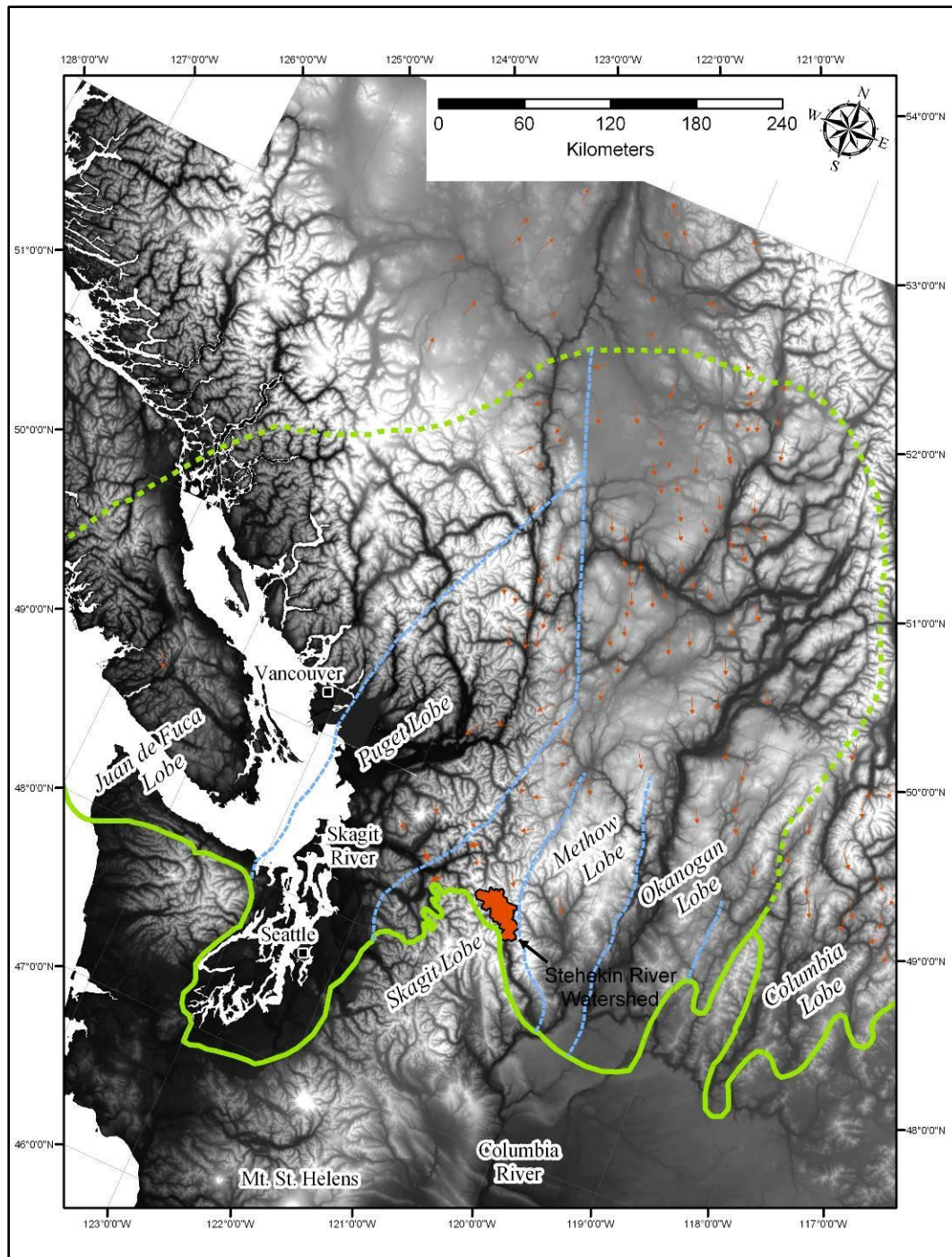


Figure 4. Map of the known extent of the Cordilleran Ice Sheet during the Fraser Glaciation. Note the various lobes of the ice sheet mapped, extending down into the United States.

truncated valley spurs, and thick accumulations of till and outwash. Between multiple ice sheet glaciations, valley glaciers flowed from cirques through the Stehekin valley forming a large, complex valley glacier system. 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 Stehekin River, these streams deposited paraglacial alluvial fans (Ryder 1971). During the Fraser

Glaciation, alpine glaciers advanced and retreated several times. Following ice sheet deglaciation, alpine glaciers advanced 5-10 km from cirques into valleys between 13 and 11.5 Ka (Riedel 2007).

2.3.1 Neoglacial

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

Glacial advance during the Little Ice Age created hundreds of small moraines and left vast fields of unconsolidated glacial till. Small cirque glaciers and permanent snow fields of today are 45-50% less extensive than at the end of the Little Ice Age, 100 years ago. Presently, cirque alpine glaciers remain at high elevations and most have a north or east aspect and are sheltered from the sun by steep cirque walls and arêtes. The giant glaciers of the last ice age 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 Stehekin River valley to depths a hundred meters or more.

There are 312 glaciers present within NOCA today. NPS staff are currently monitoring four glaciers including Sandalee Glacier within the Stehekin River Watershed. A summary of the results follow in the Hydrology section of this report.

2.4 Climate

The headwaters of the Stehekin Watershed begin on the Pacific Crest and flow down the eastern slopes of the North Cascade range (Figs. 1 and 5). The climate of the Stehekin Watershed is classified as continental, but varies substantially by elevation and distance from the Pacific Crest. Weather data is obtained from two Natural Resource Conservation Service (NRCS) snowpack telemetry sites (SNOTEL) within and nearby the watershed, a Cooperative Network station (COOP), and the glacier mass balance monitoring on McGregor Mountain (Fig. 5). Data available from these sites is compiled in Table 1 below and reveals that the western edge of the Stehekin watershed are significantly wetter and cooler than the eastern portions of the watershed. The headwaters receive approximately 380 cm of precipitation a year, including 6-9 m of snowfall during the winter months. At the opposite extreme, the low elevation eastern end of the watershed near Stehekin has an annual precipitation of 84.5 cm (Table 1).

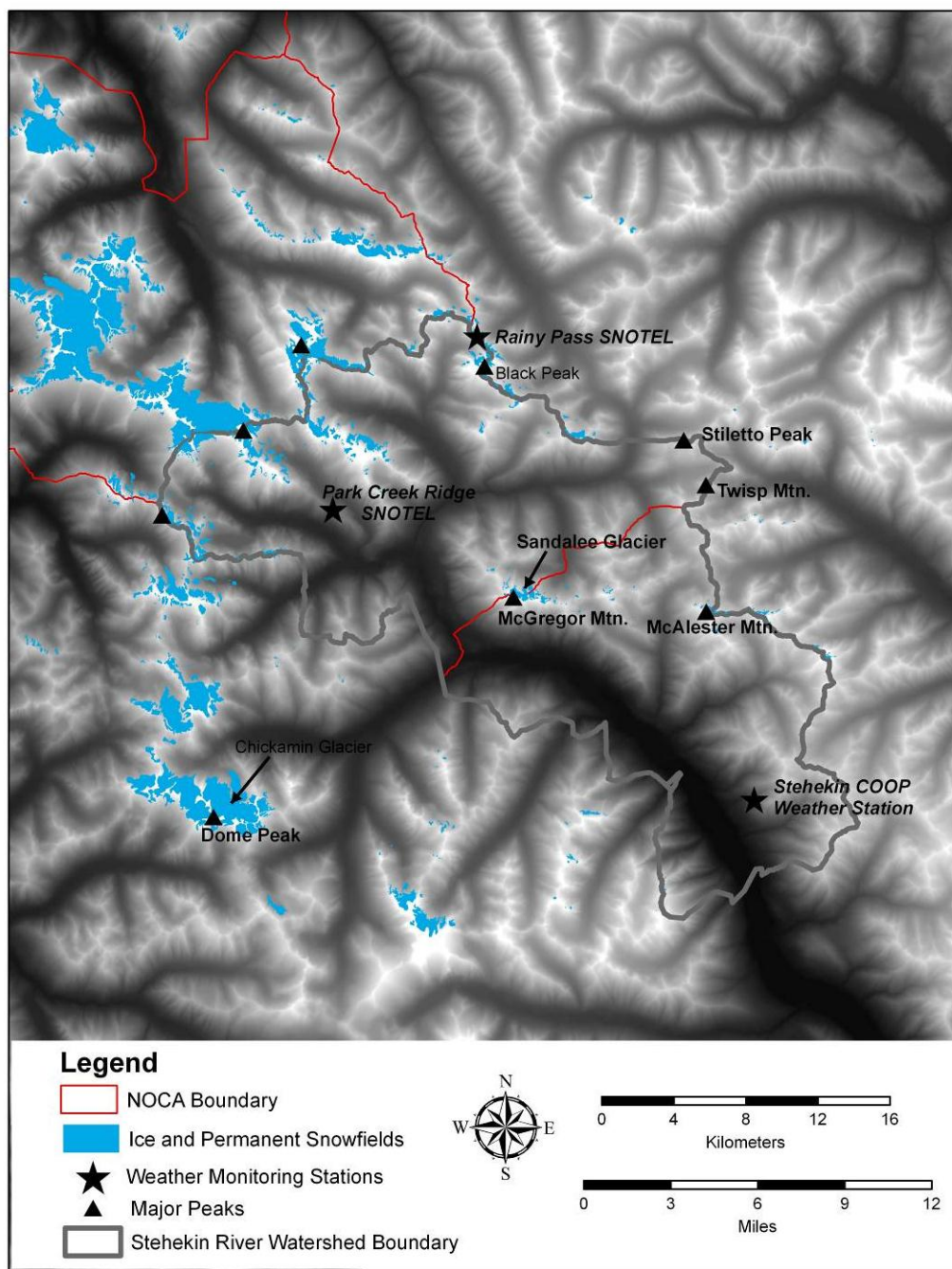


Figure 5. Digital elevation model showing permanent snowfields and glaciers in and around the Stehekin River Watershed along with weathering monitoring sites mentioned in the text.

Rainfall and temperature data were collected from both the NRCS SNOTEL and Cooperative Network station sites (Table 1). Overall, yearly temperature average highs tend to occur in August at higher elevations, with an average high temperature of 14° C near Stehekin occurring in July. Winter low temperatures tend to occur in December or January, at 2.8° C in the Stehekin valley and averaging -5° C in the high country. November and December are routinely the wettest months, averaging 24 cm in the watershed. Most precipitation occurs during the winter months of November through March, averaging 75% of the yearly accumulation. Conversely, the

summer months of June through August tend to be the driest, averaging only 6% of the yearly accumulation.

Table 1. Summary of data from SNOTEL and COOP sites located closest to the Stehekin River Watershed (NRCS 2009, NWS COOP 2009). Data is provisional and subject to revision.

Station Name	Rainy Pass (SNOTEL)	Park Creek Ridge (SNOTEL)	Stehekin (COOP)
Watershed	Skagit	Stehekin	Stehekin
Elevation (m)	1490	1400	387
Beginning Year of Data Collection	1981	1978	1906
End Year of Data Collection	In Service	In Service	In Service
Mean Annual Temperature (° C)	1.9	3.8	8.5
Average High Temperature (° C)/Month	14.7/July	13.6/Aug.	14.3/Aug.
Average Low Temperature (° C)/Month	-5.95/Dec.	-4.75/Dec.	2.8/Jan.
Mean Annual Precipitation (cm)	146.5	171.48	84.5
Average High Precipitation (cm)/Month	24.94/Nov.	30.04/Dec.	17.68/Dec.
Average Low Precipitation (cm)/Month	1.18/Aug.	1.12/July	1.2/July

2. 5 Hydrologic Setting

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

Rivers and creeks can typically reach flood stages during both the spring and late fall. Large rain on snow events typically occur between late October and December, have high flood peaks, but short durations. Spring snowmelt floods occur in April-June with large events occurring when higher than average snow-pack persists late in the season. Spring floods have durations that span weeks, with strong diurnal fluctuation, and lower peak discharge volumes than fall floods.

During large magnitude events, water levels rise in the main stem of the Stehekin River shifting channel and gravel bar positions and reintroducing water to side channels, especially in the lower Stehekin valley. Large woody debris introduced by large flood events adds an element of unpredictability to the geomorphology of the floodplain. This wood comes from mass movements, snow avalanches, and bank erosion. Massive logjams are observed throughout the watershed, especially in the main channel of the Stehekin River. As recently as 1972, the Army Corps of Engineers removed most large wood piles on the Stehekin River below Harlequin Bridge. Three comprehensive inventories of large wood accumulations in 1985, 2000, and 2007 have since documented rapid movement and storage of wood on the lower Stehekin River (Mason and Koon 1985). There are now 166 logjams and 309,000 m³ of large wood in the lower 10 miles of the Stehekin River (Reidel 2008).

There is a gage located just above the outlet of Boulder Creek that records peak annual flow of the Stehekin River (Fig. 6). The location of the Stehekin River's headwaters along the wet Pacific Crest has a strong influence on flooding. Unlike nearby rivers on the east side of the Cascade Range, the upper Stehekin River, Flat Creek, and Agnes Creek valleys are prone to fall and early winter rain-on-snow floods because their headwaters are so far west (Fig. 2). These

floods are known for rising quickly and having relatively short durations of a few days (Riedel 2008).

The Stehekin River and its tributaries also flood during periods of rapid snow melt in April-June. The largest flood on record for Stehekin River prior to 1995 was a spring flood that occurred in 1948 with a peak discharge of 18,900 cfs. Stehekin River tributaries Bridge, Rainbow, Boulder, and Company creeks are currently dominated by spring snowmelt floods. Small, steep first and second order tributaries in the valley are prone to flash flooding in summers as a result of intense thunderstorms. Those streams in southwest-facing valleys below are particularly prone to debris torrents triggered by heavy summer rainfall (Riedel 2008).

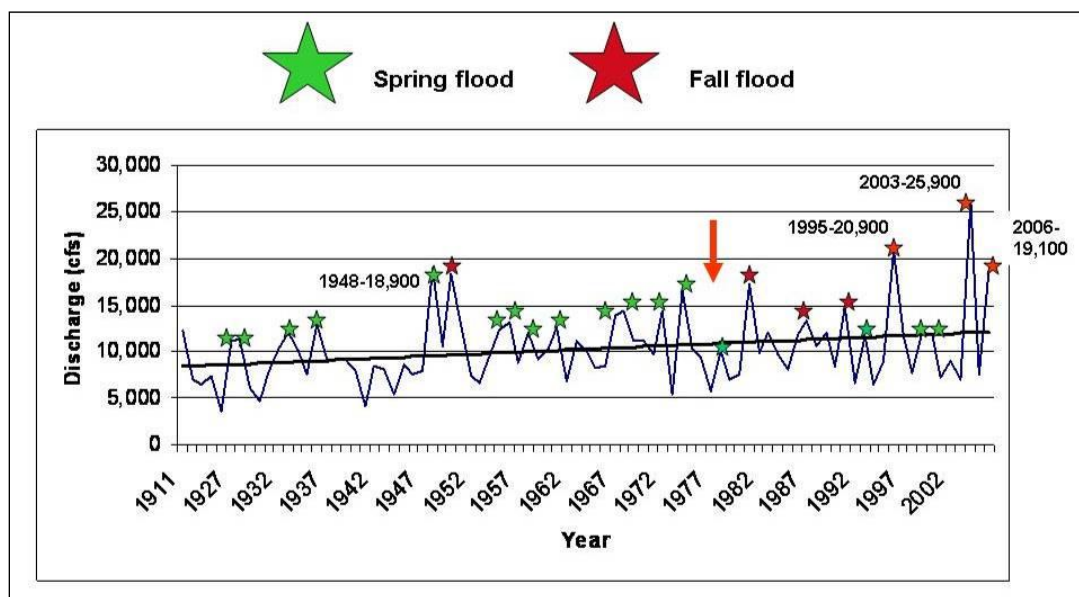


Figure 6. Peak annual flow for the Stehekin River in cubic feet per second (cfs), from 1911 to 2008, from the gauging station just above the outlet of Boulder Creek (Riedel 2008).

Glaciers have an important impact on the hydrologic regime of the Stehekin River Watershed and help produce a continual flow of water throughout the year. This contribution from glacial ice and snowfields is critical for sustaining endangered salmon and trout species downstream. Permanent snowfields and glaciers cover 3% of the Stehekin watershed, an area of 17 km². Glacially fed streams help to produce a continual flow of water throughout the year with glacial runoff contributing an average of 15% of the total watershed runoff annually or 80 million cubic meters (Fig. 7).

The glacier monitoring program at NOCA provides insight into the contribution glaciers are making to the overall watershed total run-off. Since 1993 NPS staff at NOCA has been monitoring Sandalee Glacier on the northern cirque of McGregor Mountain. Below are the results for Sandalee Glacier (Fig. 7). The vertical axis is the amount of water gained (winter balance), lost (summer balance), and retained (net balance) in meters of water equivalent averaged across the glacier. More detail regarding the status of glaciers, photographs of those monitored, and the methods of glacier monitoring within NOCA can be found in several locations (Riedel et al. 2008, NOCA 2009, Riedel et al. *in review*).

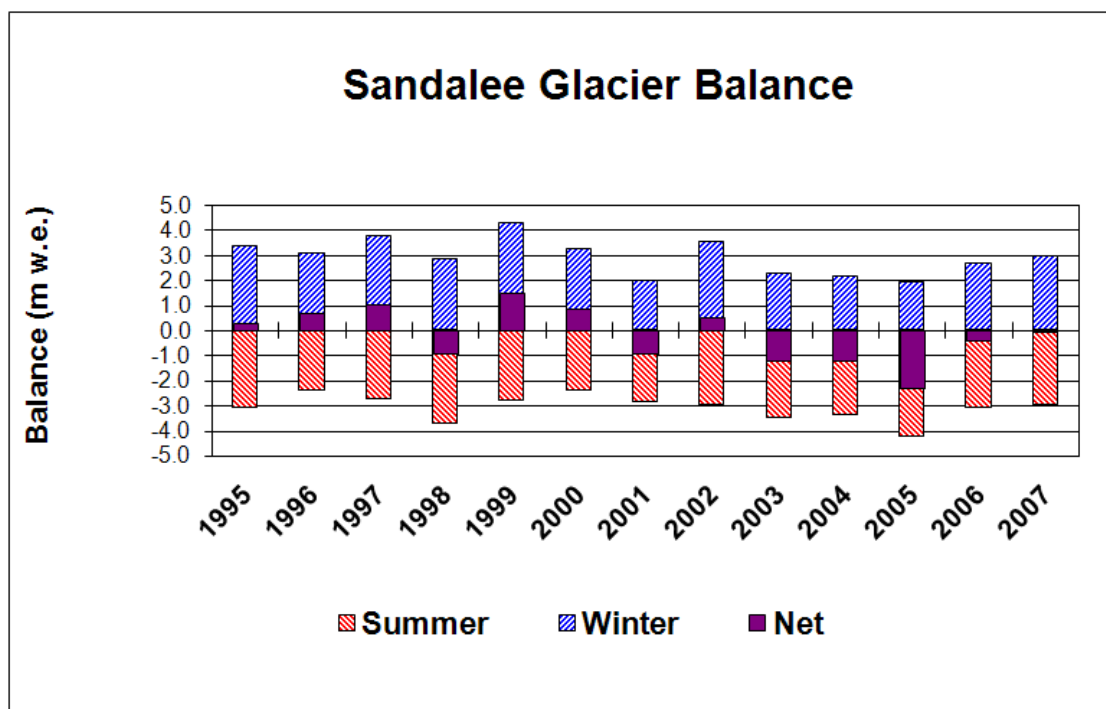


Figure 7. Mass balance chart of Sandalee Glacier, located on McGregor Mountain. The vertical axis is the amount of water gained (winter balance), lost (summer balance) and retained (net balance – solid bar) in meters of water equivalent (m w.e.) averaged across the glacier.

2.6 Vegetation

The Stehekin River Watershed displays diverse vegetation communities due to its varied climate, elevation and surficial deposits. Forest line, the upper elevation limit of closed-canopy forest, occurs around 1600 m. The vegetation zones above forest line progress from subalpine parkland, to subalpine meadow, to a sparsely vegetated alpine zone with increasing elevation. The subalpine parkland community (1600 m - 1800 m) is a mosaic of fragmented tree islands dominated by subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga mertensiana*) with smaller components of whitebark pine (*Pinus albicaulis*) and alpine larch (*Larix lyallii*) in the overstory with many of the species found in the subalpine meadow community as the understory. The dominating communities of the subalpine meadow zones are a heather-shrub community of *Phyllodoce* sp., *Cassiope* sp., and *Vaccinium* sp., or a community of moist meadow species such as *Lupinus latifolius*, *Arnica latifolia*, and *Veratrum viride*. Above 2000 meters is the sparsely vegetated alpine zone. Harsh environmental conditions prohibit much growth at these elevations, however, hardy species of lichens, sedges, and a few herbaceous species persist.

Below the subalpine forested communities is the montane forest from 1600 to 400 m. Pacific Silver fir (*Abies amabilis*) and Western hemlock (*Tsuga heterophylla*) dominate this zone. Douglas-fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*), and Western Redcedar (*Thuja plicata*) make up the lowland forest on the wetter northwestern portion of the watershed. On the dry sites to the southeast, Ponderosa Pine (*Pinus ponderosa*) and Douglas Fir dominate. Lodgepole Pine (*Pinus contorta*) tends to dominate on exposed bedrock benches. Red alder (*Alnus rubra*) and black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) occupy the riparian zone along the river corridor. Flood events isolate river channels and created areas of slow water and riparian vegetation. The understory differs in these moist and organic-rich areas

by the presence of species such as ginger (*Asarum caudatum*), wintergreen (*Pyrola picta*), and a variety of orchids and ferns.

3 – Landform Mapping at NOCA

3.1 National Hierarchical Framework for Ecological Units

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

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

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

3.1.1 Subsection (1:250,000)

The first product was a seamless coverage in the North Cascade region at the Subsection scale where the focus is on climate, bedrock geology, and topography at a regional scale. 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 Stehekin River Watershed is part of the Wenatchee Highlands and Crystalline Cascade Mountains subsections (Fig. 8).

The majority of the watershed is in the Wenatchee Highlands Subsection. However, the Stehekin River Watershed headwaters are in the Crystalline Cascade Mountains subsection. This difference in Subsection units highlights the diversity in climate, bedrock geology and topography of the watershed from east to west. The headwaters of the Stehekin are intrusive rocks of the Cascade Pass Family and characterized by a cool and wet climate. The eastern portion of the watershed, which is primarily composed of rocks from the Skagit Gneiss Complex are typically warmer and dryer.

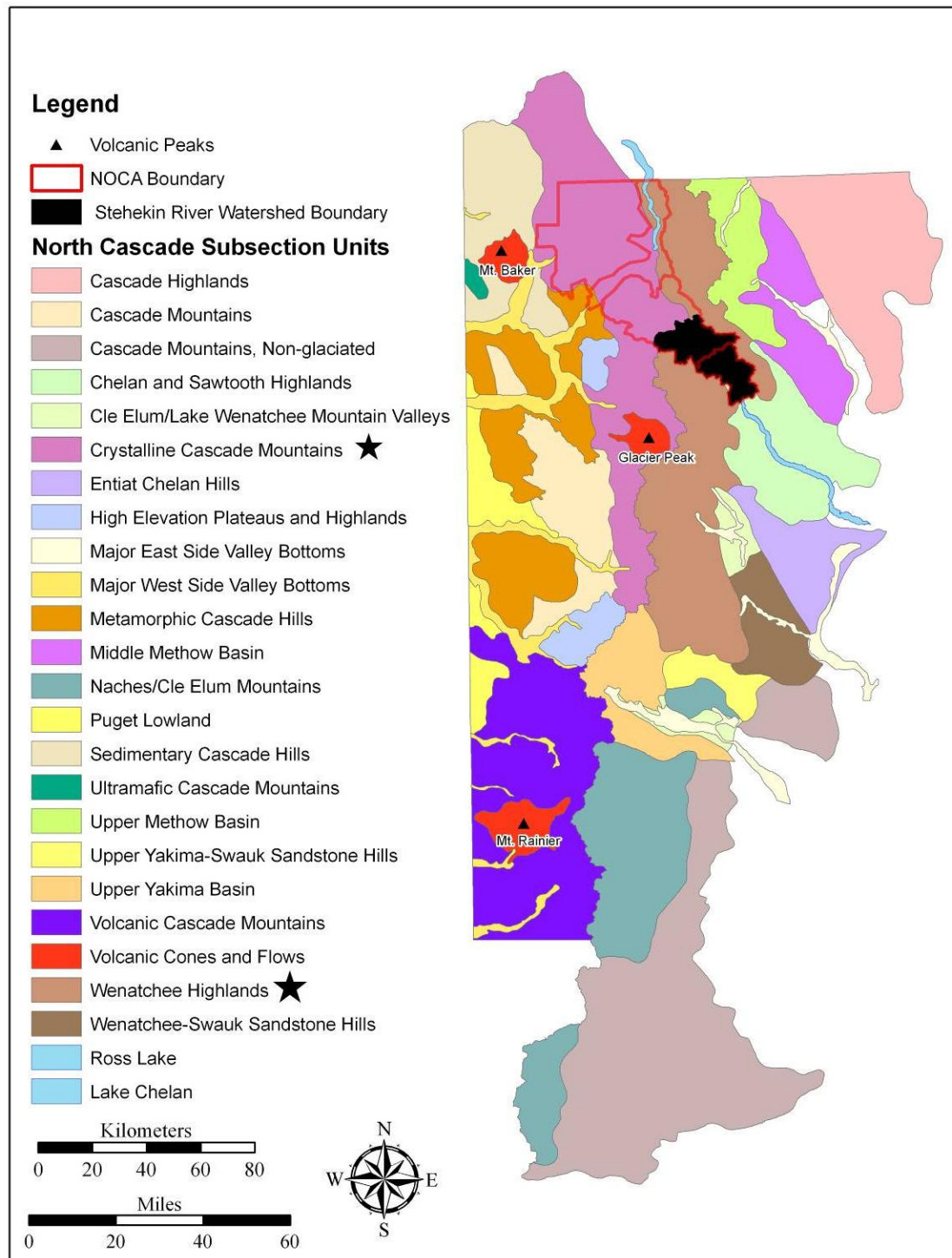


Figure 8. Subsection map (1:250,000) of the North Cascade region showing the location of the Stehekin River Watershed within the Crystalline Cascade Mountains and Wenatchee Highlands Sub-Sections and North Cascades National Park Service Complex.

3.1.2 Landtype Association (1:62,500)

Landscape scale ecological units or Landtype Associations (LTAs) are the smallest scale within the hierarchical framework that meets most NPS challenges and management needs. At this

mapping scale, geomorphic process and topography become more important than climate and bedrock geology. The first step in mapping LTAs is to identify large-scale erosional features of mountains and valleys such as valley bottom, cirque basin, glaciated valley, and river-cut valley (Davis 2004). Final map units incorporate data on vegetation and bedrock type. For example, in the North Cascades, a valley would be broken into three units that coincide with major elevation-controlled changes in vegetation and topographic breaks. Mapping is conducted by interpretation of 1:62,500 scale stereo aerial photography and topographic maps. Dominant LTA units in the Stehekin Watershed (Fig. 9) include Headland Catchment Basins, Scoured Glacial Troughwall and Headlands, Scoured Glaciated Slopes, Glacial Cirque Basins, Glacial Troughwalls, Meltwater Coulees, Glaciated Trough Valley Bottoms, Valley Bottom Outwash and Landslides Undifferentiated.

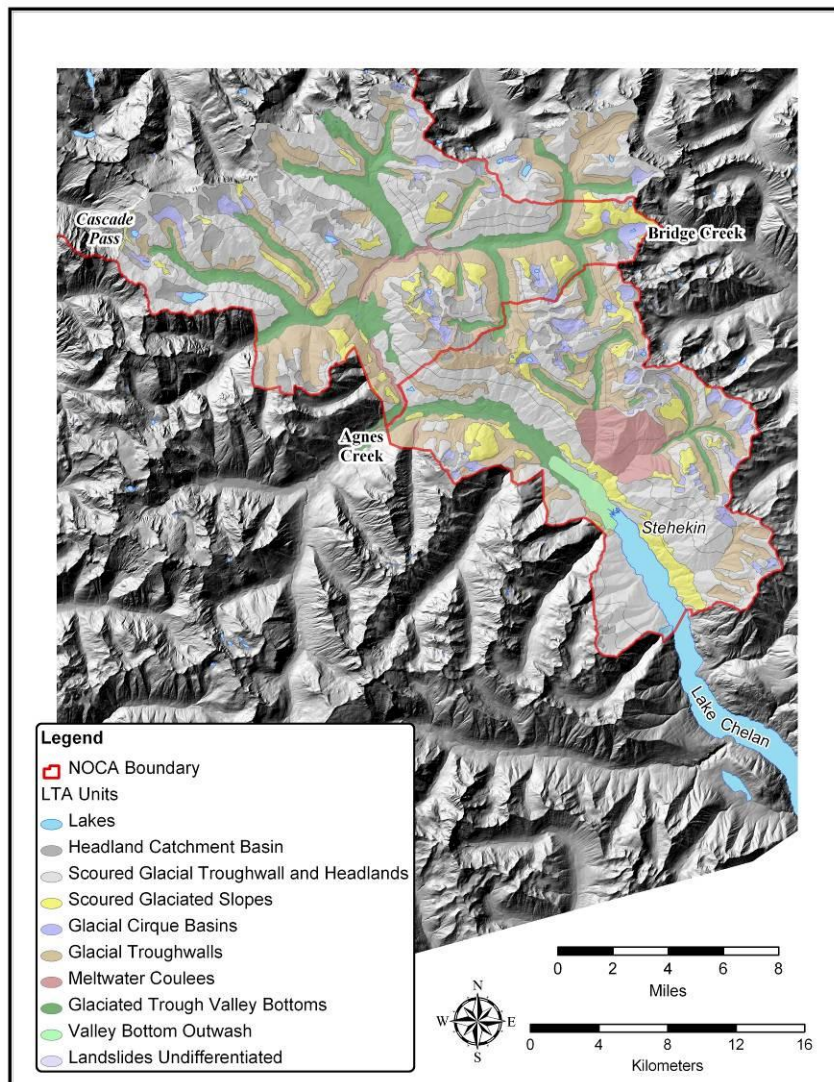


Figure 9. LTA map (1:62,500) of the Stehekin River Watershed within NOCA.

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

These are the smallest functional units of the landscape that are created by discreet geologic processes, many of which are active in the watershed today. These subdivisions of Landtypes, or

landforms, are based on topographic criteria, hydrologic characteristics, associations of soil taxa, and plant communities. They are readily identified on topographic maps and aerial photographs, but require field-verification when beneath closed canopy forests. A suite of 29 different landforms is currently being mapped at NOCA (Table 3). A detailed description of each landform, which includes information on location, associated landforms, process, material, mapping guidelines and potential natural vegetation will be published in separate NPS Technical Report.

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

Unit	Description
-High elevation landforms (primarily erosional in genesis)	
H	Horn
A	Arete
C	Cirque
O	Other Mountain
R	Ridge
P	Pass
NM	Neoglacial Moraine
PG	Patterned Ground
-Valley slope landforms (primarily erosional in genesis)	
VW	Valley Wall
RC	River Canyon
BB	Bedrock Bench
-Transitional landforms between valley slope (erosion) and valley floor (deposition)	
MM-F	Rock Fall and Topple
MM-A	Debris Avalanche
MM-S	Slump and Creep
MM-DT	Debris Torrent
MM-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
U	Undifferentiated

3.2 Landform Age

Landforms can either be depositional in nature, such as moraines and alluvial fans, or they can be erosional such as bedrock benches and horns. Many depositional features such as moraines and terraces were formed during the last ice age. Other depositional features such as debris cones and landslides are forming today. Landform age can vary greatly within a watershed depending on the surficial process that created it. Approximate ages can be assigned to depositional landforms based on their available radiocarbon dates, associated process of formation, volcanic tephra, soil development and vegetation type and age. The approximate ages of landforms at NOCA reflect their stability and are listed below in Table 4. Data were obtained from several different

radiocarbon dates on a variety of landforms within NOCA by the park geology and archeology programs (Mierendorf 1999, Mierendorf et al. 1998, Riedel 2007, Riedel et al. 2007).

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

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

3.2.1 Landforms and Soils

The North Cascades provide a challenging environment to compile a traditional soil survey. Studies in the North Cascades and the surrounding vicinity link pedogenic processes to soil-landscape relationships and provide insight to the links between landforms and soils (Rodgers 2000, Briggs 2004, Briggs et al. 2006). Soil distribution is closely linked to the geomorphic processes at play over the last 15 Ka. NRCS soil scientists incorporate landform maps into the RASP modeling scheme as an indicator of soil stability, age, 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 is not the only parent material that 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 (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 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 has a certain degree of consistency in regards to 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 on debris aprons. Landforms formed primarily through alluvial erosion tend to lack soil material strongly influenced by volcanic tephra. On landforms such as debris cones, terraces, and alluvial fans, Inceptisols dominate. Entisols are found on the youngest landforms most susceptible to recent flooding (floodplains and terraces) or recent deglaciation (cirques and little ice age moraines) that the soil profile lacks the influence of volcanic tephra. Histosols are the most independent of landform as they simply require an accumulation of organic matter (Soil Survey Staff 1999). This accumulation of organic matter can be found in micro-depressions and floodplains throughout the park where water tables are persistent and organic decomposition is slower than accumulation.

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. A common area for Histosols to form is in the small depressions between bedrock benches and valley walls where water and debris accumulate, or in extensive floodplain systems.

4 - Methods

4.1 Preliminary Methods

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

4.2 Field Methods

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

4.3 Digitizing Methods

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

4.4 Areas Surveyed

The Stehekin Valley Road, Company Creek Road and several other unimproved roads provide good access throughout the lower Stehekin valley. Numerous established hiking trails, including the Pacific Crest Trail, were used to access field investigation sites and follow each major tributary in the watershed. There are also unmaintained hunting, climbing, and animal trails that were followed throughout the watershed when available.

Field investigations in the Stehekin River Watershed were conducted over a period of decades beginning in the late 1980s. Final field investigations were completed in the summer seasons of 2001 and 2002 by Robert Burrows, Marsha Davis, Daniel Diedrich, Rich Everett, Skye Gruen, Cathi Jones, Mike Larrabee, Dan McCrumb, Jon Riedel, Wendy Ross, and Jeanna Wenger of the NOCA Resource Management staff. These areas were accessed by trail, by traveling in the riverbed via wading, and bushwhacking. Field visits to each major tributary were completed from the main stem of the Stehekin River. The Stehekin River was field checked from Cascade Pass to Lake Chelan (Fig. 2). The tributaries that were field checked include lower Agnes Creek, Boulder Creek, Bridge Creek, Flat Creek, McAlester Creek, Park Creek, and Rainbow Creek (Fig. 2). 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 Sahale Arm and McGregor Mountain. Aerial surveys were made via several helicopter flights while in transit to other NPS research projects.

5 - Results and Discussion

5.1 General Watershed Overview

Major features of the Stehekin River Watershed are deep-seated glacial canyons, long ridges, towering arêtes and horns, extreme local relief, tributary headwalls, striking asymmetry in geomorphology by aspect and the dominance of valley walls. The headwaters of the Stehekin River begin along the southeast-facing slopes of Sahale Mountain and Boston Peak above Doubtful Lake and Cascade Pass and Sahale Arm (Fig. 10). These two peaks along their arêtes confine the northwestern-most corner of the watershed. Ripsaw Ridge, Buckner Mountain, Mt. Logan, Mt. Arriva, Corteo Peak, Black Peak, and their respective arêtes and ridges form the northern edge of the watershed boundary (Figs. 10 and 11). This boundary divides the southeast flowing Stehekin River from the north flowing Thunder Creek. Along the eastern edge of the watershed Stiletto Peak, Twisp Mountain, McAlester Mountain, Rennie Peak, Reynolds Mountain and their respective arêtes, ridges, and mountain passes mark the divide between the Stehekin River Watershed and the Methow River Watershed.

Between ice sheet glaciations, valley glaciers flowed dozens of times from cirques through the Stehekin River valley forming a large, valley glacier system (Riedel 2007). The main stem of the Stehekin River is a broad U-shaped glacial valley with a flat valley bottom, straight profile and low gradient, created by both the southward excursions of the Cordilleran Ice Sheet and the multiple glaciations by alpine glaciers flowing down major tributaries. 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 Stehekin River, these streams deposited alluvial fans. Other glacial characteristics of the valley include over-steepened valley walls and truncated valley spurs.

Throughout the watershed, steep cliffs are found more often on north-facing slopes due to the influence of aspect in the development of valleys. Valley walls in the upper reaches contain sparse vegetation with little to no soil cover, particularly those that face south to southwest. Streams that drain these slopes have a flashy hydrology and are prone to debris torrents. Within the watershed, 68.59% is valley wall and 7.27% is high elevation cirque; with only 3.25% as riparian (floodplain, valley bottom and alluvial fan) (Table 5).

Floodplain in the Stehekin Watershed extends from 335 m at Lake Chelan to 1035 m in elevation in the main valley, with tributary floodplains to 1525 m. The transition from floodplain to valley bottom occurs near 1220 m throughout the watershed, with valley bottom extending up to 1700 m before merging with valley walls and debris aprons at valley heads. 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 debris accumulation zone, or debris apron, is between the valley bottom/floodplain and the valley wall and extends from 900 m to 1950 m. First and second order streams almost all have debris cones at their junctions with larger streams.

Table 5. Summary of area of each landform type within the Stehekin River Watershed.

Landform Type	Number Observed	Area (km ²)	Percent of Stehekin River Watershed (%)
Valley Wall	17	371.94	68.59
Debris Apron	281	55.06	10.15
Cirque	133	39.42	7.27
Debris Cone	303	16.57	3.06
Floodplain	9	9.12	1.68
Mass Movement-Fall/Topple	312	8.37	1.54
Valley Bottom	33	5.94	1.09
Bedrock Bench	120	5.70	1.05
River Canyon	47	5.20	0.96
Terrace	197	5.12	0.94
Ridge	104	4.11	0.76
Alluvial Fan	7	2.63	0.48
Arete	100	2.44	0.45
Pleistocene Moraine	31	2.31	0.43
Horn	56	1.97	0.36
Mass Movement-Debris Avalanche	13	1.45	0.27
Fan Terrace	35	1.19	0.22
Other Mountain	57	0.95	0.18
Neoglacial Moraine	70	0.91	0.17
Undifferentiated	23	0.81	0.15
Mass Movement-Debris Torrent	41	0.57	0.11
Pass	52	0.33	0.06
Mass Movement-Slump/Creep	14	0.13	0.02
Mass Movement-Sail	2	0.01	0.01
Totals	2057	542.24	100

5.1.1 High Elevation Landforms

High elevation landforms (cirques, Neoglacial moraines, ridges, arêtes, other mountains, horns, and passes) account for 50 km², or 9.25% of the Stehekin River Watershed (Table 5). The majority of this area is cirque basin. Particularly well-developed cirque basins are located on Sahale Mountain, Boston Peak and Buckner Mountain. Aspect has a strong control on the development of cirque basins, with those that face north and east deeper and broader than those on southerly aspects. The lower cirque floor boundaries have been mapped from 1645 m to 2250 m.

The entire watershed was inundated by the Cordilleran Ice Sheet as recently as 16 Ka. Passes and ridges below 2000-2100 m were over-run, beveled and broadened. Particularly well-developed horns in the watershed were shaped by alpine glaciers and generally stood above the level of the sheet. These peaks stood as islands of rock above the ice sheet and are known nunataks. Prominent nunataks include Sahale Mountain, Boston Peak, Buckner Mountain, Goode Mountain and Mt. Logan. Lower ridges and mountains were mostly rounded by the ice sheet and contain glacial striae and polished bedrock. Recent glacial activity is recorded in Neoglacial moraines, many of these landforms were deposited by alpine glaciers in the last 700 to 100 years. There are 70 Neoglacial moraines in the Stehekin River Watershed.

5.2 Characteristics of Sub-Watersheds

5.2.1 Main Stem of Stehekin River

The valley head of the Stehekin River is ringed by cirques with floors that extend down to 1830 m on north-facing aspects and 2200 m on south-facing aspects (Fig. 10). The main stem of the Stehekin River begins in an extremely deep cirque occupied by Doubtful Lake and near Cascade Pass (Fig. 10), which is the drainage divide between the Cascade/Skagit River watershed and the Stehekin/Columbia River watershed (Fig. 10). The headwaters of the Stehekin River are defined by four distinct basins: Pelton, Doubtful, Horseshoe, and Trapper Lake basins, each with relatively short 1st order tributaries that flow into the main stem Stehekin River. Southeast of Cascade Pass, Pelton Basin is confined by jagged arêtes and the horns of Pelton Peak, Magic Mountain and Mix-Up Peak (Fig. 10). Northeast of Cascade Pass, Horseshoe and Doubtful basins are well-defined cirques confined by the arêtes and horns of Sahale Mountain, Boston Peak, Buckner Mountain, Horseshoe Peak, Buckner Mountain, and Ripsaw Ridge (Fig. 10).

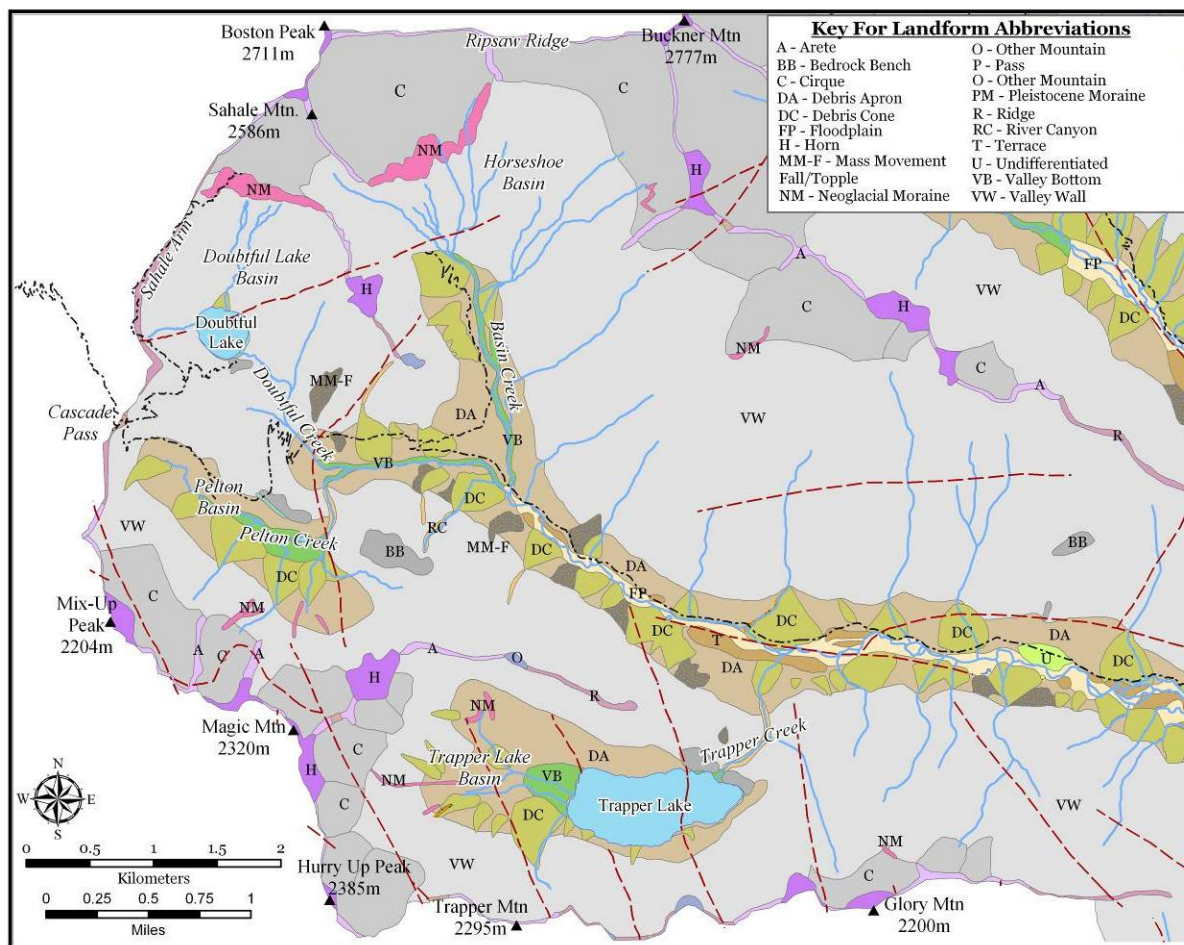


Figure 10. Landform map of the Stehekin River headwaters and the Cascade Pass area, dot-dashed black lines represent trails and red dashed lines are faults.

Doubtful Creek descends from Doubtful Lake (1640 m) and joins Pelton Creek to form the main stem of the Stehekin. Pelton Creek flows across a valley bottom at that begins at 1440 m in broad

Pelton Basin. Pelton Creek, a hanging valley, then enters into a river canyon before joining the main stem Stehekin. Valley bottom on the main stem Stehekin begins at 1160 m and flows southeast before widening into floodplain at 965 m, just downstream of its confluence with Basin Creek. In this upper reach, the Stehekin River is relatively constricted with a narrow floodplain before it widens at Cottonwood Creek, which drains Trapper Lake basin. The floodplain remains wide, with extensive ~1 m high terraces before constricting into a river canyon. The Stehekin emerges from the river canyon and is joined by tributaries Flat Creek and Park Creek (Fig. 11). At the junction of Flat Creek with the Stehekin River, the floodplain widens and near the junction with Bridge Creek the river bends to flow south-southeast (Fig. 11). The wide floodplain continues below Bridge Creek then ends at a river canyon from Tumwater to where Agnes Creek joins the Stehekin River.

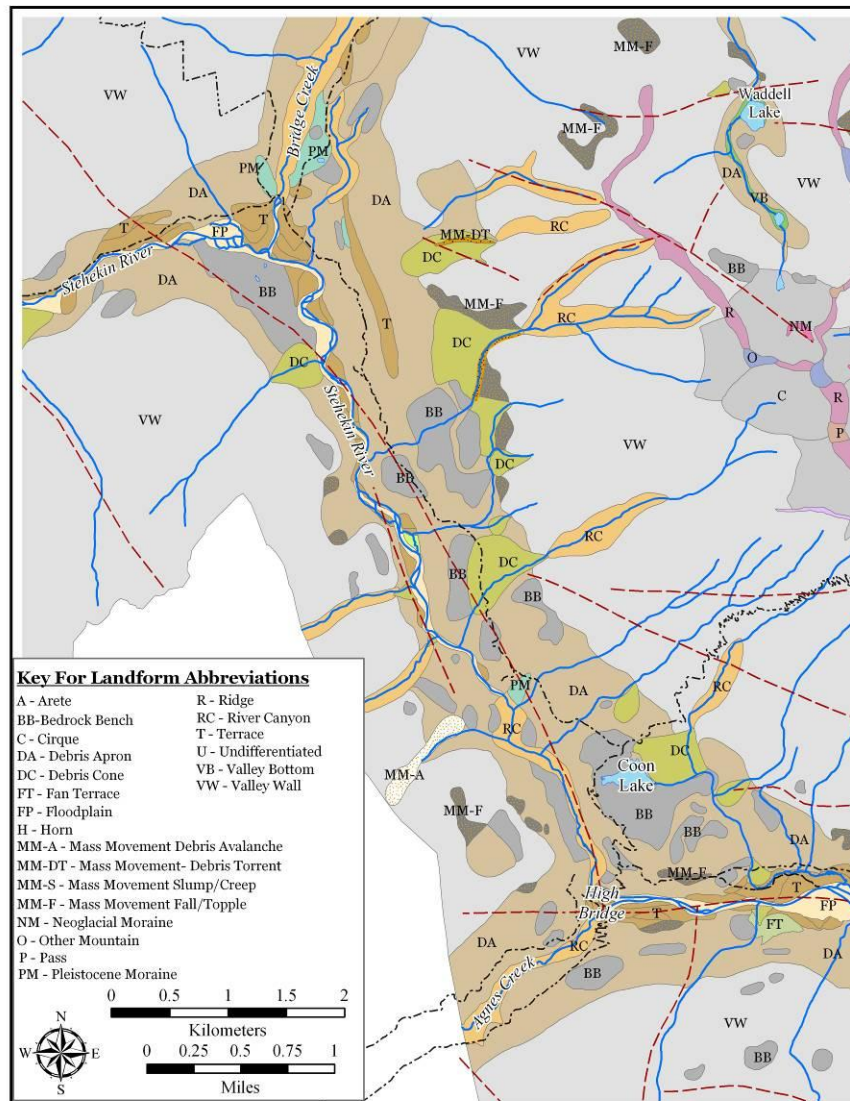


Figure 11. Landform map of the Stehekin River between Bridge Creek and High Bridge, dot-dashed black lines represent trails and red dashed lines are faults.

The deep valley fills along the Stehekin River from Flat Creek to Bridge Creek are cut into a series of fan terraces at Park Creek and multiple river terraces as high as 15 m. The deposits were likely left by the Cordilleran Ice Sheet as it retreated from this valley 13-11.5 Ka. Below High Bridge, the Stehekin River along with Agnes Creek, emerge from deep river canyons into the broad lower valley (Fig. 12). This part of the valley from Bridge Creek down, was glaciated by both alpine glaciers and the Cordilleran Ice Sheet. During multiple ice ages, glaciers created the valley's characteristic U-shape, straight profile, and flat valley floor (Riedel 2008). On the southwest side of the valley, the Cordilleran Ice Sheet left a long, lateral Pleistocene moraine 13-11.5 Ka that can be traced from the Stehekin Valley Ranch to the Orchard (Fig. 12).

The Stehekin River channel in the lower valley above McGregor Meadows is incised approximately 5 meters within sand and gravel terraces. Extensive alluvial fans deposited by major tributaries Company, Boulder, and Rainbow creeks define the area in which the Stehekin River has meandered in the past (Fig. 12). The fans contain terraces that grade to elevations more than 5 m above the modern floodplain. These fan terraces were formed when the level of Lake Chelan was higher following the end of the last ice age (Riedel 2008). Thus, base level for the lower Stehekin valley decreased until the 1920's, when Chelan Public Utility District raised the level of the lake approximately 5 m with a hydroelectric dam. Base level of the river above Buckner Orchard may be bedrock controlled because the river channel is currently superimposed across a bedrock valley spur. The river also flows against the bedrock toe of the valley wall across from the lower field of McGregor Meadows (Fig. 12).

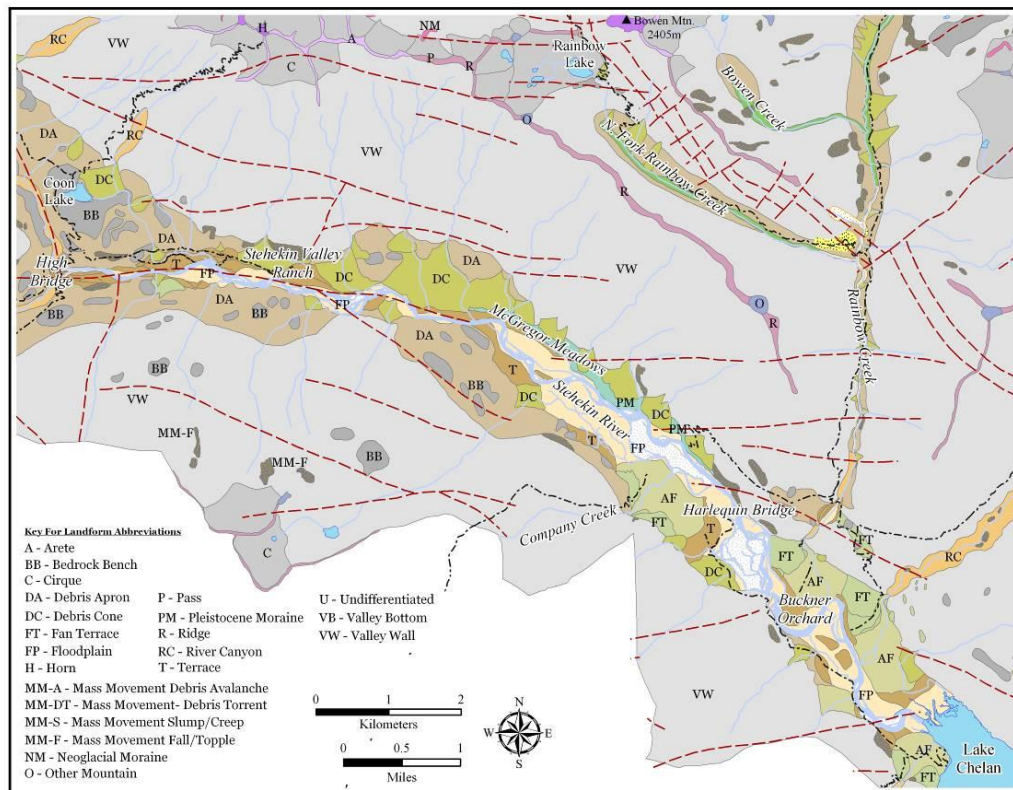


Figure 12. Landform map of the lower Stehekin valley, dot-dashed black lines represent trails, red dashed lines are faults, and white with gray speckled areas in river channel represent gravel bars.

There is a pronounced asymmetry in the geology of the lower Stehekin valley due to the extreme northeast-southwest faces of the valley walls. The hot, dry north side (southwest facing) of the valley is characterized by steep streams that frequently carry debris torrents to the valley bottom. These debris torrents on the small, steep 1st order streams can be triggered by heavy falls rains and by isolated summer thunderstorms. In contrast, forest cover is thicker on the northeast facing side of the valley, and runoff is generally less flashy and debris torrents less common. The main stem has many mass movements, predominantly rock falls and debris torrents, but very few large debris avalanches. The stability of the valley walls is due in large part to the very hard and competent Skagit Gneiss bedrock. A more detailed discussion of mass movements is presented below in the Landslide Inventory section of this report.

5.2.2 Park Creek

Park Creek drains southeast from Park Creek Pass along a fault before joining the main stem Stehekin (Fig. 13). Park Creek Pass is the drainage divide between the Thunder Creek and Stehekin River Watersheds (Fig. 2). Judging by scour marks and striae, it appears that the Cordilleran Ice Sheet barely flowed across the pass during the last ice age. The valley head of Park Creek is defined to the south and west by the long, rounded Park Creek Ridge, and the glacial horns Booker Mountain and Buckner Mountain (Fig. 13). The valley is defined to the north and east by glacial horns Storm King, Goode Mountain, and Goode Ridge (Fig. 13). The headwaters of Park Creek have high elevation cirques with floors that extend down to 1890 m, and contain several Neoglacial moraines. Valley bottom begins at 1525 m and extends down to 1244 m on main stem Park Creek. The floodplain begins at 1244 m before constricting into a river canyon until it merges with Stehekin valley. Below the river canyon, Park Creek forms an alluvial fan and a series of fan terraces on the Stehekin valley floor. The fan terraces range in height up to 25 m above the modern alluvial fan surface. There are two Pleistocene moraines located on the northeast side of the valley. These moraines likely date back to a period of alpine glacier growth from cirques approximately 13-11.5 Ka, at the end of the last ice age.

There are few mass movements in Park Creek valley with the exception of several rock falls and debris torrents. One of these debris torrents occurred during a 2006 storm and flood event contributed a significant amount of debris into the stream. Debris torrents, like this one are a major source of sediment delivery from first order tributary streams to the main channel throughout the watershed.

5.2.3 Flat Creek

There is only a small portion of Flat Creek within NOCA boundary with the remainder in the Glacier Peak Wilderness and Okanogan-Wenatchee National Forests (Fig. 2). The portions of Flat Creek that were mapped include the lower reaches of the South Fork Flat Creek and Flat Creek. The South Fork flows north from the NOCA boundary and is a relatively confined, hanging, colluvial valley with a steep gradient and valley bottom that ends at a river canyon. There are three debris avalanches on the west side of the valley and two on the east side (Fig. 14). This is the most debris avalanches of any sub-watershed within the overall Stehekin Watershed. These slides occurred along a faulted contact between Skagit Gneiss and Eldorado Orthogneiss (Fig. 3). The main fork of Flat Creek is broad with many small sets of terraces that separate active floodplain and inactive channels. Flat Creek is aptly named because alpine glaciers have left the valley straight and with little gradient. The floodplain extends from the NOCA boundary northeast before joining the Stehekin River just slightly upstream from Park

Creek (Figs. 13 and 14). This section of broad floodplain forms a wetland that may be forming due to the active Park Creek alluvial fan restricting the flow of Flat Creek and the Stehekin River.

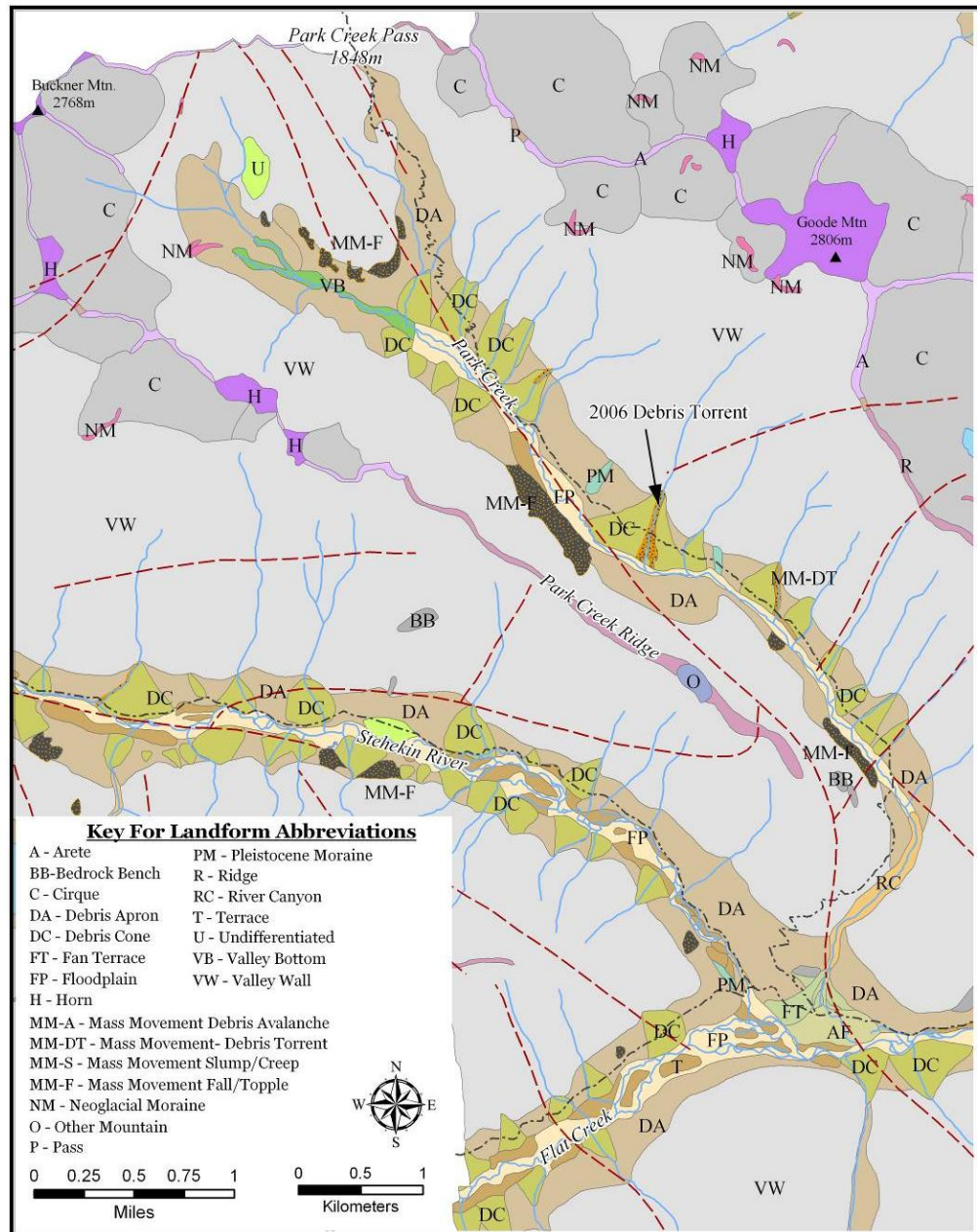


Figure 13. Landform map of Park Creek, dashed black lines represent trails and red dashed lines are faults.

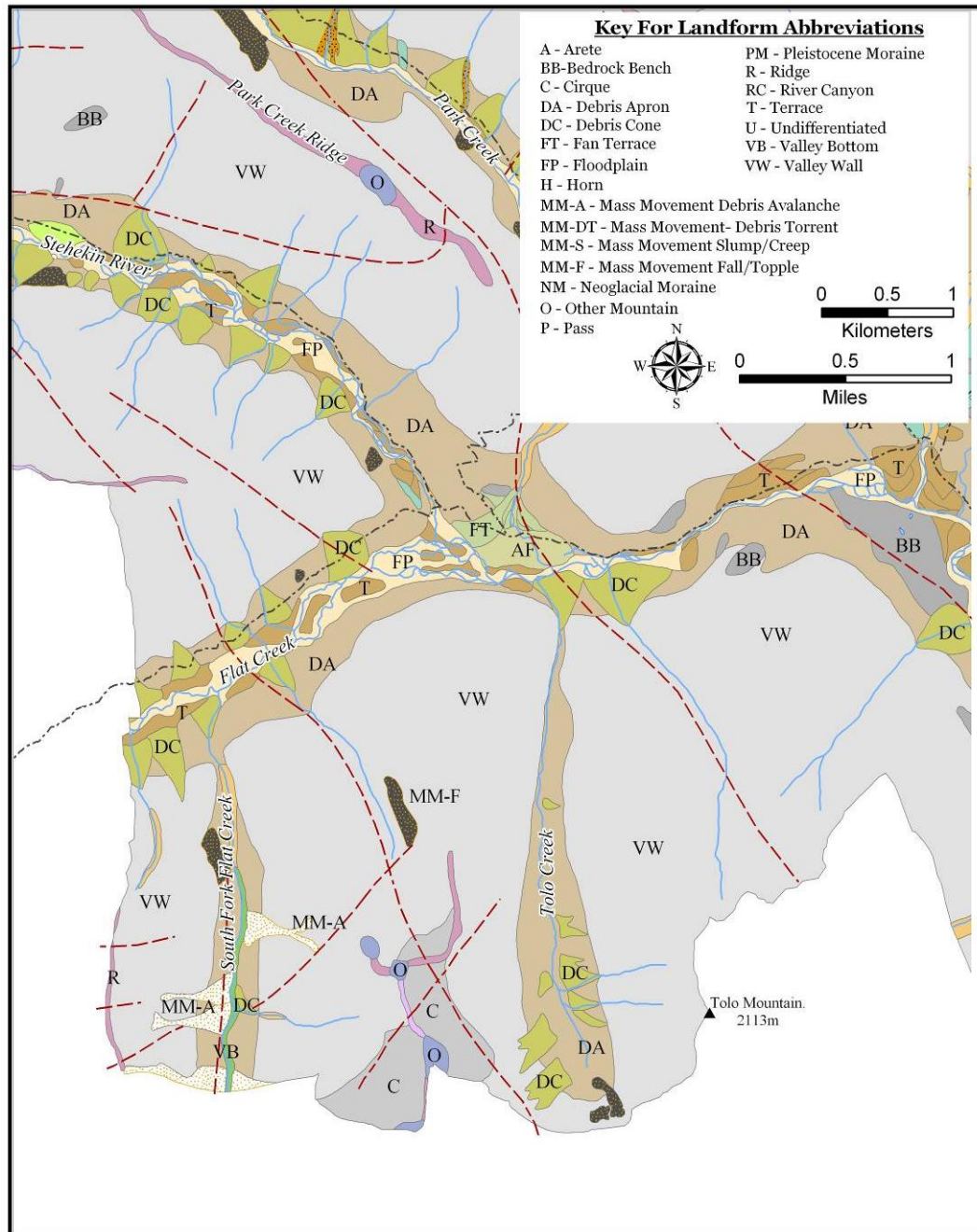


Figure 14. Landform map of Flat Creek, dot-dashed black lines represent trails and red dashed lines are faults.

5.2.4 Bridge Creek

The Bridge Creek sub-watershed includes the main fork Bridge and its tributaries North Fork, South Fork, East Fork, Maple, and McAlester Creeks. The headwaters of the main fork Bridge Creek are located just outside of the east park boundary in the Okanogan-Wenatchee National Forest (Fig. 2).

Bridge Creek begins near Rainy Pass, and was a major conduit of flow for the ice sheet from Skagit valley to Lake Chelan. Another lobe of the ice sheet also entered Bridge Creek from Fisher Pass (Fig. 16). Both of these passes were lowered and broadened by the ice sheet, and are potentially major migration routes across the Pacific Crest. Bridge Creek flows south from the NOCA boundary before bending west-southwest near its junction with McAlester Creek. The most prominent features on the floor of Bridge Creek valley are a series of large boulder bars located along the main stem from the headwaters to the north Fork. These landforms are composed of round to angular boulders as large as 1 m diameter, with the crests of the features that stand several meters above the creek. While the exact genesis of these landforms is uncertain, they are tentatively linked to sub-glacial drainage beneath the Cordilleran Ice Sheet. Bridge Creek has floodplain and a series of terraces with heights up to 18 m above the floodplain. After the confluence with McAlester Creek, Bridge Creek flows in a floodplain before plunging into a river canyon. Bridge Creek briefly emerges from the canyon with a small floodplain before descending back into another river canyon.

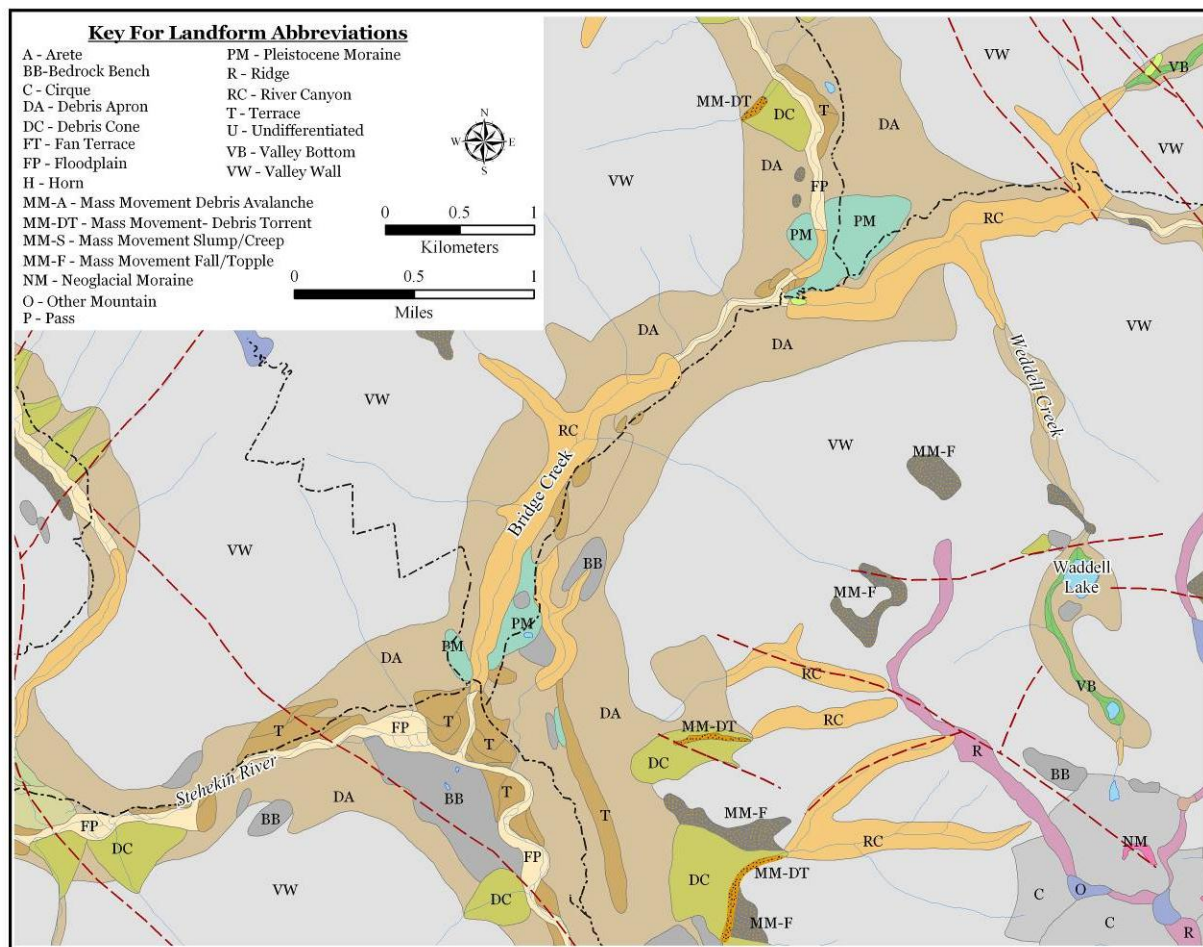


Figure 15. Landform map of the lower reach of Bridge Creek, dot-dashed black lines represent trails and red dashed lines are faults.

There is a Pleistocene moraine at the confluence of South Fork and Bridge Creek that is the source of several small slumps. Another Pleistocene moraine is present at the confluence of

North Fork and Bridge Creek. These moraines are likely left by the Cordilleran Ice Sheet approximately 13-11.5 Ka. A series of terraces were mapped at the mouth of Bridge Creek with heights up to 18 m. There are numerous mass movements that exist in the Bridge Creek sub-watershed. Debris torrents occur at the apex on many of the debris cones along with slumps at the toe of some debris cones and Pleistocene moraines. There is one large debris avalanche located just downstream from the confluence with McAlester Creek, which will be discussed in greater detail in the Landslide Inventory section of this report.

5.2.5 North Fork Bridge Creek

The North Fork of Bridge Creek splits into Grizzly Creek and North Fork Bridge Creek. Grizzly Creek is then split into Fisher Creek, Woody Creek, and Falls Creek (Fig. 16). The North Fork Bridge Creek headwaters are ringed by the impressive glacial horns of Goode Mountain, Storm King, and Mt. Logan with cirque floors extending down to 1900 m. These cirques contain small glaciers and five Neoglacial moraines. Valley bottom begins at 1525 m of elevation and extends southwest before widening into floodplain at 1000 m. The floodplain continues until descending into a short river canyon just upstream from the confluence with Bridge Creek.

The head of Fisher Creek valley is defined by Fisher Pass as opposed to well-defined cirques, arêtes and horns (Fig. 16). Fisher Creek flows southwest in valley bottom that begins at 1525 m. There is a large Pleistocene moraine at the upstream junction of Grizzly Creek and Fisher Creek. Woody Creek flows west in relatively constrained valley bottom. The valley head of Woody Creek is formed by glacial horn Corteo Peak and two small cirques with floor elevations down to 2134 m. These cirques contain two small Neoglacial moraines.

The Grizzly Creek headwaters flow from glacial arêtes and the prominent horns Mt. Arriva, Fisher Peak, and Black Peak (Fig. 16). There are cirques with floor elevations down to 1925 m containing seven Neoglacial moraines. There is a Pleistocene moraine located at the head of the debris accumulation unit of Grizzly Creek at 1700 m; all other large Pleistocene moraines mapped in the Stehekin River Watershed are found at or near the junction of two creeks. This moraine, like others within 5-10 km of valley heads, dates to a glacial advance approximately 13 Ka. Grizzly Creek flows south-southwest in valley bottom that begins at 1525 m of elevation. Valley bottom continues down to 987 m where an alluvial fan is formed at the confluence with North Fork Bridge Creek. Numerous mass movements were mapped in North Fork Bridge Creek. These mass movements were predominantly rock falls occurring on valley walls and debris torrents occurring on debris cones.

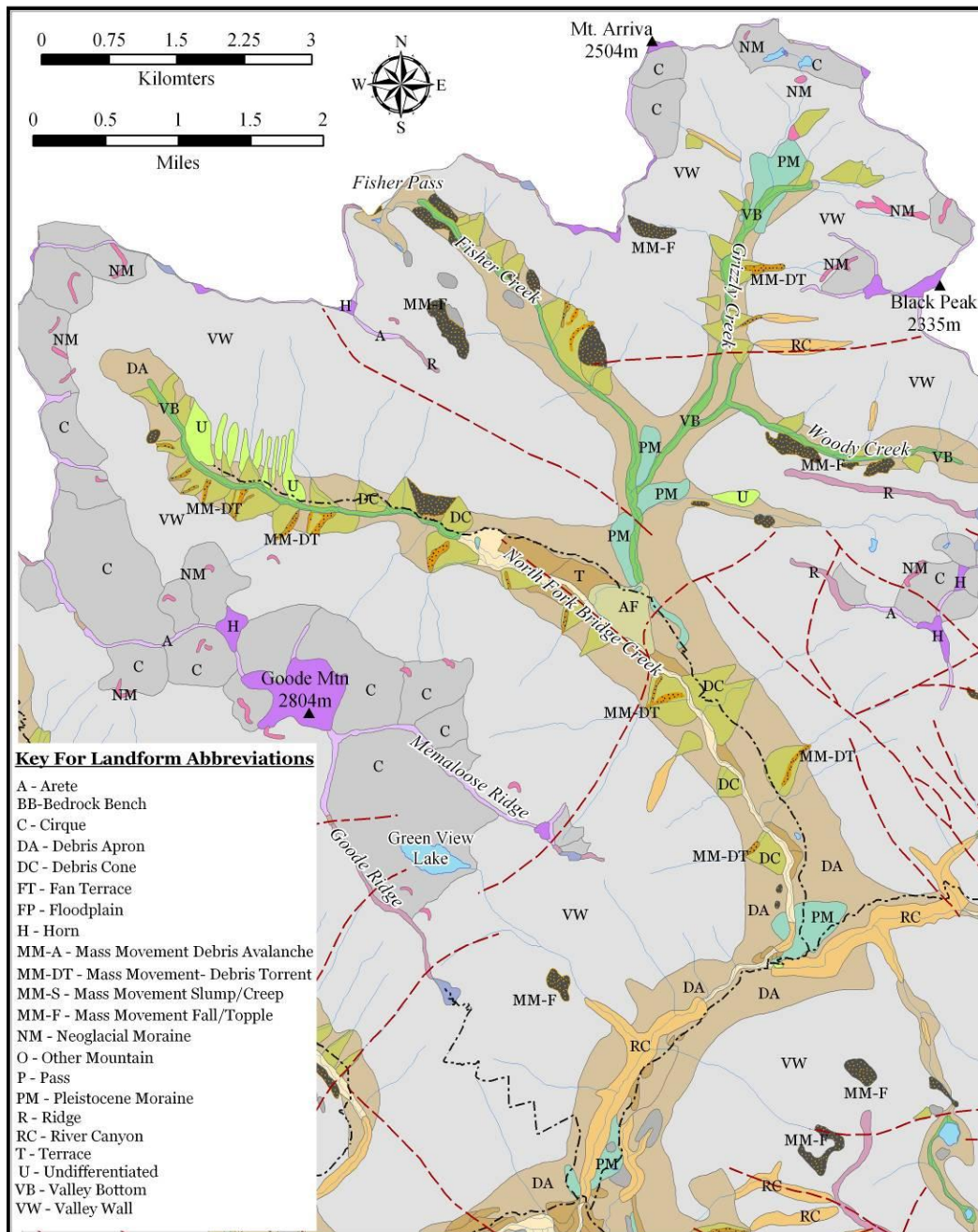


Figure 16. Landform map of North Fork Bridge Creek, dot-dashed black lines represent trails and red dashed lines are faults.

5.2.6 South Fork Bridge Creek

South Fork Bridge Creek headwaters consist of several cirques occupied by small glaciers, including the larger Sandalee Glacier, with Neoglacial moraines and the prominent glacial horn of McGregor Mountain (Fig. 17). South Fork Bridge Creek initially flows east then bends north before joining the main stem of Bridge Creek. There is ~2 km of valley bottom that changes to floodplain at elevation 1438 m. Here the valley broadens substantially to a wide floodplain with a series of 1.5 m terraces. There are no major mass movements along the South Fork, but there

are several debris torrents on first order tributary streams, one small debris avalanche, and several rock falls.

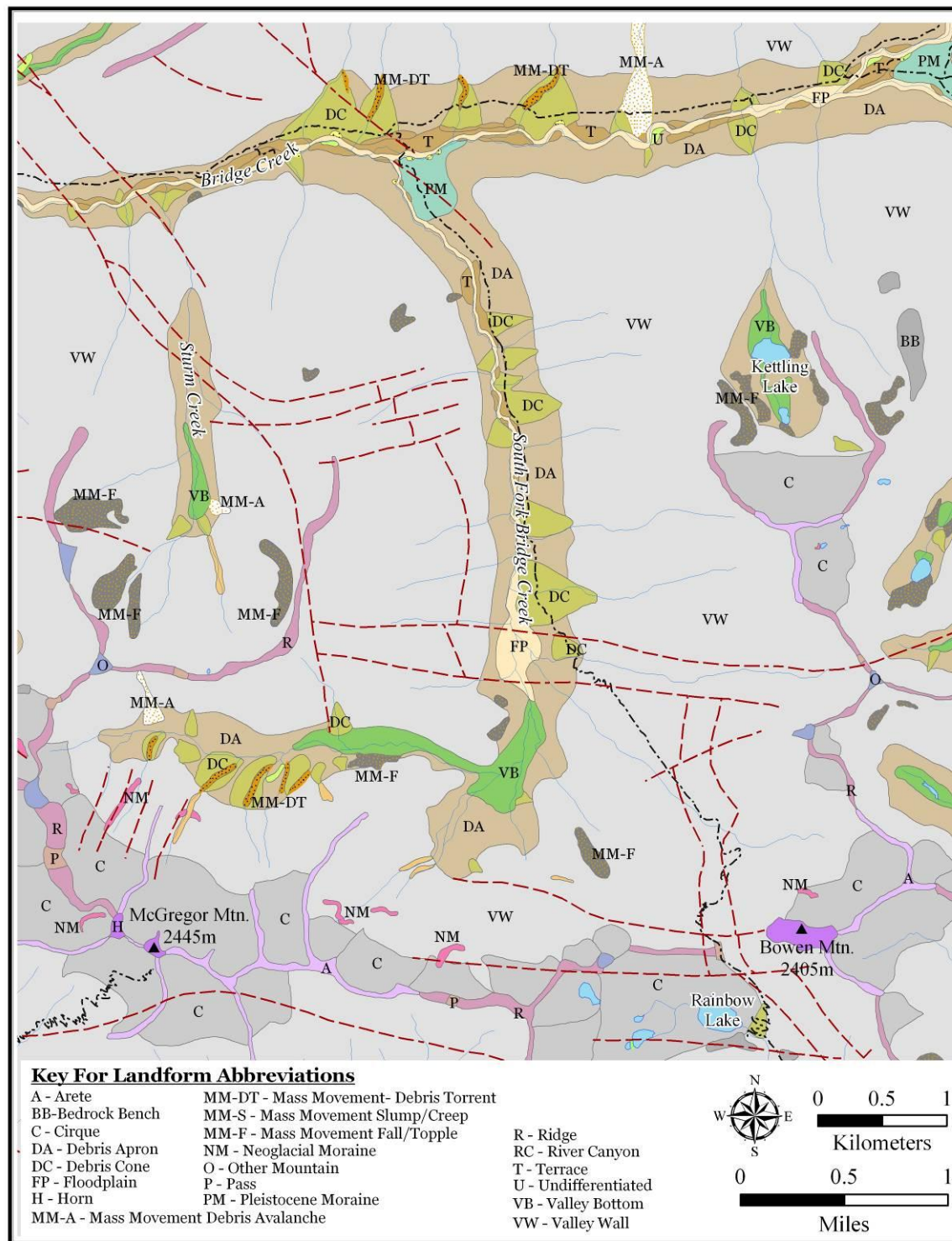


Figure 17. Landform map of South Fork Bridge Creek, dot-dashed black lines represent trails and red dashed lines are faults.

5.2.7 Maple Creek

Maple Creek flows southwest to join Bridge Creek within a relatively constricted, colluvial valley in mostly valley bottom. This high-elevation watershed is prone to large snow avalanches. The creek is a hanging valley with a short river canyon at its mouth. The Maple Creek valley head is at Horsefly Pass with the glacial horns Corteo Peak, Mt. Benzarino, Frisco Mountain and their flanking arêtes (Fig. 18). There are several cirques with floors extending down to elevations between 1830 m and 2316 m. There are 10 rock falls scattered throughout the Skagit Gneiss valley walls of the Maple Creek sub-watershed, but no large landslides.

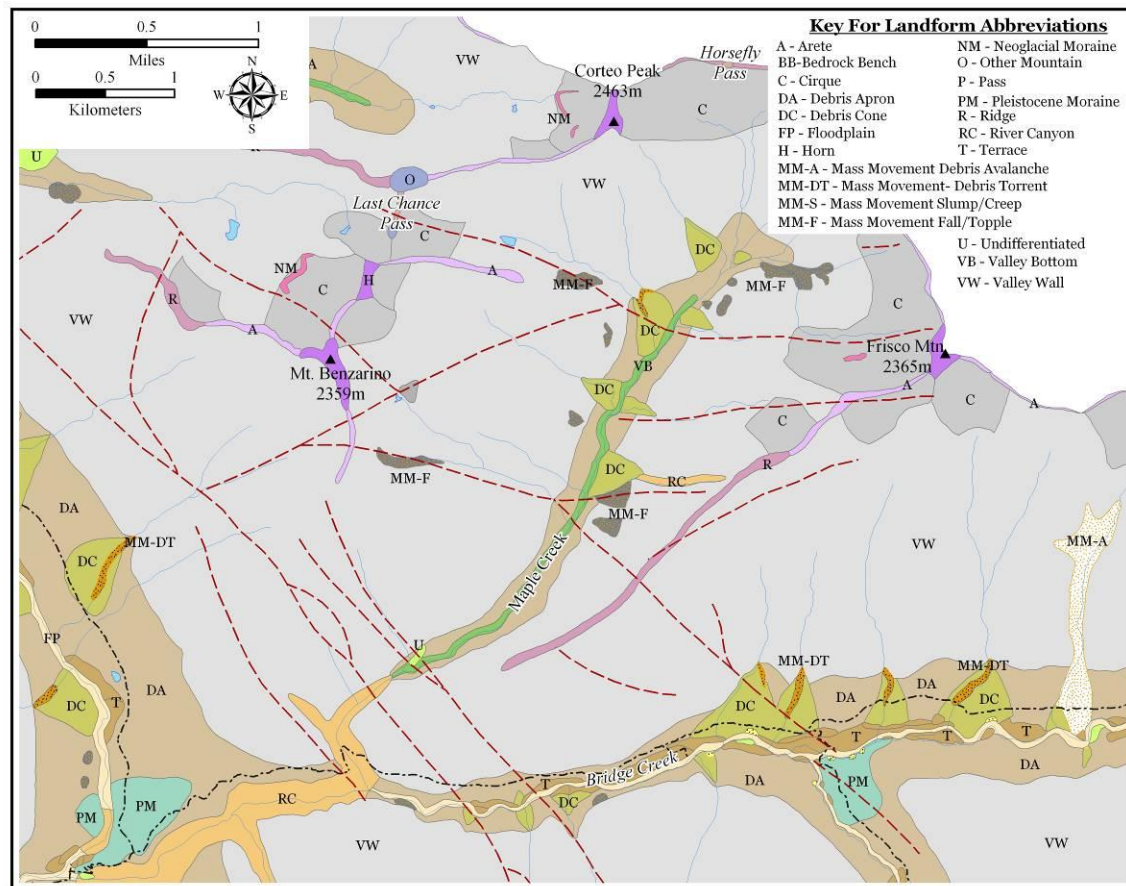


Figure 18. Landform map of Maple Creek, dot-dashed black lines represent trails and red dashed lines are faults.

5.2.8 McAlester Creek

The McAlester Creek sub-watershed includes the East Fork McAlester, Solleks, and main stem McAlester Creeks. The Solleks Creek valley is defined to the south by Rainbow Ridge and several small cirques with floors that extend down to 1950 m. McAlester Creek descends from McAlester Pass into McAlester Lake (Figs. 19 and 20). The pass is an unusually broad feature, formed in part by erosion associated with repeated excursions of the Cordilleran Ice Sheet into the Stehekin watershed. The valley bottom extends from McAlester Lake downstream to the junction with Solleks Creek. Floodplain begins here and continues north-northwest to the junction with Bridge Creek. There are a series of low terraces that are up to 3 m above the floodplain.

The East Fork of McAlester Creek flows west-southwest for 7 km before joining McAlester Creek. The East Fork headwaters include several small cirques around Stiletto Peak with cirque floor elevations down to 2072 m and several around Hock Mountain with elevations as low as 1828 m (Fig. 20). The headwaters of East Fork may have been dammed during the Pleistocene by a series of moraines creating an old lake bed. There are two Pleistocene moraines on both sides of the valley around 1207 m just below Dagger Lake and a large marshy valley bottom. These Pleistocene moraines have a very hummocky surface, large sub-rounded boulders, and pools of standing water, and are not sharp-crested. The valley bottom extends from Dagger Lake west-southwest to McAlester Creek. This colluvial valley is relatively confined with no floodplain or terraces mapped.



Figure 19. View of the McAlester Pass area (Photo courtesy of Jeanna Wenger, North Cascades National Park).

East Fork of McAlester Creek contains a unique landform feature on the North side of Hock Mountain (Figs. 20, 21 and 22). When viewed by air photos it resembles a rock glacier. The landform has all the characteristics of a rock glacier, which include: north facing aspect, completely rock covered, lobe shaped tongue, near terminus ridges (possible small lateral moraines), depressions near the tongue (possible ice melt out), the gradient of tongue having steep crested on uphill side with lower slope angle on downhill side, and limited vegetation. Exploring the feature by foot confirmed initial photo observations, but no evidence of ice was found. A stream was flowing from the eastern edge of the landform but water origin could not be confirmed. There were a few small residual snow patches on the surface that probably did not account for sole drainage source. Without the confirmation of ice, the landform was mapped as a

debris avalanche that may have buried some glacial ice (Figs. 21 and 22). However, given the low elevation of the landform, it unlikely had significant glacial cover during the Holocene. There are 13 rock falls in the McAlester Creek valley occurring mainly within the debris accumulation zone. In addition to the debris avalanche described above, there is another large debris avalanche on the west side of Hock Mountain (Fig. 20).

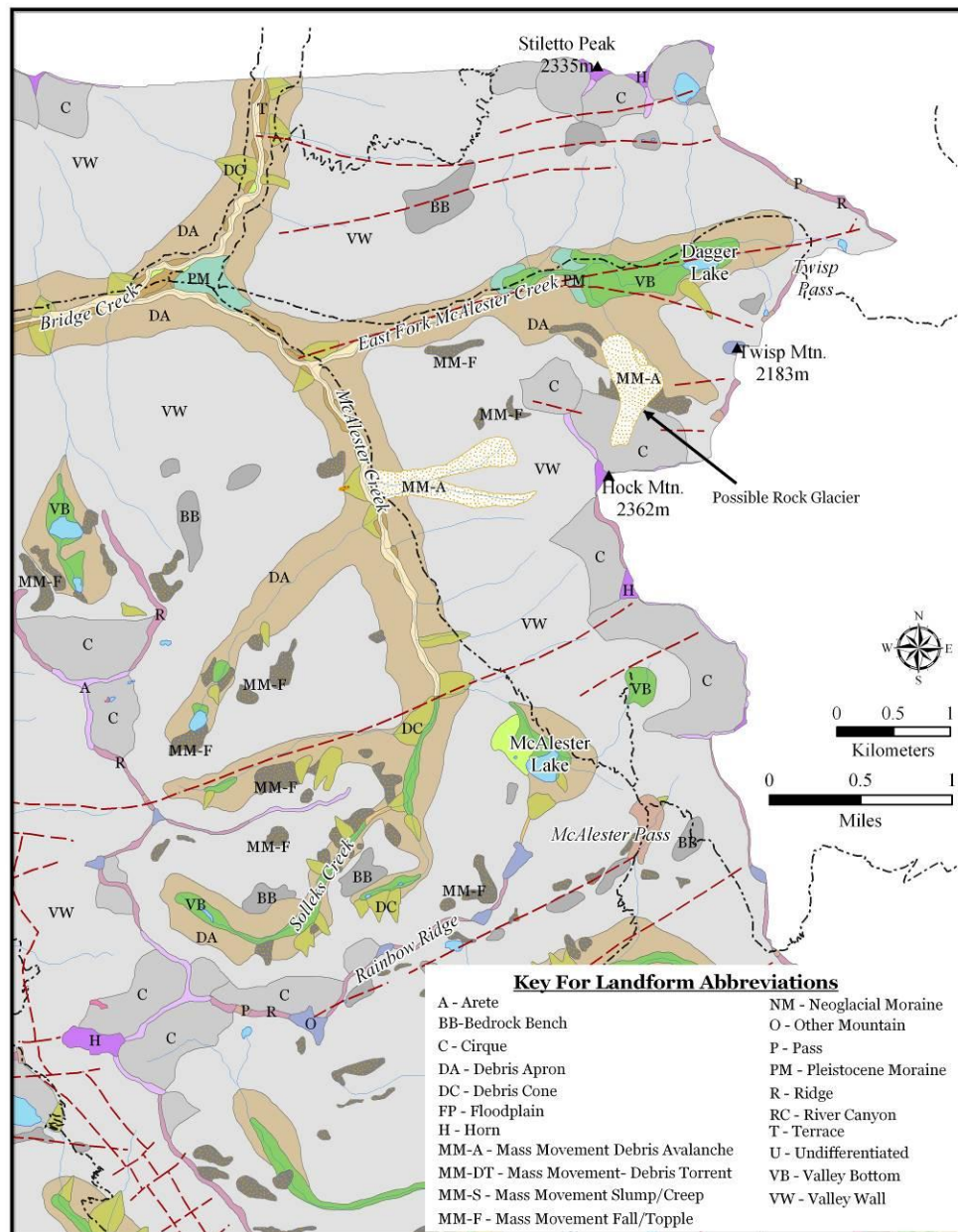


Figure 20. Landform map of McAlester Creek, dot-dashed black lines represent trails and red dashed lines are faults.



Figure 21. This debris avalanche is located at the head of the East Fork McAlester Creek on the north side of Hock Mountain. The tree covered ridge in the foreground marks the toe of this landform (Photo courtesy of Jeanna Wenger, North Cascades National Park).



Figure 22. A profile view of the toe of the debris avalanche landform located at the head of the East Fork McAlester Creek on the north side of Hock Mountain. (Photo courtesy of Jeanna Wenger, North Cascades National Park).

5.2.9 Rainbow Creek

The Rainbow Creek sub-watershed includes North Fork Rainbow Creek, Bowen Creek, Bench Creek, and Rainbow Creek. The headwater area of Rainbow Creek is bound, west to east, by Rainbow Ridge, McAlester Pass, and glacial horn McAlester Mountain (Fig. 23). There are two cirques on the north side of McAlester Mountain with Neoglacial moraines extending down to elevations of 1890 m. Rainbow Creek flows south in valley bottom that begins at 1670 m and widens to floodplain at 1220 m, several hundred meters downstream from the confluence of Bowen and Rainbow Creeks.

Bowen Creek is a steep, constricted, hanging valley. There are two cirques, with cirque floor elevations down to 2010 m on the southeast side of Bowen Mountain (Fig. 23). North Fork Rainbow Creek descends from McAlester Mountain steeply into the glacially stepped upper valley. It then becomes floodplain before joining Rainbow Creek. Downstream from the North Fork, Rainbow Creek valley narrows considerably and enters a river canyon before it emerges into floodplain along with a series of terraces ranging from 5 to 10 m above the floodplain. Rainbow Creek then returns to a short canyon for before plunging 95 m on to the floor of the lower Stehekin valley, where it forms forming a large alluvial fan. Rainbow Creek is the only tributary to the Stehekin with a significant waterfall that plunges directly onto the flat valley floor (Tabor and Haugerud 1999). There is a series of fan terraces that occur up to 300 m above the modern fan surface (Fig. 23).

There are numerous mass movement rock falls in the Rainbow Creek sub-watershed, one large debris avalanche and one large slump, which are both just upstream of the North Fork and Rainbow Creek confluence. There is also a snow avalanche impact landform (SAIL) mapped in Lake 6303 below the north face of McAlester Mountain and another mapped in an unnamed lake just above Rainbow Lake (Figs. 24 and 25). SAILS are elliptical depressions and ridge-like deposits created by a snow avalanche impact with unconsolidated sediments on valley floors. SAILS are formed by a combination of topography of the avalanche track, availability of unconsolidated debris in the impact area, and have an avalanche impact pressures exceeding 1MPa (Johnson 2003).

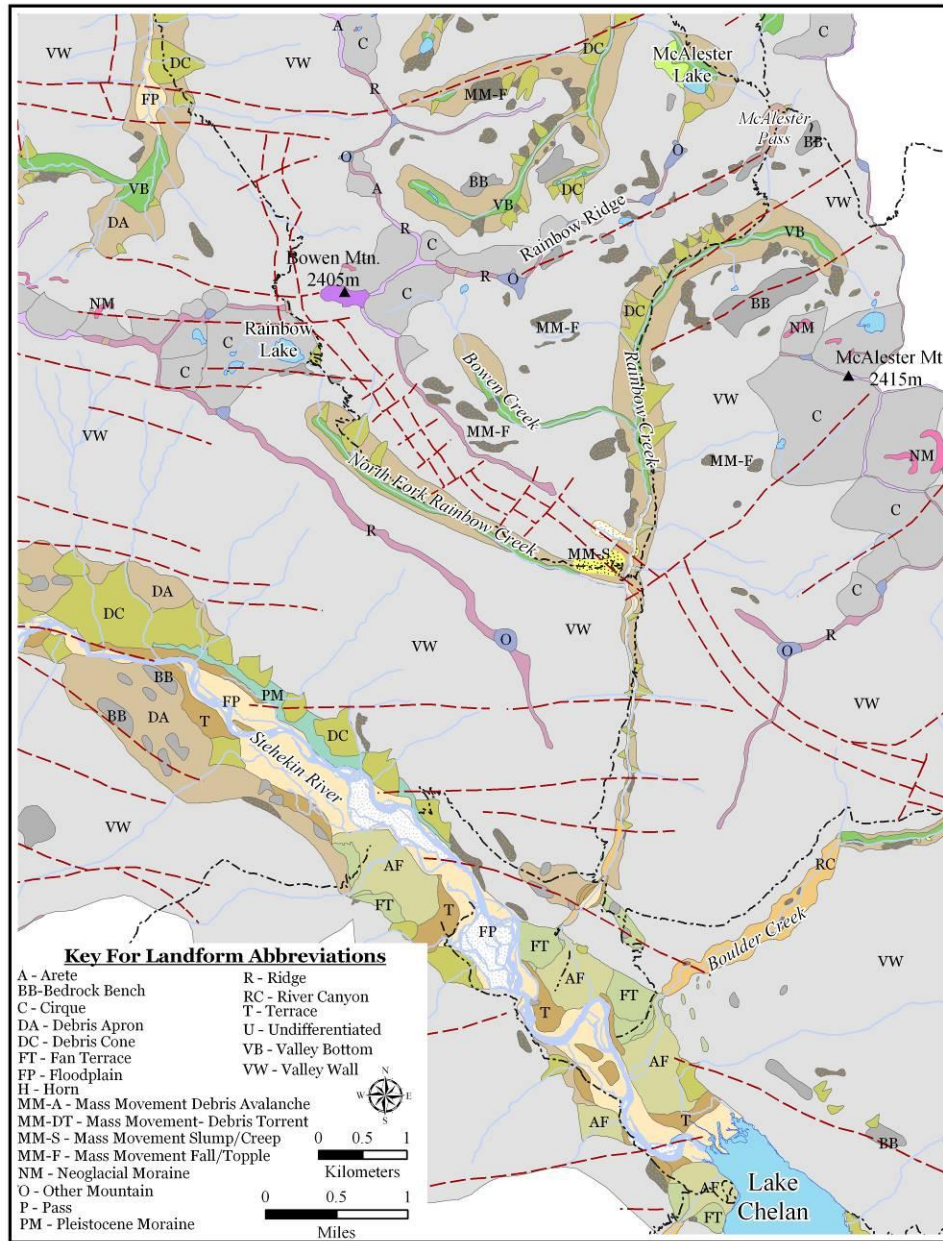


Figure 23. Landform map of Rainbow Creek, dot-dashed lines represent trails and red dashed lines are faults.



Figure 24. View looking down at the Snow Avalanche Impact Landform in an unnamed lake just northwest of Rainbow Lake, below the eastern ridge of McGregor Mountain (Photo courtesy of Sharon Brady, North Cascades National Park).



Figure 25. View of the Snow Avalanche Impact landform in Lake 6063 below the north face of McAlester Mountain (Photo courtesy of Sharon Brady, North Cascades National Park).

5.2.10 Boulder Creek

The Boulder Creek sub-watershed includes Rennie Creek, Butte Creek and Boulder Creek. The Boulder Creek headwaters are bound by glacial horn Reynolds Peak, the eastern NOCA boundary, Boulder Butte, and Purple Mountain to the south (Fig. 26). There are two cirques on the southeast side of Reynolds Peak with elevations down to 2255 m and one Neoglacial moraine. Boulder Creek flows west-southwest without floodplain or terraces in a steeply graded stream. Boulder Creek then descends from a valley bottom into a narrow river canyon extending down to the Stehekin valley floor and forms a large alluvial fan with a series of fan terraces above the modern, active fan surface (Fig. 26).

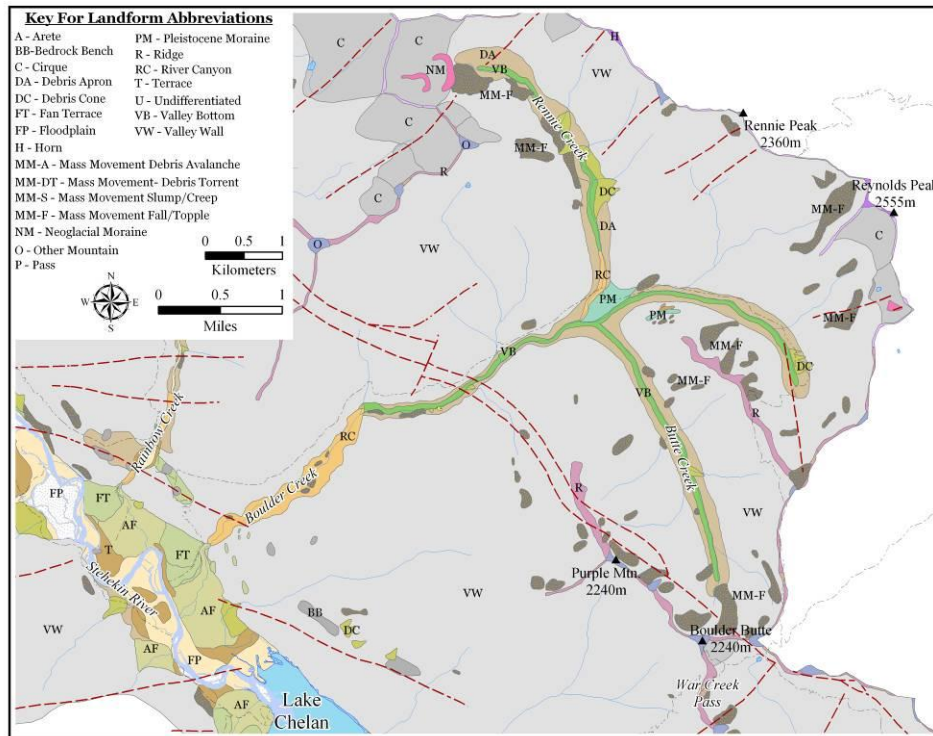


Figure 26. Landform map of Boulder Creek, dot-dashed lines represent trails and red dashed lines are faults.

Butte Creek flows north-northwest before joining Boulder Creek (Fig. 26). Butte Creek is a narrow, colluvial valley with only valley bottom present from 1700 m to 1200 m. There is a narrow band of debris apron present with one debris cone. Boulder Butte and Purple Mountain, both mapped as Other Mountain landforms, comprise the headwaters of Boulder Creek. Rennie Creek flows south-southeast in valley bottom and a short river canyon near its mouth. Rennie Creek originates in four headwater cirques with elevations down to 1900 m; these cirques hold two Neoglacial moraines, but no modern glaciers. There is one large Pleistocene moraine at the junction of Butte Creek and the upper reach of Boulder Creek. There is another smaller, lateral Pleistocene moraine along the upper reach of Boulder Creek just upstream from the confluence of Boulder Creek and Butte Creek. Below this Pleistocene moraine are two terraces 15 and 45 m above the valley bottom that are likely kame terraces formed along the margin of a former glacier. There are a myriad of small mass movement rock falls throughout the valley walls and debris apron of the Boulder Creek sub-watershed, but no large debris avalanches.

5.3 Stehekin River Watershed Landslide Inventory

Information on landslides can guide the selection of LTEM reference sites or building/maintaining public facilities such as trails, campgrounds, and bridges. A landslide database was created to accompany landform maps with data collected on 18 characteristics of each landslide, including age, activity, bedrock geology, material type, and area. For large mass movement avalanches, depth of the cavity and the volume of sediment delivered to river/creek were also estimated. Reviewing this data can tell a great deal about the overall stability of a particular area of the watershed, which can be related to factors such as bedrock type, aspect, and proximity to faults (Appendix A).

Large landslides in the steep terrain of the Stehekin River Watershed are important events in the valley's natural history. They can block streams and create lakes and/or wetlands and fish migration barriers. They also provide large woody debris to streams that help establish log jams and influence river pattern and habitat far downstream of the landslide.

A total of 382 mass movements constitute 10.5 km² of area in the watershed, which is only 2% of the total area. Debris avalanches are large landslides that generally include the failure of rock and debris. They are of particular importance due to their large size, potential to block streams, and deliver massive amounts of large woody debris and sediment to stream systems. This material can be disruptive to aquatic ecosystems, create temporary debris dams and contributes to the overall bedload of the Stehekin River. The 13 debris avalanches total an area of 1.45 km² (Table 6). This is a relatively low number for a watershed at NOCA, which could be attributed to the competency of the Skagit Gneiss bedrock that is exposed extensively throughout the Stehekin River Watershed. A total of eight of the debris avalanches mapped in the watershed delivered sediment to a stream and one of them likely blocked a creek entirely for a short time. Evidence of blockages on the river include massive debris avalanches delivered directly to the river channel and debris avalanches 'pushing' the river across to the far side of its channel, resulting in meanders controlled by debris deposits. These deposits deserve special mention for the sediment they delivered to the main stem of the system and the river channel dynamics they created upon blocking the channel. Of the thirteen debris avalanches, eight delivered a total estimated 5,200,000 m³ of sediment to creeks. The majority of debris avalanches occurred in of rocks of the Skagit Gneiss Complex and include Quaternary glacial deposits.

The largest of the debris avalanches occurred in the McAlester Creek sub-watershed on the west side of Hock Mountain (Fig. 20). This 385,000 m² landslide delivered an estimated 1,990,000 m³ of debris to the stream system. The slide occurred in tonalite of the Black Peak Batholith. Along the main fork of Bridge Creek, a 269,000 m² landslide delivered an estimated 1,285,000 m³ of debris to the stream system. This slide also occurred in tonalite of the Black Peak Batholith. Several other debris avalanches that delivered material to the stream system all occur in the South Fork of Flat Creek sub-watershed. There are five debris avalanches in this valley, which is the most of any sub-watershed in the Stehekin. These moderate sized landslides have a total area of 250,000 m² and delivered an estimated 820,000 m³ of debris to the stream system (Fig. 14). These slides occurred along a faulted contact between Skagit Gneiss and Eldorado Orthogneiss (Fig. 4). The one debris avalanche that blocked the stream entirely occurred in Rainbow Creek. This 60,000 m² landslide delivered an estimated 350,000 m³ of debris to the stream system and formed a temporary debris dam, forcing Rainbow Creek over to the east side of the valley. This

debris avalanche occurred in Skagit Gneiss near a fault zone that exposes Napeequa Schist (Fig. 23). Slumps in the watershed tended to occur in the valley bottom or from sections of glacial till and colluvium in the debris apron. Most of the rock falls tend to be on east to north-east facing slopes, where the effects of freeze-thaw are most pronounced.

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

Mass Movement Type	# of Each Type	Surface Area (km ²)	% of Total Watershed
Debris Avalanche	13	1.45	0.27
Fall/Topple	312	8.37	1.54
Debris Torrent	41	0.57	0.11
Slump/Creep	14	0.13	0.02
SAIL	2	0.01	0.01
Totals	382	10.53	2.13

Debris torrents are also important contributors to the total amount of sediment delivered to streams systems. These channelized debris flows are stratified as deposits on debris cones and are often found at the mouths of river canyons, along fault zones and below hanging valleys. There are 41 mapped debris torrents in the Stehekin River Watershed, which is a relatively high number for a watershed at NOCA. This large number of debris torrents may be due to the dryer climate and associated vegetation that naturally occurs in the eastern portions of the watershed. These dryer areas are more prone to wildfire, which is known to accelerate sediment transport from mountain drainage basins (Swanson 1981, Meyer *et al.* 1995, Meyer *et al.* 2001). Debris flows and debris torrents are frequently produced in response to convective thunderstorm activity over basins burned by wildfire (Parett 1987, Meyer and Wells 1997, Cannon 2001), as well as in response to winter frontal storms (Morton 1989, Cannon 2001). Rapid spring snowmelt, summer convective storms, and fall rain on snow events are all relatively common weather events in the Stehekin River Watershed. These climatological events occur in both recently burned and unburned basins and are likely contributing factors to the large number of debris torrents observed in the Stehekin Watershed.

6 - Future Work

6.1 Progress Report

The field component of the landform mapping at North Cascades National Park Service Complex is 100% complete. LiDAR data for the Goodell and Newhalem Creek Watersheds 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 for MORA was acquired in May of 2009 and subsequent editing of the GIS layer is currently underway. 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 and MORA is 2010. OLYM is scheduled to be complete by 2013.

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Appendix A. Landslide Inventory for the Stehekin River 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 m² and km². Measurement is taken off the GIS for all mass movements.

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

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

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

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

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

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.

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
31	1	McAlester	31-1-2	2	S		Y	Qu
31	2	East Fk. McAlester	31-2-3	3	R		N	Kt
31	3	East Fk. McAlester	31-3-3	3	R		N	Kt
31	4	East Fk. McAlester	31-4-1	1	R		N	Tkto
31	5	East Fk. McAlester	31-5-1	1	R		N	Kt
31	6	East Fk. McAlester	31-6-1	1	R		N	Kt
31	7	East Fk. McAlester	31-7-1	1	R		N	Tkto
31	8	McAlester	31-8-1	1	R		N	Tkto
31	9	East Fk. McAlester	31-9-1	1	R		N	Tkto
31	10	McAlester	31-10-1	1	R		N	Tkto
31	11	McAlester	31-11-1	1	R		N	Qu
31	12	McAlester	31-12-4	4	S		N	Qu
31	13	McAlester	31-13-3	3	S/R		Y	TKto
31	14	McAlester (W. Trib)	31-14-1	1	R		N	TKto
31	15	McAlester (W. Trib)	31-15-1	1	R		N	Qu
31	16	McAlester (W. Trib)	31-16-1	1	R		N	TKto
31	17	McAlester (W. Trib)	31-17-1	1	R		Y	Qu
31	18	McAlester (W. Trib)	31-18-1	1	R		Y	Qu
31	19	McAlester (W. Trib)	31-19-1	1	R		Y	Qu
31	20	McAlester (W. Trib)	31-20-1	1	R		N	TKto
31	21	McAlester (W. Trib)	31-21-1	1	R		N	TKto
31	22	McAlester (W. Trib)	31-22-1	1	R		N	TKto
31	23	Kettling Creek	31-23-1	1	R		N	TKto
31	24	Solleks Creek	31-24-1	1	R		N	TKto
31	25	Solleks Creek	31-25-1	1	R		Y	Qu
31	26	Solleks Creek	31-26-1	1	R		N	TKto
31	27	Solleks Creek	31-27-1	1	R		N	TKto
31	28	Solleks Creek	31-28-1	1	R		N	TKto
31	29	Solleks Creek	31-29-1	1	R		N	TKto
31	30	Solleks Creek	31-30-1	1	R		Y	TKto
31	31	Bridge Creek	31-31-2	2	S		Y	Qu
31	32	Bridge Creek	31-32-2	2	S		Y	Qu
31	33	Bridge Creek	31-33-3	3	D		Y	TKto
31	34	Kettling Creek	31-34-1	1	R		N	Tkto
31	35	McAlester	31-35-1	1	R		N	TKto
31	36	Kettling Creek	31-36-1	1	R		Y	Tkto

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
31	31	Bridge Creek	31-31-2	2	S		Y	Qu
31	32	Bridge Creek	31-32-2	2	S		Y	Qu
31	33	Bridge Creek	31-33-3	3	D		Y	TKto
31	34	Kettling Creek	31-34-1	1	R		N	Tkto
31	35	McAlester	31-35-1	1	R		N	TKto
31	36	Kettling Creek	31-36-1	1	R		Y	Tkto
31	38	Kettling Creek	31-38-1	1	R		N	Tkto
30	39	Bridge Creek	30-39-2	2	S		Y	Qt
30	40	Bridge Creek	30-40-4	4	R/S		Y	Qt
30	41	Bridge Creek	30-41-4	4	R/S		Y	TKto
30	42	Bridge Creek	30-42-4	4	R/S		Y	Qu
30	43	Bridge Creek	30-43-4	4	R/S		Y	Qu
30	44	Bridge Creek	30-44-2	2	T		Y	Qt
30	45	Bridge Creek	30-45-2	2	T		Y	Qt
30	46	Bridge Creek	30-46-2	2	T		Y	Qt
30	47	S Fk Bridge Creek	30-47-2	2	R/S		Y	TKto
30	48	S Fk Bridge Creek	30-48-1	1	R		N	TKto
30	49	S Fk Bridge Creek	30-49-1	1	R		N	TKto
30	50	S Fk Bridge Creek	30-50-1	1	R		N	Qu
30	51	S Fk Bridge Creek	30-51-1	1	R		N	Qu
30	52	S Fk Bridge Creek	30-52-1	1	R		N	Tkso
30	53	S Fk Bridge Creek	30-53-1	1	R		Y	Qu
30	54	S Fk Bridge Creek	30-54-4	4	D		Y	Qu
30	55	S Fk Bridge Creek	30-55-4	4	D		Y	Qu
30	56	S Fk Bridge Creek	30-56-4	4	D		Y	Qu
30	57	S Fk Bridge Creek	30-57-4	4	D		Y	Qu
30	58	S Fk Bridge Creek	30-58-4	4	D		Y	Qu
30	59	S Fk Bridge Creek	30-59-3	3	D		N	Qu
30	60	Strum Creek	30-60-1	1	R		Y	Tkso
30	61	Strum Creek	30-61-1	1	R		N	Tkso
30	62	Strum Creek	30-62-3	3	D		N	Tkso

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
30	64	Strum Creek	30-64-1	1	R		Y	Tkso
30	65	Bridge Creek	30-65-1	1	R		N	TKns
30	66	Bridge Creek	30-66-2	2	R/S		Y	Qt
30	67	Bridge Creek	30-67-2	2	D		Y	Qt
30	68	Bridge Creek	30-68-1	1	R		N	TKto
30	69	Bridge Creek	30-69-1	1	R		Y	Tkso
30	70	Waddell Creek	30-70-1	1	R		Y	Tkso
30	71	Bridge Creek	30-71-1	1	R		N	Tkso
30	72	Maple Creek	30-72-1	1	R		N	TKto
30	73	Maple Creek	30-73-1	1	R		N	TKto
30	74	Maple Creek	30-74-1	1	R		N	Qt
30	75	Maple Creek	30-75-1	1	R		N	Qt
30	76	Maple Creek	30-76-1	1	R		N	Qt
30	77	Maple Creek	30-77-1	1	R		Y	Qt
30	78	Maple Creek	30-78-4	4	D		Y	Qt
30	79	Maple Creek	30-79-4	4	D		Y	Qt
30	80	Maple Creek	30-80-1	1	R		N	Qt
30	81	Maple Creek	30-81-1	1	R		N	Qt
30	82	Maple Creek	30-82-1	1	R		N	TKto
30	83	Maple Creek	30-83-1	1	R		N	TKto
30	84	N Fk Bridge Creek	30-84-1	1	R		N	Tkso
30	85	N Fk Bridge Creek	30-85-1	1	R		N	Tkso
30	86	N Fk Bridge Creek	30-86-4	4	D		Y	Qag
30	87	N Fk Bridge Creek	30-87-4	4	D		Y	Qag
30	88	N Fk Bridge Creek	30-88-4	4	D		Y	Qu
30	89	N Fk Bridge Creek	30-89-4	4	D		Y	Qu
30	90	N Fk Bridge Creek	30-90-4	4	D		Y	Qu
26	91	Falls Creek	26-91-1	1	R		N	TKto
26	92	Falls Creek	26-92-1	1	R		N	Tkto
26	93	Woody Creek	29-93-1	1	R		Y	Qag
26	94	Woody Creek	26-94-1	1	R		N	Qag

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
26	96	Grizzly Creek	26-96-4	4	D		Y	Qag
26	97	Grizzly Creek	26-97-4	4	D		Y	Qag
26	98	Grizzly Creek	26-98-1	1	R		N	TKto
26	99	Fisher Creek	26-99-4	4	D		N	Qag
26	100	Fisher Creek	26-100-4	4	D		Y	Qag
26	101	Fisher Creek	26-101-1	1	R		Y	Qag
25	102	Fisher Creek	25-102-1	1	R		N	Qag
25	103	Fisher Creek	25-103-1	1	R		N	Qag
25	104	Fisher Creek	25-104-1	1	R		Y	TKto
29	105	N Fk Bridge Creek	29-105-4	4	D		N	Qag
29	106	N Fk Bridge Creek	29-106-4	4	D		N	Qag
29	107	N Fk Bridge Creek	29-107-4	4	R		N	Qag
25	108	N Fk Bridge Creek	25-108-4	4	R		N	Qag
25	109	N Fk Bridge Creek	25-109-4	4	R		Y	Qag
25	110	N Fk Bridge Creek	25-110-4	4	R		N	Qag
25	111	N Fk Bridge Creek	25-111-4	4	R		N	Qag
25	112	N Fk Bridge Creek	25-112-4	4	R		N	Qag
25	113	N Fk Bridge Creek	25-113-4	4	R		N	Qag
25	114	N Fk Bridge Creek	25-114-4	4	R		N	Qag
25	115	N Fk Bridge Creek	25-115-4	4	R		N	Qag
25	116	N Fk Bridge Creek	25-116-1	1	R		N	Qag
30	117	Deadman Creek	30-117-1	1	R		N	Tkso
29	118	Tolo Creek	29-118-1	1	R		N	Tei
29	119	Tolo Creek	29-119-1	1	R		N	Tei
29	120	S. Fk Flat Creek	29-120-3	3	D		Y	Qag
29	121	S. Fk Flat Creek	29-120-3	3	D		Y	Qag
29	122	S. Fk Flat Creek	29-122-3	3	D		Y	Qag
29	123	S. Fk Flat Creek	29-123-3	3	D		Y	Qag
29	124	S. Fk Flat Creek	29-124-3	3	D		Y	Qag
29	125	S. Fk Flat Creek	29-125-1	1	R		N	Qag
29	126	Flat Creek	29-126-1	1	R		N	Tksg

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
29	128	Upper Stehekin	29-128-1	1	R		N	Qag
29	129	Upper Stehekin	29-129-2	2	D		Y	Qag
29	130	Upper Stehekin	29-130-1	1	R		N	Qag
29	131	Upper Stehekin	29-131-1	1	R		N	Qag
29	132	Upper Stehekin	29-132-4	4	D		Y	Qag
29	133	Upper Stehekin	29-133-1	1	R		N	Qag
29	134	Upper Stehekin	29-134-1	1	R		N	TKts
28	135	Trapper Lake	28-135-4	4	D		N	Qu
28	136	Trapper Lake	28-136-4	4	D		Y	TKcs
28	137	Upper Stehekin	28-137-1	1	R		Y	Qt
28	138	Upper Stehekin	28-138-1	1	R		Y	Qt
28	139	Upper Stehekin	28-139-1	1	R		Y	Qt
28	140	Upper Stehekin	28-140-1	1	R		N	Qt
28	141	Upper Stehekin	28-141-1	1	R		N	Qt
28	142	Upper Stehekin	28-142-1	1	R		N	Qt
28	143	Upper Stehekin	28-143-1	1	R		N	Tkgo
28	144	Upper Stehekin	28-144-1	1	R		N	TKgo
29	145	Park Creek	29-145-1	1	R		N	Tkso
29	146	Park Creek	29-146-1	1	R		N	Qag
29	147	Park Creek	29-147-4	4	D		N	Qag
29	148	Park Creek	29-148-4	4	R		N	Qu
29	149	Park Creek	29-149-1	1	R		N	Qu
29	150	Park Creek	29-150-4	4	D		N	Qag
29	151	Park Creek	29-151-1	1	R		N	Qu
29	152	Park Creek	29-152-1	1	R		N	Qu
30	153	Bridge Creek	30-153-1	1	R		Y	TKsg
30	154	Stehekin River	30-154-4	4	D		N	TKsg
30	155	Stehekin River	30-155-4	1	R		N	TKsg
30	156	Stehekin River	30-156-4	4	D		Y	TKsg
30	157	Stehekin River	30-157-1	1	R		Y	TKsg
30	158	Stehekin River	30-158-1	1	R		Y	TKsg

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
30	160	Stehekin River	30-160-1	1	R		N	TKsg
30	161	Stehekin River	30-161-1	1	R		N	TKsg
31	162	Rainbow Creek	31-162-6	6	R		Y	TKto
30	163	Stehekin River	30-163-3	3	D		N	TKsg
30	164	Stehekin River	30-164-1	1	R		N	TKsg
30	165	Stehekin River	30-165-1	1	R		N	TKsg
30	166	Stehekin River	30-166-1	1	R		N	TKsg
30	167	Stehekin River	30-167-1	1	R		N	TKsg
30	168	Stehekin River	30-168-1	1	R		N	TKsg
30	169	Stehekin River	30-169-1	1	T		N	Qa
30	170	Stehekin River	30-170-1	1	R		N	Qa
30	171	Stehekin River	30-171-1	1	R		N	TKso
30	172	Stehekin River	30-172-1	1	R		N	Tkso
31	173	Rainbow Creek	31-173-1	1	R		N	TKto
31	174	Rainbow Creek	31-174-1	1	R		N	TKto
31	175	Rainbow Creek	31-175-1	1	R		N	TKto
31	176	Rainbow Creek	31-176-1	1	R		Y	TKto
31	177	Rainbow Creek	31-177-1	1	R		N	TKto
31	178	Rainbow Creek	31-178-1	1	R		N	TKto
31	179	Rainbow Creek	31-179-1	1	R		N	TKto
31	180	Rainbow Creek	31-180-1	1	R		N	TKto
31	181	Rainbow Creek	31-181-1	1	R		N	TKto
31	182	Rainbow Creek	31-182-1	1	R		N	TKto
31	183	Rainbow Creek	31-183-1	1	R		N	TKto
31	184	Rainbow Creek	31-184-1	1	R		N	TKto
31	185	Rainbow Creek	31-185-1	1	R		N	TKto
31	186	Rainbow Creek	31-186-1	1	R		N	TKto
31	187	Rainbow Creek	31-187-1	1	R		N	TKto
31	188	Rainbow Creek	31-188-1	1	R		N	TKto
31	189	Rainbow Creek	31-189-1	1	R		N	TKto
31	190	Rainbow Creek	31-190-1	1	R		N	TKto

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
31	192	Rainbow Creek	31-192-1	1	R		N	TKto
31	193	Rainbow Creek	31-193-1	1	R		Y	TKto
31	194	Rainbow Creek	31-194-1	1	R		Y	TKto
31	195	Rainbow Creek	31-195-1	1	R		N	TKto
31	196	Rainbow Creek	31-196-1	1	R		N	TKto
31	197	Rainbow Creek	31-197-1	1	R		N	TKto
31	198	Rainbow Creek	31-198-1	1	R		N	TKto
31	199	Rainbow Creek	31-199-1	1	R		N	TKto
31	200	Rainbow Creek	31-200-1	1	R		N	TKto
31	201	Rainbow Creek	31-201-1	1	R		N	TKto
31	202	Rainbow Creek	31-202-1	1	R		N	TKto
31	203	Rainbow Creek	31-203-1	1	R		N	TKto
31	204	Rainbow Creek	31-204-1	1	R		N	TKto
31	205	Rainbow Creek	31-205-1	1	R		N	TKto
31	206	Rainbow Creek	31-206-1	1	R		N	TKto
31	207	Rainbow Creek	31-207-1	1	R		Y	TKto
31	208	Rainbow Creek	31-208-1	1	R		N	TKto
31	209	Bowen Creek	31-209-1	1	R		N	TKto
31	210	Bowen Creek	31-210-1	1	R		N	TKto
31	211	Bowen Creek	31-211-1	1	R		N	TKto
31	212	Bowen Creek	31-212-1	1	R		N	TKto
31	213	Bowen Creek	31-213-1	1	R		Y	TKto
31	214	Bowen Creek	31-214-1	1	R		N	TKto
31	215	Rainbow Creek	31-215-1	1	R		N	TKto
31	216	Rainbow Creek	31-216-1	1	R		N	TKto
31	217	Rainbow Creek	31-217-1	1	R		N	TKto
31	218	Rainbow Creek	31-218-1	1	R		N	TKto
31	219	Rainbow Creek	31-219-3	3	D		BLKD	TKns
31	220	Rainbow Creek	31-220-2	2	R		N	Tkns
31	221	Rainbow Creek	31-221-2	2	D		Y	TKns
31	222	Rainbow Creek	31-222-1	1	R		N	TKto

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
31	224	Rainbow Creek	31-224-1	1	R		N	TKto
31	228	Rainbow Creek	31-228-1	1	R		N	TKto
31	229	Rainbow Creek	31-229-1	1	R		N	TKto
34	230	Rainbow Creek	34-230-1	1	R		Y	Tkso
34	231	Rainbow Creek	34-231-1	1	R		Y	TKso
31	232	Rennie Creek	31-232-1	1	R		N	Qu
31	233	Rennie Creek	31-233-1	1	R		N	Qu
31/37	234	Rennie Creek	31-234-1	1	R		N	Qu
31/37	235	Rennie Creek	31-235-1	1	R		N	Qu
37	236	Rennie Creek	37-236-1	1	R		Y	Qu
37	237	Boulder Creek	37-237-1	1	R		N	TKto
37	238	Boulder Creek	37-238-1	1	R		N	Tkto
37	239	Boulder Creek	37-239-1	1	R		N	TKto
37/35	240	Boulder Creek	37-240-1	1	R		Y	TKto
35	241	Rennie Creek	35-241-1	1	R		N	TKto
35	242	Boulder Creek	35-242-1	1	R		Y	TKto
35	243	Boulder Creek	35-243-1	1	R		N	TKto
35	244	Boulder Creek	35-244-1	1	R		N	TKto
35	245	Boulder Creek	35-245-1	1	R		N	TKto
35	246	Boulder Creek	35-246-1	1	R		N	TKto
35	247	Boulder Creek	35-247-1	1	R		N	TKto
35	248	Boulder Creek	35-248-1	1	R		N	TKto
35	249	Boulder Creek	35-249-1	1	R		N	TKto
35	250	Boulder Creek	35-250-1	1	R		N	TKto
35	251	Boulder Creek	35-251-1	1	R		N	TKto
35	252	Boulder Creek	35-252-1	1	R		N	TKto
35	253	Boulder Creek	35-253-1	1	R		N	TKto
35	254	Boulder Creek	35-254-1	1	R		N	TKto
35	255	Boulder Creek	35-255-1	1	R		N	TKto
35/34	256	Little Boulder Creek	35-256-1	1	R		N	TKso
35	257	Little Boulder Creek	35-257-1	1	R		N	TKso

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
35	259	Boulder Creek	35-259-1	1	R		N	TKso
35	260	Butte Creek	35-260-1	1	R		N	TKns
26	261	Fisher Creek	36-261-1	1	R		Y	Qag
25	262	Fisher Creek	25-262-4	4	D		N	Qag
25	263	Fisher Creek	25-263-1	1	R		Y	Qag
35	264	N Fk Bridge Creek	35-264-1	1	Y		N	Qag
35	265	Butte Creek	35-265-1	1	R		N	TKto
35	266	Butte Creek	35-266-1	1	R		N	TKns
35	267	Butte Creek	35-267-1	1	R		N	TKns
35	268	Butte Creek	35-268-1	1	R		N	TKso
35	269	Butte Creek	35-269-1	1	R		N	TKso
35	270	Butte Creek	35-270-1	1	R		N	TKto
35	271	Butte Creek	35-271-1	1	R		Y	TKto
35	272	Butte Creek	35-272-1	1	R		Y	TKto
35	273	Butte Creek	35-273-1	1	R		N	TKto
35	274	Butte Creek	35-274-1	1	R		N	TKto
35	275	Butte Creek	35-275-1	1	R		Y	TKto
35	276	Butte Creek	35-276-1	1	R		N	TKto
35	277	Butte Creek	35-277-1	1	R		N	Qu
35	278	Butte Creek	35-278-1	1	R		Y	Qu
35	279	Butte Creek	35-279-1	1	R		N	TKto
35	280	Butte Creek	35-280-1	1	R		N	TKto
35	281	Butte Creek	35-281-1	1	R		N	TKto
35	282	Butte Creek	35-282-1	1	R		N	TKto
35	283	Butte Creek	35-283-1	1	R		N	TKto
35	284	Butte Creek	35-284-1	1	R		N	Qu
35	285	Boulder Creek	35-285-1	1	R		N	TKto
35	286	Boulder Creek	35-286-1	1	R		N	TKto
34	287	Boulder Creek	34-287-1	1	R		N	TKto
34	288	Boulder Creek	34-288-1	1	R		N	TKns
34	289	Boulder Creek	34-289-1	1	R		N	TKns

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
34	291	Boulder Creek	34-291-1	1	R	2002	N	TKns
34	292	Boulder Creek	34-292-2	2	R/S		Y	TKso
34	293	Boulder Creek	34-293-1	1	R		Y	TKso
34	294	Boulder Creek	34-294-1	1	R		Y	TKso
34	295	Boulder Creek	34-295-1	1	R		Y	TKso
34	296	Boulder Creek	34-296-1	1	R		Y	TKso
34	297	Boulder Creek	34-297-1	1	R		Y	TKso
34	298	Boulder Creek	34-298-1	1	R		Y	TKso
34	299	Boulder Creek	34-299-1	1	R		Y	TKso
35	300	Fourmile Creek	35-300-1	1	R		N	TKso
35	301	Fourmile Creek	35-301-1	1	R		N	TKso
35	302	Fourmile Creek	35-302-1	1	R		Y	TKso
35	303	Fourmile Creek	35-303-1	1	R		N	TKso
35	304	Fourmile Creek	35-304-1	1	R		N	TKso
35	305	Fourmile Creek	35-305-1	1	R		N	TKso
35	306	Fourmile Creek	35-306-1	1	R		N	TKso
35	308	Fourmile Creek	35-308-1	1	R		N	TKso
35	309	Fourmile Creek	35-309-1	1	R		N	TKso
	310							
35	311	Fourmile Creek	35-311-1	1	R		N	TKso
35	312	Fourmile Creek	35-312-1	1	R		N	TKso
35	313	Fourmile Creek	35-313-1	1	R		N	TKso
35	314	Fourmile Creek	35-314-1	1	R		N	TKso
35	315	Fourmile Creek	35-315-1	1	R		N	TKso
35	316	Fourmile Creek	35-316-1	1	R		Y	TKso
35	317	Fourmile Creek	35-317-1	1	R		N	TKso
35	318	Fourmile Creek	35-318-1	1	R		N	TKso
35	319	Fourmile Creek	35-319-1	1	R		N	TKso
35	320	Fourmile Creek	35-320-1	1	R		N	TKso
35	321	Fourmile Creek	35-321-1	1	R		Y	TKso
35	322	Fourmile Creek	35-322-1	1	R		Y	TKso

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
34	324	Lake Chelan	34-324-1	1	R		N	TKso
34	325	Lake Chelan	34-325-1	1	R		N	TKso
34	326	Purple Creek	34-326-1	1	R		N	TKso
34/35	327	Purple Creek	34-327-1	1	R		N	TKso
35	328	Lake Chelan	35-328-1	1	R		N	TKso
35	329	Lake Chelan	35-329-1	1	R		N	TKso
34/35	330	Lake Chelan	34-330-1	1	R		N	TKso
35	331	Flick Creek	35-331-1	1	R		N	TKso
35	332	Flick Creek	35-332-1	1	R		N	TKso
35	333	Purple Creek	35-333-1	1	R		N	TKso
34	334	Lake Chelan	34-334-1	1	R		N	TKso
34	335	Devore Creek	34-335-1	1	R		N	TKso
34	336	Lake Chelan	34-336-1	1	R		Y	TKso
34	337	Castle Creek	34-337-1	1	R		Y	TKso
34	338	Castle Creek	34-338-1	1	R		Y	TKso
34	339	Canyon Creek	34-339-1	1	R		Y	TKso
34	340	Canyon Creek	34-340-1	1	R		N	TKso
34	341	Bridal Veil Creek	34-341-1	1	R		N	TKso
34	342	Stehekin River	34-342-1	1	R		N	TKso
34	343	Stehekin River	34-343-1	1	R		N	TKso
34	344	Stehekin River	34-344-1	1	R		N	TKso
34	345	Stehekin River	34-345-1	1	R		N	Qu
34	346	Stehekin River	34-346-1	1	R		N	TKso
34	347	Stehekin River	34-347-1	1	R		N	TKso
35	348	Fourmile Creek	35-348-1	1	R		N	TKso
37	349	Rennie Creek	37-349-1	1	R		Y	Qu
34	350	Stehekin River	34-350-1	1	R		N	TKso
	351							
29	352	Park Creek	29-352-1	1	R		N	Qu
29	353	Park Creek	29-353-1	1	R		Y	Qu
29	354	Park Creek	29-354-1	1	R		Y	Tkgo

Quad #	MM #	Sub-Drainage	I.D. #	MM Type	Material Type	Age (If Known)	Sed. Del. To Stream	Bedrock Type
33	356	Sun Creek	33-356-1	1	R		N	TKso
33	357	Moon Creek	33-357-1	1	R		N	TKso
33	358	Moon Creek	33-358-1	1	R		N	TKso
26	359	Wood Creek	26-359-1	1	R		N	Qag
26	360	North Fork Rainbow	26-360-6	6	R		Y	TKso
31	361	McAlester	31-361-1	1	R		N	TKto
31	362	McAlester	31-362-1	1	R		N	TKto
31	363	Solleks	31-363-1	1	R		N	TKto
31	364	Solleks	31-364-1	1	R		N	TKto
31	365	Solleks	31-365-1	1	R		N	TKto
31	366	Solleks	31-366-1	1	R		N	TKto
31	367	Solleks	31-367-1	1	R		Y	TKto
31	368	Solleks	31-368-1	1	R		Y	TKto
31	369	McAlester	31-369-1	1	R		N	TKto
31	370	Kettling Creek	31-370-1	1	R		N	TKto
31	371	Kettling Creek	31-371-1	1	R		N	TKto
31	372	East Fk. McAlester	31-372-1	1	R		N	Kt
29	373	Flick Creek	29-373-1	1	R		N	Qu
30	374	Stehekin River	30-374-1	1	R		N	Tkso
34	375	Company Creek	34-375-1	1	R		Y	TKso
35	376	Four Mile Creek	35-376-1	1	R		Y	TKso
35	377	Flick Creek	35-377-1	1	R		N	Tkso
35	378	Flick Creek	35-378-1	1	R		Y	Tkso
31	379	Kettling Creek	31-379-1	1	R		Y	TKto

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
1	15	8	1056.1427	0.00105614	146	159	12.192	148116.46
2	980	450	265615.4059	0.26561541				
3	200	80	10878.1674	0.01087817				
4	200	260	40455.0000	0.040455				
5	310	180	50210.4770	0.05021048				
6	151	189	21478.5780	0.02147858				
7	72	504	32453.8550	0.03245386				
8	60	192	12200.0879	0.01220009				
9	72	528	41405.5015	0.0414055				
10	60	240	15742.4361	0.01574244				
11	271	138	38115.4080	0.03811541				
12	108	24	2771.4565	0.00277146				
13	1650	300	387483.9670	0.38748397	325/217	303/77	36.6/12.2	1991634.7
14	288	204	54705.3154	0.05470532				
15	132	132	15429.3436	0.01542934				
16	168	132	22379.0004	0.022379				
17	60	216	14226.7429	0.01422674				
18	197	208	51596.6090	0.05159661				
19	48	264	15313.9583	0.01531396				
20	216	348	77007.6013	0.0770076				
21	96	60	7014.1604	0.00701416				
22	95	102	10178.6300	0.01017863				
23	63	219	17984.2770	0.01798428				
24	108	336	38934.6021	0.0389346				
25	240	120	26566.9680	0.02656697	342	294	24.4	1283930.9
26	96	228	18675.5726	0.01867557				
27	60	48	2412.5020	0.0024125				
28	48	72	2351.9777	0.00235198				
29	48	48	1837.3338	0.00183733				
30	216	144	22198.1035	0.0221981				
31	24	36	815.6697	0.00081567				
32	12	36	220.2389	0.00022024				
33	1750	180	269383.0419	0.26938304				
34	96	511	59401.0000	0.059401				
35	118	80	10701.2010	0.0107012				
36	72	72	6843.2549	0.00684325				
38	241	193	40932.6910	0.04093269				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
39	24	72	2171.7013	0.0021717				
40	420	36	21360.9441	0.02136094				
41	264	36	10937.7370	0.01093774				
42	372	48	16938.0479	0.01693805				
43	180	24	4983.6192	0.00498362				
44	36	36	1217.6521	0.00121765				
45	36	48	1565.6522	0.00156565				
46	36	48	1537.7744	0.00153777				
47	24	24	1041.9338	0.00104193				
48	120	72	5694.0195	0.00569402				
49	192	144	23163.1331	0.02316313				
50	120	72	6853.6970	0.0068537				
51	120	228	14864.9530	0.01486495				
52	446	103	46835.7600	0.04683576				
53	87	317	31602.6250	0.03160263				
54	228	36	9668.9740	0.00966897				
55	240	24	7903.5187	0.00790352				
56	360	48	17783.2956	0.0177833				
57	360	36	15399.4174	0.01539942				
58	204	36	7375.5378	0.00737554				
59	400	130	33164.9088	0.03316491				
60	456	96	39319.7718	0.03931977				
61	696	108	71813.4198	0.07181342				
62	190	110	13488.2452	0.01348825				
63	480	384	108414.8609	0.10841486				
64	504	216	75978.3333	0.07597833				
65	72	120	9500.8510	0.00950085				
66	24	72	3303.1928	0.00330319				
67	36	36	1753.3492	0.00175335				
68	60	120	5604.5384	0.00560454				
69	120	48	6172.0624	0.00617206				
70	120	408	26342.4758	0.02634248				
71	372	216	68147.2182	0.06814722				
72	204	96	19576.7902	0.01957679				
73	240	120	27099.5158	0.02709952				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
75	60	180	9985.3799	0.00998538				
76	72	48	3475.3757	0.00347538				
77	120	449	53015.3090	0.05301531				
78	72	24	4131.4083	0.00413141				
79	156	24	4158.3110	0.00415831				
80	333	107	30495.7680	0.03049577				
81	55	127	6812.1567	0.00681216				
82	94	82	8277.3945	0.00827739				
83	336	216	30810.6202	0.03081062				
84	72	96	5216.1381	0.00521614				
85	48	84	3964.2023	0.0039642				
86	216	48	11180.5078	0.01118051				
87	552	48	25910.5922	0.02591059				
88	322	26	10006.8890	0.01000689				
89	426	61	23889.0060	0.02388901				
90	264	36	9638.1499	0.00963815				
91	192	60	11303.6858	0.01130369				
92	116	212	24688.2010	0.0246882				
93	119	657	93834.6800	0.09383468				
94	62	183	10722.6510	0.01072265				
95	240	36	8152.1223	0.00815212				
96	264	36	10090.3748	0.01009037				
97	608	60	39457.4300	0.03945743				
98	480	144	70441.5106	0.07044151				
99	208	36	8763.2930	0.00876329				
100	282	30	10433.0000	0.010433				
101	240	120	29423.2004	0.0294232				
102	408	96	40861.3589	0.04086136				
103	528	120	59572.5662	0.05957257				
104	155	728	123048.5300	0.12304853				
105	216	24	5933.4001	0.0059334				
106	343	74	30584.9920	0.03058499				
107	273	67	21738.5840	0.02173858				
108	240	24	6666.3941	0.00666639				
109	216	51	21526.1619	0.02152616				
110	346	20	17081.7790	0.01708178				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
111	304	24	5347.1641	0.00534716				
112	288	36	10920.3021	0.0109203				
113	216	24	5418.4924	0.00541849				
114	264	24	8549.6373	0.00854964				
115	216	36	6555.9435	0.00655594				
116	144	120	18173.9208	0.01817392				
117	228	228	55551.3536	0.05555135				
118	352	74	28658.4770	0.02865848				
119	76	142	13915.0000	0.013915				
120	304	87	24511.9650	0.02451197				
121	780	100	77643.1330	0.07764313				
122	600	110	64972.5598	0.06497256	88	82	12.2	46071.755
123	550	180	50433.4581	0.05043346	97	54	15.24	41776.193
124	600	140	65747.8193	0.06574782	79/77	49/50	12.2/12.2	49296.011
125	132	480	47434.3282	0.04743433				
126	552	108	56695.2480	0.05669525				
127	84	72	5634.9219	0.00563492				
128	120	120	15698.5111	0.01569851				
129	24	24	1239.9207	0.00123992				
130	134	247	36192.6330	0.03619263				
131	107	198	23391.9920	0.02339199				
132	500	20	11969.5380	0.01196954				
133	144	232	37012.8520	0.03701285				
134	120	60	7628.7981	0.0076288				
135	192	12	4224.8382	0.00422484				
136	240	24	5932.9262	0.00593293				
137	168	168	26015.9276	0.02601593				
138	189	162	28555.8500	0.02855585				
139	288	144	43394.3451	0.04339435				
140	272	132	38008.7970	0.0380088				
141	173	35	9388.9355	0.00938894				
142	230	53	15721.2440	0.01572124				
143	375	128	51971.7850	0.05197179				
144	131	65	12385.6710	0.01238567				
145	72	696	55410.4203	0.05541042				
146	96	144	13837.6588	0.01383766				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
147	432	24	19227.0674	0.01922707				
148	565	60	44658.5660	0.04465857				
149	156	960	170888.7295	0.17088873				
150	216	24	7937.1028	0.0079371				
151	132	240	30828.2530	0.03082825				
152	56	181	10319.6470	0.01031965				
153	195	222	107312.0000	0.107312				
154	528	24	15851.8556	0.01585186				
155	432	816	109700.8976	0.1097009				
156	720	48	35367.0311	0.03536703				
157	192	312	49867.8764	0.04986788				
158	240	180	35388.0894	0.03538809				
159	108	168	16339.3296	0.01633933				
160	120	120	16213.7217	0.01621372				
161	132	132	15874.5999	0.0158746				
162	28	67	2159.1018	0.0021591				
163	951	112	121416.4500	0.12141645	329	138	24.384	579373.11
164	168	480	54087.2442	0.05408724				
165	108	156	14258.7611	0.01425876				
166	72	180	12111.1546	0.01211115				
167	48	84	2989.6755	0.00298968				
168	144	72	10502.8862	0.01050289				
169	72	360	24182.2261	0.02418223				
170	120	456	31102.6956	0.0311027				
171	168	120	19277.3975	0.0192774				
172	146	528	86774.4300	0.08677443				
173	144	120	16892.9137	0.01689291				
174	336	528	80370.9208	0.08037092				
175	24	192	6243.1332	0.00624313				
176	96	144	9748.0584	0.00974806				
177	108	240	28713.4792	0.02871348				
178	48	72	3146.8449	0.00314684				
179	24	120	2791.4176	0.00279142				
180	96	96	5192.6793	0.00519268				
181	108	192	18749.1197	0.01874912				
182	84	36	3552.8101	0.00355281				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
183	60	120	7254.7538	0.00725475				
184	60	156	8480.3655	0.00848037				
185	48	156	6830.2642	0.00683026				
186	132	35	4361.6787	0.00436168				
187	96	120	6354.7248	0.00635472				
188	60	168	11051.4560	0.01105146				
189	36	240	10003.0000	0.010003				
190	96	204	12059.9359	0.01205994				
191	156	72	11758.4449	0.01175844				
192	80	88	6466.5216	0.00646652				
193	36	264	11494.1824	0.01149418				
194	360	120	42905.2169	0.04290522				
195	24	96	2113.8114	0.00211381				
196	104	43	4177.8252	0.00417783				
197	85	44	4610.9263	0.00461093				
183	60	120	7254.7538	0.00725475				
184	60	156	8480.3655	0.00848037				
185	48	156	6830.2642	0.00683026				
186	132	35	4361.6787	0.00436168				
187	96	120	6354.7248	0.00635472				
188	60	168	11051.4560	0.01105146				
189	36	240	10003.0000	0.010003				
190	96	204	12059.9359	0.01205994				
191	156	72	11758.4449	0.01175844				
192	80	88	6466.5216	0.00646652				
193	36	264	11494.1824	0.01149418				
194	360	120	42905.2169	0.04290522				
195	24	96	2113.8114	0.00211381				
196	104	43	4177.8252	0.00417783				
197	85	44	4610.9263	0.00461093				
198	133	310	41384.1130	0.04138411				
199	90	100	9761.1660	0.00976117				
200	227	76	16948.2660	0.01694827				
201	56	57	3275.0000	0.003275				
202	96	60	5087.6767	0.00508768				
203	99	200	19822.9240	0.01982292				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
204	96	240	22461.3388	0.02246134				
205	31	214	7898.8179	0.00789882				
206	25	221	5902.1519	0.00590215				
207	81	476	44772.9450	0.04477295				
208	84	108	9170.6371	0.00917064				
209	183	72	23641.4980	0.0236415				
210	67	104	8007.9819	0.00800798				
211	360	144	35789.5307	0.03578953				
212	120	384	43042.8667	0.04304287				
213	188	113	21121.0680	0.02112107				
214	66	448	33543.9650	0.03354397				
215	100	255	25070.1133	0.02507011				
216	288	180	50762.9408	0.05076294				
217	91	258	21814.4260	0.02181443				
218	72	312	27570.8762	0.02757088				
219	520	140	60785.3789	0.06078538	131	169	30.48	353143.62
220	264	552	105786.9257	0.10578693				
221	180	40	4555.6143	0.00455561				
222	105	163	15019.9480	0.01501995				
223	112	123	17900.9670	0.01790097				
224	72	84	5250.2800	0.00525028				
228	180	60	11346.7944	0.01134679				
229	120	48	5530.1171	0.00553012				
230	36	216	9757.4303	0.00975743				
231	24	192	2692.1693	0.00269217				
232	298	435	142018.4200	0.14201842				
233	142	230	47103.6290	0.04710363				
234	336	96	32184.6720	0.03218467				
235	442	110	52383.9920	0.05238399				
236	116	485	46150.6560	0.04615066				
237	211	96	19399.8590	0.01939986				
238	101	295	39598.7230	0.03959872				
239	240	240	43631.9166	0.04363192				
240	528	960	175993.2775	0.17599328				
241	108	132	12483.4554	0.01248346				
242	252	144	31115.2028	0.0311152				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
243	120	216	17753.6079	0.01775361				
244	288	288	103527.1924	0.10352719				
245	132	216	17906.6949	0.01790669				
246	60	228	14871.2741	0.01487127				
247	72	240	17279.9636	0.01727996				
248	276	360	56879.4914	0.05687949				
249	480	108	50528.5816	0.05052858				
250	312	276	80811.8605	0.08081186				
251	24	60	2014.8188	0.00201482				
252	12	48	1887.9152	0.00188792				
253	36	120	4895.6455	0.00489565				
243	120	216	17753.6079	0.01775361				
244	288	288	103527.1924	0.10352719				
245	132	216	17906.6949	0.01790669				
246	60	228	14871.2741	0.01487127				
247	72	240	17279.9636	0.01727996				
248	276	360	56879.4914	0.05687949				
249	480	108	50528.5816	0.05052858				
250	312	276	80811.8605	0.08081186				
251	24	60	2014.8188	0.00201482				
252	12	48	1887.9152	0.00188792				
253	36	120	4895.6455	0.00489565				
243	120	216	17753.6079	0.01775361				
244	288	288	103527.1924	0.10352719				
245	132	216	17906.6949	0.01790669				
246	60	228	14871.2741	0.01487127				
247	72	240	17279.9636	0.01727996				
248	276	360	56879.4914	0.05687949				
249	480	108	50528.5816	0.05052858				
250	312	276	80811.8605	0.08081186				
251	24	60	2014.8188	0.00201482				
252	12	48	1887.9152	0.00188792				
253	36	120	4895.6455	0.00489565				
243	120	216	17753.6079	0.01775361				
244	288	288	103527.1924	0.10352719				
245	132	216	17906.6949	0.01790669				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
246	60	228	14871.2741	0.01487127				
247	72	240	17279.9636	0.01727996				
248	276	360	56879.4914	0.05687949				
249	480	108	50528.5816	0.05052858				
250	312	276	80811.8605	0.08081186				
251	24	60	2014.8188	0.00201482				
252	12	48	1887.9152	0.00188792				
253	36	120	4895.6455	0.00489565				
254	24	48	1497.4176	0.00149742				
255	324	108	34023.9549	0.03402395				
256	163	178	26577.9220	0.02657792				
257	112	239	27601.1290	0.02760113				
258	108	168	16478.0870	0.01647809				
259	109	191	21090.7990	0.0210908				
260	96	72	7483.2743	0.00748327				
261	291	421	106856.3600	0.10685636				
262	440	40	15529.5160	0.01552952				
263	120	60	11876.2572	0.01187626				
264	240	372	98542.8861	0.09854289				
265	192	60	13739.0480	0.01373905				
266	156	60	10756.9647	0.01075696				
267	108	480	56103.4344	0.05610343				
268	336	144	48706.6999	0.0487067				
269	204	96	22628.2040	0.0226282				
270	276	288	86476.7978	0.0864768				
271	264	144	27182.2811	0.02718228				
272	648	216	137739.6214	0.13773962				
273	168	120	15903.4650	0.01590347				
274	168	96	14994.5160	0.01499452				
275	192	576	54782.7860	0.05478279				
276	72	96	6157.5220	0.00615752				
277	48	96	4569.7836	0.00456978				
278	72	168	9438.7154	0.00943872				
279	216	228	40271.4863	0.04027149				
280	156	72	11847.9260	0.01184793				
281	144	36	8411.9094	0.00841191				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
282	192	72	14788.5888	0.01478859				
283	144	72	10733.0275	0.01073303				
284	180	96	16869.8942	0.01686989				
285	120	48	5547.1731	0.00554717				
286	360	240	55093.4433	0.05509344				
287	104	204	19832.8650	0.01983287				
288	144	96	11402.4350	0.01140244				
289	96	24	2999.9286	0.00299993				
290	120	72	8790.7676	0.00879077				
291	228	120	28533.1317	0.02853313				
292	60	36	2411.3973	0.0024114				
293	72	336	22391.5525	0.02239155				
294	24	216	9325.8721	0.00932587				
295	24	72	2382.2216	0.00238222				
296	24	120	4142.6040	0.0041426				
297	72	144	10706.5645	0.01070656				
298	60	96	5790.0248	0.00579002				
299	24	72	2986.9889	0.00298699				
300	144	216	19509.1949	0.01950919				
301	240	138	326.0000	48909.203				
302	312	168	40447.9034	0.0404479				
303	80	79	5663.4395	0.00566344				
304	384	372	67682.4412	0.06768244				
305	83	173	17874.6270	0.01787463				
306	459	50	22502.4860	0.02250249				
307	86	185	23299.6520	0.02329965				
308	228	240	39566.9936	0.03956699				
309	169	366	72871.4920	0.07287149				
310								
311	196	241	46740.0630	0.04674006				
312	152	308	50112.1990	0.0501122				
313	468	312	104372.9751	0.10437298				
314	168	624	72802.3459	0.07280235				
315	144	240	27659.0126	0.02765901				
316	158	185	33085.2770	0.03308528				
317	48	96	4521.4772	0.00452148				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
318	124	61	7317.5513	0.00731755				
319	408	264	61220.9796	0.06122098				
320	144	120	14699.2122	0.01469921				
321	33	372	15247.8960	0.0152479				
322	60	195	12690.0760	0.01269008				
323	47	70	4823.9546	0.00482395				
324	312	72	21735.2151	0.02173522				
325	108	24	3985.3002	0.0039853				
326	192	72	12091.0197	0.01209102				
327	192	144	21760.0477	0.02176005				
328	118	142	20175.5880	0.02017559				
329	96	48	4414.5306	0.00441453				
330	60	156	8892.9250	0.00889293				
331	72	72	6742.1751	0.00674218				
332	370	220	63246.7150	0.06324672				
333	47	40	2910.5940	0.00291059				
334	48	96	5393.0259	0.00539303				
335	48	84	4289.0313	0.00428903				
336	204	48	12139.5637	0.01213956				
337	720	216	98554.2288	0.09855423				
338	72	24	1916.8839	0.00191688				
339	108	36	4223.1805	0.00422318				
340	120	96	9501.4879	0.00950149				
341	144	108	12580.7015	0.0125807				
342	84	456	32535.5746	0.03253557				
343	144	768	63678.7655	0.06367877				
344	96	408	40388.2602	0.04038826				
345	60	288	19337.6380	0.01933764				
346	96	264	21378.8170	0.02137882				
347	72	384	32755.3324	0.03275533				
348	108	96	8857.2441	0.00885724				
349	120	432	41963.8705	0.04196387				
350	310	71	29450.906	0.02945091				
351								
352	56	200	11376.298	0.0113763				

MM #	For all Types				Values for Volume Calculations: For MM-As Only			
	Length (m)	Width (m)	Surface Area (km ²)	Surface Area (m ²)	Length (m)	Width (m)	Depth (m)	Volume (m ³)
353	108	145	16348.564	0.01634856				
354	101	113	13546.919	0.01354692				
355	136	178	26978.535	0.02697854				
356	124	279	44955.352	0.04495535				
357	128	81	11190.107	0.01119011				
358	380	59	22314.52	0.02231452				
359	107	376	43476.438	0.04347644				
360	55	21	1390.9854	0.00139099				
353	108	145	16348.564	0.01634856				
354	101	113	13546.919	0.01354692				
355	136	178	26978.535	0.02697854				
356	124	279	44955.352	0.04495535				
357	128	81	11190.107	0.01119011				
358	380	59	22314.52	0.02231452				
359	107	376	43476.438	0.04347644				
360	55	21	1390.9854	0.00139099				
361	104	322	56920.52	0.05692052				
362	80	141	11871.929	0.01187193				
363	47	74	4562.9595	0.00456296				
364	71	207	15080.477	0.01508048				
365	28	160	5707.2866	0.00570729				
366	148	172	25602.654	0.02560265				
367	97	91	12048.724	0.01204872				
368	147	90	14699.63	0.01469963				
369	105	62	6927.5522	0.00692755				
370	83	439	37314.404	0.0373144				
371	58	235	18487.746	0.01848775				
372	74	217	16709.291	0.01670929				
373	128	53	764399.06	0.76439906				
374	64	131	11337.526	0.01133753				
375	56	41	3001	0.003001				
376	48	379	19440.201	0.0194402				
377	64	67	6410.021	0.00641002				
378	73	55	4342.8115	0.00434281				
377	64	67	6410.021	0.00641002				
378	73	55	4342.8115	0.00434281				
379	131	128	21297.916	0.02129792				

MM#	Percent Slope (%)	Slope Aspect (°)	Form	Position	Top (m)	Toe (m)
1	22	36	CC	VB	1274	1262
2	5	66	Comp	VW	2012	1719
3	340	11	Comp	VW	1768	1743
4	0	57	Comp	VW	1951	1853
5	345	88	Comp	VW	1951	1792
6	47	110	Comp	VW	1902	1780
7	191	33	Comp	VB	1725	1682
8	263	50	FL	VW	1902	1829
9	321	51	FL	VW	1597	1536
10	217	120	CV	VW	2012	1975
11	43	65	FL	VW	1451	1305
12	77	26	CV	CH	1366	1317
13	270	46	Comp	CH	1963	1292
14	335	60	Comp	VW	1939	1725
15	187	10	FL	VW	1707	1597
16	143	60	CC	VW	1939	1829
17	324	66	FL	CH	1768	1719
18	15	95	CC	VW	1963	1812
19	96	40	CC	VW	1780	1707
20	21	50	Comp	VW	1890	1731
21	29	55	FL	VW	1768	1670
22	344	66	FL	VW	1975	1890
23	345	51	FL	VW	1878	1829
24	93	42	Comp	VW	1597	1475
25	138	60	FL	VW	1731	1573
26	45	40	CC	VW	1597	1536
27	316	60	FL	VB	1689	1670
28	319	44	FL	VB	1689	1670
29	318	45	FL	VB	1689	1670
30	8	40	Comp	VW	1841	1731
31	339	50	CC	VB	1097	1085
32	349	30	CV	CH	1061	1049
33	184	52	Comp	CH	1853	1049
34	80	53	Comp	VW	1951	1786
35	80	51	FL	VW	1548	1475
36	39	40	FL	VB	1707	1682
38	11	45	CV	VW	1999	1853

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

MM#	Percent Slope (%)	Slope Aspect (°)	Form	Position	Top (m)	Toe (m)
76	316	40	FL	VW	1609	1585
77	347	60	Comp	CH	1731	1609
78	203	40	CV	CH	1573	1536
79	161	24	CV	CH	1561	1512
80	110	23	FL	VW	1829	1658
81	151	47	CV	VW	1609	1530
82	139	60	CC	VW	1524	1457
83	58	28	Comp	CH	1951	1804
84	104	40	FL	VW	914	890
85	102	22	FL	VW	902	890
86	48	49	CV	CH	1049	951
87	237	29	CV	CH	1085	1000
88	27	20	CV	CH	1012	933
89	80	20	CV	CH	1024	927
90	9	46	CV	CH	1097	975
91	313	33	FL	VW	1341	1274
92	338	50	FL	VW	1548	1457
93	352	27	FL	VW	1585	1463
94	1	20	FL	VW	1646	1609
95	20	29	CV	VW	1475	1390
96	66	44	CV	CH	1548	1426
97	265	50	CV	CH	1707	1524
98	99	59	Comp	VW	2134	1792
99	35	57	CV	CH	1585	1469
100	9	40	CV	CH	1585	1445
101	198	60	CV	VW	1646	1500
102	218	40	FL	VW	1707	1622
103	34	38	Comp	VW	1682	1622
104	70	36	Comp	VW	1829	1695
105	148	31	CV	VW	1042	981
106	10	19	CV	VW	1097	1024
107	34	47	CV	VW	1244	1122
108	10	45	CV	VW	1256	1146
109	25	43	CV	CH	1341	1158
110	18	40	CV	VW	1341	1262
111	2	40	CV	VW	1329	1256
112	10	32	CV	VW	1366	1268
113	68	38	CV	VW	1402	1311

MM#	Percent Slope (%)	Slope Aspect (°)	Form	Position	Top (m)	Toe (m)
114	60	35	CV	VW	1402	1305
115	95	56	CV	VW	1463	1366
116	81	72	CV	VW	1561	1451
117	106	60	CC	VW	1317	1158
118	313	56	CC	VW	1768	1573
119	344	40	Comp	VW	1768	1682
120	272	73	Comp	VW	1707	1256
121	89	72	Comp	VW	1829	1256
122	89	62	Comp	VW	1597	1195
123	87	74	Comp	VW	1585	1152
124	280	83	Comp	VW	1646	1122
125	50	72	Comp	VW	1158	1049
126	297	33	Comp	VW	1463	1280
127	150	59	FL	VW	805	744
128	70	52	CV	VW	792	719
129	35	20	CC	VB	780	774
130	20	67	Comp	VW	853	732
131	356	50	CV	VW	902	786
132	221	29	CV	VW	975	823
133	234	72	FL	VW	1036	914
134	17	57	CV	VW	1183	1109
135	52	70	CV	VW	1585	1451
136	142	56	CV	CH	1402	1280
137	31	52	FL	VW	1030	878
138	39	67	FL	VW	1042	914
139	210	80	CV	VW	1097	914
140	48	62	CV	VW	1158	951
141	36	89	FL	VW	1646	1500
142	27	75	CV	VW	1207	1036
143	205	68	Comp	VW	1646	1317
144	167	60	CV	VW	1268	1143
145	41	53	Comp	VW	1098	1037
146	31	50	CC	VW	1159	1091
147	189	33	CV	CH	1280	1122
148	197	31	CV	CH	1341	1244
149	44	53	Comp	VW	1341	1183
150	233	35	CV	CH	1341	1274
151	136	80	CV	VW	1463	1354

MM#	Percent Slope (%)	Slope Aspect (°)	Form	Position	Top (m)	Toe (m)
152	106	40	FL	VW	1585	1561
153	315	44	Comp	VW	1890	1646
154	271	58	CV	VW	1159	866
155	236	31	Comp	VW	1171	793
156	200	33	CV	CH	1037	811
157	249	65	FL	VW	939	799
158	228	67	CV	VW	915	768
159	260	70	CV	VW	817	738
160	84	55	CV	VW	768	671
161	76	69	CV	VW	854	732
162	40	5	FL	VW	1924	1921
163	41	53	Comp	VW	1220	695
164	89	77	Comp	VW	1037	854
165	50	70	CV	VW	732	634
166	81	47	FL	VW	707	622
167	81	40	FL	VW	622	598
168	122	41	Comp	VW	732	652
169	348	40	FL	VW	524	488
170	160	59	FL	VW	610	500
171	192	69	Comp	VW	659	512
172	185	60	FL	VW	573	427
173	219	47	CV	VW	1500	1402
174	288	63	Comp	VW	1805	1524
175	332	38	CV	VW	1707	1634
176	0	84	Comp	VW	1707	1610
177	128	67	Comp	VW	1585	1707
178	348	109	CC	VW	1768	1695
179	19	44	CV	VW	1744	1695
180	29	80	CC	VW	1756	1665
181	29	30	FL	VB	1695	1646
182	0	53	FL	VW	2012	1951
183	353	53	FL	VW	2012	1963
184	336	48	CC	VW	2000	1963
185	346	46	FL	VW	1890	1841
186	104	33	CV	VW	1927	1860
187	202	63	FL	VW	1829	1768
188	195	67	FL	VW	1805	1744
189	124	53	CV	VW	1878	1841

MM#	Percent Slope (%)	Slope Aspect (°)	Form	Position	Top (m)	Toe (m)
190	129	38	FL	VW	1878	1817
191	155	43	FL	VW	1927	1860
192	110	28	CC	VW	1890	1854
193	211	46	CC	VW	1909	1872
194	359	36	Comp	VW	1841	1659
195	34	80	CV	VW	1866	1817
196	318	14	FL	VW	2018	2000
197	332	42	FL	VW	2000	1976
198	136	56	Comp	VW	1890	1756
199	159	50	CV	VW	1634	1573
200	162	47	CV	VW	1682	1554
201	153	46	FL	VW	1573	1536
202	146	40	FL	VW	1585	1536
203	144	53	CV	VW	1585	1524
204	134	80	CV	VW	1548	1500
205	50	25	FL	VW	1767	1706
206	40	29	Comp	VW	1890	1792
207	143	60	Comp	VW	1939	1768
208	220	46	FL	VW	2073	1999
209	0	83	FL	VW	2012	1902
210	34	54	FL	VW	1823	1768
211	73	18	Comp	VW	1939	1853
212	56	53	Comp	VW	1902	1786
213	47	10	FL	VW	1743	1707
214	45	31	CV	VW	1878	1670
215	86	71	Comp	VW	1378	1311
216	100	63	Comp	VW	1634	1402
217	99	66	Comp	VW	1341	1268
218	118	53	Comp	VW	1292	1207
219	118	68	Comp	CH	1475	1140
220	138	45	Comp	VW	1341	1122
221	290	40	CC	VB	1158	1122
222	304	60	CV	VW	1634	1536
223	307	40	CV	VW	1878	1804
224	218	71	CC	VW	1768	1707
228	330	27	CC	VW	1676	1628
229	331	11	FL	VW	1707	1676
230	281	60	CC	VW	841	817

MM#	Percent Slope (%)	Slope Aspect (°)	Form	Position	Top (m)	Toe (m)
231	294	44	CC	VB	732	707
232	89	19	Comp	VB	1926	1786
233	91	30	CV	VW	1804	1695
234	88	67	CC	VW	1951	1817
235	85	65	Comp	VW	1963	1756
236	79	33	CV	VW	1646	1585
237	155	20	CC	VW	2280	2219
238	194	33	CV	VW	2292	2146
239	269	39	Comp	VW	2182	2067
240	197	44	Comp	VW	2286	1999
241	76	64	CV	VW	1646	1554
242	194	40	Comp	VW	2164	2036
243	162	45	CV	VW	2036	1945
244	288	48	Comp	VW	2134	1951
245	273	32	Comp	VW	2036	1993
246	309	60	CC	VW	2012	1963
247	348	15	Comp	VW	1987	1957
248	103	60	Comp	VW	2036	1914
249	45	43	CC	VW	1951	1792
250	13	48	Comp	VW	1841	1646
251	343	40	FL	VW	1646	1597
252	345	40	FL	VW	1695	1670
253	347	67	CV	VW	1670	1628
254	337	60	FL	VW	1628	1603
255	187	40	FL	VW	1548	1414
256	342	40	CC	VW	1966	1829
257	326	30	CC	VW	1963	1881
258	315	60	CC	VW	2012	1926
259	272	50	CC	VW	2012	1902
260	18	63	CC	VW	2024	1963
261	210	43	CC	VB	1548	1329
262	210	46	CC	VB	1548	1350
263	210	42	CV	VB	1582	1536
264	200	56	FL	VB	1216	1201
265	147	90	CV	VW	2012	1896
266	27	53	CV	VW	2085	1987
267	28	60	Comp	VW	2109	2012
268	29	50	Comp	VW	2097	1902

MM#	Percent Slope (%)	Slope Aspect (°)	Form	Position	Top (m)	Toe (m)
269	110	57	FL	VW	2073	1951
270	21	46	Comp	VW	2067	1890
271	52	50	FL	VW	1792	1664
272	335	53	Comp	VW	2097	1719
273	44	32	CV	VW	2085	2030
274	43	27	Comp	VW	2024	1963
275	83	50	CV	VW	1975	1853
276	80	30	FL	VW	1859	1811
277	51	48	FL	VB	1646	1603
278	47	43	CC	CH	1585	1536
279	95	53	CV	VW	1829	1676
280	232	33	CV	VW	1548	1481
281	238	68	CV	VW	1865	1768
282	228	80	CV	VW	1707	1561
283	225	73	FL	VW	1707	1561
284	261	37	CV	VW	1439	1500
285	324	33	CC	CH	1658	1634
286	22	47	CC	D	2268	2097
287	353	67	FL	VW	1317	1225
288	304	53	CC	VW	1554	1603
289	357	30	FL	VW	1597	1554
290	341	49	FL	VW	1670	1311
291	347	35	CC	VW	1780	1682
292	331	40	CV	VB	963	927
293	343	57	CV	VB	963	927
294	341	42	FL	VB	884	817
295	105	60	CV	VB	744	719
296	150	67	CV	VB	732	695
297	289	56	Comp	VW	744	658
298	316	86	CV	VW	732	646
299	191	71	FL	VW	543	506
300	44	63	Comp	D	2146	2054
301	17	60	Comp	VW	2121	1902
302	140	64	Comp	VW	2134	1939
303	125	65	CV	VW	1756	1682
304	324	48	CC	VW	2219	2060
305	347	67	Comp	D	2097	2012
306	348	40	Comp	D	2060	1682

MM#	Percent Slope (%)	Slope Aspect (°)	Form	Position	Top (m)	Toe (m)
307	345	72	FL	VW	1914	1792
308	211	70	Comp	VW	1805	1610
309	333	38	Comp	VW	1780	1646
311	345	43	CV	VW	2085	1988
312	342	57	Comp	VW	2134	2024
313	339	48	Comp	VW	2293	2037
314	259	46	Comp	VW	2122	1927
315	239	62	Comp	VW	1915	1811
316	271	56	Comp	VW	1793	1634
317	332	60	CC	VW	1646	1610
318	304	70	CV	VW	1561	1463
319	276	79	Comp	VW	1915	1598
320	328	70	CC	VW	2012	1927
321	327	58	Comp	CH	1585	1427
322	239	64	FL	CH	1159	1061
323	338	60	FL	VB	744	695
324	238	48	Comp	VW	1000	841
325	292	90	CC	VW	1146	1012
326	274	80	CC	VW	1305	1159
327	225	56	CV	D	1409	1299
328	217	67	FL	D	1476	1421
329	208	60	FL	D	1518	1476
330	239	55	CV	VW	750	683
331	236	50	CV	VW	1659	1591
332	322	33	Comp	CH	1720	1573
333	273	70	CC	VW	1768	1683
334	67	50	FL	VW	390	329
335	5	20	CV	VW	409	390
336	108	44	Comp	CH	1110	1000
337	102	32	CV	CH	1165	927
338	61	50	FL	CH	1652	1744
339	39	67	CC	CH	1890	1805
340	10	62	CC	VW	1817	1707
341	336	50	CC	VW	1549	1457
342	31	27	FL	VW	488	439
343	238	67	Comp	VW	488	360
344	240	80	CV	VW	732	622
345	220	53	Comp	VW	476	366

MM#	Percent Slope (%)	Slope Aspect (°)	Form	Position	Top (m)	Toe (m)
346	53	50	CV	VW	439	384
347	51	55	FL	VW	439	366
348	250	103	CC	VW	1865	1777
349	75	260	FL	VW	1710	1305
350	190	45	FL	VW	585	414
352	250	100	FL	VW	1487	1414
353	185	67	FL	VW	1439	1341
354	185	50	FL	VW	1414	1341
355	40	47	FL	VW	1743	1622
356	350	41	FL	VW	1640	1512
357	5	45	FL	VW	1646	1585
358	5	36	FL	VW	1597	1439
359	350	41	FL	VW	1780	1707
360	45	15	FL	VW	1792	1788
361	290	50	COMP	VW	1975	1792
362	350	63	FL	VW	1920	1853
363	320	29	FL	VB	1743	1725
364	120	77	FL	VW	2036	1966
365	190	55	FL	VW	2012	1987
366	165	100	FL	VW	2091	1914
367	170	57	FL	VW	1756	1676
368	170	62	FL	VW	1756	1658
369	85	32	FL	VB	1536	1500
370	60	58	FL	VB	1768	1673
371	265	80	FL	VB	1817	1743
372	30	42	FL	VB	1780	1731
373	170	123	FL	VW	1527	1366
374	185	67	FL	VW	533	463
375	10	35	FL	VW	488	463
376	340	55	FL	VW	1829	1646
377	350	138	FL	VW	1756	1622
378	270	40	FL	VW	1768	1731
379	240	36	FL	VB	1731	1638

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