National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Long Term Monitoring of Glaciers at Mount Rainier National Park

Narrative and Standard Operating Procedures Version 1.0

Natural Resource Report NPS/NCCN/NRR—2010/175

ON THE COVER
R. Lofgren standing in front of the debris covered Nisqually terminus 2003.
Photograph by: R. Burrows

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Natural Resource Report NPS/NCCN/NRR—2010/175

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January 2010

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

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Please cite this publication as:

Riedel, J. L., J. M. Wenger, and N. D. Bowerman. 2010. Long term monitoring of glaciers at Mount Rainier National Park: Narrative and standard operating procedures version 1.0. Natural Resource Report NPS/NCCN/NRR—2010/175. National Park Service, Fort Collins, Colorado.

NPS 105/100950, January 2010

Change History

Version numbers will be incremented by a whole number (e.g., Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g., Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures included in the plan. The following revisions have occurred to this protocol since September 1, 2009.

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Abstract

The purpose of this report is to explain the background, monitoring need, protocols, and standard operating procedures (SOPs) for glacier monitoring in Mount Rainier National Park (MORA) by the National Park Service. Only two, the Emmons and Nisqually glaciers, of the 27 glaciers found on Mount Rainier are monitored as ‘index glaciers’ to represent glacial conditions at the park. Four sampling protocols are outlined in this report: yearly mass balance, yearly summer glacier meltwater discharge, ten-year glacier area/volume changes for the Emmons and Nisqually glaciers, and a 20-year inventory of all glaciers on Mount Rainier.

The primary focus of this program is on detailed annual mass balance monitoring on the Nisqually and Emmons glaciers which have been monitored since 2002. Already both glaciers show signs of area and volume loss.

This protocol is published into two volumes

- Volume 1. Narrative and Standard Operating Procedures (SOPs)
- Volume 2. Appendices

Acknowledgements

Many people have contributed to this effort. We would particularly like to thank Dr. Robert Krimmel and Carolyn Driedger of the U.S. Geological Survey, and Dr. Andrew Fountain at Portland State University, for guiding development of this draft protocol. Staff at Mount Rainier National Park who contributed include Barbara Samora, Paul Kennard, and Rebecca Lofgren. We would like to thank Mount Rainier climbing rangers for their support with field logistic. Finally, we thank data managers John Boetsch, Ron Holmes, and Bret Christoe for assistance with development of the database management portions of this document.

1 - Introduction

Glaciers are a critical resource and feature of Mount Rainier National Park (MORA) that have undergone substantial change in the past century. Currently there is approximately 90 km^2 (35 mi^2) and 4.2 km^3 (1.0 mi^3) of ice on Mount Rainier, but since 1913 the total area of the mountain covered by glaciers has decreased 21 % and the total volume by 25% (Nylen 2002).

The sensitive and dynamic response of glaciers to variations in both temperature and precipitation makes them excellent indicators of regional and global climate change at multiple time scales. This feature of glaciers is particularly valuable at remote high elevation sites in the North Coast and Cascades Network (NCCN), where meteorological data are not available. Glaciers also provide valuable insight to climate change over longer time periods than most other climate measures (Paterson 1981).

The importance of glaciers to the park ecosystem and park management is also stressed in the park's General Management Plan and more recently at a network Vital Signs Workshop held in Spring 2001. A glacier monitoring protocol development study plan was initiated at an interagency meeting in 2001. At this meeting five alternative approaches to monitoring glaciers in the park were assessed and key attendees proposed a combined approach. This approach involves the use of both repeat mapping and surface measurements (mass balance) and was outlined in Riedel (2001).

Yearly glacier mass balance monitoring measures the gain of snow and loss of snow, firn, and ice from field measurements at points on the glacier. Winter balance is the gain of a winter season snowfall. Summer balance is the loss of snow, firn, and ice from ablation (mostly melting). Net balance is the difference of these two quantities. Glacier-wide mass balances are calculated from the point data as well as summer glacier meltwater discharge. Area/volume changes are an independent measure of longer term glacier surface change and can be compared with cumulative balance data measured in the field. Glacier area/volume changes are determined from remapping glaciers at ten-year intervals.

1.1 Background

1.1.1 Geographic Setting

Mount Rainier National Park encompasses 954 km^2 (368 mi^2) on the west side of the Cascade Range of Washington State, and is located about 100 kilometers (60 miles) southeast of the Seattle metropolitan area (Figure 1). Mount Rainier National Park is approximately 97 percent designated wilderness and 3 percent National Historic Landmark District and receives approximately 2 million visitors per year.

At 4,393 m (14,411 feet), Mount Rainier is the most prominent peak in the Cascade Range. It dominates the landscape of a large part of western Washington State. The mountain stands 4km (2.5 miles) higher than the lowlands to the west and 2.5 km (1.5 miles) higher than the adjacent mountains. It is an active volcano that last erupted approximately 150 years ago (Scott et al. 1995).

Climate on Mount Rainier is primarily dependent on the Pacific storm track, altitude, aspect, topography, upper air wind speed and direction, and moisture (Hayes et al., 2002). Weather and climate information has been gathered at the Paradise Ranger Station since 1948. At 1,677 m (5,500 feet) this site represents climate close to the terminus of the Nisqually Glacier, with a mean annual temperature of 2.83 degrees C (37.1 degrees F) and a mean annual precipitation of 2.92 m (115 inches). Most of the precipitation, 2.59 m (102 inches) water equivalent, occurs as snowfall during the winter season, October through May. The average June through September temperature is 9.51 degrees C (49.1 degrees F). The winter season snowfall and the summer season temperature are important quantities to relate to glacier balance terms.

As of 1994 there were 27 major glaciers on Mount Rainier (Figure 2) with a combined area of 90 km^2 (35 mi^2) and numerous unnamed permanent snow or ice patches (Nylen 2002). The Emmons Glacier has the largest area (11.6 km^2, 4.3 mi^2) and Carbon Glacier has the lowest terminus altitude (1100 m; 3,600 feet) of all glaciers in the conterminous 48 states. In 1981 the total volume of all ice and snow on Mount Rainier was estimated to be 4.42 billion m^3 (156 billion ft^3) (Driedger and Kennard 1986). The glaciers are dynamic. For example, the Nisqually Glacier has shown dramatic changes in dimension within the last century (Heliker et al. 1983; Nylen 2002). Mount Rainier's glaciers are important indicators of climatic change, major visitor attractions, host most of the climbing routes on the mountain, and are sources of water for park aquatic ecosystems, hydroelectric projects, municipal water supplies, and recreation pursuits outside of the park. This active volcano presents significant hazards to those downstream during potential volcanic eruptions and jökulhaups (catastrophic glacial outburst floods). For example, the most recent significant outburst flood occurred in 1947 on Kautz Creek, with smaller outburst floods on the Nisqually River in the 1940s and 1950s and Tahoma Creek in the 1990s. Roughly 800 years ago the Electron Mudflow (lahar) was carried all the way to the Puget Lowland via the Puyallup River (Scott et al. 1995).

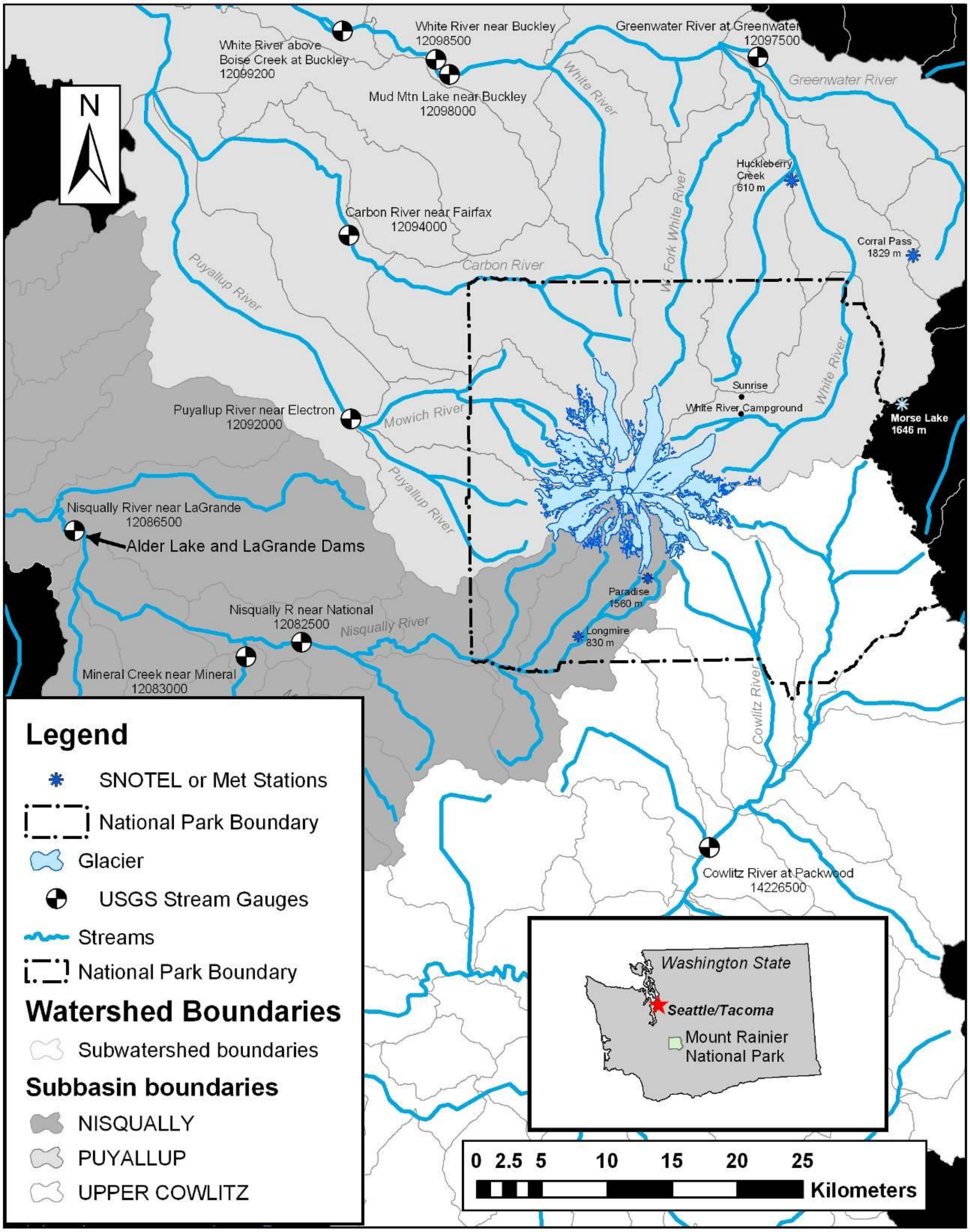

Figure 1. Locator map of Mount Rainier, with major watersheds, streams, USGS stream gauges, and weather stations discussed in text.

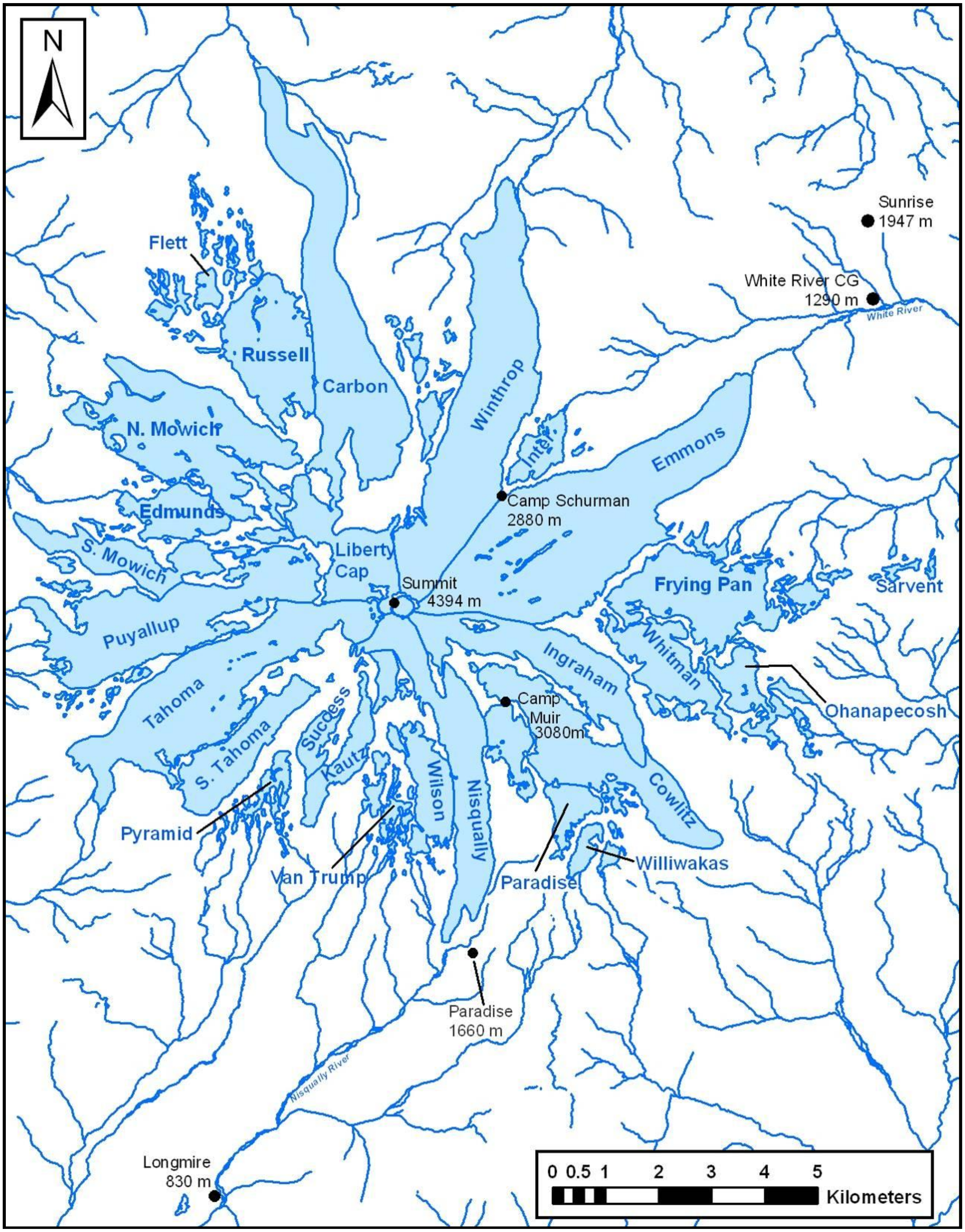

Figure 2. The 27 major glaciers on Mount Rainier with sites and altitudes discussed in text.

The park is part of a complex mountain ecosystem with diverse vegetation, reflecting the varied climatic and environmental conditions encountered across the Park's 3,900-meter (12,800-foot) altitude range. Approximately 58 percent of the park is forested, 23 percent is subalpine parkland, and the remainder is alpine, half of which is vegetated and the other half consists of permanent snow, ice, and rock. Forest ages range from less than 100 years old in disturbed areas and moraines left by receding glaciers to old-growth stands 1,000 or more years (Franklin et al. 1988). Some alpine heather communities have persisted in the park for up to 10,000 years (Franklin and Dyrness 1988).

1.1.2 Protocol Development

The Mount Rainer glacier monitoring program is part of a larger effort to monitor abiotic factors important to the stability and function of the park ecosystem. Other abiotic ecosystem factors monitored include glacier hydrology, geologic disturbance/hazards, weather, solar radiation, and air quality. These data contribute to a larger body of climatic and hydrologic data on and around Mount Rainier collected by the NPS, United States Geological Survey (USGS), Natural Resource Conservation Service (NRCS), Northwest Weather and Avalanche Center (NWAC), the hydroelectric industry, and university researchers.

A protocol development study plan was initiated at an interagency meeting at the USGS-Water Resource Division (USGS-WRD) Tacoma Office in September 2001. Participants included staff from North Cascades National Park (NOCA), MORA, USGS-WRD, and Portland State University. Five alternative approaches to monitoring glaciers in the park were assessed. These included:

1. Surface mass balance monitoring with snow depth probes and ablation stakes
2. Hydrologic mass balance monitoring
3. Mass changes using repeated mapping
4. Mass changes using an energy balance model
5. Surface elevation changes at margin with surveys

We reviewed the discussion from the Tacoma meeting, recommendations provided by professionals who could not attend the meeting, and compared traditional monitoring approaches (Ostrem and Haakensen 1999). We proposed a combined approach to monitoring the glaciers in the park. This approach involves the use of both repeat mapping and surface measurements and was outlined in Riedel (2001) (in Appendix K. Administration History). The NPS entered into a Cooperative Agreement (No. 1443-CA9000-99-003, see Appendix K) with Dr. Andrew Fountain and Portland State University of Portland, Oregon to assist in protocol development. Dr. Fountain evaluated 1) a comparison of remote sensing approaches for assessing topography and extent of Mount Rainier glaciers, and 2) preferred methods (Fountain 2002, summarized in Appendix K). Our implementation in the last few years of the original study plan and his recommendations form the basis of the protocols presented here. Finally, the first several years of field work have greatly defined what is possible to measure and accomplish in the field.

Surface mass balance was chosen as the primary indicator of glacier change for several reasons. First, it accounts for ~89% of the annual change in volume of temperate glaciers (Mayo 1992). Second, it can be readily measured on the only accessible part of a glacier – its surface. Third, measurement of this quantity allows for direct assessment of changes in glacier volume, offers a high altitude climate proxy, and provides estimates of glacial runoff. Finally, mass balance is a universally recognized glacier index and is directly comparable to other glacier monitoring program results in the region and around the world (e.g., World Glacier Monitoring Service 2003). Surface mass balance has few drawbacks which mainly include personnel and time. Due to the considerable area and large altitude range of the glaciers on Mount Rainier, several multiple day visits a year are necessary to acquire the intended data. Two to four staff is required per visit to carry the heavy equipment and to safely access some potentially dangerous areas on the glaciers (i.e. navigating crevasse fields). Due to the limitations of personnel and time this glacier monitoring program uses only two, the Emmons and Nisqually glaciers, of the 27 glaciers found on Mount Rainier as “index glaciers” to represent glacial conditions in the park.

Mass changes using decadal repeat mapping was chosen as the secondary indicator of glacier change and allows for a quantitative measurement of glacier margins and volume changes. It also provides monitoring of glacial advance/retreat, and development of surface features such as crevasses and ponds. However, there are several limitations to the repeat mapping approach. Repeated mapping does not provide a measurement that can be linked to annual change in aquatic ecosystems nor can data be compared to glacier monitoring networks at the regional and global scale.

There was considerable discussion about the appropriate technology for repeat mapping. Participants at the meeting agreed that kinematic global positioning survey (GPS) assisted photogrammetry was currently the method of choice. It offers the advantage of providing other ecosystem data relevant to park management, can be obtained at a relatively low cost, and can have more flexibility on acquisition timing compared to Satellite and LiDAR constraints. However, a GPS ground survey involves a large time commitment and can have access issues on the large crevassed glaciers. Satellite data or LiDAR could also be used in place of or in combination with photogrammetry using aerial photographs. LiDAR has the advantage of limited distortion and the ability to analyze digital data more rapidly.

1.2 Monitoring Need

Glaciers are a critical resource and feature of the park that have undergone substantial change in the past century. Currently there is approximately 90 km^2 (35 mi^2) and 4.2 km^3 (1.0 mi^3) of ice on Mount Rainier, but since 1913 the total area of the mountain covered by glaciers has decreased 21 % and the total volume by 25% (Nylen 2002).

The importance of glaciers to the park ecosystem and park management is stressed in the park’s General Management Plan (http://planning.nps.gov/document/moragmp.pdf), and more recently at a network Vital Signs Workshop held in Spring 2001. At this meeting of resource management professionals, glaciers were identified as a vital sign of ecological condition in the park that should be monitored. Participants in this workshop indicated that monitoring should focus on “…present and future spatial extents of glaciation and snowpack, and its interconnection with ecological and hydrological systems…" This group also suggested that all glaciers in the park be inventoried periodically.

The importance of glaciers to the greater Cascades Ecosystem is illustrated in a glacier-ecosystem conceptual model (Riedel et al. 2008). Glacier dynamics are driven generally by climate and in special cases tectonic/volcanic processes such as geothermal ablation and insulation of ice by debris and landslide deposits. The magnitude of geothermal ablation at the bases of Mount Rainier glaciers is unknown. Debris cover accumulates on the glaciers from rock avalanches and by transport of debris within and on top of the ice to the ablation area. The setting (topography, aspect, slope, bedrock type, tectonics) of the glacier interacts with weather and climate and glacier movement to influence changes in the geometry of the glacier surface and margin. Glaciers integrate these factors and export sediment and landforms (soils and terrestrial habitat) and meltwater (aquatic habitat, nutrient cycling, and water supply). Further, glaciers are habitat to a number of species, and are the sole habitat for at least one species – ice worms (*Mesenchytraeus* spp.). Glaciers significantly change the distribution of aquatic and terrestrial habitat through their advance and retreat. They directly influence aquatic habitat by the amount of cold, turbid meltwater they release. The glaciers typically provide sediment to their runoff streams in excess of the stream's transport capacity. This creates braided stream systems within the park that have wide, open, aggrading floodplains and frequently changing channels. Glaciers also indirectly influence habitat through their effect on nutrient cycling and microclimate. Many of the subalpine and alpine plant communities in the park flourish on landforms and soils created by glaciers since the end of the last ice age, approximately 10,000 years ago.

The influence of glaciers on the park's hydrology is immense in both the quantity and timing of discharge of glacial meltwater. For example, in North Cascades National Park in the Thunder Creek watershed (13% glacier covered), glaciers contribute as much as 45% of the total summer runoff. More importantly, glacial meltwater delivery peaks during the hottest, driest time of year in the Pacific Northwest. Therefore, glaciers buffer the park's hydrologic systems during seasonal and interannual droughts. Endangered species such as salmon, and the hydroelectric and agricultural industries, among others, benefit from the stability glaciers impart to the region's hydrologic systems.

The sensitive and dynamic response of glacier surface elevations and margin positions to perturbations in both temperature and precipitation makes them excellent indicators of regional and global climate change at multiple time scales (Bitz and Battisti 1999; Burbank 1979; Burbank 1982; Harper 1993; McCabe and Fountain 1995; Nylen 2002). This feature of glaciers is particularly valuable in alpine landscapes where meteorological data are not available at high elevations. Glaciers also provide valuable insight to climate change over longer time periods than most other climate measures (Paterson, 1981). Numerous studies have observed and mapped historical changes in glacier terminus positions on Mount Rainier (Russell 1898; Harrison 1956; Sigafoos and Hendricks 1961, 1972; Post 1963; Meier 1966; Veatch 1969; Burbank 1979; Burbank 1982; Heliker et al. 1983; Nylen 2002). In addition, studies of preserved moraines and tills document the prehistoric glacier change (Crandell and Miller 1964; Crandell and Miller 1974; Porter and Burbank 1979; Burbank 1981; Heine 1997).

The large volume of glaciers on an active volcano presents a significant geological hazard to NPS visitors and staff, and communities downstream of Mount Rainier. Monitoring for geohazards is not the focus of this program but incidental observations of changes on the glaciers and on the mountain that may be related to hazards will be reported to appropriate personnel in the park and at the USGS Cascade Volcano Observatory.

The importance of glacier monitoring is recognized worldwide. Most countries with significant glacial resources have monitoring programs. Further, glaciers in or near many NPS areas in Washington and Alaska have been monitored by a variety of agencies and institutions including the National Park Service, University of Washington, Nichols College, and the US Geological Survey. Within the North Coast and Cascades Network (NCCN), NOCA and Olympic National Park (OLYM) have glacier monitoring programs.

1.3 Goals and Objectives

The general goal of the glacier monitoring program is to provide information on glacier change (glacial advance/recession and range of variation and trends in mass balance) and ecosystem dynamics (glacial runoff/stream buffering). The glacier monitoring program outlined below is designed to meet four more specific goals, developed at the Vital Signs workshop, the Tacoma meeting mentioned previously, and by NOCA staff.

1. Monitor change in area and mass of park index glaciers (see Section 2 of this protocol).

2. Relate glacier changes to status of aquatic and terrestrial ecosystems.

3. Link glacier monitoring observations to research on climate and ecosystem change.

4. Share information on glaciers with the public and professionals.

First, to monitor changes in glacier area and mass, glaciers must be monitored at multiple spatial and temporal scales. Objectives identified to reach this program goal are:

- Collect a network of point surface mass balance measurements sufficient to define elevation versus balance relationships to estimate glacier averaged winter, summer and net balance for Emmons and Nisqually glaciers.
- Map and quantify surface elevation changes of Emmons and Nisqually glaciers every 10 years.
- Identify trends in glacier mass balance.
- Inventory margin position, area, condition, and equilibrium line altitudes of all park glaciers every 20 years (see Standard Operating Procedure [SOP] 12. 20-Year Glacier Inventory).
- Monitor changes in surface features of glaciers, including ponds and ice falls.

To reach our second program goal we identify three primary links between glaciers and mountain ecosystems: glacial melt water, glacial microclimate influences, and glacial landforms/sediment and soils. In addition to mass balance, important indicators we will monitor include glacier melt, water discharge, and glacier area/volume change. Impacts of glacier change on aquatic and terrestrial ecosystems will be assessed by two approaches. For terrestrial ecosystems, glacier area/volume changes will be assessed for all glaciers at 20-year intervals. For aquatic ecosystems, annual variation in summer melt water discharge will be estimated in Nisqually and White River watersheds.

The third program goal will be accomplished by research conducted by professors and their graduate students from regional universities and by NOCA and park staff. Research questions include three primary subject areas: 1) glaciology, 2) glacier change and ecosystem dynamics and 3) glacier-climate relationships and climate change. As glaciology research questions are answered, the accuracy of monitoring will be improved. Suggested research questions at the time of this writing include:

1. Is glacier mass balance at Mount Rainer related to cycles in trans-Pacific climate such as El Nino/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO)?

2. What are the hydrological and ecological impacts of modern and Little Ice Age glacier change at Mount Rainier?

3. What is the temperature regime of firn and ice on the upper mountain?

4. Is there significant internal accumulation in the snow and firn of the upper mountain? (Internal accumulation is refrozen and retained meltwater in the upper firn layers of the glacier. The meltwater is from the current year's snowpack and percolates down into previous year's firn layers).

5. What is the contribution of geothermal melting at the beds of the glaciers?

6. What are the timing and relative quantities of meltwater storage and release from the glaciers?
7. What is the response time of the termini to changes in climate trend?

8. What are the flow rates and ice fluxes of the glaciers?

9. Are the measurement locations for long term monitoring representative of the elevations they represent?
    a. Do the measurement locations in debris covered ice accurately represent the total area of debris covered ice on Emmons and Nisqually glaciers?
    b. Do measurement locations in the upper ablation area/accumulation area adequately represent crevasse zones and icefalls?
    c. Are snow depth measurement locations representative for the elevations they represent, particularly on the upper mountain?

10. Does 10 years of net mass balance data explain the loss or gain in glacier volume with the 10-year remapping effort?

To accomplish program goal four, the data and information gathered in this program are shared with a variety of audiences from school children to colleagues and the professional community. See Section 4.9 and SOP 13 (Products and Reporting) for further details.

1.4 Measurable Objectives

Based on the broader goals and related objectives identified above, there are eight measurable objectives for monitoring the index glaciers in this protocol. Staff will monitor:

- Winter balance at predefined locations and other measurement locations
- Summer balance at predefined locations
- Net balance at predefined locations
- Winter, summer, and net mass balances and glacier area averaged balances estimated from data collected at predefined locations and local weather data
- Glacier margin position/area and surface cover (Equilibrium Line Altitude (ELA), snow/firn and ice distribution, and debris cover) for all glaciers (20-year intervals)
- Annual glacial contribution to summer runoff for Nisqually and White River watersheds
- Glacier surface elevations and changes (10-year intervals for Emmons and Nisqually glaciers)
- Surface conditions (ice falls, ice cliffs, snow/firn and/or ice distribution, supraglacial ponds, and debris cover) and terminus condition (10-years intervals in late fall for Emmons and Nisqually glaciers)

2 - Sample Design

As new research is conducted and new technology becomes available it is important that the sample design and protocols be updated to reflect new approaches. These protocols are considered adaptive and a chart is provided at the beginning of each Standard Operating Procedure (SOP) to record updates. This protocol narrative will be updated as necessary and changes recorded in the revision history log at the beginning of this document.

Sample design consists of a multi-scaled approach that incorporates different measurement frequencies for different indicators. Monitoring scale includes individual glaciers, watersheds, and the entire population of park glaciers. Sampling frequency includes seasonal, annual, decadal, and 20-year periods.

The primary focus is on detailed yearly mass balance monitoring of the two index glaciers, the Nisqually and Emmons glaciers. This monitoring is accomplished during site visits in spring, summer, and fall. Measurements are collected utilizing snow probes, ablation stakes, and snow cores to measure winter accumulation, summer melt, and snow density, respectively. Measurements are taken at the same predefined locations seasonally and are referenced by one of the six placed ablation stake locations on each of the two glaciers. Winter and summer balance point data are integrated for glacier-wide balance estimates. Trends in mass balance are monitored by tracking cumulative sums of winter, summer, and net balances.

Area and margin position change of the entire population of park glaciers are monitored by aerial photography or satellite imagery every 20 years and every 10 years for the index glaciers. Index glaciers are also remapped every 10 years to provide surface elevation/volume changes and accurate base maps for mass balance calculations.

Area changes can be linked to mass balance data to understand glacial contribution to runoff at watershed and park-wide scales. Area change and mass balance indicators are used to monitor the third indicator – glacial meltwater discharge. These measurements will provide a seasonal estimate of water accumulation, storage and loss, and an estimate for interpolation to the larger population of glaciers in the park. These data are useful for the hydroelectric industry, fisheries managers, and NPS aquatic ecosystem monitoring program.

2.1 Index Glacier Selection

The 27 major glaciers (Figure 2) mapped for glacier area and margin position every 20 years include Van Trump, Wilson, Nisqually, Paradise, Williwakas, Cowlitz, Ingraham, Whitman, Ohanapecosh, Fryingpan, Emmons, Sarvent, Inter, Winthrop, Liberty Cap, Carbon, Russell, Flett, North Mowich, Edmunds, South Mowich, Puyallup, Tahoma, South Tahoma, Pyramid, Success, and Kautz.

Detailed surface mass balance measurements focus on the two index glaciers, the Nisqually and Emmons glaciers for several reasons. First, the lower portions of these glaciers are the most accessible in the park, which is important because the steam drill and other stake placing equipment is transported overland (no helicopter support necessary). Second, major climbing routes along both glaciers will allow safe access to high altitude areas where we can conduct snow probing through the melt season. Third, these glaciers cover nearly the entire altitude range of glaciers on the mountain, thus the entire range of conditions are monitored. Selection of these glaciers will also allow us to monitor aspect-related extremes in climate and glacier change, with Emmons on the northeast side of the mountain and Nisqually the southwest side. Finally, these two glaciers in particular, have an excellent record of historic and prehistoric change (e.g. Harrison 1956, Heliker et al. 1983, Nylen 2002). These glaciers have the following characteristics:

2.1.1 Emmons Glacier (Figures 3 and 5)

- USGS 7.5 minute Quadrangles: Sunrise, Mount Rainier East, Mount Rainier West.
- Glacier Type, Characteristics, and Location: This alpine valley glacier is northeast-facing, heavily crevassed, and steep at the head with reduced slopes down the glacier to a relatively flat terminal area. It lies on the northeast side of Mount Rainier.
- Drainage Basin: White River
- Area: 11.6 km2 in 1994
- Altitude Range: 1,480–4,320 m
- Other: This glacier as we know it is probably only a few thousand years old and was reformed after the 5700 year old Osceola mudflow event, when the Emmons and Winthrop Glaciers were melted (Hoblitt et al. 1998). In December 1963, a large rock avalanche fell from the north side of Little Tahoma Peak covering much of the lower Emmons Glacier with shattered rock (Crandell and Fahnestock 1965). In 1994 remnants of this avalanche covered the lower glacier from the terminus (1,480 m) up to ~1,700 m in elevation.

2.1.2 Nisqually Glacier (Figures 4 and 5)

- USGS 7.5 minute Quadrangles: Mount Rainier East, Mount Rainier West.
- Glacier Type, Characteristics, and Location: This alpine valley glacier is south-facing, heavily crevassed, and steep at the head with reduced slopes down the glacier to a relatively flat terminal area, and an abrupt, steep nose. This glacier's accumulation area lies in complex and steep topography with a major icefall and ice cliff (so that some mass in transferred down the glacier by avalanching). Wilson Glacier is a tributary and is a significant contributor of ice to the lower Nisqually. The Muir Snowfield is attached to the mid-Nisqually and is also considered part of the glacier system. This glacier monitoring program uses measurement locations (stake 1 and stake 2, discussed below) on the nearby Ingraham Glacier and Muir Snowfield to represent concurrent altitudes on Nisqually and Wilson Glaciers.
- Drainage Basin: Nisqually River
- Area: 6.9 km^2 in 1994. This includes both the Wilson Glacier and Muir Snowfield.
- Altitude Range: 1,450–4,380 m
- Other: Nisqually glacier has a long history of observation, particularly at the terminus (eg. Harrison 1956, Heliker et al. 1983, Hodge 1972, LeConte 1906, Sigafoos and Hendricks 1961, Veatch 1969).

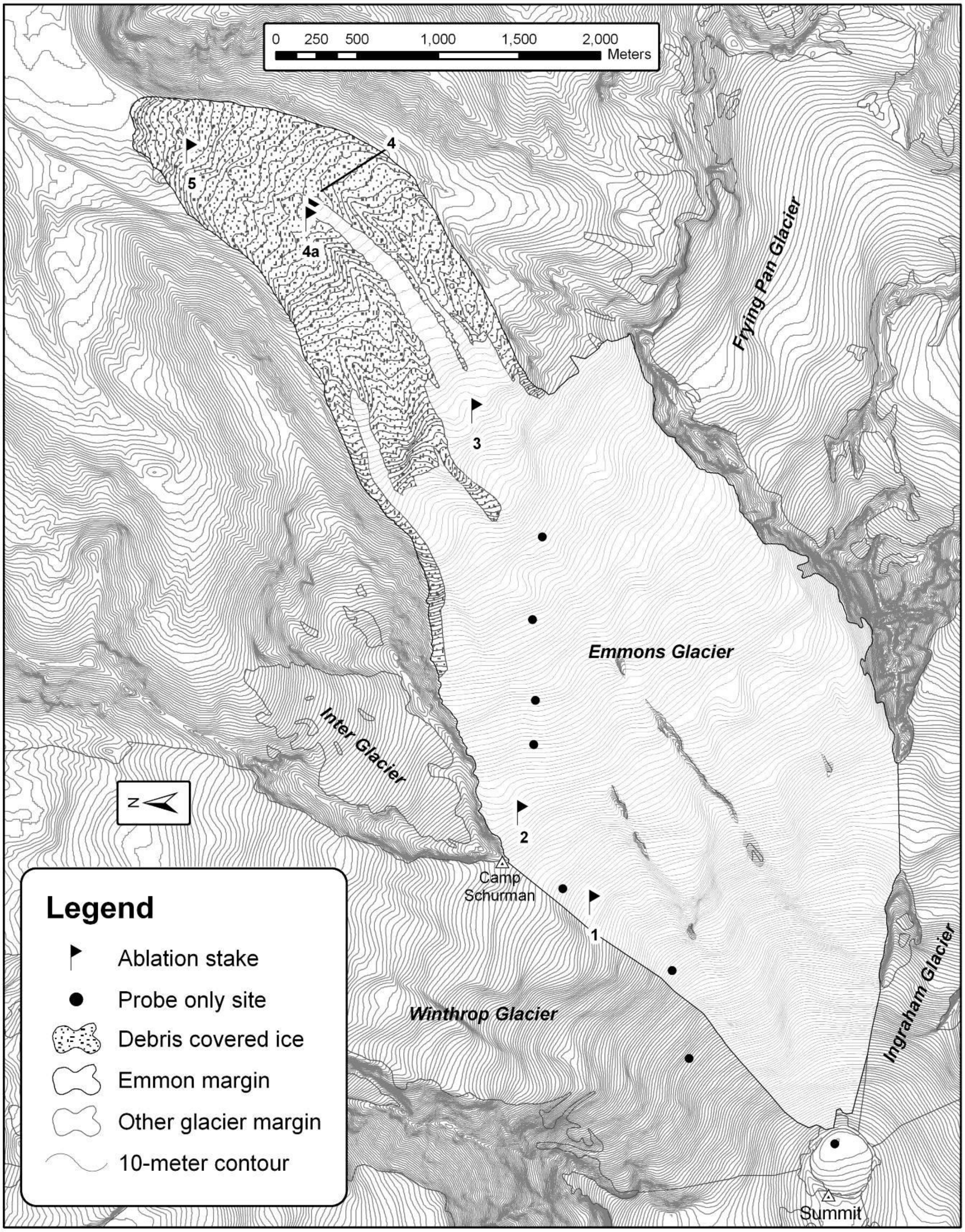

Figure 3. Emmons Glacier margin (1994), debris cover (2001), and measurement locations.

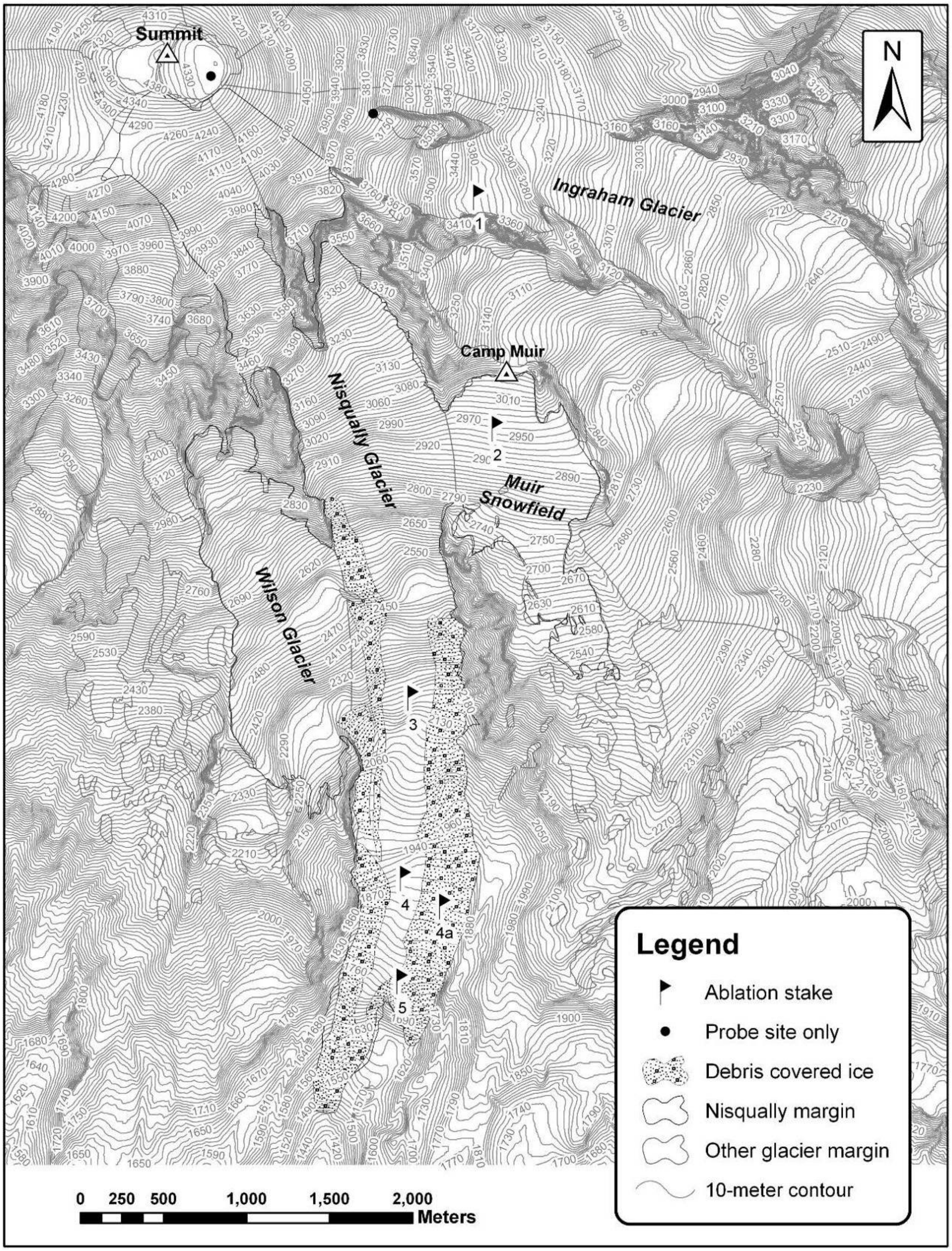

Figure 4. Nisqually Glacier margin (1994), debris cover (2001), and measurement locations.

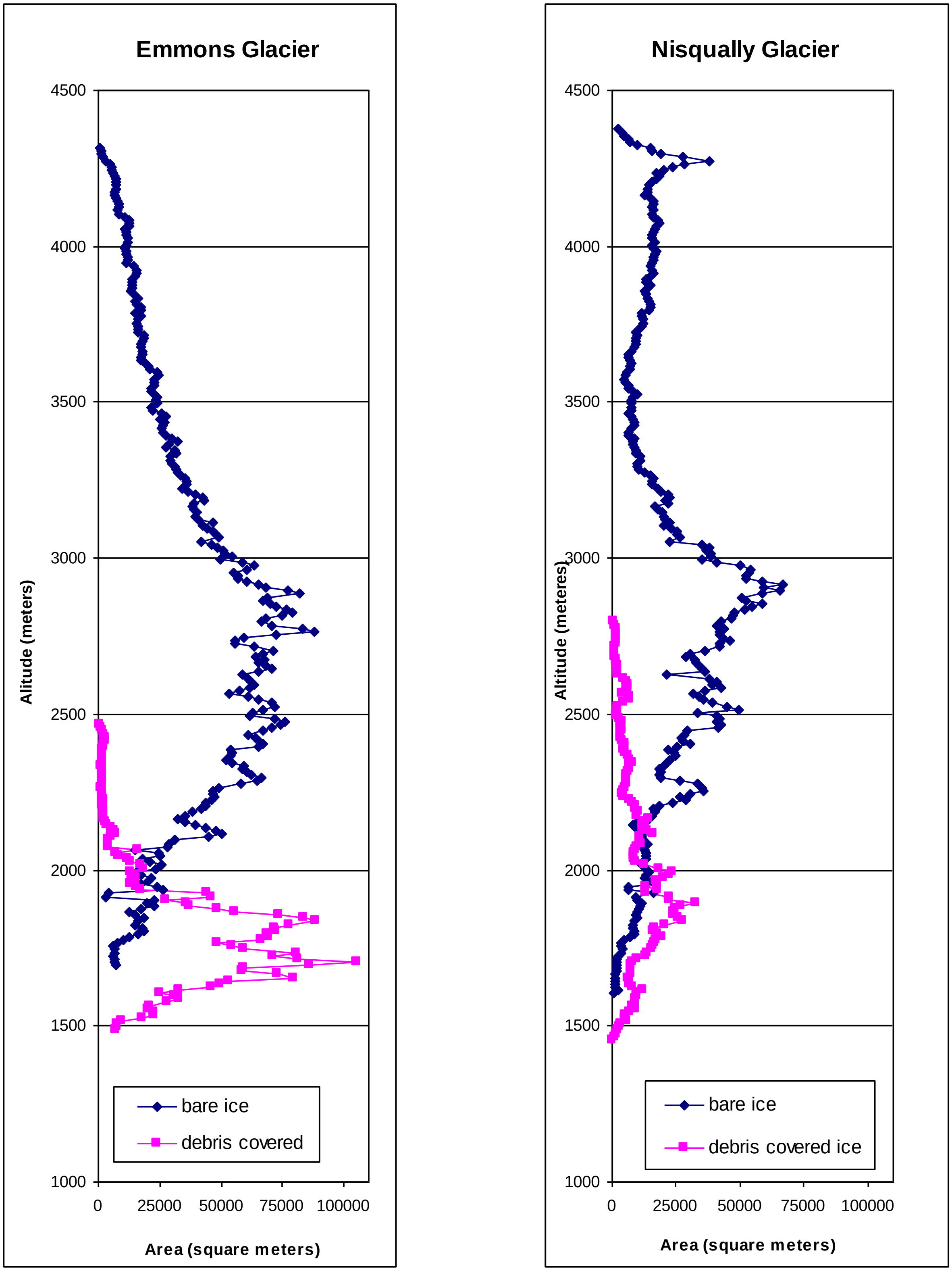

Figure 5. Area altitude distributions by 10-meter bands of the Emmons and Nisqually Glaciers, showing 1994 glacier margins and 2001 debris cover.

2.2 Glacier Mass Balance Monitoring

2.2.1 Methods Overview

Numerous options exist for monitoring glacier mass balance, but surface measurements are an accurate, relatively easy way to monitor annual changes in winter balance, summer balance, and net balance. An unknown subsurface loss in mass is not detected by surface measurements. Mayo (1992) suggests that approximately 89% of the ablation of South Cascade Glacier in a given year occurs on the glacier's surface, while the rest occurs at the bed and margins. Subsurface melting may be appreciably more on Mount Rainier volcano where geothermal heating may be significant. It is hoped that data collected at different times and scales and additional research will allow us to assess subsurface melting in the future.

Mass balance measurement methods used in this project are modified from procedures used at NOCA for 16 years (Riedel et al. 2008 and established during 45 years of research on the South Cascade Glacier by the USGS-WRD (Meier 1961; Meier and Tangborn 1965; Meier et al. 1971; Tangborn et al. 1971; Krimmel, 1994, 1995, 1996a, 1996b). These approaches are very similar to those used around the world. Similar methodology is described in the literature by Ostrem and Stanley (1969), Patterson (1981), and Ostrem and Brugman (1991). Data reduction methods follow a modification of those outlined in Ostrem and Brugman (1991) and Krimmel (1994, 1995, 1999a, 1999b, 2001).

Emmons and Nisqually Glaciers have some very different characteristics from other glaciers monitored in the Pacific Northwest:

1. They are approximately an order of magnitude larger in area.

2. The glaciers have an extremely large altitude range from 4,300 to 1,500 m, thus the weather and climate changes significantly from the top to the bottom of the glaciers. This creates winter and summer seasons of different lengths dependent on altitude (see Appendix C. Analysis for the Best Timing of Glacier Visits).

3. These glaciers are considered 'small alpine glaciers (<20 km^2)' by Fountain and Vecchia (1999). They suggest that the number of point measurements needed to calculate glacier-wide mass balance is scale invariant and that 6 to 10 sites are sufficient. However, on these glaciers a single measurement point is assumed to represent a wide swath of glacier surface that may have significant variability of surface roughness and cover, including debris covered ice (of variable thickness debris), crevasse fields, and icefalls.
4. There are substantial areas that are heavily crevassed and have major ice falls and substantial debris covered ice areas that change through time.

5. They have possible significant subglacial geothermal ablation (i.e., summit firn caves and steam emissions are a very common occurrence) (Kiver and Mumma, 1971).

6. The glaciers have relatively high velocity ice flow.

7. In addition, this large mountain significantly influences its own weather and climate. Precipitation shadow effects, wind redeposition of snow, avalanching of snow and ice,

surface slope, aspect, and shading are important factors that influence balance distributions, timing of maximum and minimum balance, and glacier dynamics.

These characteristics present some challenges in measuring mass balance variables and determining glacier wide mass balances. Key aspects of the monitoring protocol address these problems and include:

1. Each index glacier has six predefined measurement locations from near its terminus to ~3,100 m altitude (see Figures 3 and 4 and SOP 1 [Field Season Timeline, Preparations, and Procedures] for locations).

2. Multiple spring visits are timed to catch near-to-maximum balance conditions at differing altitudes and aspects (see Section 2.2.2, SOP 1, and Appendix C.)

3. Multiple fall visits are timed to catch near-to-minimum balance conditions at differing altitudes (see Section 2.2.2, SOP 1, SOP 7 [Balance Determination above 3,100 meters], and Appendix C).

4. This program has comparable measurement and calculation methods to other mass balance monitoring programs (see SOP 2 [Snow Depth Probing], SOP 3 [Snow Density Determination with Snow Core], SOP 4 [Operation of the Steam Drills], and SOP 5 [Mass Balance Calculations]).

5. Measurement locations are placed at adjacent locations in bare and debris-covered ice areas (same altitude) and represent separate summer mass balance estimates for debris covered ice (SOP 6. Ablation Measurement and Summer Mass Balance Estimation of Debris-covered Ice).

6. In some years, an early to mid-July visit is made to the upper mountain, above 3,100 m, to assess conditions. The maximum balance is assumed and assessed at this time (SOP 7. Balance Determination Above 3,100 Meters).

7. In years without reliable higher altitude data, winter balance (see Section 2.2.2) is assumed to follow the same pattern of decreasing balance observed between 2002–2004. ‘Winter balance’ (b_w) is the sum of all accumulation and ablation during the winter season (also referred to as the accumulation season). Winter balance from 2004 was chosen to model the pattern of decreasing balance with elevation because reliable data was collected high on the mountain (SOP 7).

8. Summer balance (see Section 2.2.2) is estimated above the highest measurement locations by using an average of July and August upper atmospheric temperature data to find the altitude of zero summer balance (SOP 5, SOP 7).

9. Mount Rainier glaciers have significant flow contributing to annual and cumulative balances and terminus behavior. As a result, cumulative balances recorded at measurement locations will not directly reflect changes in surface elevation determined from photogrammetric analysis at those specific locations. However, cumulative net mass balance for the entire glacier is directly comparable to glacier wide volume.

2.2.2 Measurement System

Glacier mass balance terms and variables used in this report follow the convention of Ostrem and Brugman (1991) and Mayo et al. (1972). Measurements are performed at points on the glacier surface and are interpolated and extrapolated for the entire glacier area. 'Balance' (b) is a change in mass measured between two points in time. By convention the 'balance year' (BY) is the period between two times of minimum balance in late fall (Figure 6).

Accumulation includes all processes that add mass to the glacier such as snowfall, wind drifting, avalanching, rime ice buildup, rainfall, superimposed ice, and internal accumulation. 'Winter balance' (b_w) is the sum of all accumulation and ablation during the winter season (also referred to as the accumulation season). The time of maximum winter balance occurs in late March to early May (~July near the summit), depending on the altitude of each measurement location (see Appendix C, SOP 1). The b_w is the product of accumulated snow depth or vertical height, (h_{snow}) between the upper surface down to the previous year's summer surface, and the snow density (ρ) at a single point on the glacier surface.

$$b_w = h_{snow}\rho \qquad \text{(Eq. 1)}$$

The summer surface is the surface of firn and ice on which the new winter season's snow is deposited. A dirty layer and significant change in density typically identifies it. Ablation includes all processes that remove mass from the glacier such as melting and runoff, evaporation, sublimation, calving, and wind erosion. The 'summer balance' (b_s) includes the total of all ablation and accumulation during the summer season at a single point on the glacier surface (always a negative value as indicated below).

$$b_s = -(h_{snow}\rho_{snow} + h_{firn}\rho_{firn} + h_{ice}\rho_{ice}) \qquad \text{(Eq. 2)}$$

Summer balance is determined at the end of the BY. The symbols b_w and b_s refer to values measured and/or calculated at measurement locations. Likewise the 'local net balance' (b_n) is the change in balance calculated at a measurement point during one BY (Figure 6). These balance values are expressed in meters of water equivalent (m water equivalent).

$$b_n = b_w + b_s \qquad \text{(Eq. 3)}$$

Values integrated across the surface of the glacier are referred to as winter mass balance (B_W), summer mass balance (B_S), and net mass balance (B_N). These mass balance values have the same relationship as the local values and are expressed in cubic meters of water equivalent (m^3).

$$B_N = B_W + B_S \qquad \text{(Eq. 4)}$$

Note for park glaciers, B_S is the sum of all the summer mass balances of all applicable surface types by area:

$$B_S = B_R + B_D \qquad \text{(Eq. 5)}$$

Where B_R is regular, snow, firn, and ice and not debris covered mass balance; and B_D is debris-covered ice mass balance (see figures 3–5 for debris cover and ice boundaries and area altitude distributions).

Area averaged values for winter, summer, and net mass balance are denoted $\overline{b_w}$, $\overline{b_s}$, and $\overline{b_n}$ respectively. These values are the respective mass balance divided by glacier area.

Firn and ice densities are given as a decimal fraction relative to the maximum density of water, which is 1.0 g/cm^3. Estimates of material density include $\rho_{ice} = 0.9$ for glacier ice, $\rho_{firn2} = 0.7$ for two year old firn, and $\rho_{firn} = 0.6$ for one-summer-old and one-year-old firn. These estimates are based on research at South Cascade Glacier (SCG) (Krimmel, 1994–2001). Snow densities are discussed below.

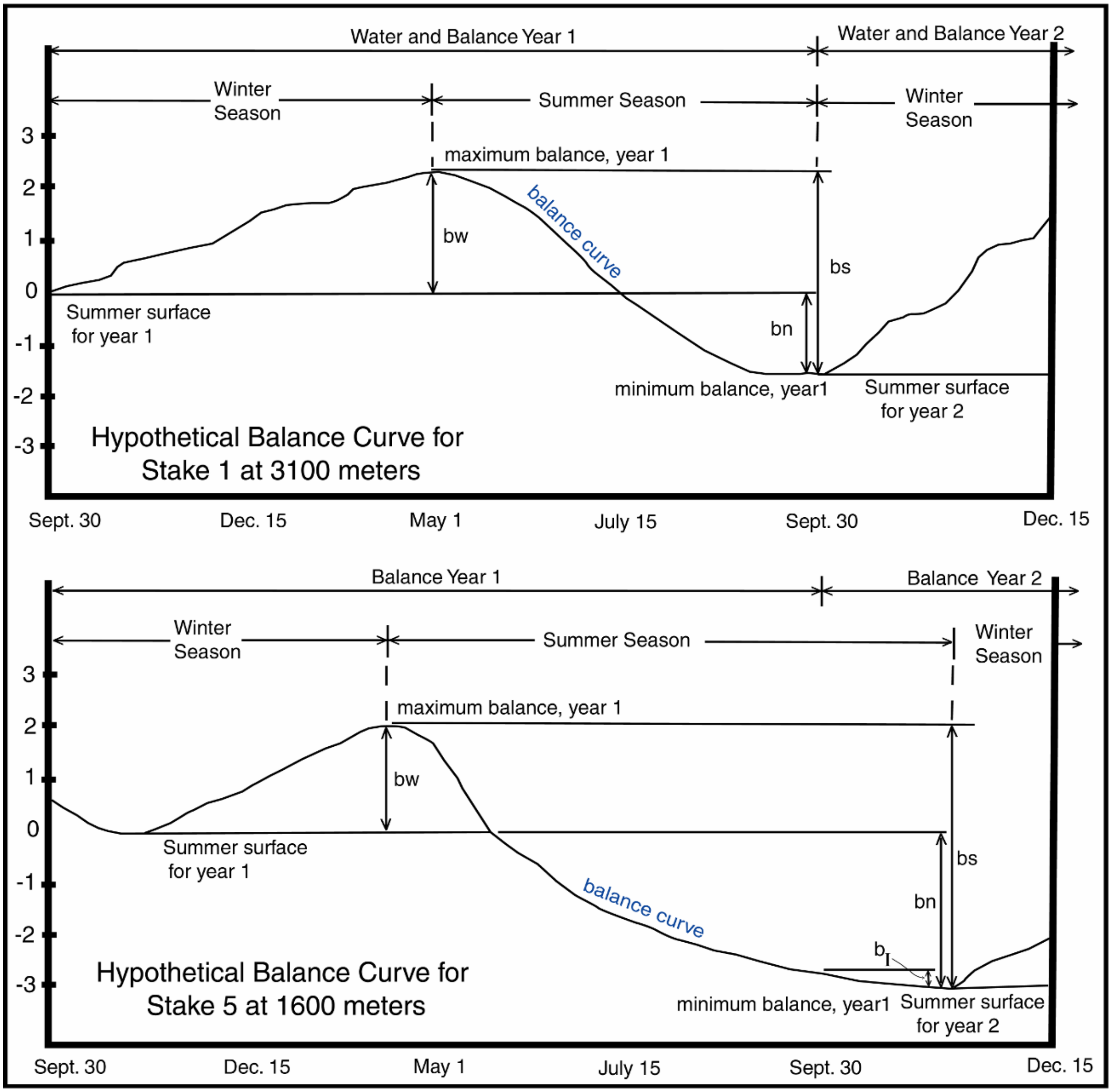

Figure 6. Idealized glacier balance curves. These illustrate the offset timing for different altitudes of balance minimums and maximums on Mount Rainier glaciers. The figure shows basic balance quantities based on the stratigraphic system. The quantity, b_l, describes the change in balance between the end of the Water Year and Balance Year.

Winter balance is measured by probing the snow depth at predefined locations with each location representing a larger area of the glacier. Snow depth is measured by using two different designs of snow depth probes: (1) a variable length probe in one-meter aluminum and stainless steel segments that screw together developed by Taylor Scientific Engineering of Seattle, Washington and, (2) a variable length probe composed of copper-coated steel army tank radio antenna segments, M116A mast sections. The “Taylor probe” is used in shallower snow on the lower elevations of the glacier as it tends to be relatively delicate, while the “tank antenna” probe is typically used in the accumulation area where a tougher, more rugged probe is needed. Snow depth is probed down to the previous year’s summer surface and is recognized as either a change in density between snow and firn or a dirty layer (if using a snow core or snow pit). Snow depth is measured at six ablation stake locations (see below) and other selected locations on the glacier. Five to ten snow depth measurements are taken on an elevation contour transect with a global positioning system (GPS) located/recorded center point (most often at an ablation stake site), resulting in a minimum of 30–60 measurements per glacier. See SOP 2 for detailed snow depth probing procedure. Snow depths range from 2 to 10 m depending on location, altitude, and the previous winter’s accumulation. If probes are unreliable and a snow pit or snow core (see below) could not detect the summer surface, probes are taken again during a summer visit when the current year’s snowpack has warmed and the previous year’s summer surface is more definitive. The measurement of melt from the ablation stake (see below) between spring and summer is then added onto the summer probe depth to calculate winter balance.

The snow depth probe cannot always reliably detect the previous year’s summer surface, especially in the accumulation zones, so a snow coring device or a snow pit is used to positively identify the previous summer’s surface. At higher elevations where the summer surface can be vague, a sediment surface marker is scattered on the glacier in the fall before snow starts to accumulate. The following spring or summer a snow core can detect this “dirty” layer and pin point the previous year’s summer surface depth.

The snow coring device mentioned above is also used to determine snow density. Two different core models are used to find snow density: Taylor Scientific Engineering, Inc.; and Kovacs. Both coring devises rely on a core tube to collect a snow column, a cutting shoe to break through ice layers, extension rods to lower the core, and tee handle to auger in the core. See SOP 3 for detailed snow coring procedures and snow density determination. Snow density (ρ_{snow}) on each glacier is measured at two to three sites per visit during the spring and early summer visits (SOP 1). Density measurements at a minimum of two sites during a visit to a glacier are crucial for determining the density versus altitude gradient. This gradient is then used for the interpolation between and extrapolation above and below measuring sites. In some years, snow density is measured in the summit crater during the summer visit. Bulk density of the entire recovered column of snow is determined by dividing the mass by the calculated volume of the snow column.

Ablation stakes are used to measure summer balance. Both glaciers have six stakes covering an elevation range of ~1,600m and a stake density of 0.5 points/km^2 and 1.0 points/km^2 on the Emmons Glacier and Nisqually Glacier, respectively. Ablation stakes are constructed from 1.5 meter sections of PVC water-line tubing with 22 mm (7/8-inch) outer diameter and 3 mm (1/8-inch) wall thickness (PVC 1120 schedule 40, 600 psi). Depending on the glacier, the particular stake location, and the amount of accumulation that year, the PVC sections are combined into 7.5 to 12 meter long stakes. They are joined using 50 to 70 mm sections (2 to 3 inches) of 16 mm (5/8-inch) wooden dowel that fit inside the tubing. Individual sections are joined flush and taped together with duct tape. The positions of the stakes are recorded as GPS waypoints and are placed in the same location every year. See SOP 1 for specific coordinates. Stake locations serve as predefined measurement locations for most other types of measurements on the glacier, i.e., snow probing and snow coring.

This protocol sometimes describes the glaciers as having ‘upper’ and ‘lower’ altitude areas which coincides with stake numbered locations. There are six ablation stakes placed on each glacier with stake number one placed at the highest altitude and the rest consecutively placed below. Stake number one and two are located in the ‘upper’ glacier area and stakes three through five are located on the “lower” glacier. Stakes 4a and 5 are placed in debris-covered ice.

Ideally, ablation stakes are placed near the centerline of the glacier and from top to bottom. However, accessibility dictates stake locations. Stakes need to be accessible on foot in the fall when glacier surfaces become extremely crevassed and broken. The amount of stake drilling equipment needed plus challenging weather and snow conditions limits our stake placement access in the spring to a maximum of ~3,100 m on the Emmons and ~3,300 m for the Nisqually glaciers. Crevasses near the upper stakes dictates that two are placed toward the margins of the glaciers. In the case of Nisqually, stakes are located on the nearby Muir Snowfield and at Ingraham Flats; on Emmons at the north edge of the glacier near Camp Schurman (Figures 3 and 4). Stakes on the lower glacier follow the approximate centerline. The lowest most stake is placed near the terminus. On the Nisqually, the terminus stake site was abandoned due to steep ice and falling rock hazard and is now located ~300 m above the terminus

Stakes are placed in holes using a backpack-mounted propane steam drill. Two different steam drill models and are manufactured by Taylor Scientific Engineering, Inc., and Kovacs. Both consist of a water boiler chamber, propane line, a heavy perforated tip for self auguring, a radiator hose connecting the boiler to the tip, and a safety steam release valve. See SOP 4 for instructions on how to use the steam drills safely and properly. The drill can make holes of up to 13 m in depth. Deep burial precludes the need to redrill stakes during summers of particularly high melt. However, the depth of holes drilled into debris covered ice is often limited so a second visit in August may be necessary to redrill the stakes.

Stakes are placed each spring when snow depth is probed for winter balance. Measurements of surface level change at the stakes are made during subsequent visits. The change in surface elevation at the stake indicates the mass lost (snow, firn, and ice melt) at the surface during the summer season (summer balance). Mid-summer stake measurements and snow depth probing provide an important check for spring snow depth measurements. In the fall when several meters of melt has occurred, the exposed stakes are broken down to near the glacier surface and packed out to be reused the following spring.

As a result of the large altitude range of these glaciers, stakes and other measurement locations of differing altitudes have variable timing and length of winter and summer seasons (Figure 6). Lower stations will have a longer summer season and corresponding shorter winter season compared to an upper elevation station which will have a shorter summer season and longer winter season. For example, based on the Paradise SNOTEL data the lower area of Nisqually Glacier has a summer season that occurs on average between early May and late October; while on the mid glacier, Stake 1 at ~3,100 m, the summer season occurs between early June and early October (see Appendix C).

Mayo et al. (1972) outline a system to combine the Stratigraphic and Annual (Fixed Date) systems to estimate mass balance. The Stratigraphic System uses successive minimum balances to define the Balance Year, BY. The BY is not necessarily 365 days long and is of slightly different length every year, depending on the weather and altitude of the measurement point on the glacier. The Fixed Date System uses the Water Year (WY) October 1 to September 30, to relate glaciological data to hydrological data. This protocol primarily uses a two-season stratigraphic approach to calculate mass gained (b_w) and mass lost (b_s) on a seasonal basis (Figure 6). However, this glacier monitoring program calculates the "final balance increment" (b_I) for stakes on the lower glaciers and includes the data in the following year's summer balance. This is the change in balance between the balance minimum and the end of the hydrologic year (Figure 6) (Mayo et al. 1972). Summation of these measurements allows for calculation of the mass and area averaged balances of a given glacier for a given balance year.

Balance maximums and minimums do not occur simultaneously across the entire surface and as a result the calculations of glacier-wide/ mass balances at any one point in time can be complicated. The simplest method to address this is to calculate time transgressive mass balances based on the maximum and minimum point balances at varying altitudes, so that a "snow/ice flood crest" quantity for each balance is generated. While this has meaning for the overall balance of the glacier it ignores the timing and differences of balance of the hydrologic year versus the balance year. The only place and time where and when this is potentially significant is on the lower glaciers during the fall when the water year ends/starts and the balance year continues past this date. Melt on the lower glaciers will sometimes continue for up to six weeks past the end of the Water Year (Appendix C.). The magnitude and relative importance of this balance increment (b_I), which is effectively missed summer runoff, is unknown. However, with visits to the lower Nisqually at the end of the water year *and* at the approximate end of the balance year (SOP 1) will provide the data needed to assess it. Also, measurement stakes on the lower glaciers which are left in the ice at the end of the BY are measured the following year and captures any additional melt. SNOTEL and Camp Muir meteorological data can also assist in assessing the magnitude of b_I runoff.

Generally, two spring visits are made to each glacier: an early one (late March/early May) to the lower stakes and a later one (mid April/early May) to the upper stakes. A visit in early June is made to each of the lower glaciers to place ablation stakes into the debris covered ice. Summer or mid season visits are made in early to mid July. Two fall visits are made to each glacier, an early one (mid September) to the upper stakes and a later one (mid October) to the lower stakes. The schedule of visits, trip options, and specific tasks are explained in more detail in SOP 1.

2.3. Glacier Imagery and Mapping

Changes in glacier geometry are monitored with vertical imagery quantitatively for the 27 major glaciers in the park at 20 year intervals and 10 year intervals for the index glaciers. Index glaciers are also assessed annually on a qualitative basis with terrestrial-based photography. Remapping of Nisqually and Emmons Glaciers is conducted every ten years.

Vertical aerial photographs are taken at least every ten years (or more frequently when funding allows) of the index glaciers to assess equilibrium line altitude and to measure the area of the glacier covered by snow, firn, bare ice, debris-covered ice, and stagnant ice. These color photographs are taken in stereo-pairs at 1:12,000 scale late in the ablation season (between early September and early October), before the first winter snow covers the glacier (for detailed specifications see SOP 10 [Vertical Aerial Photography]). The photo prints are archived at the NPS office for reference and future use, and negatives are retained by the contractor.

Currently there are three options for decadal remapping of the index glaciers; photogrammetry, LiDAR, and high precision GPS survey. Using the high precision GPS survey or the photogrammetry methods, the decadal vertical aerial photographs mentioned above are also used for remapping. For more accurate maps, the 10-year cycle may be adjusted by one or two years if photographs were taken when new snow was already on the ground. Mapping should be done in years of minimal snow because anomalously high snow can (1) obscure the terminus and make it impossible to derive significant terminus change results and (2) make the surface elevation change comparison less meaningful because the amount of snow remaining is anomalously high. Plus the high albedo of snow can make photogrammetry difficult and less accurate.

Affordability and technology improvement in LiDAR may make surface mapping by this method viable in the future. However, good photo identifiable ground control points are still necessary.

In some cases it is necessary to redefine the glacier perimeter by subsequent aerial photography and field observation. Errors in determining the area of a given glacier may result from measurement of areas covered by snow or debris, and improperly located ice divides.

Terrestrial-based photographs are taken annually of each index glacier as a record of annual change of the terminus, relative surface elevation against bedrock, equilibrium line altitude, and snow, firn, and ice coverage. These color photographs are taken during field visits at the same locations and of the same views of the glaciers every year. Photos are taken *at least* once a year in the late summer or early fall (August–October). However, photographs in the spring or early summer also provide an excellent record of snow cover and are taken when weather permits. See SOP 15 (Repeat Terrestrial Photography) for descriptions, coordinates, and sample photos of the photo stations. Refer to SOP 17 (Managing Photographic Images) for managing and naming conventions.

2.4 Area and Volume Change Analysis

Areas of all glaciers are assessed from analysis of air photos or IKONOS satellite imagery approximately every 20 years. Glacier area changes provide a direct measure of the advance and retreat of park glaciers, the concomitant creation and destruction of terrestrial and aquatic habitat, and baseline data for evaluating geohazards. Methods are further described in SOP 12 (Twenty-Year Glacier Inventory) and follow the methods of Nylen (2002).

Nisqually and Emmons Glaciers are remapped every 10 years to assess area changes, advance/retreat of termini, surface elevation/volume changes, and to provide accurate base maps for mass balance calculation. Glaciers are mapped and the area and volume change is quantified by photogrammetric analysis. In addition, the analysis compares changes in altitude, slope, and curvature, which are key indicators in longer term changes in glacier mass balance (Etzelmuller and Sollid 1997, Jacobsen and Theakstone 1997). Methods are further described in SOP 11 (Glacier Mapping and Volume Change Determination Specifications).

3 - Field Methods

Access to each glacier is dictated by seasonal visit and avalanche and weather conditions. Standard Operating Procedure 1 discusses access options with each field trip. Generally, the Nisqually Glacier is accessed from Paradise and the Emmons Glacier from White River Campground.

NOCA and park Resource Management Division staff, park climbing rangers, and/or volunteers may be necessary to carry out each trip. See SOP 1, which includes the optimal team sizes for each visit to each glacier. Optimal team size depends on the tasks of a particular visit.

3.1 Spring Visits

The timing of the spring visits generally coincides with the transition from accumulation season to ablation season. Generally two spring visits are made to each glacier, an early one to the lower glacier and a later to the upper glacier. For the schedule of visits and specific tasks, see SOP 1. Generally, spring visits have three objectives;

1. Measure the snow depths on the glacier;

2. Place ablation stakes into the glaciers; and

3. Take snow core measurements for density determination.

Winter snow depth down to previous year's summer surface is determined using the snow depth probe. Snow depth is probed at five to 10 points in the vicinity of each stake location to establish an accurate average value. An initial probe at the exact point for the stake hole is a check for crevasses as well as to find the snow depth. Three to nine other points are probed laterally on contour from either side of the stake. Extra probe measurement locations are sampled in the same manner as at stake locations. Fewer probe measurements may be taken when probing is difficult. However, more probe measurements should be made on a later visit to the site. See SOP 2 and Appendix D (Field Data Forms) for details and example data sheets.

Ideally the summer surface is firn or ice that is impossible to penetrate with the probe. It can be difficult to identify this surface, however, when there is little change in density between the ice layers in the current year's snowpack and one-year old firn. This situation often occurs after a strongly positive balance year (with residual snow), especially on the upper sections of the glacier. In these situations snow depth can be easily overestimated. Probing can also underestimate a given winter's snowpack because of the formation of ice layers that are created during winter freeze thaw cycles and/or precipitation events. One other difficulty with probing occurs when a significant temperature gradient exists in the snowpack with snow at the surface at the melting point but at depth it is below freezing so that the probe tends to freeze in and "stick". Difficulties with probing and any distinct ice layers encountered while probing along with the interpreted summer surface depth are recorded on the data sheet. The ice layers can be referred to if there is any doubt as to the level of the summer surface at subsequent site visits and when calculating winter balance.

If the previous summer surface is difficult to detect from probe data, then a snow core, snow pit or crevasse stratigraphy is used to find the depth of the summer surface. This surface may be observed as a distinct “dirty” layer, or at higher elevations, as a substantial sediment layer where a surface sand marker was placed the previous fall (see SOP 3). If the dirty layer cannot be detected then snow densities will be measured to find a significant change in density between successive year’s snowpacks. If the snow depth in the spring is deep it may be necessary to conduct summer surface analysis during the following summer or fall site visit.

Ablation stakes are placed in the same approximate GPS recorded locations year after year. Holes for the ablation stakes are drilled vertically into the snow and ice with a backpack mounted steam drill at each location and not perpendicular to the surface (Paterson 1981). The top of the stakes are placed +0.5 to 3.0 m below the surface (depending on altitude). Typically, lower altitude stakes are placed at a greater depth below the surface because of higher ablation rates. Specific stake length and placement depth are determined in the office before the field visit based on the general snowpack level in the spring. Typical stake lengths and depths are listed in SOP 1. After the stake is placed in the hole, the depth of the top below the surface is measured and recorded on the field data sheet. Standard Operating Procedure 1 has example field data sheets.

3.2 Summer Visits

The timing of the summer visit coincides with the warming of the current year’s snowpack, melting any persistent ice layers and making the previous year’s summer surface more definitive. Two to three separate hikes from trailheads may be needed to accomplish all the summer visit objectives. This involves one to two day trips into the lower glaciers and to the highest stakes. A separate visit in early June is made to each of the lower glaciers to place ablation stakes into the debris covered ice. The timing of this visit is determined when the lower glacier is free of snow and the debris is exposed. Trip options and tasks are explained in more detail in SOP 1.

Generally, visits to the glaciers in summer have seven objectives:

1. Measure stake heights.

2. Measure the snow depths at the stake locations to verify spring snow depth measurements.

3. Gather snow depth measurements at additional locations between stakes and possibly the upper mountain (above ~3,100 m).

4. Investigate crevasse stratigraphy for remaining snow depth.

5. Take snow core measurements for density determination and summer surface verification at one or two stake sites per glacier.

6. Place stakes in debris covered ice on the lower glaciers.

7. Measure debris thicknesses on the lower glaciers.

8. If necessary, in late summer redrill stakes that are at risk of melting out before the end of the summer season.

3.3 Fall Visits

Generally two fall visits are made to each glacier, an early one to the upper glacier and a later one to the lower glacier. The timing of this visit more or less coincides with the minimum balance and the end of the balance year. Again timing of this visit is subject to weather. SOP 1 outlines tasks in detail but the main objectives for the fall visit include:

1. Measure each stake's height. Break down exposed (melted out) stake sections and transport out for use next year.

2. Investigate crevasse stratigraphy for remaining snow depth.

3. Mark remaining ice bound sections in glacier at glacier surface for identification in the following year.

4. Redrill stakes 3–5 that have less than 0.75 m stake remaining in ice to capture any 'winter' melt.

5. Probe snow if snow remains on the glacier surface. Fall snow depth probing provides an important check on winter balance measurements and is a direct measure of net balance in those areas with a positive net balance.

6. Spread sediment surface marker over a 3 m x 3 m area at stake 1 and 2 for identification in the following year (see Section 2.2.2).

7. Measure debris thicknesses at lower glacier stakes.

8. Take digital photo of glacier terminus.

Often new snow has accumulated on the glacier previous to the fall visit. In this case the depth of new snow at each stake is measured but is not included in the final fall measurement in the field. See SOP 1 for equipment lists.

4 - Data Handling, Analysis, and Reporting

This chapter describes the procedures for data handling, analysis, and report development. Additional details and context for this chapter may be found in the NCCN Data Management Plan (Boetsch et al., 2005), which describes the overall information management strategy for the network. The NCCN website (http://science.nature.nps.gov/im/units/nccn/) also contains guidance documents on various information management topics (e.g., report development, GIS development, GPS use).

4.1 Information Management Overview

Project information management may be best understood as an ongoing or cyclic process, as shown in Figure 7. Specific yearly information management tasks for this project and their timing are described in Appendix B (Yearly MORA Project Task List). Readers may also refer to each respective chapter section below for additional guidance and instructions.

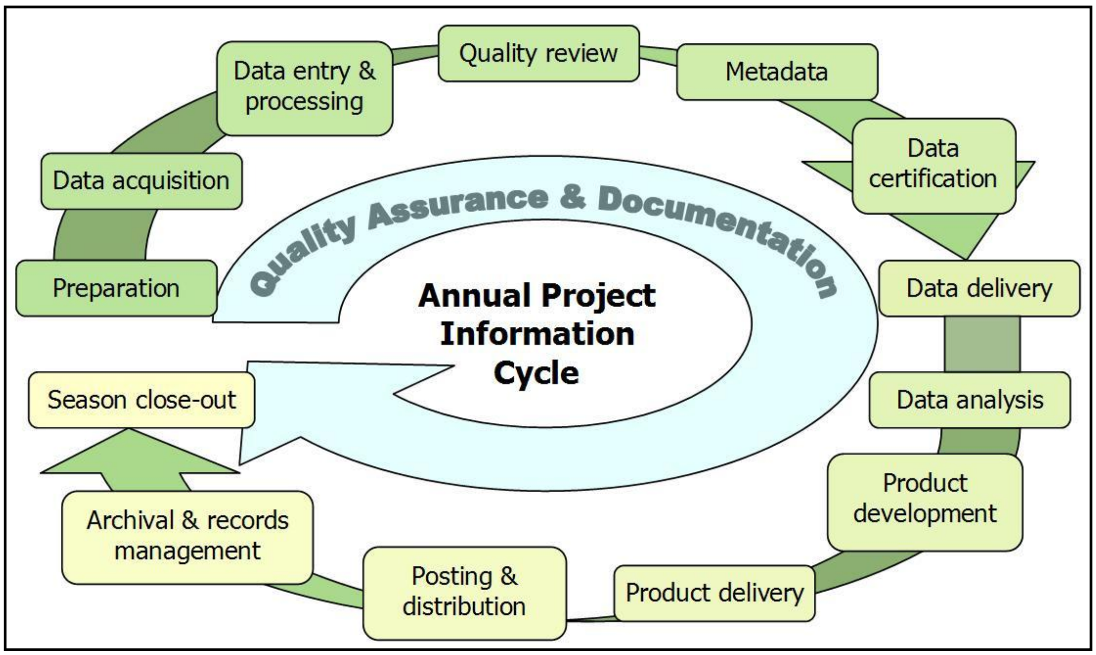

Figure 7. Diagram of the typical project information life cycle.

Figure 7 is an idealized schematic that represents the cyclical stages of project information management, from pre-season preparation to season close-out. Note that quality assurance and documentation are thematic and not limited to any particular stage. The stages of this cycle are described in greater depth in later sections of this chapter, but can be briefly summarized as follows:

- Preparation: Training, logistics planning, print forms and maps
- Data acquisition: Field trips to acquire data
- Data entry and processing: Data entry and uploads into the working copy of the database, GPS data processing, etc.
- Quality review: Data are reviewed for quality and logical consistency

- Metadata: Documentation of the year's data collection and results of the quality review
- Data certification: Data are certified as complete for the period of record
- Data delivery: Certified data and metadata are delivered for archival and upload to the master project database
- Data analysis: Data are summarized and analyzed
- Product development: Reports, maps, and other products are developed
- Product delivery: Deliver reports and other products for posting and archival
- Posting and distribution: Distribute products as planned and/or post to NPS clearinghouses
- Archival and records management: Review analog and digital files for retention (or destruction) according to NPS Director's Order 19 (NPS 2003). Retained files are renamed and stored as needed.
- Season close-out: Review and document needed improvements to project procedures or infrastructure, complete administrative reports, develop work plans for the coming season

4.2 Pre-Season Preparations for Information Management

4.2.1 Set Up Project Workspace

A section of the networked file server at the host park, NOCA, is reserved for this project, and access permissions are established so that project staff members have access to needed files within this workspace. Prior to each season, the Project Lead should make sure that network accounts are established for each new staff member, and that the Data Manager is notified to ensure access to the project workspace and databases. Additional details may be found in SOP 22 (Workspace Setup and Project Records Management).

4.2.2 Implement Working Database Copy

Prior to the field season, the Data Manager will implement a blank copy of the working database and ensure proper access on the part of the project staff. Refer to Section 4.3 for additional information about the database design and implementation strategy.

4.3 Overview of Database Design

We maintain a customized relational database application to store and manipulate the data associated with this project. The design of this database is consistent with NPS I&M and NCCN standards; see the data dictionary and other documentation in Appendix J (Glacier Monitoring Protocol Database Documentation). The Data Manager is responsible for development and maintenance of the database, including customization of data summarization and export routines.

The database is divided into two components – one for entering, editing and error-checking data for the current season (i.e., the 'working database copy'), and another that contains the complete set of certified data for the monitoring project (i.e., the 'master project database'). A functional comparison of these two components is provided in Table 1.

Table 1. Functional comparison of the master project database and the working database.

Project Database Functions and Capabilities	Working Database	Master Database
Software platform for back-end data	MS Access	MS SQL Server
Contains full list of sampling locations and taxa	X	X
Portable for remote data entry	X	
Forms for entering and editing current year data	X	
Quality assurance and data validation tools	X	X
Preliminary data summarization capabilities	X	
Full analysis, summarization and export tools		X
Pre-formatted report output		X
Contains certified data for all observation years		X
Limited editing capabilities, edits are logged		X
Full automated backups and transaction logging		X

Each of these components is based on an identical underlying data structure (tables, fields and relationships, as documented in Appendix J). The working database is implemented in Microsoft Access to permit greater flexibility when implementing on computers with limited or unreliable network access. The master database is implemented in Microsoft SQL Server to take advantage of the backup and transaction logging capabilities of this enterprise database software.

Both components have an associated front-end database application ("user interface" with forms, queries, etc.) implemented in Microsoft Access. The working database application has separate screens for data entry, data review, and quality validation tools. The master database application contains the analysis and summarization tools, including pre-formatted report output and exports to other software.

During the field season, the project crew will be provided with its own copy of a working database into which they enter, process, and quality-check data for the current season (refer to Section 4.4 and SOP 19 [Data Entry and Verification]). Once data for the field season have been certified they will be uploaded into the master database, which is then used to inform all reporting and analysis. This upload process is performed by the Data Manager, using a series of pre-built append queries.

4.4 Data Entry and Verification

After each field trip, technicians should enter data in order to keep current with data entry tasks, and to catch any errors or problems as close to the time of data collection as possible. The working database application will be found in the project workspace. For enhanced performance, it is recommended that users copy the front-end database onto their workstation hard drives and open it there. This front-end copy may be considered "disposable" because it does not contain any data, but rather acts as a pointer to the data that reside in the back-end working database. Whenever updates to the front-end application are made available by the Data Manager, a fresh copy should be made from the project workspace to the workstation hard drive.

The functional components for data entry into the working database are described in SOP 19. Each data entry form is patterned after the structure of the field form, and has built-in quality assurance components such as pick lists and validation rules to test for missing data or illogical combinations. Although the database permits users to view the raw data tables and other database objects, users are strongly encouraged only to use these pre-built forms as a way of ensuring the maximum level of quality assurance.

Crew members will enter their data as the season progresses and the project lead will do preliminary data reduction for early season reporting. The database is linked to applications for data reduction from points to area-averaged balance values (winter, summer, and net), uncertainty, and summary of measurements and results. See SOP 5 for data processing procedures and examples. At the end of the field season the Project Lead is responsible for performing the quality review, correcting, and certifying the year's data (see Section 4.5).

4.4.1 Data Verification

Data quality is examined at several levels and at several times during the year. Data is assessed for precision and accuracy during field data collection, data reduction, and peer review. These steps are discussed briefly below and in more detail in SOP 1, SOP 2, and SOP 5.

To help reduce data recording errors, field data are recorded during measurement on simple, standardized forms. To facilitate following up on questions regarding data quality, field forms include the date and personnel responsible for the values reported. Ideally, field data should be checked by a second staff member before leaving the glacier (see SOP 5 and Appendix D).

Probing data obtained in spring is cross-checked with mid-summer and fall probe and stake data. Ablation data obtained from stakes is cross-checked with the probe data (see SOP 2 and SOP 5). Data are also compared to data collected on SCG by the USGS, and with nearby NRCS snow survey sites.

As data are being entered, the person doing the data entry should visually review them to make sure that the data on screen match the field forms. This should be done for each record prior to moving to the next form for data entry (see SOP 19). At regular intervals and at the end of the field season the Field Lead should inspect the data being entered to check for completeness and perhaps catch avoidable errors. The Field Lead may also periodically run the Quality Assurance Tools that are built into the front-end working database application to check for logical inconsistencies and data outliers (this step is described in greater detail in Section 4.5 and also in SOP 20 [Data Quality Review and Certification]).

4.4.2 Regular Data Backups

Upon opening the working database, the user will be prompted to make a backup of the underlying data (see SOP 19). It is recommended that this be done on a regular basis – perhaps every day that new data are entered – to save time in case of mistakes or database file corruption. These periodic backup files should be compressed to save drive space, and may be deleted once enough subsequent backups are made. All such backups may be deleted after the data have passed the quality review and been certified.

4.4.3 Field Form Handling Procedures

As the field data forms are part of the permanent record for project data, they should be handled in a way that preserves their future interpretability and information content. Refer to SOP 16 (Field Form Handling Procedures).

4.4.4 Image Handling Procedures

Photographic images may be considered a type of data, and as such should be handled and processed with care. For opportunistic photos refer to SOP 17 for details on how to handle and manage these files. See SOP 15 for these annual specific naming conventions.

4.5 Data Quality Review

After the data have been entered and processed, they need to be reviewed by the Project Lead for quality, completeness and logical consistency. The working database application facilitates this process by showing the results of pre-built queries that check for data integrity, data outliers and missing values, and illogical values. The user may then fix these problems and document the fixes. Not all errors and inconsistencies can be fixed, in which case a description of the resulting errors and why edits were not made is then documented and included in the metadata and certification report (see Sections 4.6 and 4.7, and SOP 20).

Due to the high volume of data changes and/or corrections during data entry, it is not efficient to log all changes until after data are certified and uploaded into the master database. Prior to certification, daily backups of the working database provide a crude means of restoring data to the previous day's state. After certification, all data edits in the master database are tracked in an edit log so that future data users will be aware of changes made after certification. In case future users need to restore data to the certified version, we also retain a separate, read-only copy of the original, certified data for each year in the NCCN Digital Library.

4.6 Metadata Procedures

Data documentation is a critical step toward ensuring that data sets are usable for their intended purposes well into the future. This involves the development of metadata, which can be defined as structured information about the content, quality, condition and other characteristics of a given data set. Additionally, metadata provide the means to catalog and search among data sets, thus making them available to a broad range of potential data users. Metadata for all NCCN monitoring data will conform to Federal Geographic Data Committee (FGDC) guidelines and will contain all components of supporting information such that the data may be confidently manipulated, analyzed and synthesized.

At the conclusion of the field season (according to the schedule in Appendix B) the Project Lead will be responsible for providing a completed, up-to-date metadata interview form to the Data Manager. The Data Manager will facilitate metadata development by consulting on the use of the metadata interview form, by creating and parsing metadata records from the information in the interview form, and by posting such records to national clearinghouses. Refer to SOP 18 (Metadata Development) for specific instructions.

4.7 Data Certification and Delivery

Data certification is a benchmark in the project information management process that indicates that: 1) the data are complete for the period of record; 2) they have undergone and passed the quality assurance checks (Section 4.5); and 3) that they are appropriately documented and in a condition for archiving, posting and distribution as appropriate. Certification is <u>not</u> intended to imply that the data are completely free of errors or inconsistencies which may or may not have been detected during quality assurance reviews.

To ensure that only quality data are included in reports and other project deliverables, the data certification step is an annual requirement for all tabular and spatial data. The Project Lead is primarily responsible for completing a NCCN Project Data Certification Form, available on the NCCN website. This brief form should be submitted with the certified data according to the timeline in Appendix B. Refer to SOP 20 and SOP 21 (Product Delivery Specifications) for specific instructions.

4.8 Data Processing, Reduction and Analysis

4.8.1 Uncertainties and Error

Field measurements subject to uncertainty and error are snow depth, stake height, snow density, stake/probe position and altitude, and discrepancies in measurement timing with actual maximum and minimum balances. Positional error associated with measurement locations is discussed here but not used in determining error on a glacier-wide basis. Other factors such as internal accumulation, superimposed ice, internal melt, and basal melt are considered insignificant compared to errors in surface balance measurements and are therefore ignored (Mayo et al., 1972). Base map errors are also ignored as they are extremely difficult to quantify. However, they can be quite significant. Driedger and Kennard (1986) encountered 60+ meter errors in glacier elevation on USGS 7.5 minute quadrangle maps that were not related to glacier change while conducting an ice radar/depth survey on Mount Rainier.

We estimate error for each measurement or set of measurements collected in the field. Errors are then calculated on an annual, stake-by-stake, glacier-by-glacier basis. An example calculation sheet is included in SOP 9 (Mass Balance Error Calculations and Determinations). Error estimates for the Emmons glacier in 2003 are $b_w = 2.19 \pm 0.54$, $b_s = -5.01 \pm 0.85$, and $b_n = -2.82 \pm 1.00$. All quantities are meters water equivalent. The percent errors are 24%, 17%, and 35% respectively. The percent error for b_n may become inordinately large when $b_n \sim 0$.

Errors for b_w, b_s, and b_n at each stake or other probe location are calculated using propagation equations (Bevington and Robinson, 1992; A. Rasmussen, University of Washington, personal communication, 2003). Errors in stake/probe position and altitude contribute to error but the complexity of including these quantities in error propagation equations prohibits including them.

4.8.1.1 Probe Measurement: Snow probing is probably the greatest source for error in the winter balance measurements. This error is caused by variable penetration into and sometimes through the summer surface and departures of the probe from the vertical. However, rarely do we rely on one probe measurement and ideally 10 measurements are taken in the vicinity of the stake or at a probe location. Inherent in this range of values are the uncertainties for each individual measurement and variations in snowpack depth. However, the measurement reading error for a single probe measurement is estimated at $\pm$ 0.03 m depth. This is assuming that the summer surface is correctly identified.

In conditions in which residual snow and firn exists as the summer surface under the current year’s snowpack, probes can tend to penetrate past the summer surface and overestimate snow depth. These conditions tend to exist on the upper glacier the year following a strong positive mass balance year. In these cases the summer surface may not be distinct and/or there may not be a significant difference in density between firn and new snow. In contrast, probing after a strong negative balance year results in less variability because hard firn and ice make up the previous year's summer surface on most of the glacier. The error associated with this problem is best observed by comparing standard deviation of probe depths. In years when this is a problem, a snow corer is used to identify the snow/firn boundary, and summer and fall probes can be used to help constrain the snowpack depth.

Ice layers in the winter snowpack mistaken for the summer surface may cause an underestimate of winter balance. However, probing in the summer and fall will catch these errors because the ice layers generally disintegrate later in the season and a shallower snowpack is easier to probe.

Variability of the probe measurements at each stake are the primary measure of uncertainty. The standard deviation for the probes used to calculate winter balance is used as the value for error.

4.8.1.2 Stake Measurement: The estimated measurement error for an individual stake measurement is + 0.03 m depth, which is primarily from departure of the stake from being vertical. Stake data can underestimate ablation primarily due to stake sinking (Ostrem and Brugman 1991). Ostrem and Brugman (1991:29) documented sinking through a summer season for ~ 32 mm diameter wood, plastic, aluminum, and steel stakes (note that our stakes are 22 mm diameter PVC plastic). They observed that after 200 days, which is comparable to a Cascade glacier summer season, a plastic stake sank ~0.25 m water equivalent resulting in an underestimation of summer balance. We hypothesize that this error is greater when the base of a stake is placed in firn than if it is placed in ice because the stake may make more progress in 'self drilling' in the less dense firn. This occurs higher on the glacier, above the ELA where snow still remains at the end of the summer season and is buried by the following year's snowfall. However, Krimmel (1999a) suggests more stake sinking may occur on the lower glacier in areas of extreme ice melt. Thus stake sinking may be important on the upper and lower glacier.

Stake sinking was assessed at Sandalee Glacier in NOCA in 2000 (Riedel et al. 2008). Stake sinking may have occurred at all four stakes but only one stake had an appreciable difference for the summer season. The lowermost stake may have sunk 0.44 m snow depth (0.22 m water equivalent). The base of this stake was in 1999 firn and thus possibly more prone to sinking than in ice. Any apparent sinking fell within the probe depth error values, so it is impossible to draw firm conclusions. Because of the unpredictable nature of and apparently small amount of stake sinking, this factor is disregarded in error calculations.

4.8.1.3 Snow Density: Snow density is measured at the top and bottommost stakes on each glacier. When snow density is directly measured at the top and bottom of the glacier the estimated error is + 0.01 g/ml.

4.8.1.4 Stake Position and Altitude: Errors in recording stake position and altitude are not included in error calculations. Estimated positional (X-Y) error is + 10 m with the use of GPS to record locations. Altitude error is much more difficult quantify and such an attempt is beyond the scope of this report.

4.8.1.5 Non-Synchronous Measurements with Actual Maximum and Minimum balances: Systematic errors due to the non-synchronous timing of glacier visits to the actual timing of maximum and minimum balances are assumed to be negligible.

4.8.1.6 Estimated Error at Each Measurement Location: The uncertainty or error for balance at each measurement location (stake and probe locations where multiple measurements are taken) is calculated from the error determined or estimated from each variable used to calculate balance. Error calculations for each balance variable are not provided here, but we focus on a general explanation of equations that are applied to winter, summer, and net balance errors. Detailed procedures and an example Excel worksheet and formulas are included in SOP 9**.** Variances for each variable are used and carried through the error propagation equations. Standard Deviations are easily determined once all variables are considered and carried through.

The general error propagation equation (Bevington and Robinson, 1992) is:

$$\sigma_x^2 = \sigma_u^2(\delta x/\delta u)^2 + \sigma_v^2(\delta x/\delta v)^2 + \ldots + 2\sigma_{uv}^2(\delta x/\delta u)(\delta x/\delta v)\ldots \qquad \text{(Eq. 6)}$$

In all glacier error calculations, the errors are assumed to be uncorrelated therefore the covariances (σ_{uv}^2) equal zero and the equation is simplified. The example below describes multiplication and addition operations involving two or more variables with an assigned error for each one.

In the case where two variables are multiplied together for example at a stake: $b = h * \rho$ where b = balance, h = snow, firn, or ice depth, and ρ = snow, firn, or ice density. Errors determined for h and ρ are assumed to be standard deviations and the variances are easily calculated. The partial derivatives are functions of the other variables:

$$(\delta b/\delta h) = \pm\, a\rho \text{ and } (\delta b/\delta \rho) = \pm\, ah \qquad \text{(Eq. 7)}$$

In this case we set a = 1 because the variables are unweighted and the error propagation equation becomes:

$$\sigma_b^2 / b^2 = \sigma_h^2/h^2 + \sigma_\rho^2/\rho^2 \qquad \text{(Eq. 8)}$$

In the case where two or more variables are added together, for example

$$b_s = b_{snow} + b_{firn} + b_{ice}$$

where b_s = summer balance (water equivalent), b_{snow} = snow ablation, b_{firn} = firn ablation, b_{ice} = ice ablation. Again the covariances = 0.

$$\sigma_{bs}^2 = \sigma_{bsnow}^2 + \sigma_{bfirn}^2 + \sigma_{bice}^2 \qquad \text{(Eq. 9)}$$

To continue the example through, the combined error for b_s at stake is the combination of Equations 7 and 8:

$$\sigma_{bs}^2 = (\sigma_{hsnow}^2/h_{snow}^2 + \sigma_{\rho snow}^2/\rho_{snow}^2)/\ \sigma_{bsnow}^2$$
$$+ (\sigma_{hfirn}^2/h_{irn}^2 + \sigma_{\rho firn}^2/\rho_{firn}^2)/\ \sigma_{bfirn}^2 \qquad \text{(Eq. 10)}$$
$$+ (\sigma_{hice}^2/h_{ice}^2 + \sigma_{\rho ice}^2/\rho_{ice}^2)/\ \sigma_{bice}^2$$

4.8.1.7 Propagation of Uncertainties in Glacier-Wide Mass Balance Calculations: To come up with an overall estimate of error for a balance value (associated with a set of measurements) the variances for each measurement location are averaged.

$$\sigma_b^2 = (\sigma_{stk1}^2 + \sigma_{stk2}^2 + ... + \sigma_{prb1}^2 + \ldots + \sigma_n^2) / n \qquad \text{(Eq. 11)}$$

This is perhaps not the most statistically rigorous method but it yields a relative error estimate that is comparable between balance years and glaciers.

4.8.1.8 Cumulative Error Comparison: As outlined in Section 2.5 and SOP 11 (Glacier Mapping and Volume Change Determination Specifications) DEM comparison with field-based balances and calculations provides an independent comparison of glacier wide cumulative changes.

4.8.1.9 Estimated Error in Finding Zero Summer Balance Altitude Near the Summit: There are two methods used for finding the annual summer zero balance altitude: using re-analysis upper atmospheric gridpoint data and using a summer lapse rate calculated from Longmire and Paradise weather station data. Error associated with finding zero summer balance altitudes is discussed here but not used in determining error on the upper mountain.

Positional other factors such as internal accumulation, superimposed ice, internal melt, and basal melt are considered insignificant compared to errors in surface balance measurements and are therefore ignored (Mayo et al. 1972). Base map errors are also ignored as they are extremely difficult to quantify.

4.8.2 Data Reduction for Mass Balance

Mass balance and glacier area averaged balances are determined using a b(z) function and 10-meter elevation bands. Surface area (not two-dimensional map area) for the 10-meter elevation bands, are determined by GIS analysis (see SOP 5). A b(z) function is determined for b_w, b_s regular ice, and b_d debris-covered ice (see Equation 5) and then are applied to the mid-point altitude of each band (mid-point altitude). The balances are then integrated for the glacier by summing the mass balances of the 10-meter bands.

To calculate balance on the upper mountain, above, ~3,100 m, data is extrapolated to higher altitudes from the lower stake data (SOP 7). There are two methods for finding $b_{s,}$ using a lapse rate from two nearby weather stations or interpolating data from NCEP-NCAR reanalysis grid point (Rasmussen and Conway 2003). This data is used to calculate the average July and August freezing altitude, which is assumed to be zero summer balance, and provides the highest data point. There are two methods for finding b_w that are chosen depending on data quality and coverage. If a visit is made to the upper mountain during maximum accumulation in July, and probe data are deemed reliable, a b(z) function is used. If there is no additional data then pattern of decreasing b_w with elevation is modeled based on previous observations. We are presently using the peak accumulation altitude for the current year and shift the 2004 altitude versus b_w

curve to this measurement point. The year of 2004 had reliable and complete snow depth data extending to the summit, and was chosen to model the balance slope. These upper mountain balance b(z) functions are applied to the mid-point altitude of each 10-meter elevation band as mentioned above.

As new glacier maps are made at ~10-year intervals, mass balance will be integrated using two different map sets using the methods of Elsberg et al. (2001). Annual winter, summer, and net balances are calculated on the most recent base maps. Annual balances that are calculated on the map most current to the year in question are used for annual and cumulative runoff calculations.

4.8.3 Glacial Meltwater Discharge

Glacier contributions to summer season streamflow are estimated using summer balance data and the balance increment from Emmons and Nisqually Glaciers with the area-altitude distributions of all glaciers in the respective White and Nisqually River watersheds (Figure 8). These watersheds are important because they have gauging stations near the park, drain into hydroelectric and flood control projects, and have long-term monitoring glaciers within them. White River above Boise Creek at Buckley, USGS 12099200 stream gauge is used for the White River Watershed. In the Nisqually River Watershed the first stream gauge is USGS 12082500 Nisqually River near National (Figure 1). See SOP 8 (Watershed-wide Glacier Runoff Calculations) for calculation procedures.

The primary contribution of meltwater and sediment from glaciers to streams and aquatic ecosystems occurs in summer. Glacier meltwater contribution to the late summer streamflow has the effect of “buffering” or moderating the variation of streamflow during the region’s seasonal summer drought (Fountain and Tangborn, 1985). Runoff estimates are calculated from May to October.

Our estimates of summer glacial contribution to watershed runoff are minimum estimates for three reasons:

1. Hodge (1972) circumstantially demonstrates with ice flow velocities of the lower Nisqually Glacier that the glacier stores water during the winter and spring and then releases that water in the summer. This stored water is additional discharge to that of summer surface melt.

2. An unknown amount of englacial and subglacial melting occurs during both summer and winter seasons.

3. Some surface runoff may not be accounted for due to nonsynchronous measurements with actual balance maximums and minimums, but these are assumed to be negligible.

Area-elevation distributions of glacierized areas for each of the selected watersheds are determined using GIS analysis. Using the most recent inventoried glacier extents, GIS analysis determined glacierized area in 50 m elevation bands for each watershed. Each band in the watersheds is multiplied by the summer balance for that elevation band to determine summer glacial runoff. The mass balance increment (B_I), discussed in Section 2.2.2 (Figure 6), is added to the new WY summer runoff. See SOP 5 and SOP 8 for detailed calculations. Values from each 50 m band are summed to determine total glacier runoff for a given watershed. These estimates are compared as a percentage of the total summer runoff for USGS river gauges as reported in the USGS Water Resources Data Report Washington.

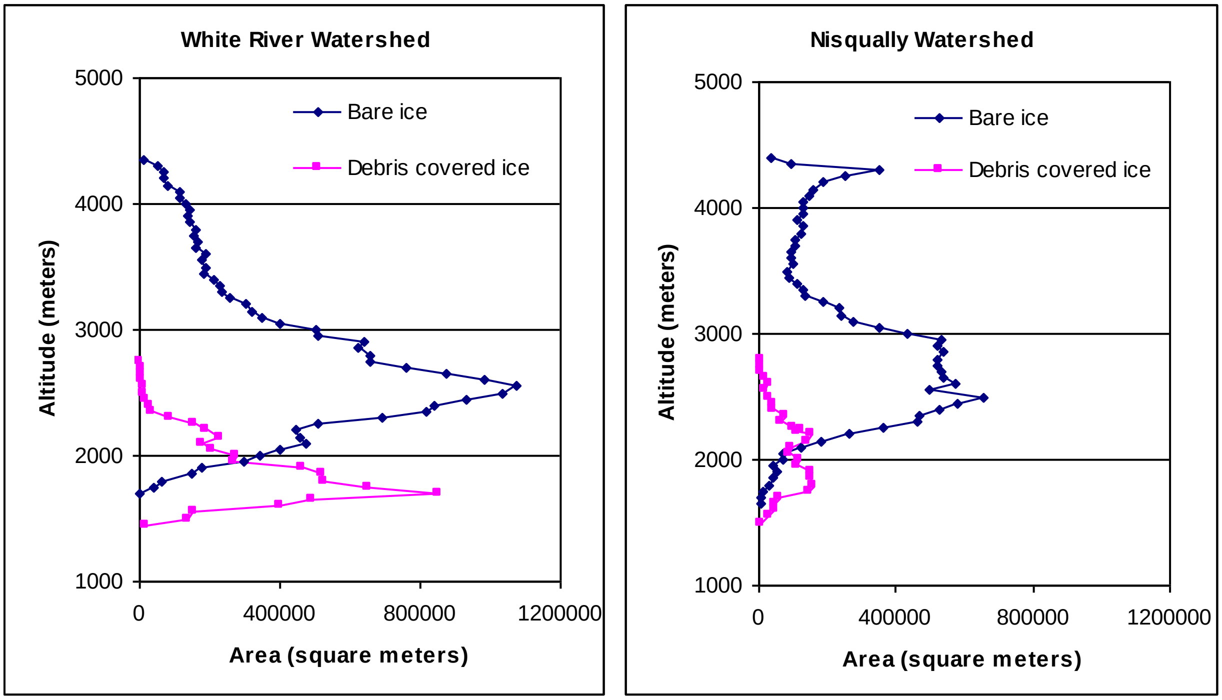

Figure 8. Area altitude distributions by 50-meter bands of glacierized areas within White River and Nisqually watersheds. Showing 1994 glacier margins and 2001 debris cover.

4.9 Reporting and Product Development

Refer to SOP 21 for the complete schedule for project reports and other deliverables and the people responsible for them.

4.9.1 Recommended Reporting Schedule

The main reports produced include a detailed annual summary report and a cumulative ten-year summary report. Annual summary reports will be extracted from the NCCN Glacier Database and posted to the NPS Data Store.

The annual report will:

- Summarize balance at stakes, mass balance (glacier-wide), and glacier area-averaged balance for each glacier each year.
- Estimate a percentage of the total summer runoff for USGS river gauges.
- Identify data quality concerns and/or deviations from protocols that affect data quality and interpretability.
- Make data available to professional hydrologists and water resource managers in the NRCS Snow Survey Report, National Snow and Ice Data Center, World Glacier Monitoring Service.

The ten-year report will:

- Summarize and elucidate patterns and trends in the balance data.
- Summarize any additional data collected in the ten-year period (e.g., ice depth data from radar, surface elevation from GPS surveys, etc.).
- Contain a comparison of remapping results with cumulative balance results from annual balance data.
- Evaluate operational aspects of the monitoring program, such as whether any stake and probe sites need to be eliminated or moved due to access problems, whether the sampling period remains appropriate (the optimal sampling dates could conceivably change over time in response to climate change), etc.
- Be published in NPS Technical Reports and peer reviewed journals (e.g., Pelto and Riedel 2001).

4.9.2 Recommended Report Format with Examples of Summary Tables and Figures

The report format will follow the Natural Resource Publications Management guidance and use document templates available at: http://www.nature.nps.gov/publications/NRPM/index.cfm.

The primary goal for reporting data is to make it available to other aspects of our monitoring program. At the writing of this protocol the NCCN is developing a relational database. Once developed this will be the primary reporting site. Another goal for reporting and publication is to reach a wide audience from other park employees to park visitors to professional scientists in a number of disciplines. This includes: reports in the NOCA newsletters "Challenger" in the park newsletter "The Tacoma News;" reports in the NOCA employee newsletter "Complex Issues;" reports on NCCN Internet site (with links to other glacier sites); training to park interpretive staff; presentations for the public at visitor centers and campgrounds; presentations and posters to other scientists at professional meetings (e.g., Riedel and Burrows 2003; and the data is available annually to professional hydrologists and water resource managers in the NRCS Snow Survey Report http://www.wa.nrcs.usda.gov/snow/, National Snow and Ice Data Center, World Glacier Monitoring Service and more infrequently in NPS Technical Reports and peer reviewed journals (e.g., Pelto and Riedel 2001). In addition, after the spring field visits, preliminary snow depths, snow densities, and estimates for b_w are summarized in The Glacier Page http://www.wa.nrcs.usda.gov/snow/data/NPS_Glacierpage_2009.pdf. This is included in the NRCS May Snow Survey Report and is typically distributed regionally. See SOP 13 for full procedures.

Mass balance summary charts are included in most reports to all audiences and include average net balance for each glacier by year and cumulative net balance per glacier per year. A location map of the glaciers (Figure 2) is included and if there is room, detailed maps of each glacier (Figures 3 and 4). Glacier meltwater discharge results are reported on the "glacier page".

4.9.3 Recommended Methods for Long-term Trend Analysis (5–10 years)

Long-trend analyses are primarily conducted using cumulative net balance curves. These curves will show tendencies in glacier mass gain and loss over the period of record. In addition, these records can be compared and correlated to other glacier mass balance records in North America and the world. Cumulative balance data are also compared to the most recent El Nino/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) indices and regional climate data.

4.10 Product Delivery, Posting, and Distribution

Refer to SOP 21 for the complete schedule for project deliverables and the people responsible for them. To package products for delivery, refer to SOP 23 (Product Distribution). Upon delivery they will be posted to NPS websites and clearinghouses (e.g., NatureBib, NPS Data Store) according to instructions in this SOP.

To permit sufficient time for priority in publication, certified project data will be held upon delivery for a period not to exceed 2 years after it was originally collected. After the two-year period has elapsed, all certified, non-sensitive data will be posted to the NPS Data Store. Note that this hold only applies to raw data, and not to metadata, reports or other products which are posted to NPS clearinghouses immediately after being received and processed. Refer to SOP 23.

4.11 Archiving and Records Management

All project files should be reviewed, cleaned up and organized by the Project Lead on a regular basis (e.g., annually in January). Decisions on what to retain and what to destroy should be made following guidelines stipulated in Records Disposition Schedule, (Director's Order 19, Appendix B), which provides a schedule indicating the amount of time that the various kinds of records should be retained.

4.12 Season Close-out

After the conclusion of the field season, the Project Lead, NPS Lead, and Data Manager should meet to discuss the recent field season, and to document any needed changes to the field sampling protocols, the working database application, or to any of the information management SOPs associated with the protocol.

All field equipment (e.g. glacier travel and scientific equipment) should be clean, dry and placed in the North Cascades National Park, Marblemount Physical Science building storage area. There is plenty of drying space and obvious or labeled bins where all gear is stored. The steam drill and snow core each have special metal storage cases. Any damaged or lost equipment should be fixed or replaced. The steam drill should be emptied of any remaining water. Fall retrieved PVC stakes should be left to dry through the winter in the storage area. The wooden dowels which were placed inside the PVC will shrink over the winter and will be easier to dismantle come the following spring.

This protocol will be reviewed annually following completion of the field season. More thorough reviews will be conducted every 10 years when new base maps are constructed for index glaciers. Furthermore, the project lead will examine new technologies as they become available to determine if they can be used to obtain data on measured variables.

5 - Personnel and Training Requirements

Operation of the park glacier monitoring program primarily relies minimally on these personnel: the NOCA Park Geologist, a NOCA Physical Science Technician-Permanent (PST-Perm), and a park Biological Science Technician-Term (BST-Term). In addition, the involvement of the park Chief of Resource Management, other NOCA and park Resource Management Divisions employees, and volunteers are crucial in administrative and fieldwork tasks. In addition one park Climbing Ranger or science technician is hired for one pay period to assist with field work.

Minimum qualifications for each of the three primary personnel are a background in earth/environmental sciences, with some glaciology/glacial geology coursework and/or experience, and all must be competent in glacier travel and basic crevasse rescue. Other personnel and volunteers that assist with field work must be competent in glacier travel and basic crevasse rescue or be trained to do so. More specifically:

1. Park Geologist, GS-11 Permanent– M.S. in Geology with specific experience in glaciology.

2. Physical Science Technician, GS-8/9 Permanent (PST-Perm)–B.S. in Geology or related field with specific experience in glaciology.

3. Biological Science Technician, GS-9 Term (BST-Term)–B.S. in Environmental Science, Biology or related field.

The three primary personnel work as a team, but have different roles and responsibilities to accomplish the objectives of the glacier monitoring program. The NOCA Park Geologist with the support of the park Chief of RM is responsible for general oversight, budget, personnel, planning, and also arranging contracts. At the present time the Park Geologist also contributes to field work, data analysis, and reporting as needed. The PST-Perm is primarily responsible for running field aspects of the program, by organizing field operations and logistics and directing other employees and volunteers in the field. This position is also responsible for data handling, analysis, and assisting with reporting in technical reports. The BST-Term assists in field logistics and operations, data handling, analysis, and reporting as needed. This position reports to the park Chief of RM but works closely with the PST-Perm on the details of the program. All personnel act as liaisons for the program to other park staff and the public. The Park Geologist is responsible for professional publications and summary reports.

For new employees primary training for their roles and responsibilities is accomplished on the job by reading the protocols, briefings, and by experience. Additional glacier travel training is required for compliant and safe execution of duties for each of the primary personnel. The PST-Perm needs a background or training in using ESRI ARCGIS (ArcInfo9.2 at the time of this writing). All staff need to review the Job Hazard Analysis (Appendix I. Job Hazard Analysis) once a year while going through the annual safety checklist with a supervisor.

6 - Operational Requirements

6.1 Annual Workload and Schedule

Table 2 summarizes approximate dates and deadlines on which field work, administrative, and reporting events should occur. See SOP 1 for a detailed field schedule. See Section 4.1 and Appendix B for further clarification.

Table 2. Dates and deadlines for preparation, field work, and administrative deadlines.

Date	Event
March 1	Schedule work and logistics
March 1	Check equipment and supplies; buy and/or repair as needed
March 15	Organize field gear. Prepare data sheets.
April 1	Spring visit to lower Emmons Glacier
April 15	Spring visit to all Nisqually stakes
May 1	Spring visit to mid Emmons Glacier/Camp Muir
May 15	Data entry and initial analysis
Deadline: May 20	Produce and Submit Glacier Page to NRCS
June 15	Place stakes on lower glaciers
June	Budget programmed
Deadline: July 1	Submit aerial photography contract (and mapping contract every 10 years).
July 1	Midsummer visit to all stakes.
Deadline: July 15	Purchases and Contracts complete (cutoff date for purchase credit card)
July 15 to August 1	Data entry and continuing analysis
September 20 to Oct 15	Fall field visits.
Deadline: September 30	NCCN Budget Request
Mid October	NW Glaciologists Meeting
October 1 to November 20	Data entry and final Analysis
early November	GSA Annual Meeting
early December	AGU Annual Meeting

6.2 Facility and Equipment Needs

Minimum facilities include:

- Storage for all equipment
- Vehicle parking space
- Vehicle preferably 4wd with high clearance and a tow hitch (for pulling snowmobiles)
- Access to workshop or tools for stake fabrication
- Offices for staff
- Computer with capability for GIS
- Computer software:
    - ArcInfo9.1
    - MS Word
    - MS Excel
    - MS Access
    - Origin7 or other scientific graphing program
    - Adobe Illustrator or other graphics/drawing program
    - Adobe Photoshop or other image processing program

Equipment needed is listed in SOP 1.

6.3 Budget Considerations

The cost of monitoring glaciers at Mount Rainier is summarized in Table 3. Most support comes from the NPS. Considerable savings are realized because this project is tied to NOCA which allows, staff, equipment, and infrastructure costs to be shared.

The staffing plan and budget are designed to provide adequate funds for data analysis, management, and reporting activities. When considering that the North Coast and Cascades Network takes about 30% of its available funds 'off the top', we are probably spending closer to 50% of our current budget on this activity.

Time commitments for staff are summarized below:

- Field Work: Multiple employees and volunteers. See SOP 1.
- Data handling and analysis: 1 employee ~80 hours
- Reporting: 1 employee ~80–160 hours, except in years in which the 10-year report is done additional 160 hours.

Table 3. Summary of fiscal year 2009 annual budget for Mount Rainier glacier monitoring.

Personnel: Physical Science Technician (PST) Biological Science Technician (BST)	Job Component	Pay Period Commitment	2009 Costs[1]
GS 8 term -PST	Spring field preparations	1pp	$2,543
GS 5 seasonal ranger	Spring visit to glaciers	1pp	$1,467
GS 9 term -PST	spring visit to glaciers -data collect	1pp	$2,808
GS 8 perm. -PST	spring visit to glaciers -data collect	1pp	$2,543
GS 8 perm. - PST	spring data enter and analysis	0.5pp	$1,404
GS 5 seasonal ranger	summer visit to glaciers	0.5pp	$733
GS 8 perm. -PST	summer visit to glaciers = data an.	0.5pp	$1,272
GS 9 term - PST	August stake check-redrill	0.5 pp	$1,404
GS 5 seasonal Ranger	August stake check-redrill	0.5pp	$733
GS 9 term -PST	fall visit to glaciers	1pp	$2,808
GS 8 perm. -PST	fall visit to glaciers	1pp	$2,543
GS 8 perm.-PST	fall data handling and analysis	2pp	$5,086
GS 8 perm.-PST	reporting	2pp	$5,086
GS 12 perm. Geologist	oversight and reporting	2pp	$8,147
GS 11 perm. Data Manager	database management	1pp	$3,399
GS 11 perm. Data Manager	report publishing assistance	0.5pp	$1,699
		Sub Total	$43,678
Miscellaneous			
Supplies			$300
25% GSA vehicle			$1,250
Per Diem			$500
Annual Aerial Photos			$0
		Sub Total	$2,050
Remapping and Inventory			
Aerial Photos and digital elevation model contracts for 10-year glacier remapping (2010, 2020, 2030, etc.)			$15,000
20-year Glacier Inventory (2020, 2040, 2060)			$35,000
	Annual Total		$45,728
	Decadal Total		$60,728
	20-year Total		$95,728

[1]Salaries based on 2009 OPM wages and salaries for Seattle, Washington. GS grade calculated for step 1 $ with GS5 seasonal benefit rate of 7.6% and GS 8, 9, 11, and 12 with term/permanent benefit rate of 36%.

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SOP 1. Field Season Time Line, Preparations, and Procedures

Version 6/25/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figure and Tables

Page

Overview and Explanation

Field trips are made seasonally to each glacier to collect winter and summer balance data at the times of maximum and minimum balance. Estimates of minimum and maximum balances at the stake locations are summarized in Table SOP 1.1. These estimates are derived from an analysis of snowpack and mean daily temperature data from nearby weather stations (see Appendix C. Analysis for the Best Timing of Glacier visits).

Five visits a year to each glacier must be planned and prepared for. The sequence of field visits, tasks for those visits, and personnel required are outlined below. Precise field dates will be dictated by weather and staff availability. Access to each data collection location is dependent on the seasonal field visit, the task to be accomplished, and the current safety (i.e. avalanche and crevasse danger) concerns. Access and route selection is described below under “Schedule and work details”. General route locations along with measurement locations can be viewed in Figures SOP 1.1 and SOP 1.2. All team members involved in field visits should review and discuss all field related SOPs including Appendix I (Job Safety Hazard Analysis).

We sometimes describe the glaciers as having “upper” and “lower” altitude areas which coincides with stake numbered locations. There are six ablation stakes placed on each glacier with stake number one placed at the highest altitude and the rest consecutively placed below (Figures SOP 1.1 and SOP 1.2). Stake number one and two are located in the “upper” glacier area and stakes three through five are located on the “lower” glacier. One stake is labeled 4a which is at the same altitude as stake four but is placed in debris covered ice. Stake five is also placed in debris covered ice. For the first spring trip (placing the lower stakes), the Emmons Glacier should always be visited before the Nisqually.

Field Time Line and Task List

This work plan relies on staff from NOCA (North Cascades National Park) and MORA (Mount Rainier National Park): one Physical Science Technician from NOCA and one from MORA as the primary participants. Help from other technicians, volunteers, and climbing rangers are essential to completing the work. Total work time required for a glacier monitoring season is ~590 person-hours. An additional ~70 hours of driving for the person from Marblemount and ~ 15 hours of driving for the people from Longmire.

Driving directions to each of the field sites is relatively easy with I-5 road signs directing you to Mount Rainier National Park: Paradise and White River. To access Paradise and the Nisqually Glacier from Marblemount take Hwy 20 west to I-5 south. Take exit 127 (Hwy 512) east to Hwy 7. Follow Hwy 7 to Elbe and then take Hwy 706 (turning into Nisqually-Longmire road) all the way to Paradise. Park in the day or overnight parking area, depending on the seasonal trip, near the Paradise visitor center.

To access White River campground and the Emmons Glacier from Marblemount take Hwy 20 west to I-5 south. Take exit 142 towards Auburn. Take Hwy 164 to Enumclaw and then Hwy 410 to Sunrise road. There will be a large day use and overnight climbers parking area just before the campground and White River trailhead.

Late March to Early April

Emmons Glacier:

Task: Place stakes 3 and 4; snow probe at stakes 3–5; and snow core at stakes 3 and 5.
Personnel: a 3 person team is optimal
Schedule and Work Details:

- Day 1: 6–8 hrs for travel to White River from Marblemount by car and snowmobile. Accommodations in the White River Ranger Station cabin (WR).
- Day 2: 10–12 hrs to do task. Accommodations at (WR).
- Day 3: 8 hrs to travel back to Marblemount.

The route leaves from (WR) follows the White River and Moraine Trails into the Emmons Glacier Basin. The route then leaves the trail and remains off trail, traveling to the terminus and the GPS located stakes.

Nisqually Glacier:

Task: Place stakes 3–4; probe at stakes 3–5; snow core at stakes 3 and 5. Probe at Paradise SNOTEL.
Personnel: 3 people
Schedule and Work Details:

- Day 1: 5 hrs to drive from Marblemount to Longmire. Accommodations in Longmire (tent or apartment).
- Day 2: 10–12 hrs to do task. Accommodations in Longmire (tent or apartment).
- Day 3: 5 hrs to drive back to Marblemount

The route leaves near the Paradise visitor center and uses the Alta Vista and Skyline trails to Glacier Vista. At Glacier Vista, the route drops onto the Nisqually Glacier near Stake 4a. The Paradise SNOTEL is located on the right (northwest) side of the road ~0.5 miles from Paradise down the Longmire-Paradise Road. Park at the water treatment facility and hike five minutes to the east until the weather station is encountered.

Mid-April to Early May

Emmons Glacier:

Task: Place stakes 1, 2, and 2x; snow probe at stakes 1, 2, 2x; snow core at stakes 1 (if time permits, core at stake 2 and 3). Accommodations at Camp Schurman Hut (CSH) and White River Campground (WRC).
Personnel: 4 people (needed to efficiently carry all equipment)
Schedule and Work Details:

- Day 1: 6–8 hrs for travel from Marblemount to WRC by car and snowmobile. Accommodations at WRC.
- Day 2: 10–14 hrs for travel to CSH via Inter Glacier by skis; probe at stake 2, 2x; place stakes 2 and 2x. Open up camp, accommodations at CSH.
- Day 3: 8–10 hrs to probe at and place stake 1; core at stake 1 (if time permits, core at stake 2); finish any unfinished work from the day before; (If conditions and weather permit, descend Emmons Glacier; probe at and/or measure stakes 3, 4, 4a, 5) Accommodation at WRC.
- Day 4: 6–8 hrs to return to Marblemount by car and snowmobile.

For the trip in mid April to early May there are three options for traveling to CSH. The quickest option is to ski via the Glacier Basin Trail up to Glacier Basin. Take the Inter Glacier to the ridge crest and at Curtis Camp drop down onto the Emmons glacier near stake 2. Once on the Emmons Glacier, the climb to CSH is ~one hour. Time permitting, staff can do some work at stakes 2 and 2x. There are several drawbacks to this route; avalanche potential on the SE-facing slopes below Camp Curtis and NNE slopes of the Inter Glacier. The Emmons Glacier may also have crevasse danger. The second option is to ski up the Inter glacier and boot up and over Steam Boat Prow to CSH. This route is easy to follow and can be a safer alternative if south facing slopes have a high avalanche potential. The drawbacks to this route are avalanche danger heading up the NE-facing Inter Glacier and descending from Steam Boat Prow with challenging rock, snow, and ice. The slowest option is to head directly up the Emmons Glacier carrying out work along the way up to CSH. Usually time is limited enough just getting to CSH let alone accomplishing any work along the way. Though avalanche danger is low, the threat of a large avalanche starting high up on the mountain is always possible on this route in the spring. Crevasse danger can also be a concern in low snow years. The duration of the Emmons trip will vary depending on weather, snow, avalanche, crevasses, and road conditions and whether or not snowmobiles are used. This trip is very remote (this time of year) and heavily relies on the use of the CSH to execute the tasks. Only very fit field crew should make this trip. It is important to leave early ~6:30am to safely reach the CSH in daylight hours.

Nisqually Glacier:

Task: Place stakes 1–2; probe at stakes 1–2; snow core at stakes 1 and 2; Probe at Paradise SNOTEL.

Personnel: 3 people

Schedule and Work Details:

- Day 1: 5 hrs to drive from Marblemount to Longmire. Accommodations in Longmire (tent or apartment).
- Day 2: 10 hrs for travel to Camp Muir; place stake, probe, and core at stake 2; and probe (if time permits) at extra points. Accommodations at Camp Muir (tent or hut).
- Day 3: 10–12 hrs to probe, place stake, and core at stake 1; descend the Muir Snowfield; probe snow depth at SNOTEL site; drive back to Marblemount.

This trip heavily relies on the use of the Muir ranger hut to quickly execute the task. If the Muir ranger hut is unavailable for glacier staff to use during this field trip, an extra person or two will be needed to carry overnight group camping supplies. The route leaves from near the visitor center at Paradise and follows the climbing route to Camp Muir and onto the Ingraham Glacier.

Early June

Nisqually and Emmons Glacier:

Task: Place stakes and probe at 4a, and 5, on lower Nisqually; Probe at Paradise SNOTEL. Place stakes and probe 4a and 5 on lower Emmons.

Personnel: 3 people.

Schedule and Work Details:

- Day 1: 5 hrs to drive to Longmire. Accommodations in Longmire (camp or tent)
- Day 2: 10–12 hrs to place stakes and probe at stakes 4a and 5 on lower Nisqually; drive to White River (drive is 1.5 hrs); camp at WRC.

- Day 3: 12 hrs to place stakes and probe at stakes 4a and 5 on lower Emmons; drive back to Marblemount.

For route descriptions see schedule above for late March to early May.

Early to Mid-July

Nisqually and Emmons Glacier:

Tasks: Measure and probe at all stakes, snow core at selected stakes, probe and core at selected additional locations (see below).

Personnel: 3 people

Schedule and Work Details:

- Day 1: 5 hrs for NOCA staff to drive down to Longmire. Accommodations in Longmire (tent or apartment).
- Day 2: 10–12 hrs to measure stake and probe at stakes 5, 4a, 4, and 3 on lower Nisqually; snow core at stake 4; climb Nisqually Glacier to Camp Muir; measure stake, probe, and core at stake 2 on Muir Snowfield. Accommodations at Camp Muir.
- Day 3: 8–9 hrs to measure stake, probe and core at stake 1 (Ingraham flats); return to Longmire; drive to WRC (1.5 hr drive). Accommodations at WRC.
- Day 4: 8–10 hrs to hike up to and measure, probe, and core at Emmons Glacier stake 1 and 2; probe and measure stake 2x; probe at 2960 m (below CSH). Accommodations at CSH.
- Day 5: 10 hrs to descend Emmons Glacier; (if time permits) probe at 2680, 2570, 2400, 2280 meters altitude on descent; probe at and measure stakes 3, 4, 4A, and 5 on lower glacier; return to WRC; return to Marblemount.

Alternative Schedule for Early to Mid-July

Nisqually and Emmons Glacier:

Tasks: Snow depth sampling transect of entire mountain from lower Nisqually to summit to lower Emmons. Probe, snow core, and measure at stakes. Probe and core at selected additional locations on transect (see below).

- Alternative Day 1: 5 hrs for NOCA staff to drive down to Longmire. Camp in Longmire
- Alternative Day 2: 10–12 hrs to measure stake and probe at stakes 5, 4a, 4, and 3 on lower Nisqually; snow core at stake 4; climb Nisqually Glacier to Camp Muir; measure stake, core, and probe at stake 2 on Muir Snowfield. Accommodations at Camp Muir.
- Alternative Day 3: 12–14 hrs to measure stake, probe and (if time permits) core at stake 1 on the Ingraham Glacier; climb to summit via Disappointment Cleaver (DC) or Ingraham Direct climbing routes; probe at the top of DC (3870 m) and in the summit crater (as conditions allow snow core in the summit crater); descend Emmons Glacier route; probe on route at 3760, 3460, and 3020 meters altitude and at stakes 1; core at Emmons Glacier stake 1. Accommodations at CSH.
- Alternative Day 4: 12 hrs to descend Emmons Glacier from CSH; probe, core, and measure stake 2 and 2x; (if time permits) probe at 2680, 2570, 2400, 2280 meters

altitude on descent; probe at and measure stakes 3, 4, 4A, and 5 on lower glacier; prearrange car shuttle from WRC; return to Marblemount.

This trip has an alternative schedule which takes you up and over the summit of Mount Rainier collecting data along the way and is the most efficient.. The alternative route uses less time (estimated at 39–43 hrs verses 41–46 hrs), uses one less day, puts less miles on the legs, and collects more data. This alternative does have a higher potential for safety, weather, and altitude related issues that may compromise the goal of the mission. If the alternative schedule is used the mission must have a good weather forecast and experienced climbing participants. Departure from Camp Muir early in the morning (2:00 or 3:00 a.m.) is important to enable reaching Disappointment Cleaver early in the morning before the temperature warms and the danger of rockfall increases.

The trip order and route may change from year to year depending on environmental factors. Weather may dictate the reverse of this schedule, starting with the east facing Emmons Glacier. Crevasse danger should always be assessed below stake 2 on the Emmons Glacier if descending from CSH. If crevasse danger is high, hike from CSH down to WRC via Glacier Basin, camp at WRC, and return the next morning via the moraine trail (see “Emmons Glacier, late March to early April” route above) to gather stake 3–5 data.

Late June to September (Climbing Rangers’ work season)

Muir Snowfield and Upper Emmons Glacier:

Tasks: Measure height of stakes 1 (Ingraham flats) and 2 (near Camp Muir) and upper Emmons Glacier stakes 1, 2, and 2x every one to two weeks.
Personnel: 1–2 Climbing Rangers while at Camp or on travel to and from summit and/or to Camps Muir and Schurman.

Late July to Mid August

Lower Nisqually and Lower Emmons Glaciers:

Tasks: Re-drill stakes on lower glaciers as needed (typically this will be stakes placed in the debris covered ice of the lower glaciers in which it is difficult to drill sufficiently deep holes to last the whole summer).
Personnel: 2 people
Schedule and Work Details:

- Day 1: 5 hrs to drive to Longmire from Marblemount.
- Day 2: 8–10 hrs to check stakes and re-drill as needed on lower Nisqually Glacier; drive around to White River (drive is 1.5 hrs).
- Day 3: 13–14 hrs to measure stakes and re-drill as needed on lower Emmons Glacier; return to Marblemount.

For route descriptions see late-March to early May schedule above.

Late September and Early October

Nisqually and Emmons Glacier

Tasks: Final visit of the balance/water year to measure stakes, probe any remaining snow, scatter a surface sand marker at stake 1 and 2, mark glacier surface on ablation stake, and if necessary re-drill lower stakes to monitor remaining fall melt. Ideally, a crew from MORA will do the Nisqually Glacier, Muir Snowfield, Ingraham flats visit. A separate crew will drive from NOCA to visit the Emmons Glacier, all visits are during a good weather window. Personnel: 2–3 people per crew.

Schedule and Work Details:

- Day 1: 5 hrs to drive from Marblemount to Longmire the night before. Accommodation in Longmire (tent or apartment).
- Day 2: 8–10 hrs to probe at, measure, and mark Nisqually stakes 3, 4, 4A, and 5. Accommodation in Longmire (tent or apartment).
- Day 3: 14–15 hrs to collect surface sand marker; travel to Camp Muir; probe at and measure stakes 1 and 2; scatter sand marker at stakes 1 and 2; return to Longmire. If stakes 1 and/or 2 is frozen into the ice leave stake, mark surface of glacier/snow, and remove all stake sections above marker. Accommodations in Longmire (tent or apartment).
- Day 4: 8–12 hrs to drive around to WRC (drive is 1.5 hrs); probe at, measure, mark, and (if needed) re-drill Emmons stakes 3, 4, 4A, and 5 on lower Emmons Glacier. Accommodations at WRC.
- Day 5: 7–9 hrs to collect sand surface marker, hike to CSH; probe at and measure stakes 2, and 2x on Emmons Glacier; scatter sand marker at stake 2. Accommodations at CSH.
- Day 6: 8 hrs to probe at, measure, and mark stake 1; scatter sand surface marker at stake 1; hike down to the car; drive back to Marblemount. If stakes 1, 2 and/or 2x are frozen into the ice leave stake, mark surface of glacier/snow, and remove all stake sections above marker.

The sequence of the above visits can be changed around to fit weather conditions. Though this visit is usually the fastest, it can also be the most dangerous with exposed crevasses, rock fall, and limited outside support (in case of emergency help may be hours away because much of the park staff is off for the season).

For general route descriptions see early to mid July schedule above with the fall route specifics below. Do not hike the Emmons glacier direct route to reach CSH on this visit; it is too dangerous and slow. If you choose to drop down onto the Emmons Glacier below Camp Curtis, be very cautious of rock fall and wear helmets. When descending onto the Emmons Glacier, watch for crevasse and stone fall danger. If you choose to go over Steam Boat Prow to reach CSH put on crampons (if needed) and helmet before descending. The short descent can often be icy. On the Nisqually glacier, watch for falling ice and stone near stake 3. Helmets should be worn when traversing from Camp Muir over to Ingraham Flats due to stone fall hazards.

On both glaciers, the upper glacier stakes (1–2) should always be initiated first, secondary to the lower elevation stakes 3–5. Weather and timing may dictate reorganizing these trips.

Late October to Mid November

Lower Nisqually Glacier:

Tasks: Final visit to measure stakes and probe any remaining snow at the end of the balance year (minimum balance) on the lower glacier. MORA staff will make this visit.

Personnel: 2 people

Schedule and Work Details:

- Day 1: 6–8 hrs to probe at, measure, and mark stakes 3, 4, 4a, and 5 on lower Nisqually glacier.
- Optional Day 2: 8–10 hrs drive to white river campground from Longmire to probe at, measure, and mark stakes 3, 4, 4A, and 5 on lower Emmons Glacier.

The late October to mid November trip is carried out in years when staff is available and or a large flood event has occurred. For route descriptions see late March to early May schedule above.

Table SOP 1.1. Estimated average minimum and maximum balance dates by measurement location on Nisqually and Emmons glaciers. For detail, see Appendix C (Analysis for the Best Timing of Glacier Visits).

Glacier	Stake	Altitude (meters)	Date of Maximum Balance	Earliest Recorded Maximum Balance	Latest Recorded Maximum Balance	Date of Minimum Balance	Earliest Recorded Maximum Balance	Latest Recorded Maximum Balance	Comments
Nisqually	1	3382	26-Jun	N/A	N/A	28-Sep	N/A	N/A	Min and Max dates are freezing level dates only
	2	2960	15-Jun	N/A	N/A	3-Oct	N/A	N/A	Min and Max dates are freezing level dates only
	3	2175	28-May	N/A	N/A	14-Oct	N/A	N/A	
	4	1890	19-May	N/A	N/A	19-Oct	N/A	N/A	
	4A	1870	18-May	N/A	N/A	20-Oct	N/A	N/A	
	5	1778	12-May	1-Apr	23-May	22-Oct	9-Oct	18-Nov	Earliest and latest dates from Paradise SNOTEL. Just below stake.
	Terminus	1450	15-Apr	N/A	N/A	29-Oct	N/A	N/A	
Emmons	1	3118	15-Jun	N/A	N/A	30-Sep	N/A	N/A	Min and Max dates are freezing level dates only
	2	2810	3-Jun	N/A	N/A	10-Oct	N/A	N/A	Min and Max dates are freezing level dates only
	3	1970	2-May	N/A	N/A	15-Oct	N/A	N/A	
	4	1700	20-Apr	11-Mar	21-May	27-Oct	9-Oct	14-Nov	from Morse Lake SNOTEL
	4A	1705	20-Apr	11-Mar	21-May	27-Oct	9-Oct	14-Nov	from Morse Lake SNOTEL
	5	1580	15-Apr	N/A	N/A	4-Nov	N/A	N/A	
	Terminus	1480	31-Mar	N/A	N/A	5-Nov	N/A	N/A	
Summit Crater		4315	25-Jul	N/A	N/A	16-Aug	N/A	N/A	Freezing level dates only

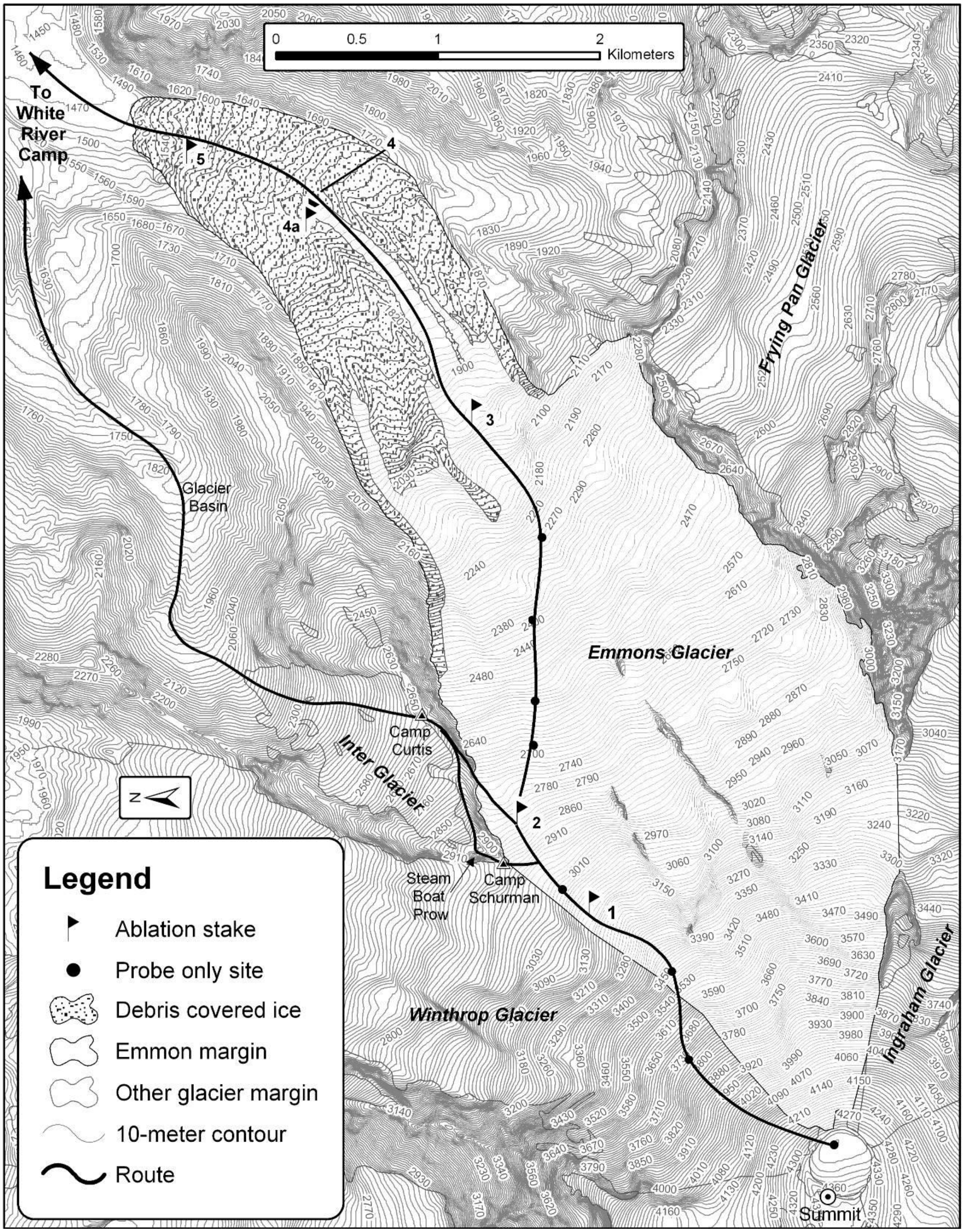


Figure SOP1.1. The Emmons Glacier showing field sites and access routes. Route selection is based on seasonal field visit, weather, and snow conditions. Emmons Glacier margin and debris cover were mapped in 1994 and 2001, respectively.

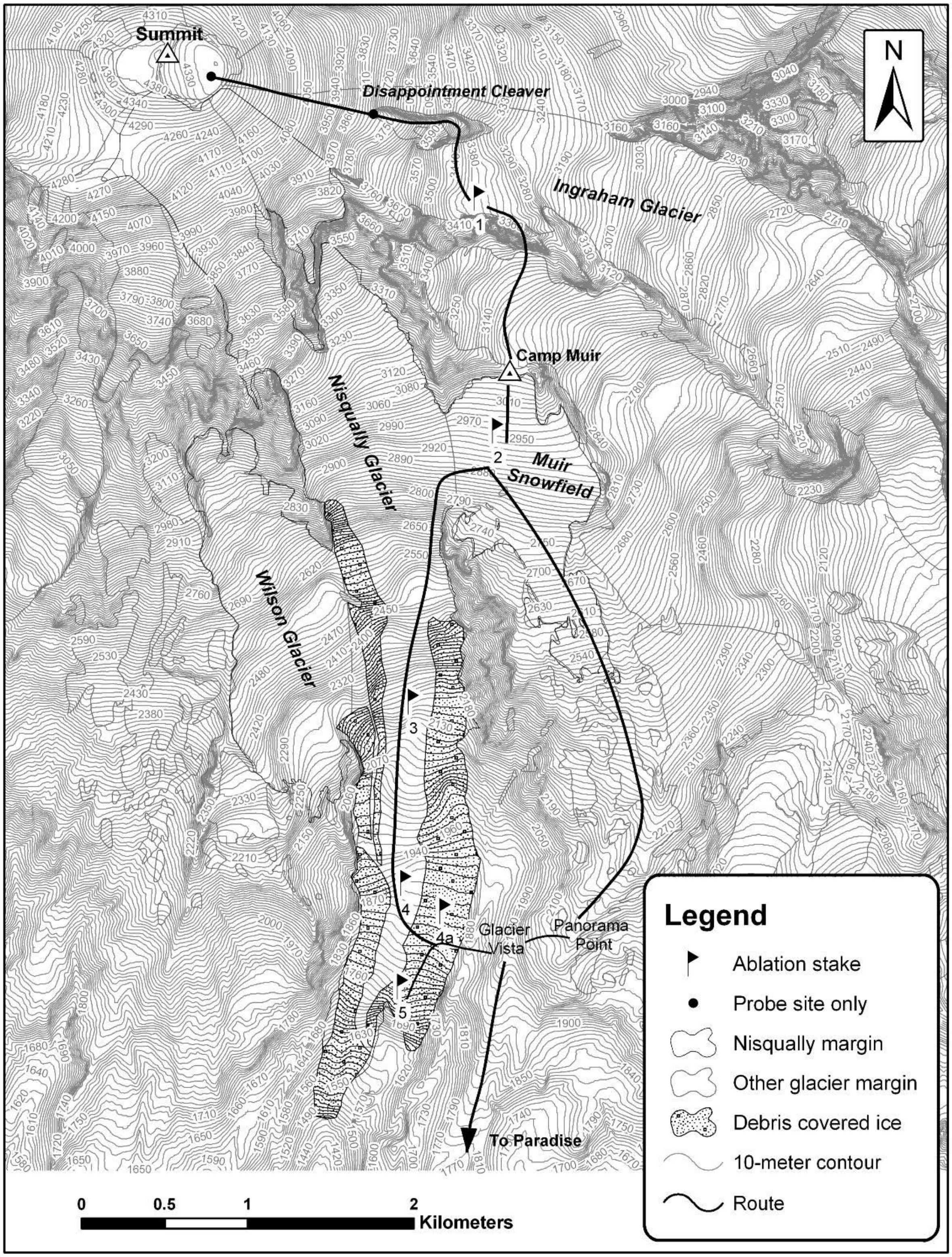


Figure SOP 1.2. The Nisqually Glacier showing field sites and access routes. Route selection is based on seasonal field visit, weather, and snow conditions. Nisqually Glacier margin and debris cover were mapped in 1994 and 2001, respectively.

Field Preparations

Most field season preparations occur well before the logistically challenging spring field work. Preparations for the spring field season should begin in early-March. Preparing for this first round of field work requires approximately 20 hours of work, subsequent visits require only a half an hour of work for one person. More time may be required if equipment needs repair or if logistics become complicated (scheduling around staff availability and inclement weather).

1. Equipment check and preparation: All equipment is stored in the Resource Management building at the Marblemount Ranger Station and in the maintenance storage building at Longmire. Staff should use the “Spring Glacier Monitoring Equipment List” (see below) to compile and pack all field forms, equipment, and supplies. In addition, the following equipment checks should be done at this time:
   - Check the steam drill hoses, valves, and connections for damage and excessive wear.
   - Fill all 2.5 gallon propane tanks.
   - Test run the steam drills to confirm everything is operating properly. See SOP 4 (Operation of the Steam Drills) for detailed instructions and safety precautions.
   - Check snow probes for damage and excessive wear. Clean and lubricate the coupling threads. If necessary re-number each probe section consecutively into 1m long lengths with 12.7mm (½ inch) colored electrical tape and sharpie.
   - Inspect ropes and glacier travel equipment for damage and excessive wear.

2. Purchases: Often sections of ablation stakes are lost the preceding year so new PVC (water-line tubing with 22 mm (7/8-inch) outer diameter and 3 mm (1/4-inch) wall thickness (PVC 1120 schedule 40, 600 psi)) along with new 16 mm (5/8-inch) wooden dowel needs to be purchased. Note: Not all 5/8-inch wooden dowels are exactly the same diameter. For this reason one should bring a small section of PVC tubing to the hardware store to test fit the dowel. Darrington Hardware and Supply Inc. (1220 State Route 530 Northeast, Darrington, WA 98241-9744, (360) 436-1260) currently is the best vendor for dowels.

3. Ablation Stake Preparation: Ablation stakes are constructed on the glaciers from 1.5 meter PVC sections. Depending on the glacier, the particular stake location, and the amount of accumulation that year, the PVC sections are combined into 6 to 12 meter long stakes. The bottom of each stake has two sections that are perforated with small holes. One of these perforated sections has a wooden dowel cemented into the bottom to aid in stake sinking. Holes can be made using a standard electric hand drill with a 5mm drill bit. Holes allow the stake to fill with water and thus keep the stake from “floating” if water is present. All stake sections are joined using pieces of wooden dowel that fit inside the tubing. Usually dowels are trimmed in the field with a pocket knife to exactly fit inside tubing. Individual PVC sections are joined flush and taped together with duct tape. For easier transport, the desired number of sections per stake are bundled together; those bundles are grouped for each glacier. Tables SOP 1.2–3 detail the stake lengths and number of sections required for each glacier.

4. Wooden Dowel Preparation: Wooden dowels are usually sold in three or four feet sections. With a chop saw, each section needs to be cut into 50 to 70 mm (2 to 3 inch) pieces of wooden dowel. Edges of each piece should be sanded for easy insertion into PVC sections. To figure out how many dowels are needed, count the number of PVC sections per stake and subtract one. If the stake is 6m, four 1.5m PVC sections are required and three wooded dowels are needed to couple a four section stake. Dowels are carried in a separate small stuff sack along with duct tape, a sharpie marker, and a multi-tool/pocket knife (for trimming the dowels in the case they are too large in diameter to fit into the PVC).

5. GPS Preparation: Locations of the stakes are predetermined using a map and GPS. Make sure that the proper stake coordinates have been loaded into the GPS's memory and that there is sufficient battery life. Tables SOP 1.2–3 list the GPS coordinates for each stake for both glaciers. Figures SOP 1.1 and SOP 1.2 show approximate locations in map view.

6. Field Data Sheet Preparation: Field data sheets need to be prepared before every glacier visit. Blank data sheets should be copied on write in the rain paper. Except for the spring visit, measurements from previous glacier (but current year) visits should be transferred

Table SOP 1.2. Nisqually Glacier stakes. Measurements are in meters. Coordinates are in UTM, NAD83.

Stake	X	Y	Z	Stake Length	No. of Sections	Top Below Surface	Placement Date	Site Character
1	596439	5188702	3382	9	6	+0.5	mid April	Ingraham Flats
2	596550	5187304	2960	9	6	+0.5	mid April	upper Muir Snowfield
3	596042	5185677	2175	10.5	7	1.0	mid April	lower glacier, bare ice
4	595996	5184588	1890	12	8	1.5	mid April	lower glacier, bare ice
4A	596234	5184418	1870	9	6	1.0	early/mid June	lower glacier, debris-covered ice
5	595977	5183966	1778	9	6	1.0	early/mid June	near terminus, debris-covered ice

Table SOP 1.3. Emmons Glacier stakes. Measurements are in meters. Coordinates are in UTM, NAD83.

Stake	X	Y	Z	Stake Length	No. of Sections	Top Below Surface	Placement Date	Site Character
1	596323	5191005	3118	9	6	+0.5	early May	above Schurman
2	596876	5191448	2810	9	6	0	early May	mid glacier
2x			2800	9	6	0	early May	mid glacier
3	599353	5191728	1970	12	8	1.5	early April	lower glacier, bare ice
4	600587	5192733	1700	12	8	2	early April	lower glacier, bare ice
4A	600537	5192750	1705	9	6	+0.5	early/mid June	lower glacier, debris-covered ice
5	600956	5193487	1580	9	6	+0.5	early/mid June	Near terminus, debris-covered ice

Field Procedures

Spring Procedures on Glacier

See Spring Equipment List below.

1. Locate stake placement by preprogrammed GPS handheld unit

2. Probe snow for previous year's summer surface and record measurements (refer to SOP 2. Snow Depth Probing). Make three to five probes on elevation contour on both sides of the stake placement site for a total of six to ten probes. On the upper stakes, 1 and 2, make at least one probe, time permitting, three meters above or below stake placement to ensure probing is not over a crevasse. Alternate probing between partners.

3. Check probe consistency. Probe depths should not be within 1m difference of average if a minimum of 6 probes are available. Decide on summer surface and probe to this point but do not erase collected data. Instead make a note. If fewer than six probes repeat validation in summer and record all layers.

4. Connect all hoses, light steam drill, and wait for pressure to build (see SOP 4. Operation of the Steam Drill)

5. Drill hole for stake. Once pressure is built within drill, hold the hose tip vertically above snow (perpendicular to the sky not the slope) and insert into the snow, let the hose drill without exerting downward pressure.

6. Turn gas off at ~0.3 m before reaching desired hole depth. With the gas off keep the steam flowing until depth is reached. If you turn steam valve off early, unwanted pressure may build.

7. Assemble and label the PVC stakes. Depending on the glacier, the particular stake location, and the amount of accumulation that year, the PVC sections are combined into 6- to 12-meter-long stakes. Stakes are joined using the wooden dowels that fit inside tubing. Individual sections are joined flush and taped together with duct tape. When wetted the dowels swell and provide a reliable coupling. Remember to put the PVC section that contains the glued wooden dowel and 5 mm diameter holes in the bottom. Labeling uses the last two digits of the current year, the stake location number, and the segment number. The label is written on the top of each segment close to the wooden dowel and duct tape (e.g., "06-1-5," which translates to the year "2006-stake 1-segment 5").

8. Place PVC stake in hole. One person stands above the hole holding assembled stake with arms spaced out to balance stake upright. Second person pushes the end of the stake up into the air to create a vertical line for insertion. While inserting stake, check each segment label for correct labeling.

9. Record PVC stake height and note if stake is below or above snow surface. If the stake is placed below the snow surface use a tape measure or section of probe to locate the top of the stake. If the snow surface around the stake is variable, lay the center of an ice axe on

the snow and take the measurement where the axe meets the stake.

10. Take snow core. Snow cores are taken at different times of the year at different locations on the glacier depending on visit. See above "procedures" for visit. Core the entire snowpack if possible. On both the Nisqually and Emmons, look for sediment marking at the base of the core at stakes 1 and 2. Record in the "Notes" section of the field form what "push" it was found on and meters down from that push. (see SOP 3. Snow Density Determination with the Snow Core).

11. Probe at locations between stakes as time allows.

12. Have field partner verify data collection.
    a. Calibrate probe length. Check to see if each taped marking measures out one meter interval.
    b. Check probe connection order. Probe should be assembled in sectional order.
    c. Confirm probe depth.
    d. Check each snow core push weight, length, and depth.
    e. Compare probe depth and sediment marker depth (via snow core).
    f. Confirm distance from glacier surface to top of stake.

13. Take oblique digital photos. Use a two mega pixels or better camera to photograph as much of the glacier as possible from the terminus and/or designated control points. See SOP 15 (Repeat Terrestrial–Based Photography) for photo point coordinates and descriptions. See SOP 17 (Managing Photographic Images) for storage procedures.

Summer Procedures on Glacier

See Summer Equipment List below.

1. Locate stake placement by preprogrammed GPS handheld unit.

2. Measure height of stake from glacier surface. If the stake is not found, i.e. not melted out yet, look for hole in snow. Usually stake hole is visible and the stake top is not far below snow surface. Record the number of whole segments plus any remaining meters of stake above/below snow surface. Record label off the top of stake you measured to. If segments of stake are broken off and packed off glacier, record the number of segments packed out.

3. Check mid-season stake melt to mid-season probes and probe melt. Make sure these numbers agree within 0.5 m.

4. If applicable, measure past year's stake heights. There may be several other stakes from past years still embedded in the ice or laying on the glacier surface nearby. Usually past year's stakes are only found at stake locations 3–5. If found, record the height of the stake to the nearest section break and record the label off this section. With a sharpie, darken the stake label.

5. Probe snow for previous year summer surface and record measurements (see SOP 2. Snow Depth Probing). Alternate probing between partners. Record depths.

6. Take snow core. Snow cores are taken at different times of the year at different locations on the glacier depending on visit. See above “time line and task list” for appropriate location and visit. Core the entire snowpack if possible. On both the Nisqually and Emmons, look for sediment marking at the base of the core at stakes 1 and 2. Record in the “Notes” section of the field form what “push” it was found on and meters down from that push. (see SOP 3. Snow Density Determination with the Snow Core)

7. If sediment marker is not found and probes are unreliable, decide whether or not to dig a pit. If the snowpack is too deep, make note to dig during the fall visit.

8. Record type of surface, snow, firn, or ice. Look for type of crystal structure (round vs. jagged), snow surface morphology (suncups), color (white, grey, blue), sediment concentration, density, and depth.

9. Probe at locations between stakes as time allows.

10. Look for and record crevasse stratigraphy. Preferably near a stake, but any elevation is fine as long as the elevation is recorded and stratigraphy is in a stable crevasse zone (i.e., not falling seracs). Look for dirty layer of previous year and note both sides of crevasse walls (i.e., South and North facing).

11. Take oblique digital photos. (See “Spring procedures” list #13 above)

12. Have field partner verify data collection.
    a. Calibrate probe length (check to see if each taped marking measures out one meter interval.
    b. Check probe connection order. Probe should be assembled in sectional order.
    c. Confirm probe depth.
    d. Compare probe depth and sediment marker depth (via snow core).
    e. Confirm distance from glacier surface to top of stake.
    f. Check stake melt.

Fall Procedures on Glacier

See Fall Equipment List below.

1. Acquire sediment from sand bar on Nisqually or White Rivers. Fill about five 2.5-gallon stuff sacks per glacier with sand and pack it up to stakes 1 and 2 on both the Nisqually and Emmons glaciers. If there are only a few field participants it may be necessary to acquire sediment higher up on the mountain from moraines close to the stakes.

2. Measure height of stake from glacier surface (see item no. 2 under Summer Procedures on Glacier). If stake is melted out (lower stakes) look for drill hole. If stake is missing look in nearby crevasse for stake segments.

3. Check end season stake melt to spring data. Make sure melt from stakes and probes agree.

4. If applicable, measure past year's stake heights. There may be several other stakes from past years still embedded in the ice or laying on the glacier surface. Record the height of the stake to the nearest segment break and record the label off this section.

5. Mark glacier surface. Use a black sharpie to mark a line on stake at the glacier surface. Write "Fall" with current year and arrow pointing to line. Darken stake labeling for future readings. Leave stake in glacier if ≥0.5 m remains under the ice. Make a note as to how many sections are left behind. Stakes 1 and 2 on both the Nisqually and Emmons glaciers should be pulled unless frozen in glacier. If left, mark stakes as described above.

6. Remove and break apart stake segments above "fall" marked line. Bundle these for transport with duct tape or bungee cord.

7. Probe remaining snow and record measurements (see SOP 2. Snow Depth Probing).

8. Dig a pit. If unable to find sediment surface marker or/and probes were unreliable during the spring and summer visits, dig a pit at surface marker location and find previous year's summer surface.

9. Record type of surface, snow, firn, ice. Look for type of crystal structure (round vs. jagged), snow surface morphology (suncups), color (white, grey, blue), sediment concentration, density, and depth.

10. Look for and record crevasse stratigraphy. (see above item no. 10 under Summer Procedures on Glacier, above)

11. Have field partner verify data collection.
    a. Calibrate probe length (check to see if each taped marking measures out one meter interval.
    b. Check probe connection order. Probe should be assembled in sectional order.
    c. Confirm probe depth.
    d. Confirm distance from glacier surface to top of stake.
    e. Check stake melt. Count segments and check label measurement.

12. Take oblique digital photos. (See item no. 13 under *Spring Procedures on Glacier*, above)

13. Spread sediment marker three meters by three meters at stakes 1 and 2 on both the Nisqually and Emmons glaciers.
    a. GPS middle of sediment marker (make sure GPS has at least a seven meter or greater accuracy reading).
    b. Take a photo of marker.

14. Determine ELA (Equilibrium Line Altitude). From a good vantage point on or near the glacier, note the snow line on field data sheet.

Glacier Monitoring Equipment Lists

Spring Glacier Trip Equipment List

Ablation Stakes (for spring and summer visits):

__ Appropriate number of stake bundled 1.5 m segments depending on visit (every one full stake should have two sections perforated with one of these having a plugged base with wooden dowel.
__ 4” dowels (Bring more than are necessary.)
__ 2 rolls of duct tape
__ 3 10-meter measuring tapes

Snow depth Probe (make sure all segments are included and 1-m intervals are marked with tape and marker):

__ 2 small vice grips
__ Leather or Rubber palm gloves for probing
__ wax, sun screen, spray oil, or soap

Snow coring device:

__ Snow tube
__ Tube head with one-way valves
__ Extension Rods
__ T-handle
__ Mass scale
__ Stuff sack/ditty bag for measuring snow mass
__ Instructions

Steam Drill and Accessories (for spring and summer visits):

__ Filled 2.5 gallon propane tank
__ 2 small propane/butane fuel canisters (backup for Heucke drill) optional
__ Propane hose and regulator
__ 2 large piezo electric starter torches
__ 2 8-inch crescent wrenches
__ 2 pairs of pliers
__ Screwdriver and clamp kit
__ Fill drill with water if needed.

Other Equipment:

__ GPS (make sure stake locations are loaded)
__ Altimeter
__ Compass
__ 2 template field data forms for each glacier on write in the rain paper
__ 2 template extra probe data forms for each glacier on write in the rain paper
__ 2 template snow core data forms for each glacier on write in the rain paper
__ 2 maps of each glacier and maps showing approach routes

__ Shovel with metal head
__ Clipboard
__ 3 pencils
__ 2 sharpies
__ Radio with correct frequency for park
__ Extra radio battery
__ Charged camera and/or film
__ Extra batteries for camera and GPS (AA)

Keys and Combinations:

Emmons Glacier:

__ Key for white river gate
__ Key for White River cabin
__ Keys for Camp Schurman (usually one for propane storage and glacier travel equipment cabinets, a different key for upstairs sleeping bag storage area).
__ Combination for Camp Schurman

Nisqually Glacier:

__ Key for Longmire apartment
__ Key/combination for Camp Muir

Glacier Safety Equipment:

__ Helmet
__ Rope
__ Crampons as needed
__ 2 pickets, runners, and carabiners
__ 2 ice screws with draws and carabiners as needed
__ Ice Axe with leash
__ Avalanche transceivers (as needed)
__ Harness kit including
    __ Waist, foot, and one extra small prussik
    __ 1–2 pulleys
    __ 2 locking pear/large carabiners
    __ 3–4 regular carabiners
    __ 1 1-inch ~6-feet long webbing (or equivalent) with locking carabiner

Personal Equipment:

__ Fleece layer
__ Rain Gear
__ Gaiters
__ Boots and socks
__ Hat (warm and ball cap)
__ Gloves
__ Sunglasses
__ Sunscreen
__ First Aid Kit
__ Water and Food

- __ Headlamp

Overnight Gear as needed (may not need if staying in Ranger Huts):

- __ 1 stove
    - __ filled fuel canister
    - __ 1 or 2 pots
- __ Overnight food and breakfast as needed
- __ Sleeping bag
- __ Sleeping pad
- __ Down jacket
- __ Tent

Travel Equipment:

- __ Skis
    - __ Ski Boots
    - __ Poles
    - __ Skins
    - __ Glob stop for skins
    - __ goggles
- __ Snowshoes
    - __ Poles

Summer Glacier Trip Equipment List

Data collection items:

- __ 2 GPS units and extra batteries
    - __ Altimeter
    - __ Compass
- __ Shovel with metal head
    - __ Clipboard
    - __ Radio with correct frequency for park
    - __ Extra radio battery
    - __ Charged camera and/or film
    - __ Extra batteries for camera and GPS (AA)
- __ 2 template field data forms for each glacier on write in the rain paper
- __ 2 template extra probe data forms for each glacier on write in the rain paper
- __ 2 template snow core data forms for each glacier on write in the rain paper
- __ 2 maps of each glacier and maps showing approach routes
- __ 2 small measuring tapes – 1 for each team
- __ 2 probes marked and taped
- __ 2 pairs of pliers or leatherman
- __ 1–2 pairs of probing gloves (not vital in shallow snow)
- __ 2–4 pencils
- __ 2 sharpies
- __ duct tape

Snow coring device:
- See Spring equipment list

Snow depth Probe:
- See Spring equipment list

Keys and Combinations:
- See Spring equipment list

Overnight Gear as needed (may not need if staying in Ranger Huts):
- See Spring equipment list

Personal Equipment
- See Spring equipment list

Glacier Safety Equipment

__ Helmet
__ Rope
__ Crampons
__ 2 pickets, runners, and carabiners
__ 2 ice screws with draws and carabiners
__ Ice Axe with leash
__ Harness kit including
  __ Waist, foot, and one extra small prussik
  __ 1–2 pulleys
  __ 2 locking pear/large carabiners
  __ 3–4 regular carabiners
  __ 1 1-inch ~6-feet long webbing (or equivalent) with locking carabiner

Fall Glacier Trip Equipment List

Data collection items:
- See Summer equipment list

Glacier Safety Equipment:
- See Summer equipment list

Snow depth Probe:
- See Summer equipment list

Keys and Combinations:
- See Summer equipment list

Overnight Gear as needed (may not need if staying in Ranger Huts):
- See Spring equipment list

Personal Equipment
- See Spring equipment list

Glacier Safety Equipment

- See Spring equipment list

Surface Snow Marker:

__ 5 (minimum) 2.5-gallon stuff sacks filled with sediment per glacier

SOP 2. Snow Depth Probing

Version 2/11/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures

Overview and Explanation

Measuring winter balance is an integral measurable objective of this protocol. One of two key tasks for measuring winter balance is using a metal probe to measure snow depth at measurement locations on the glacier. Probing snow depth is fairly straight forward but there are important procedures to follow to insure safety, probe integrity and longevity, and accurate measurements. The custom fabricated probes are especially expensive and need special attention in their maintenance and care to insure probe longevity and health. We use two different designs for snow depth probes: (1) a variable composition (aluminum, stainless steel) probe of one-meter segments that screw together, developed by Taylor Scientific Engineering, Inc. of Seattle, Washington; and (2) a variable length probe composed of copper-coated, steel, army tank radio antenna segments, (part number: M116A mast sections). These also are one meter segments that screw together, but the tube threads overlap so that each segment has an effective length of 0.96 meter. We have two sets of probes that are custom fabricated by Taylor Scientific Engineering, Inc., one set is made of aluminum and the other of stainless steel. The Taylor stainless steel probes tend to come apart in conditions of difficult probing. These should be used only when the snowpack is isothermal and less than 6-meters in thickness, thus excluding the use of these probes during spring visits.

Snow depth probing is always taken at each of the stake placement locations and additional site locations. See Figure 3 and 4 in the main narrative or Figures SOP 1.1 and SOP 1.2 in SOP 1 (Field Season Time Line, Preparations, and Procedures) for these locations. Six stakes are placed on each glacier and span an altitude of 1530m (5,000ft). Stake one is the highest placed stake and stake five is the lowest placed stake. Stakes four and five are located in debris covered ice. We sometimes describe the glaciers as having “upper” and “lower” altitude areas which coincide with stake placements. Stake number one and two are on the “upper” glacier and stakes three through five are on the “lower” glacier.

Procedures

1. Probe Packaging, Transport, and Coupling/Decoupling: Always use the plastic carrying tubes for transport into the field. If these are not available then it is permissible to carry the probe segments in a bundle fastened with thick rubber bands. Do not use duct tape as the tape adhesive gums up the probe. Probes should be carefully screwed together completely until the sections ends are flush. Grease or light machine oil can be used to keep the threads from seizing. Care should also be taken when decoupling to avoid damage. If vice-grips are needed, a piece of leather should be used between the probe and vice-grip to protect the probe.

2. Taking a Snow Depth Measurement: Snow depth down to the previous year’s summer surface is determined using the snow depth probe. Ideally this surface is firn or ice that is impossible to penetrate with the probe. It can be difficult to identify this surface when there is little change in density between the ice layers in the current year’s snowpack and one-year-old firn. This situation often occurs after a strongly positive balance year (with residual snow), especially on the upper sections of the glacier. In these situations snow depth can be easily overestimated. Probing can also underestimate a given winter’s snowpack because of the formation of ice layers that are created during winter freeze thaw cycles and/or precipitation events. Stakes 4a and 5 on the lower debris covered ice

will always have a definitive rock layer to probe to. At these stakes, probe depths very considerably (2.5 m within mean probe depth) due to undulating debris/ice surface. Keep these points in mind when probing, with experience the previous summer surface can be identified (See **SOP 3: Snow Density Determination with Snow Core** for confirming snow probe depth with the snow core). See **SOP 1 (Field Season Time Line, Preparations, and Procedures)** for probe locations.

a. Do not assemble any more than 5 sections of the Taylor probe while it is not inserted into the snow. Do not assemble any more than 7 sections of the tank antenna probe while not inserted in snow. If you need more length, attach additional sections as the probe is worked down into the snowpack. The tank antenna probe sections need to be screwed together in the correct sequence so that the length markings are correct. Each probe section should be pre-numbered consecutively into 1m long lengths with 12.7mm (½ inch) colored electrical tape and sharpie.
b. Whether to use gloves and what type to use depends on personal preference and the weather and snow conditions. Some of the glove options used by the current staff are grip-rubber-palmed gardening gloves, nomex flight gloves (with leather palms), lightweight fleece insulated gloves with textured grip, and leather-palmed gloves.
c. Carefully and steadily raise the probe to an upright position. Spread your hands as far apart on the probe as possible to minimize flex and insert it <u>vertically</u> into the snow (NOT perpendicular to the snow surface). Ask your field partner if the probe is vertical.
d. Using the needed amount of force, jab the probe down through the snow in short, downwardly progressive, up and down strokes.
e. Keep track of the number of sections that are in the snowpack.
f. As you work the probe down feel for ice layers and dense snow (layers of increased resistance to probing). The skill of detecting ice and dense snow layers takes some practice to develop. When a layer of resistance is encountered record it on the data sheet (see Figures SOP 2.1–5). When the previous year's summer surface is encountered (often by a subtle but definite ring in the probe), record this on the field sheet.
g. In the spring when the snowpack is polythermal, with snow at the freezing/melting point near the surface but at a lower temperature at depth, take great care to prevent the probe from freezing into the hole. This situation can often be encountered in the spring anywhere on the glaciers and on the upper mountain in early summer.
    i. First apply a small amount of lubricant (i.e., Sunscreen, cooking oil, grease, etc.) to the bottom section of the probe.
    ii. NEVER leave the probe at the bottom of the last stroke when you stop probing. If you encounter an ice layer and need to make a measurement mark this point on the probe with your hand and pull the probe up 6–12 inches off the bottom of the hole while making the measurement.
    iii. If the probe becomes really difficult to slide (starts feeling really "sticky") because it is freezing into the snowpack, <u>keep the probe moving</u>. If it keeps getting stuck and no downward progress is made it's better to give

up the effort, not risk getting the probe stuck and take the snow depth measurements at the summer visit. If time permits do a snow core at this location.

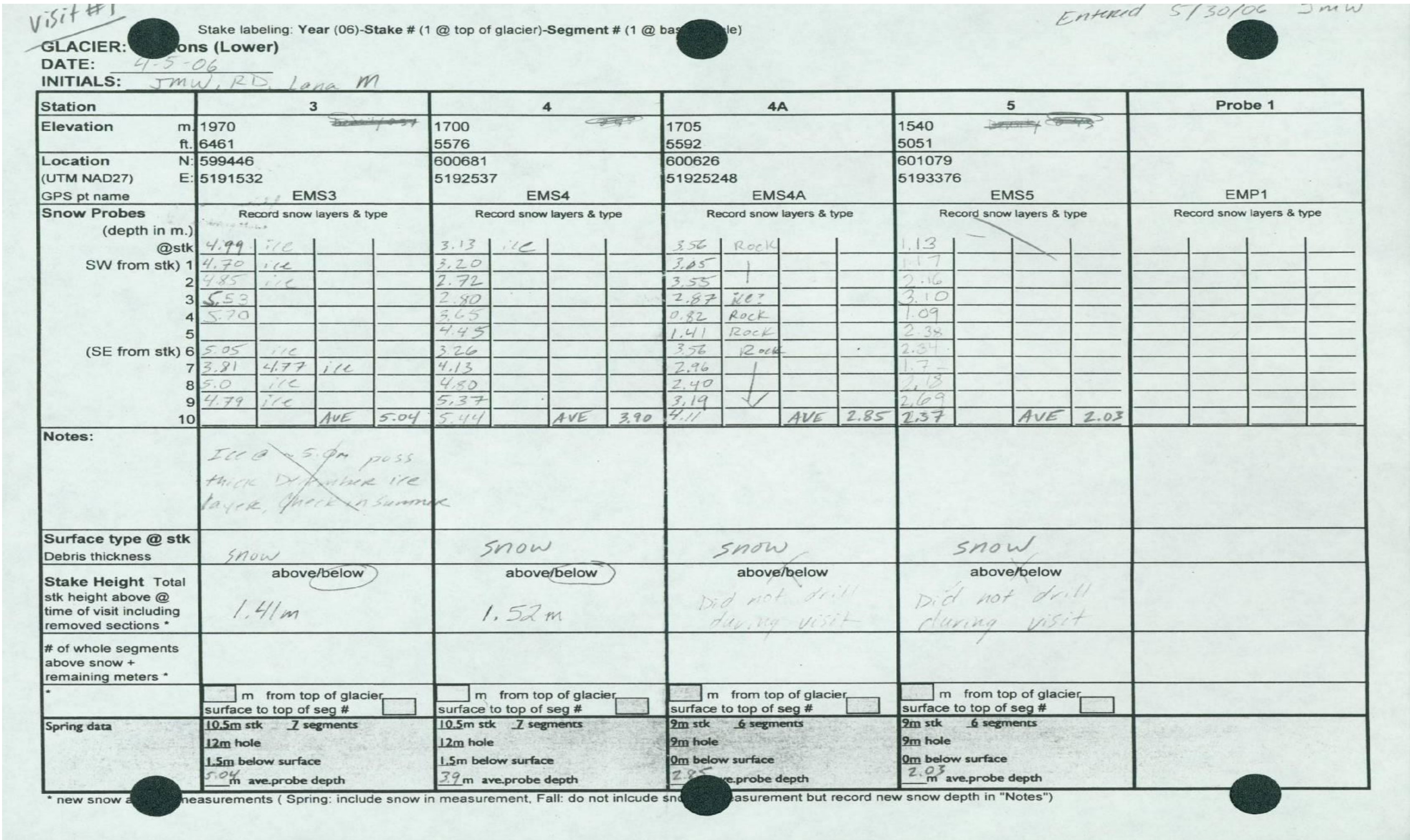
iv. If the probe does get stuck, try pulling it out with two people. If that approach doesn't work then attach a prussik loop with a standard prussik knot to the probe. Pull up using an ice axe through the loop. Sometimes this requires two people. This method is generally successful. If the prussik approach still doesn't work then attach a pair of vice grips to the probe and twist in the same direction as to screw together the probe sections. This is a last resort because tight vice-grips tend to damage the probe.

h. Each person should alternate between recording and probing to catch any errors.

3. Quantity and pattern of snow depth measurements: Snow depth is probed at a minimum of three (but preferably 10) points along a 15- to 30-meter-long transect on elevation contour at each stake location to establish an average value. An initial probe at the exact point for the stake hole is used to check for crevasses as well as to find the snow depth. Five points on either side of the stake are then probed for a total of ten probes. If time permits, probe once at three meters above or below stake location to check for crevasses in the area. The additional probe is a good check at stake 1 and 2 where large crevasses exist in the vicinity. Crevasses near these stake locations tend to run perpendicular to the slope and it is rare but possible to probe the entire transect on top of a single crevasse. When probing on transect, the probe may not "push through" to air indicating a crevasse, instead it may catch on the crevasse wall inaccurately recording the bottom of the snowpack. Occasionally snow conditions and time constraints permit only one probe measurement to be taken in the spring. In these cases, probing during the summer visit and depth loss from the stake measurement are used to calibrate for spring depth. Additional locations on the glaciers are probed if time permits.

4. Recording the Data: Data are recorded on a standardized data sheet (see example field sheets in Figures SOP 2.1–5). Individual probe measurements, including ice layers and location relative to the stake are recorded on these sheets along with other observations and notes.
   a. After recording data, examine all probes for consistency (≤1.0 m depth difference in probe mean except for measurements taken at the stakes placed in debris).
   b. If a snow core was taken at the same location make sure probes and core agree with one another.
   c. During the summer and fall visits compare probe depths to spring probes and snow melt from stakes. Melt from probes compared to stakes should agree within 0.5 m. Re-probe if necessary.
   d. Each person should alternate between probing and recording to catch any errors.

5. Care and Maintenance of the Probes:
    a. Remove the probe sections from the carrying tube after each field trip to let them dry out.
    b. Clean and lubricate the coupling threads at least once a year in the spring or more often as needed.
    c. Replace the tape marking lengths on the tank antenna probe as needed. Use colored electrical or similar plastic marking tape.
    d. If probes become bent or broken, set them aside for repair or replacement.
    e. Keep an inventory/log of bent and broken probe sections.


Visit #1

Entered 5/30/06 JMW

Stake labeling: Year (06)-Stake # (1 @ top of glacier)-Segment # (1 @ ba[illegible]le)

GLACIER: [illegible]ons (Lower)
DATE: 4-5-06
INITIALS: JMW, RD, Lana M

Station	3	4	4A	5	Probe 1
Elevation m.	1970	1700	1705	1540	
ft.	6461	5576	5592	5051	
Location (UTM NAD27) N:	599446	600681	600626	601079	
E:	5191532	5192537	51925248	5193376	
GPS pt name	EMS3	EMS4	EMS4A	EMS5	EMP1
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type
@stk	4.99 ice	3.13 ice	3.56 Rock	1.13	
SW from stk) 1	4.70 ice	3.20	3.05	1.17	
2	4.85 ice	2.72	3.55	2.16	
3	5.53	2.80	2.87 ice?	3.10	
4	5.70	3.65	0.82 Rock	1.09	
5		4.45	1.41 Rock	2.38	
(SE from stk) 6	5.05 ice	3.26	3.56 Rock	2.34	
7	3.81 4.77 ice	4.13	2.96	1.7_	
8	5.0 ice	4.80	2.40	2.18	
9	4.79 ice	5.37	3.19	2.69	
10	AVE 5.04	5.44 AVE 3.90	4.11 AVE 2.85	2.37 AVE 2.03	
Notes:	Ice @ ~5.0m poss thick ~~D~~ [illegible] ice layer, check in summer				
Surface type @ stk / Debris thickness	snow	snow	snow	snow	
Stake Height Total stk height above @ time of visit including removed sections *	above/below 1.41m	above/below 1.52m	above/below Did not drill during visit	above/below Did not drill during visit	
# of whole segments above snow + remaining meters *					
*	m from top of glacier surface to top of seg #	m from top of glacier surface to top of seg #	m from top of glacier surface to top of seg #	m from top of glacier surface to top of seg #	
Spring data	10.5m stk 7 segments; 12m hole; 1.5m below surface; 5.04 m ave.probe depth	10.5m stk 7 segments; 12m hole; 1.5m below surface; 3.9 m ave.probe depth	9m stk 6 segments; 9m hole; 0m below surface; 2.85 ave.probe depth	9m stk 6 segments; 9m hole; 0m below surface; 2.03 m ave.probe depth	

* new snow a[illegible]measurements (Spring: include snow in measurement, Fall: do not inlcude sn[illegible]asurement but record new snow depth in "Notes")

Figure SOP 2.1. Sample spring field data sheets: lower Emmons Glacier 2006

Visit #2

GLACIER: Emmons (Upper)

Stake labeling: **Year** (06)-**Stake #** (1 @ top of glacier)-**Segment #** (1 @ base)

DATE: 5-5-06

INITIALS: JMW, NB, RD, Jennifer E.

Entered date: 5/30/06 Entered by: JMW
Verified date: Verified by:
Updated date Updated by:

Station	**1A**	**1**	**2**	**Probe**	**Probe**
Elevation m	3111	2887	2806		
ft.	10,200	9469	9204		
Location N	596323	596749	596969		
(UTM NAD27) E:	5191005	5191250	5191252		
GPS pt name	EMS1A	EMS1	EMS2	EMP_	EMP_
Snow Probes	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type

(depth in m.)	1A				1				2				Probe				Probe			
@stk	6,85	9.42			5.44	6.66			4.95	5.70										
N W from stk) 1	6.67	8.90			4.64	~~9.7~~+			5.32	6.05										
2	7.45				4.53	5,84	6.24	7.53/8.0	~~7.6~~	8.27ice										
3	7.15	8.22			4.59	4.95	5.81	7.86	4.87	7.82ice										
4	7.03	8.0	8.35		4.55	5.75	7.54													
5																				
S (E from stk) 6	6.90	9.17			4.73	5.80	6.53	8.0	5.0	7.64	9.41									
7	6.85	9.09			4.75	6.90	7.69	8.0	5.76	6.61	8.93	9.58ice								
8	6.66	8.95ice			4.48	5.20	7.32		5.77	7.56	9.62									
9	6.66	8.72																		
10			AVE =	6.91?			AVE =	6.16?			AVE =	5.51?								

	1A	1	2	Probe	Probe
Notes:	probe 1 - likely went through firn - Dense possibly all? probes? bw = 0 ← summer surface ? ? ?? →	bw = 0	bw = 0		
Surface type @ stk Debris thickness	snow	snow	snow		
Stake Height Total stk height above @ time of visit including removed sections *	above/below 2.28m	above/below 0.55	above/below 0.70		
# of whole segments above snow + remaining meters *					
*	___ m from top of glacier surface to top of seg # ___	___ m from top of glacier surface to top of seg # ___	___ top ___		
Spring data	9m stk 6 segments ~~9m~~ hole 11m hole stk @ surface 2m below ___m ave.probe depth	9m stk 6 segments 9.5m hole 0.5m below surface ___m ave.probe depth	9m stk 6 segments 9.5m hole 0.5m below surface ___m ave.probe depth		

* new snow and stk measurements (Spring: include snow in measurement, Fall: do not inlcude snow in measurement but record new snow depth in "Notes")

Figure SOP 2.2. Sample spring field data sheets: upper Emmons Glacier 2006

Visit #4

Stake labeling: **Year** (06)-**Stake #** (1 @ top of glacier)-**Segment #** (1 @ ba[…]le)

GLACIER: Emmons (Summer)
DATE: 7-4-06
INITIALS: JMW, Jamie W

Entered date: 10/10/06 Entered by: JMW
Verified date: Verified by:
Updated date Updated by:

7/4/06

Station	1A 7/5/06	1 7/5/06	2 7/5/06	3 7/4/06	4 7-4-06	4A	5
Elevation m.	3111	2887	2806	1970	1700	1705	1540
ft.	10200	9469	9204	6461	5576	5592	5051
Location N:	596323	596749	596969	599446	600681	600626	601079
(UTM NAD27) E:	5191005	5191250	5191252	5191532	5192537	51925248	5193376
GPS pt name	EMS1A	EMS1	EMS2	EMS3	EMS4	EMS4A	EMS5
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type ice?	Record snow layers & type	Record snow layers & type	Record snow layers & type	
@stk	4.65 6.12 7.23	4.22 4.62 5.81 Firn	2.18 4.09 6.98	0.67	no snow	no snow	
(S from stk) 1	4.97 6.53	2.62 6.54	4.53 5.64 7.26	0.35			
2	4.81 6.30 6.55	2.42 3.87 ice	3.35 4.59 ~~7X~~	0.25			
3	3.75 4.82 6.30	3.77 6.70 Firn?	4.70 5.32 Firn?	0.71			
4	~~2.60~~ ice throwout	3.60 4.77 Firn?	4.80 5.49	0.85			
5	3.24 4.33 Firn	3.08 7.0+ Crevasse	4.78 7+	0.98			
(N from stk) 6	3.88 4.70 5.14 Firn?	4.46 5.09	3.96 6.88 Firn?	0.39			
7	4.61 6.30 Firn?	4.16 4.48 crevasse	3.50 3.85 6.57	0.80			
8	3.63 4.62 5.55 5.94	7.0+ crevasse?	4.43 7.0	0.61			
9	3.40 4.46 5.67	~~2.94~~ 5.24 ice	3.53 6.73	0.75			
10	3.82 ~~5.44~~ Crevasse	~~2.36~~ ice	5.80	0.79			
Notes:	AVE 4.66m Couldn't find stk / X take out O use as bw	AVE 4.58 X take out O use as bw	AVE 4.41 X take out O use as bw	AVE 0.65			
Surface type @ stk Debris thickness	snow	snow		snow/ice	ice	debri 0.22	0.17 cm debri
Stake Height Total stk height above @ time of visit including removed sections *	above/below not melted out yet	above/below 1.5 0.15 = 1.65	above/below 1.5 +0.05 = 1.55	above/below 1.5 +1.14 = 2.64	above/below 1.5 1.5 0.32 3.32	above/below 2.47 (w/ debris)	above/below 2.12 (including 0.17 of debris)
# of whole segments above snow + remaining meters *		1 seg + 0.15	1 seg + 0.05	1 seg + 1.14	2 seg + 0.32	1 segment + 0.97 (w/ debris)	1 segment + 0.62 (w debris)
*		0.15 to top of 06-1-5	0.05 to top of 06-2-5	1.14 to top of 06-3-6	0.32 to top of 06-4-5	0.97 from ice to the top of 06-4a-3	0.62 from ice to the top of 06-5-3
Spring data	9m stk 6 segments 10m hole 0m below surface ___m ave.probe depth	~~10.5m stk 7 segments~~ 9m stk 6 seg 9.5m hole ~~1m above surface~~ 0.5 below ___m ave.probe depth	9m stk 6 segments 9.5m hole 0.5m below surface ___m ave.probe depth	10.5m stk 7 segments 12m hole 1.5m below surface ___m ave.probe depth	10.5m stk 7 segments 12m hole 1.5m below surface ___m ave.probe depth	~~9m stk 6 segment~~ 6m 4 seg ~~9m hole~~ 5m hole ~~0m below surface~~ ___m ave.probe depth	~~9m stk 6 seg~~ 6m stk 4 seg ~~9m hole~~ 5m hole 0m below surface ___m ave.probe

stk 4b 2005
1.18 to the top of 05-4b-2
(0.20 debri)

stk 4a 2005
0.35 from debris to the top of 05-4a-1
(0.09 debri)

stk 4 2005
0.37 to top of 05-4-1 ice

stk 3 2005
0.20 to top of 05-3-2

* new snow and stk measurements (Spring: include snow in measurement, Fall: do not inlcude snow in measurement but record new snow depth in "Notes")

Figure SOP 2.3. Sample summer field data sheets: Emmons Glacier 2006

Visit # 7

Stake labeling: **Year** (06)-**Stake #** (1 @ top of glacier)-**Segment #** (1 @ b[illegible]hole)

GLACI[illegible]mmons
DATE: 10/10/06
INITIALS: Jmw, Nicole m. Fall 2006

Entered date: Entered by:
Verified date: Verified by:
Updated date Updated by:

Station	1A	1	2	3	4	4A	5
Elevation m.	3111	2887	2806	1970	1700	1705	1540
ft.	10200	9469	9204	6461	5576	5592	5051
Location N	596323	596749	596969	599446	600681	600626	601079
(UTM NAD27) E:	5191005	5191250	5191252	5191532	5192537	51925248	5193376
GPS pt name	EMS1A	EMS1	EMS2	EMS3	EMS4	EMS4A	EMS5
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	
@stk							
S from stk) 1							
2							
3							
4							
5							
(N from stk) 6							
7							
8							
9							
10							
Notes:	Did not visit			2005 + (2004?) stk melted out. Both had 2 bottom sections laying on ice	stk barely in ice + melted @ 45° angle, wonder if measurement is altered??	Can not find	left 1 seg in ice
Surface type @ stk Debris thickness				left 1 seg in ice / ice	Did not leave stk in. / ice		0.12 debris
Stake Height Total stk height above @ time of visit including removed sections *	above/below	above/below	above/below	above/below 1.5 1.5 1.5 1.5 1.5 1.5 + 0.18 = 9.18	above/below 1.5 1.5 1.5 1.5 1.5 1.5 + 1.20 = 10.20m	above/below	above/below Total 1.5 1.5 + 1.5 0.17 0.12 = 4.79m
# of whole segments above snow + remaining meters *							2 seg + 0.17
*				0.18 From ice to top of 06-3-1	1.20 from ice to top of 06-4-1 (Base)		0.17m from debris to top of 06-5-1 (Base)
Spring data	9m stk 6 segments 10m hole ___m below surface ___m ave.probe depth	10.5m stk 7 segments 9.5m hole 1m above surface ___m ave.probe depth	9m stk 6 segments 9.5m hole 0.5m below surface ___m ave.probe depth	10.5m stk 7 segments 12m hole 1.5m below surface ___m ave.probe depth	10.5m stk 7 segments 12m hole 1.5m below surface ___m ave.probe depth	9m stk 6 segments 9m hole 0m below surface ___m ave.probe depth	~~9m stk 6 seg~~ 4 seg ~~9m hole~~ 0m below surface ___m ave.probe

2006
5
second placed stk
0.79 from debris to top of 06-5nd-3
0.10 debris
1.50
0.79
+0.10
2.39 total

Figure SOP 2.4. Sample fall field data sheets: lower Emmons Glacier 2006

Visit#6

Stake labeling: **Year** (06)-**Stake #** (1 @ top of glacier)-**Segment #** (1 @ bas

GLACIER: mons
DATE: 9-22-06
INITIALS: JMW, NB

Fall '06

Entered date: Entered by:
Verified date: Verified by:
Updated date Updated by:

Station	**1A**	**1**	**2**	**3**	**4**	**4A**	**5**
Elevation m.	3111	2887	2806	1970	1700	1705	1540
ft.	10200	9469	9204	6461	5576	5592	5051
Location N	596323	596749	596969	599446	600681	600626	601079
(UTM NAD27) E:	5191005	5191250	5191252	5191532	5192537	51925248	5193376
GPS pt name	EMS1A	EMS1	EMS2	EMS3	EMS4	EMS4A	EMS5
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	
@stk	Could not		Could not				
S from stk) 1							
2	penetrate						
3							
4	through						
5							
(N from stk) 6	2006 snow						
7							
8	~0.50 to 1.0m	~0.50m of					
9	of remaining 06	remaining 2006					
10	snow. Taken from Cravasse	snow taken from Cravasse					
Notes: new snow covers 2006 snowpack which is hard from 2 weeks of heavy rain then drop in temp.	0.27m new snow not included in stk or probe measurement	0.15 new snow	0.14 new snow				
Surface type @ stk Debris thickness	new snow						
Stake Height Total stk height above @ time of visit including removed sections *	above/below +1.27 0.27 new snow 1.54 above	above/below stk gone	above/below stk gone	above/below	above/below	above/below	above/below
# of whole segments above snow + remaining meters *	~~1 seg + 1 seg?~~ 0 seg + 1.27 + new snow						
*	1.27 to top of 06-1A-6						
Spring data	9m stk 6 segments 10m hole ___m below surface ___m ave.probe depth	10.5m stk 7 segments 9.5m hole 1m above surface ___m ave.probe depth	9m stk 6 segments 9.5m hole 0.5m below surface ___m ave.probe depth	10.5m stk 7 segments 12m hole 1.5m below surface ___m ave.probe depth	10.5m stk 7 segments 12m hole 1.5m below surface ___m ave.probe depth	9m stk 6 segment 9m hole 0m below surface ___m ave.probe depth	9m stk 6 seg 9m hole 0m below surface ___m ave.probe

Figure SOP 2.5. Sample fall field data sheets: upper Emmons Glacier 2006

SOP 3. Snow Density Determination with Snow Core

Version 1/24/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures

Overview and Explanation

A second key component of winter balance and meeting goal 1 of this protocol is measurement of snow density. Due to the large elevation difference on both glaciers and timing of visits, snow density on each glacier is measured at several locations and at several times during the season. See SOP 1 (Field Season Time Line, Preparations, and Procedures) for visit dates and locations. If time is limited snow density is measured at the ablation stake location which is closest to the mid-point altitude of each glacier. Bulk density of the entire recovered column of snow is simply determined by dividing the mass of the snow column by the calculated volume. If one measurement is made at the midpoint elevation of the glacier this value is assumed to be the average for the entire glacier. If the densities are measured at the top and bottom stakes then the linear function of density vs. elevation between these two points is used to determine snow density at the elevation for each stake. See Figure SOP 3.1 for an example field data sheet.

From past data, average density of the spring snowpack has been ~ 0.5 g/ml at South Cascade Glacier and NOCA glaciers (Appendix L: Glacier Snow Densities). Based on this data, when not measured directly, $\rho = 0.5$ g/ml $\pm$ 0.03 is assumed for spring snow at all glaciers.

The snow core also serves as a tool for finding the previous year's summer surface. Probing the snow depth at higher elevations on each glacier have commonly proven unreliable in the spring when the snowpack is still cold for probing and winter ice layers prevail. In the fall before snow starts to fall, sediment is scattered on the glacier surface in a three by three meter area at one or two location on the glacier. Once the column of snow is recovered in the snow core, the sediment will provide a definitive visual check of the summer surface level (see SOP 1 for timing and locations).

Procedures

Two different core models are used to find snow density. The detailed procedures for proper use of the snow cores provided by both manufactures, Taylor Scientific Engineering, Inc. and Kovacs, are in Figures SOP 3.2 and SOP 3.3. The only modification we have made to this procedure is the way in which the weight of the snow is measured:

1. The core is carefully emptied into the trough and its length measured.

2. Instead of measuring the weight of the entire core in the trough we empty the contents into a nylon stuff sack and weigh this.

3. Push number, snow depth (at the bottom of each push), core length and weight are measured in the field. Upon return to the office volume, density, and water equivalent can be calculated in a Microsoft Excel Worksheet. A completed standardized data sheet with corresponding calculations is included in Figure SOP 3.1.

If the previous summer surface is difficult to detect by probing, then the snow core can be used to find the depth of the summer surface, usually a dirty surface. At higher elevations, near stake 1 and 2 on both glaciers, locate the center point of the sediment surface marker by GPS and core until the distinct sediment layer is observed. Exact GPS coordinates change from year to year and will be noted on the previous year's "fall" data sheet. If the dirty layer cannot be detected, look for a change in snow densities and snow crystals and the presence of a hoar layer. There is sufficient space on the field data sheet for these notes. If coring is abandoned without retrieving a full depth core there are three options to choose from:

1. If cores were made at other locations use these other cores to make a density gradient curve.

2. If only one core was taken and was not at the glacier midpoint, use a density of 0.5 g/ml.

3. For the surface sediment marker; make a note to return in the summer or fall to locate.

Snow Core Notes

Glacier:	North Klawatti	Location:	Above and north of Stake1
Date:	5/19/2003	Elevation:	7700 ft
Initials:	RB, JP, & AR		2348 m
	Depth of Pit (m):	na	
	Probe Depth at Site (m):	5.76	
Core diameter = 0.060 m	Core Area= 0.002826	m^2	Density of Water = 1000 kg/m3

Core Push	Snow Depth (m)	A Core Length from Snow Depth (m)	**B** Measured Core Length (m)	Core Weight (kg)	C Core Volume (m3)	D (=B/C) Density (kg/m3)	E (=D/1000) Density (Fraction of Water)	(A*E) Water Equivalent (m)	Remarks
1	1.55	1.55	1.45	1.75	0.00410	427	0.43	0.66	
2	3.05	1.5	--	1.90	0.00424	448	0.45	0.67	
3	4.08	1.03	--	1.45	0.00291	498	0.50	0.51	
4	4.67	0.59	--	0.80	0.00167	480	0.48	0.28	
5	5.09	0.42	--	0.65	0.00119	548	0.55	0.23	
6	5.71	0.62	--	1.00	0.00175	571	0.57	0.35	
	Total Core:		5.71	7.55	0.01614	468	0.47	2.67	Total Water Equivalent (m)
								679	Total Water Equivalent (inches)

Figure SOP 3.1. Sample snow core field data sheet.

HYDRO-TECH

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Mar 88

INSTRUCTIONS FOR SNOW CORER

This equipment is used to obtain snow cores, and is an improved version of a unit I've used for years in all kinds of snow to depths of 30 ft. The tube and cutter are the same - the improvements are in the quick-disconnects and in the weighing scale.

Components are as follows:
- Core Tube, with quick-disconnect top end for core removal
- Scale and cradle for snow water equivalent
- Quick-disconnect T-handle and extension tubes
- Trough for core examination
- Pusher for core removal if necessary
- Digger for removing frozen or stuck core from tube
- Ruler, spatula, notebook
- All contained in sacks in a carrying case.

Specifications

Core Tube $2\frac{1}{2}$" dia by .035" wall, stainless steel, 5 ft long, waxed inside, cutter on the ID, quick release top end for core removal. Same unit for both English and Metric sets.

Core Dia 2.36 in = 6.0 cm

Core Area 4.37 in^2 = 28.22 cm^2

Max Core Length 59" = 150 cm

SWE Measurement Range 0 to 40 inches water equivalent for English units
0 to 100 cm water equivalent for Metric units

Extensions 1" dia by .063 wall aluminum tube, with quick disconnect connections
First extension is shorter so top end starts convenient depth units:
Distance to top of first extension: (from cutter end of core tube)
English units: 10 ft.
Metric units: 3 m.
Distance to top of subsequent extensions:
English units: 5 ft.
Metric units: 1.5 m.
The ruler has both inch and cm scales and is used with the extensions to get core depth.
Aluminum parts are black anodized.

Accessories Core trough, core pusher, digger, ruler, spatula, notebook.

Case Above all contained (with extensions to 30 ft) in a case 5"X 7" X 71" weighing 30 lbs.

Instructions

Quick-Disconnects

To pop apart, grab the knurled collar, pull up and rotate CCW. To connect (handle and extensions) start pins in slot, push tube or handle to bottom and twist CW - collar pops in slot to lock.

For the core tube top end - Grab the knurled collar, pull up and rotate 45°

Figure SOP 3.2. Taylor Scientific Engineering, Inc. snow core directions.

2

CCW as for extensions and handle. Top end will pop off. To reinstall: Set the top end carefully in place and rotate until the small dowel pin drops into its slot, then rotate the collar 45° CW and let the spring push the collar all the way down. This drives the 4 pins out to hold the tube. Keep snow out from under the collar during this operation so it will lock securely.

Be careful with the core tube top end so pins extend and retract smoothly. If you have any difficulty with this let me know.

Following are some "how-to" tips on taking snow cores with this equipment:

__To take core:__

Install top end and handle

Hold tube vertically - a small carpenters level can be used.

Push tube down smoothly, rocking handle back and forth a little. If you hit an ice layer, turn CW to cut through. Don't lift tube until you're as deep as you want to go. Near the surface keep the twisting to a minimum to keep core intact. In new snow you should be able to nearly fill the tube.

Before retrieving the tube let it set still for a few seconds. This allows the core to bond a bit inside the tube, especially on the upper inside edge of the cutter. Now take the handles and give a quick little upward jerk of a couple inches. You're using suction to help break off the core. (The core is a piston - the check valves in the top end let air out during penetration, then close during the little jerk to help break it off.) If you practice a bit you'll see it's quite easy, and works nearly all the time.

Bring the tube to the surface.(If the core did not come with the tube, go down, take a few more inches and repeat the above procedure.)

__Remove the top end__, and center the tube in the cradle and weigh with the scale. The number is inches of snow water equivalent.

Remove the core through the top end. Usually it will slide out easily. If you Nudge it with the pusher want to keep it, lay the tube in the trough, tip up a bit, and let the core slide out of the tube as you pull it away from the closed end of the trough. Usually the core will slide out intact. It can then be weighed separately, or studied for stratigraphy, crystal size and shapes, sectioned to get densities of layers, liquid water content, dye tracing, etc.

Sometimes a wet snow core will jam in the tube. __Don't bang the tube__. If the sun is out let the tube warm a bit, or use your bare hands. Use the pusher, but don't "pack" the core - it just makes it worse. The digger is used like a brace and bit to break up the core if nothing else works. Another trick is to carry along a propane torch to __warm__ the tube - but take it easy as the inside of the tube is waxed. Resist the temptation to bang the tube with anything hard - the dents will plague you forever.

If you're interested in densities, measure the length of core in the trough. Also measure the depth of the hole. The difference is the compaction of the snow during the coring.

To continue, replace the top end of the tube, and attach the __shortest__ extension, the one with the yellow tape. (This makes the upper end 10 ft, and each subsequent extension adds 5 ft, so you can get depths easily.) Install the handle, and lower the tube slowly and carefully into the hole with a minimum of scraping of the sides.

Repeat the same coring procedure as for the first section, but the snow will be harder, and you'll have to push a little harder as you do the rocking motion. Keep the extension centered in the hole as much as possible. Use the same pause, and little jerk to break off the core.

__As you retrieve the tube, keep scraping to a minimum__. The top end of the core tube is designed to bring the scrapings up instead of jamming them against the wall. This is especially important in deep snow. The more snow dropped down the hole on the tube the higher the probability of getting stuck, especially if the snow is wet. You'll then have to dig, or if impractical, then you can pour hot water down the hollow extension tubes.

Figure SOP 3.2. Taylor Scientific Engineering, Inc. snow core directions (continued).

3

You can save yourself a lot of grief by being very careful during retrieval in deep snow. Keep the extensions centered and lift the tube smoothly. Have a helper reach over your shoulder and pop off a couple extensions so tube doesn't get forced off center.

When going back down keep the tube centered and square as best you can. Your helper can pop on the extensions. Your next core will have some scrapings on the top - usually not enough to worry about. If necessary, you can usually sort this out in the trough as you look at the core.

If you're interested in the depth hoar at the base of the snow-pack, core into the dirt a couple inches. This makes a plug to hold in the hoar crystals. If you're interested in snow creep and glide, the holes can be filled with sawdust, then dug out in cross-section later. Markers can also be placed in the sawdust and get settlement as well.

Please pass along any comments, suggestions, etc. that you have on this equipment. There are a lot of features here which are the result of a lot of experience in sampling snow, but there is always something to learn, and some improvement that can be made in equipment usefulness or reliability. I'm very interested in your experience and application, so just let me know.

Phil Taylor

Figure SOP 3.2. Taylor Scientific Engineering, Inc. snow core directions (continued).

Kovacs MECHANICAL ICE DRILLING AND CORING EQUIPMENT

Three coring systems are manufactured that can retrieve an ice core through ice and firn easily. The proprietary core barrel is a light weight filament wound composite tube about 1.15 m long with plastic flighting. The cutting shoe is aluminum and the cutting teeth are heat treated steel. Stainless steel dogs, located in the shoe, help to capture the core at the time of extraction from the ice. The drive head (patent pending) is stainless steel and aluminum and allows for extremely fast coupling and uncoupling from the core barrel. Three stainless steel 1 m long extensions or lowering rods are also a part of the system. Additional extensions can be purchased. A tee handle is included for turning the core barrel by hand and an adapter is provided for turning the system using a 1/2 inch (1.5 cm) electric drill operating at 400 rpm or less These coring systems are a highly up-graded version of the well known and regarded coring system used by researchers at the Cold Regions Research and Engineering Laboratory. These systems are furnished with a robust shipping case with lift handle.

Mark II

Mark II Coring system will retrieve a 9 cm diameter core.

Our core barrel systems are fabricated upon receipt of an order from our customer. Two (2) months plus shipping time for delivery of the MARK 2 and 3 systems is required. The MARK 5 coring system requires (3) months lead time for fabrication.

Our ice auger flights are 5 cm in diameter, 1 m long and join one to another via a patented push-button connector, which allows for quick connection of one auger section to another. This method of assembly means that there are no pins or connector bolts to lose or care for and no bolts on which clothing can snag. An adapter is required for turning the augers using a 1/2 inch (1.5 cm) electric drill. We strongly recommend powering our flights with a heavy duty electric drill rated at 550 to 650 RPM. Drilling rates of 1 m in 15 seconds in ice are achievable with this mode of power drive. If one wishes to turn the augers by hand, a hand brace is available. The 5.1 cm wide ice cutting bits are interchangeable with any auger flight. The bits can be sharpened by hand filing

We have drilled 24 m through a multiyear pressure ridge and 23 m through a grounded ice island (tabular ice berg) with these augers using a 1/2 inch (1.5 cm) electric drill to power the flights.

Our equipment is being used by the Australian, German, Greenpeace, New Zealand, UK and U.S. Antarctic research programs, as well as, by almost every university, private and government research group working in the Arctic

Figure SOP 3.3. Kovacs snow core directions.

SOP 4. Operation of the Steam Drills

Version 1/24/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures

Overview and Explanation

Summer balance at the index glaciers is a measurable objective for goal 1, and is measured between late April and late Early October annually. Melt is measured against vertical ablation stakes drilled 7–10 m into each glacier. Stake locations, lengths, and depths for each glacier are summarized in Tables SOP 1.2–3 in SOP 1 (Field Season Time Line, Preparations, and Procedures). Approximate stake locations can be viewed in map view in Figures SOP 1.2–3 in SOP 1 or in Figures 3–4 in the Narrative. We use two models of steam drill for drilling holes in which to place the ablation stakes: Heucke Ice Drill and Taylor Scientific Engineering, Inc. Steam drill. The Heucke Ice Drill is the preferred model for our use because of its lighter weight and deeper drilling capability. There are times when both drills are needed simultaneously and the Taylor steam drill is maintained and used regularly as well. The safety instructions, operation manual, technical information, and field packaging information for the Heucke drill are included in Figures SOP 4.1–4. Read this to become familiar with the first use of the drill! The list below outlines how the Taylor drill is different in characteristics and procedures. Bear in mind the list of "Mandatory Safety Measures" for the Heucke drill is applicable to both drills.

Procedures: Taylor Scientific Engineering, Inc. Steam Drill

1. The Taylor drill has a large screw on plate that is the cover for the top of the boiler. Water is added through this opening. Take great care in screwing this plate down with the Allen wrench that should be attached with a cord to the drill frame.
    a. Make sure that the rubber o-ring is in place on the top of the boiler.
    b. Evenly seat the plate on the boiler, and line up the pin on the boiler with the hole on the plate.
    c. Tighten the plate down by tightening the screws in a star pattern as if tightening the nuts on a car tire.
    d. When using either drill in helicopter operations fill the drill with hot water before the flight.
    e. Snow can be placed and melted directly in the boiler of the Taylor drill.

2. The Taylor drill uses propane only. The flow regulator and dial on the hose that attaches to the propane tank should be adjusted so that the flow is 5 psi.

3. Unlike the Heucke drill the Taylor drill has a water level gauge. This is the glass tube that is attached to the side of the boiler.
    a. Operate the drill with water levels only between the white tape markings.
    b. Be sure to turn the burner off and relieve the pressure before removing the top plate and refilling the drill with snow or water.

4. On the top and bottom of the water gauge are two valves. The upper is to relieve the steam pressure in the drill without opening the hose valve. The lower is to empty water from the boiler after the burner has been turned off.

5. The pressure indicator dial is located on the boiler top plate.
    <u>Do not let pressure exceed 30 psi!</u>, which is the relief valve setting. If the relief valves blow they can be reseated by lightly tapping them down.

6. Lighting the propane burner. Be Careful!
    a. Wear gloves and reach under the boiler with the long butane lighter. Click the lighter while slowly opening the propane valve.
    b. When lighting <u>DO NOT</u> put your face down near this operation. Look first to see where the top of the burner is so that you can aim the lighter to this location when reaching underneath.
    c. After reaching a certain age the piezoelectric lighter on the Heucke drill does not seem to work. When this occurs use the above lighting procedure for the Heucke drill.

HEUCKE ICE DRILL

MANDATORY SAFETY MEASURES

1. Changing gas containers and heating the equipment may be done only outdoors.

2. When connecting up gas containers always follow the manufacturer's instructions.

3. Please use the furnished pliers to screw the gas hose on tightly. Bear in mind that some of the hoses are equipped with a left-hand thread. To ensure smooth handling put a drop of oil on it once in a while. The bore hoses however should always be screwed on by hand only.

4. Be aware that your face is not too close to the exhaust passage when igniting the burner.

5. Always wear **waterproof gloves** when handling the heated equipment.

6. The cap on the boiler also serves as a safety valve and must not be changed or damaged in any way.
In case the nozzle in the drill tip is clogged or the red steam valve is closed, the steam escapes through an opening underneath the filler cap when pressure rises above 2 bar. **Keep at a safe distance to avoid scalding.**
A second safety valve is placed in the middle of the boiler. It opens at 2.5 bar in case the safety valve in the boiler cap should fail.

7. Never open the filler cap as long as the boiler is under pressure. First release possible residues of steam by carefully opening the red steam valve after the rubber hose has been removed. Do not rely solely on the manometer. It could be clogged by ice.

8. Never leave the equipment unattended.

9. Before carrying the unit on the back, the heat must be turned off and the circular bowl must be emptied.

10. Do not step on the hose and never bend it excessively. The minimum radius is 15 cm (6 inches). **Take off your crampons!**

11. **Important**: Never allow the water level in the boiler to drop to zero. Accidental heating of an empty boiler will cause its destruction within a very short time. If pressure quickly falls to zero this is a sure sign of lack of water. Shut off the gas immediately ! Refer to no. 9 of the operating instructions.

Duration of operation with one boiler full (4.5 l.): about 45 to 60 minutes!

Please keep in mind:
A portable ice drill light enough to be carried
on your back cannot possibly made of cast iron.
It is necessarily somewhat fragile and must be handled with care.

Figure SOP 4.1. Safety precautions for using the Heucke Ice Drill.

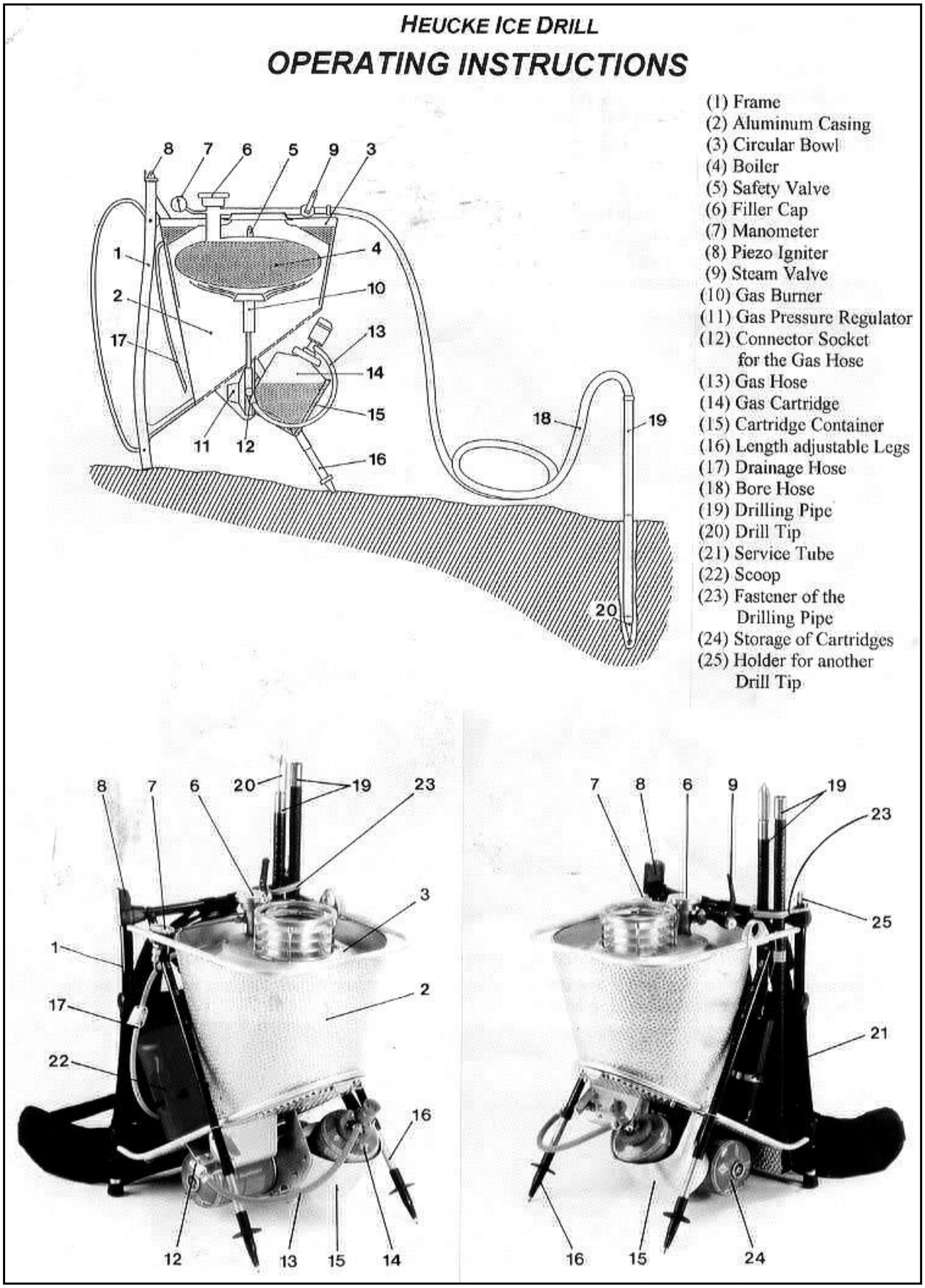
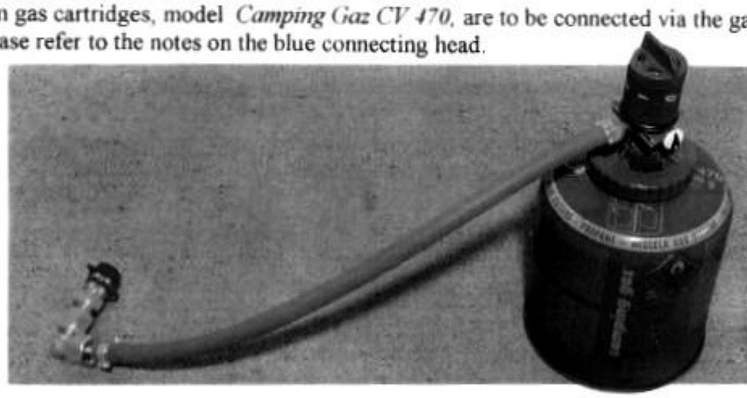


Figure SOP 4.2. Operating instructions for using the Heucke Ice Drill.

1. Putting up the Drill.
The drilling device must be set up in such a way that the circular bowl (3) is horizontal. You can pull out the two forelegs (16) for adjusting the device to the terrain. For loosening a leg please turn the lower end to the left and for fixing it in the correct position turn to the right. The position can be easily controlled by means of a little water in the circular bowl. The wind should come from the side with the carrying belts.

2. Connecting Gas Containers.
a) Propane cylinders of any size (including refillable minimum content bottles with 425 g) as well as butane cylinders containing 2 or 3 kg of gas *(Camping Gaz bottles 904 and 907)* are to be connected by means of the gas connecting hose **A**, if necessary with the appropriate adapter piece for the gas bottle. ~~A selection of 6 adapter pieces is added, including a *Camping Gaz Bottle Security Valve*~~

b) 450 gram gas cartridges, model *Camping Gaz CV 470*, are to be connected via the gas connecting hose **B.** Please refer to the notes on the blue connecting head.



c) 450 gram gas cartridges with threaded joint (M 10x1) of the makes *Coleman, Primus, Markill, Epigas, Husch, Kovea, Taymar, Parasene* and others with the same dimensions are connected to the drill by means of the gas connecting hose **C**.

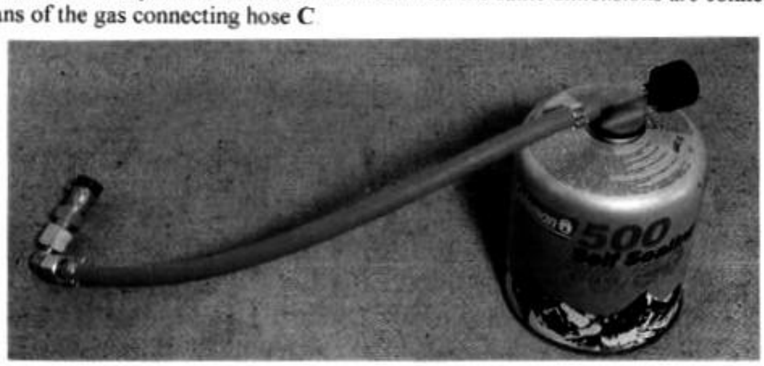
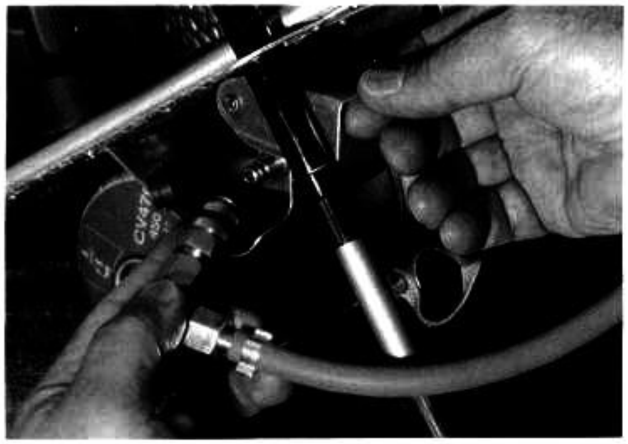


Figure SOP 4.2. Operating instructions for using the Heucke Ice Drill (continued).

d) Tapping cartridges with 190 grams (e.g. *Camping Gaz C 206)* can only be connected by making use of special accessories obtainable from the vendors.

After the gas hose has been connected to the gas container you must slip it on the connector socket (12) on the left-hand side of the drill (after taking off the red protective cap).



Remark: When running the drill with propane gas cylinders we recommend you to take **at least one** additional 450 gram cartridge (and the appropriate connecting hose) as a **"stand-by tank"** with you. Thus, you don't need to take a second gas cylinder with you and moreover you are always able to consume the total contents of the cylinder. One cartridge allows about 65 minutes of heating time.

3. Filling the Boiler.

Open the filler cap (6) by pressing and turning it to the left and make use of the scoop (22) to fill about **4.5 liters** (max. 4.7 liters) of water into the boiler. In addition give 1 liter into the circular bowl. Close the filler cap tightly and open the red steam valve (9) (faucet in horizontal position).

If liquid water cannot be expected to be found at the bore place, it is recommended to fill the boiler at the last water filling opportunity in order to be able on the spot to melt snow in the circular bowl during the drilling works. An additional container would be useful for having melting water on stock.

4. Igniting the Gas Burner.

Open the gas supply and ignite the burner by pressing the red key of the piezo-igniter (8) (at the left-hand upper side of the frame). If this doesn't work, you can ignite the burner by means of matches that are added in the service tube (21). **(Attention: put on gloves! Be aware that your face is not too close to the exhaust passage.)**

5. Connecting the Bore Hose.

The bore hose (18) can be connected during the water heats up. The upper end of the hose shall be screwed by hand tightly on the steam valve, thereby taking account of the depth marker. Please do not use any tool! The two-part drilling pipe (19) shall be screwed at the other end of the hose: first the upper part and then the lower part with the drill tip. Mistakes cannot occur. The gaskets are all tightly built in and cannot get lost.

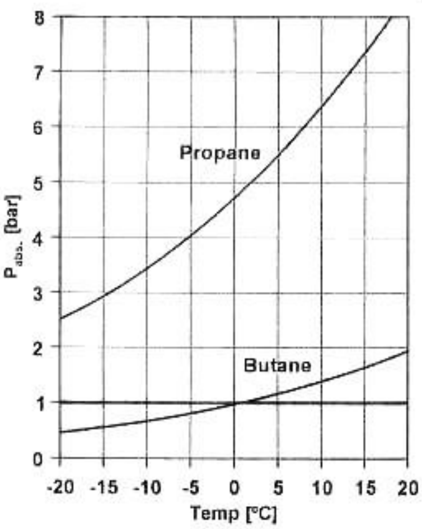
Remark: In case of higher drilling depths (from about 12 m) it is unfavorable, due to considerable pressure and temperature losses, to start with two bore hoses coupled together. We recommend you to drill at first with **one** hose only (the long one) and connect later, if necessary, the second one for extension. For that purpose, please **put on gloves,** close the red steam valve, and screw off the first hose from the device. Then, the second hose shall be mounted in betweeen by means of the coupling nipple (which can be found in the black service tube). Please take the depth markers into account. To resume drilling, open the steam valve again.

Figure SOP 4.2. Operating instructions for using the Heucke Ice Drill (continued).

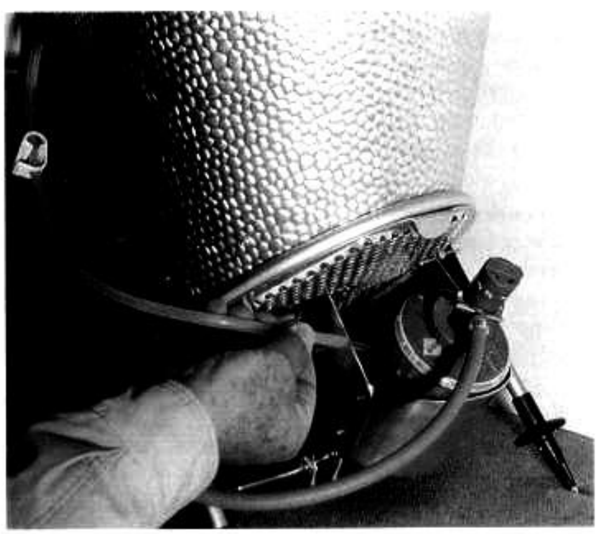
6. Starting the Drilling Process.
Once steam is discharged from the drill tip, please **close** the red steam valve (vertical position) and observe the manometer (7) until the pressure has increased to about 1 bar. Then the steam valve can be re-opened and the drilling be started. **Attention: turn the steam valve slowly!**
Place the drilling pipe vertically on the ice and keep it in good direction until a vertical bore is guaranteed. The weight of the drilling pipe is sufficient for an optimum drilling progress.

7. Making use of the Circular Bowl.
During the heating operation you can use the circular bowl for melting snow and preheating water. You can lead the warm water via the small drainage hose with plastic clip (17) into the red scoop (22) or into another storage container to use it for the next boiler filling. This saves time and energy. You can use it also for warming up gas containers see paragraph 8) or for preparing a beverage or heating up sausages.

8. Bringing Butane Containers to the Right Temperature.
When using **butane gas** for operating the drill (all 450 gram cartridges as well as the blue *Camping Gaz* bottles), you must keep the containers at the right temperature for holding the gas pressure. At low surrounding temperatures and by drawing gas, the gas pressure of butane decreases strongly with the consequence of a considerable decrease in the burner performance. See the diagram



Gas pressure curves of propane and butane



In order to avoid this effect, cartridges are brought to temperature by filling warm water (20 to 40°C, 70 to 100°F) into the cartridge container (15). You can draw warm water, e.g., from the circular bowl via the small drainage hose (illustration at right) or it can come from a thermos flask you have taken with you.

Figure SOP 4.2. Operating instructions for using the Heucke Ice Drill (continued).

If the water has cooled down, this procedure has to be repeated, or the water must be re-heated by means of a little of steam from the drill tip.
For butane gas **bottles** we recommend to take a suitable plastics bowl with you for being able to make a warm water bath.

Do not heat gas cartridges above 50°C (120°F) !
Danger of explosion !

9. Water Level in the Boiler.
The boiler has a movable hemisphere built in that is moved up and down by the steam bubbles during heating operation. Once the water level has decreased to 0.3 liters, the hemisphere will knock rhythmically against the bottom of the boiler, a rattling noise will be perceived. At about 0.1 liters of water level the generated bubbles are not anymore sufficient to raise the hemisphere, and the rattling ceases. This is a clear signal for a lack of water and means: **turn the heating off!**

10. Refilling the Boiler.
Before refilling the boiler you must first close the red steam valve, unscrew and remove the bore hose and let the remaining steam escape by **slowly** opening the steam valve. When the boiler has lost its pressure –**only then** – are you allowed to open the cap and fill up new water.
It makes sense to refill the boiler each time you start a new drill hole. One filling of the boiler is enough for 45 to 60 minutes of drilling time.

11. End of the Drilling.
When the intended depth of the borehole is reached, close the gas supply and wait for about ½ minute before pulling the bore hose out of the hole.

12. Transport of the Device.
Before transporting the drilling device to the next bore location it is imperative that you empty the circular bowl and turn the heating off.

13. Ending the Drilling Operation.
After removing the connection of the gas hose from the drill do not forget to close the connector socket with the red protection cap.
In cases of danger of frost you should empty the boiler by turning the drill upside down, and open the steam valve. Small amounts of remaining water are harmless. To avoid ice blockage in the bore hose be careful to empty it in advance.

Bore hose connections: **please fix them always by hand.**	**Gas hose connections:** **Please fix them always with the aid of the pliers (service tube).**

Please keep in mind:
An ice drill that should be easily portable on your back
cannot be made of cast iron!
Therefore: be careful with the device!

Figure SOP 4.2. Operating instructions for using the Heucke Ice Drill (continued).

HEUCKE ICE DRILL

TECHNICAL DATA

No. 1102

Boiler: Volume	5 litres, fill in 4.5 litres
Operating temperature	115 to 130 ° C
Operating pressure	0.8 to 1.7 bar
Safety valve in the filler cap opens at	1.8 bar
Second safety valve	2.5 bar

Heating: 1 gas burner, power 4.4 kW, working pressure 80 mbar

Fuel: Propane or butane

Gas consumption: appr. 370 grams / hour

Gas consumption for every drilling meter in ice (to assess the needed supply):
15 to 20 grams.*

Usable gas containers:
450 gram cartridges *Camping Gaz CV 470*.
450 gram cartridges with threaded joint (M10x1), brand names: *Primus, Coleman Markill, Husch, Epigas, Taymar, Kovea, Parasene* and others with the same dimensions.
Gas bottles.

Time needed to heat up from 0 to 100°C with full boiler:
12 to 15 minutes.

Operation time with one full boiler:
45 to 60 minutes

Drilling speed (when water is boiling):
11 to 15 minutes to drill a hole of 6 meters into ice,*
21 to 30 minutes to drill a hole of 12 meters into ice.*

Hole diameter (in ice): about 30 to 35 mm, at least 25mm*,
35 to 42 mm with the large drill tip.

Maximum drilling depth:
length of the hose plus 0.7 meters .
Maximum possible depth with this unit: 13 meters.

Dimensions and weights:

Ice drill (WxHxD)	39x59x40 cm	8.7 kg
Drilling pipe with drill tip *	L = 143 cm	1.5 kg
Rubber hose, depending on the length		0.4 kg/m
1 cartridge *Camping Gaz CV 470* or *Primus*	full / empty	0.65 / 0.20 kg
Transport box (W/H/D)	74x43x53 cm	7.7 kg

Total weight of the box containing the complete drilling equipment
(without gas containers): 25.3 kg

Filler cap replacement: *MERCEDES-BENZ No. 123.501.02.15*

* = with small drill tip (∅21 mm)

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November 2002

Figure SOP 4.3. Technical information for the Heucke Ice Drill.

Figure SOP 4.4. Showing the correct way to package the Heucke Ice Drill for field transport.

SOP 5. Balance Calculations

Version 6/9/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures

Overview and Explanation

This SOP describes how stake balances, mass balances, and area averaged balances are calculated from field data, weather data, and mapping products. Measurable variables include winter, summer and net balance. Values are determined from seasonal stake data and ten year glacier mapping information.

As we develop a relational database in Access, we will continue to use Microsoft Excel workbook templates for balance calculations for each glacier each year. Each workbook has a set of linked spreadsheets for data reduction from points to area-averaged balance values (winter, summer, and net), uncertainty, and summary of measurements and results. The workbooks are filled out progressively and calculations are done as data is collected throughout the field season. This SOP provides an overview of worksheet operations but it is mandatory to take some time with and manipulate the Excel Workbook to learn how worksheets and cells are linked in calculations. Selected Emmons Glacier 2006 worksheets are included below in Figures SOP 5.1–6 as examples.

A relational Access database will replace current Excel procedures in 2008. This is then linked to applications for data reduction from points to area averaged balance values (winter, summer, and net), uncertainty, and summary of measurements and results. Once the database is finalized, new procedures will be written and substituted for current ones. Both data reduction methods will be used simultaneously for 2 years to ensure the database is working properly.

The raw data are entered progressively and preliminary calculations are conducted as data is collected throughout the field season. The data reduction methods outlined here are somewhat unique to this program, however, they follow the general principles from Ostrem and Brugman (1991) and Krimmel (1994–2001). Summaries of their methods are described in the protocol narrative as a basis for the description of our methods.

Emmons Glacier 2006

Stake and Probe Comparisons

	Station:	1a	1	2	3	4	4A	5
	Elevation (m):	3111	2887	2806	1970	1700	1705	1570
5/5/2006	Spring Probe Depth	6.85	6.66	5.70	4.99	3.13	2.86	2.03
7/3/2006	Summer Probe Depth	4.65	4.62	4.09	0.67	0.00	0.00	0.00
10/12/2006	Fall Probe Depth	NA	NA	NA	NA	0.00	0.00	0.00

Summer Comparison

Ablation from Probe	2.20	2.04	1.61	4.32			
Ablation from Stakes	NA	2.20	2.25	4.05	4.84	3.75	2.26
Difference Stake-Probe	NA	-0.16	-0.64	0.27	na	na	na

Fall Comparison

Ablation from Probe	#VALUE!	#VALUE!	#VALUE!	#VALUE!	3.13		na
Ablation from Stakes	3.82	NA	NA	10.59	12.88	6.26	4.93
Difference Stake-Probe	#VALUE!	#VALUE!	#VALUE!	#VALUE!	-9.75	na	na

Fall-Summer Comparison

Ablation from Probe	#VALUE!	#VALUE!	#VALUE!	4.05	#VALUE!		na
Ablation from Stakes	0.00	0.00	0.00	0.00	0.00		0.00
Difference Stake-Probe	#VALUE!	#VALUE!	#VALUE!	4.05	#VALUE!		na

Figure SOP 5.1. Stake and Probe comparison worksheet for Emmons Glacier 2006.

Spring Visit Probe Depth Report, Emmons Glacier

BY: **2006**

Summary 5/5/2006

Stake	N	ave	Min	Max	Difference	Std Dev.	Variance
1a	9	6.91	6.66	7.45	0.79	0.26	0.07
1	7	6.16	5.20	6.90	1.70	0.60	0.36
2	6	5.53	4.87	6.05	1.18	0.47	0.23
3	9	5.04	4.70	5.70	1.00	0.35	0.12
4	11	3.90	2.72	5.44	2.72	0.99	0.99
4A	11	2.86	0.82	4.11	3.29	0.98	0.96
5	11	2.03	1.09	4.11	3.02	0.67	0.45
				Ave.	1.96	0.62	

stk	values not used
1	9.5
2	7

	Depth			Depth	
	6.85	stk		4.99	stk
	6.67	S		4.7	S
	7.45			4.85	
1a	7.15		3	5.53	
	7.03			5.7	
	6.9				
	6.85	N		5.05	N
	6.66			4.77	
	6.66			5	
				4.79	

	Depth			Depth	
	6.66	stk		3.13	stk
	6.24	S		3.2	S
	5.81			2.72	
	5.75			2.8	
1	6.53		4	3.65	
	6.9			4.45	
	5.2	N		3.26	N
				4.13	
				4.8	
				5.37	
				5.44	

	Depth			Depth			Depth	
	5.7	stk		3.56	stk		1.13	stk
	6.05	S		3.05	S		1.17	S
	4.87			3.55			2.16	
	5			2.87			3.1	
2	5.76		4a	0.82		5	1.09	
	5.77			1.41			2.38	
		N		3.56	N		2.34	N
				2.96			1.72	
				2.4			2.18	
				3.19			2.69	
				4.11			2.37	

Figure SOP 5.2. Stake and Probe comparison worksheet for Emmons Glacier 2006 (spring data only).

	Glacier:	Emmons							
	Balance Year:	2006		Area (m2):	11,592,123				bs freezing point
	Station:	1a	1	2	3	4	4A	5	
	Elevation (ft):	10200	9469	9204	6461	5576			
	Elevation (m):	3111	2887	2806	1970	1700	1719	1570	3839.6
	Firn 2or 3 years old (m w.e.)	0	1.27	0.84	0	0	0	0	
	Firn from previous year (snow depth, meters)	0	3.07	1.53	0	0	0	0	
	2003 end of season stake height	0			0	0.00	0.00	0	
	Winter Balance (4/5/06-5/2/06)	5/5/2006	5/5/2006	5/6/2006	4/5/2006	4/5/2006	4/5/2006	4/5/2006	
	Snow Depth (m)	6.91	6.16	5.53	5.04	3.90	2.85	2.03	
	Density (g/ml)	0.43	0.43	0.43	0.43	0.43	0.43	0.37	
bw	Winter Balance (m w.e.)	2.97	2.65	2.38	2.17	1.68	1.23	0.75	
	Stake Length (m)	9	9	9	10.5	10.50		NA	
	Surface Characteristics	snow	snow	snow	snow	snow	snow	snow	
	Stake Height (m)	-2.28	-0.55	-0.7	-1.41	-1.52	NA	NA	
	Mid Season Measurements (5/31/06)						stk placed	stk placed	
	Snow Depth (m)						1.13	1.41	
	Density (g/ml)								
	Mid-season Water Equivalent (m)								
	Mid-season Stake Ht. (m)								
	Original Stake Height (m)								
	Mid-season snow Melt (m)						1.72	0.62	
	Surface Characteristics						snow	snow	
	Debris Thickness								
	Stake Length						6m	6m	
	2005 stake heights								
	Melt since fall 2005								
	Mid Season Measurements (7/4/06)								
	Snow Depth (m)	4.66	4.58	4.41	0.65	0.00	0.00	0	
	Density (g/ml)							0	
	Mid-season Water Equivalent (m)							0	
	Mid-season Stake Ht. (m)	NA	1.65	1.55	2.64	3.32	2.47	2.12	
	Original Stake Height (m) ()	-2.28	-0.55	-0.7	-1.41	-1.52	1.12	1.15	
	Mid-season stk Melt (m)	NA	2.2	2.25	4.05	4.84	1.35	0.97	
	Mid-season total Melt (m)	NA	2.2	2.25	4.05	6.00	3.74	1.59	
	Surface Characteristics				ice/snow	ice	debris	debris	
	Debris Thickness						0.22	0.17	
	Mid Season Melt Standard Error stks 1-4								
	2005 stake melt					1.30	0.89		
	Ice Melt between fall '05 and spring '06.					1.16	0.67		
	Mid Season Measurements (8/11/06)								
	Mid-season Stake Ht. (m)						2.80	3.12	
	Original Stake Height (m) ()						1.12	1.15	
	Mid-season stk Melt (m)						1.68	1.97	
	Mid-season Melt (m)						4.07	2.59	
	Surface Characteristics						debris	debris	
	Debris Thickness						0.20	0.17	
	Mid Season Melt Standard Error stks 1-4								
	End Season Measurements (9/22/06)	9/22/2006	9/22/2006	9/22/2006	10/10/2006	10/10/2006	10/10/2006	10/10/2006	
	End Stake Height (m)	1.54	NA	NA	9.18	10.20	NA	4.79	
	Original Stake Height (m)	-2.28	-0.55	-0.7	-1.41	-1.52	1.12	1.15	
	New Stake Melt	3.82	NA	NA	10.59	11.72	NA	3.64	
	Final Melt (m)	3.82	5.75	5.88	10.59	12.88	6.26	4.26	
	Surface Characteristics				ice	ice	debris	debris	
	Debris Thickness						NA	0.12	
							0.00		
	End Snow Melt (m)	3.82	5.75	5.53	5.04	3.90	2.85	2.03	
	Water Eq. Melt (m x 0.5 g/ml)	1.64	2.47	2.38	2.17	1.68	1.23	0.75	
	End 1-year Firn Melt (m)			0.35					
	Water Eq. Melt (m x 0.6 g/ml)			0.213					
	End 2-year Firn Melt (m)								
	Water Eq. Melt (m x 0.7-0.8 g/ml)								
	End Ice Melt (m)				5.55	8.98	3.41	2.23	
	Water Eq. Melt (m x 0.8-0.9 g/ml)				4.99	8.08	3.07	2.01	
bs	**Summer Balance (m w.e.)**	-1.64	-2.47	-2.59	-7.16	-9.76	-4.29	-2.76	0.0
	Remaining Snow/Firn (m)	3.09	0.41	1.18	0.0	0.0	0.0	0.0	
	Remaining 1-year old firn (m)	0.0	1.27	0.84	0.0	0.0	0.0	0.0	
bn	**Net Balance (bw) + (bs)**	1.33	0.17	-0.21	-4.99	-8.08	-3.07	-2.01	

Figure SOP 5.3. Example of stake data worksheet for Emmons Glacier, 2006.

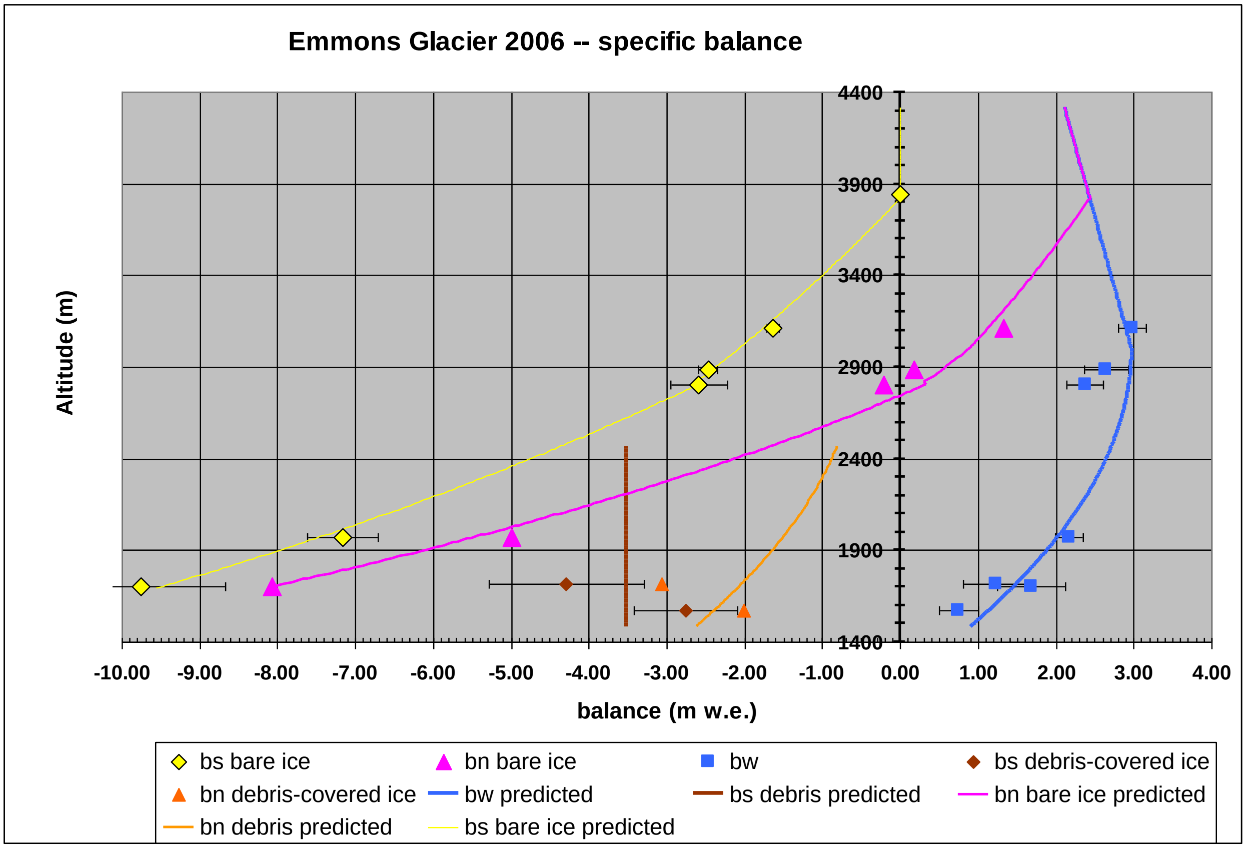


Figure SOP 5.4. Specific balance vs. altitude for Emmons Glacier, 2006

Emmons Glacier **2006**

Summary Report

Calculations:

Done by: JMW 5/30/06- Updated 3/27/2007JMW, updated 4/18/2007

Winter bw = -9E-07x2 + 0.0054x - 5.1249 R2 = 0.8694

Stakes 1A, 1, and 2 all have two or three trackable (spring and summer) layers and are difficult to determine what layer is bw (see field sheets). Layers ranged from ~4.5m to ~9m. Chose probe data around 5m, accumulation correlated nicely with increase in elevation when compared to lower stakes. Still figuring out how to account for bw for upper mountain with no data points. The full depth snow pack at stk 5 fell within a day of our visit and had a very low density, 0.37. Couldn't plot stk 3, density 0.43, and stk5 density data together as density would increase with elevation. Without additional locations of density taken, density 0.43 is used for the entire glacier except for stk 5 which uses 0.37. Even though there were two density measurements taken on glacier, they were not correlated, hence in the uncertainty report, the variance of density only takes into account one measurement (see uncertainty worksheet).

bw >3000m = -9E-07x2 + 0.0054x - 5.1249 R2 = 0.8694

bw ≥3000m inserted 2004 slope with adjustment made to max depth=4.93679+(-0.000653571*C168) See below

2004 slope: y=3.48679+-0.000653571x

2006 had 2.98m w.e. max accumulation at 3000m (altitude taken from trend line of lower elevation stk data)

2004 depth at 3000m was 1.53m w.e.

Max accumulation difference: 2.98m w.e. -1.53m=difference of 1.45m w.e.

Offset 3.48679m w.e. +1.45m w.e.

New 2006 equation: y=4.93679+0.000653571x

Summer

Stk 4a was not found during fall visit. Last recorded melt from stake was on 8/11/06. Final melt for 4a was taken from mid season melt ratio of stake 4a and stake 5. New 4a and 5 stakes were placed in August but origianl stakes were still in ice, so original stakes were used to calculate melt. Ice melt between fall 05 and spring 06 is added to mid season and final melt for stake 4a and 4 (Stake 5 had no melt= interesting??) Stake 1 and 2 were not found during fall visit. Mid season melt ratio was taken from stake 3 for stakes 1 and 2. Could not probe in Fall at stakes 1A, 1, or 2 due to recent rain/ freeze crust. bs was calculated using two different regression curves (see below) curve was broken into two parts at stake two (2806m).

lapse rate for

Mean July and August Longmire to Paradise lapse rate for 2006 was 5.59C/1km. Freezing level was at 3839.6m.

altitudes1700-2810m bs=13.822Ln(x) - 112.34 R2 = 0.9933

altitudes 2810 to 4320m bs= 8.602Ln(x) - 70.956 R2 = 0.9949

	Nisqually Data Summary	**2006**	
BW	Winter Mass Balance (m3 w.e.)	28,307,212	Uncertainty ±
ave bw	Average Winter Balance (m w.e.)	**2.44**	**0.53**
BS	Summer Mass Balance (m3 w.e.)	-38,424,414	
ave bs	Average Summer Balance (m w.e.)	**-3.31**	**0.73**
BN	Net Mass Balance (m3 w.e.)	-10,117,201	
ave bn	**Average Net Balance (m w.e.)**	**-0.87**	**0.91**
	Equilibrium Line Altitude,meters(curve)	**2745**	
	Equilibrium Line Altitude (map)	**NA**	
	Accumulation Area (km2)	4.60	
	Ablation Area (km2)	7.00	
	Total Area (km2)	11.59	
	Accumulation/Area Ratio	0.40	

Figure SOP 5.5 Summary report for the Emmons Glacier, 2006

EMMONS GLACIER BAND BALANCE SUMMARY AND CALCULATIONS

Total Glacier Area =	11,592,123 sq. meters	Percent Area =	100
Debris-covered area =	2,556,980 sq. meters	Percent Area =	22
Area above 3100 m =	2,449,732 sq. meters	Percent Area =	21

Total-Band Balance	BW= 28,307,212	BS= -38,424,414	BN= -10,117,201

Average balances from Altitude Band Calcs		
bw= 2.44	bs= -3.31	bn= -0.87

Winter Band Balance, **ENTIRE GLACIER** within 10-meter altitude bands.

bw <3000m = -9E-07x2 + 0.0054x - 5.1249 R2 = 0.8694

bw ≥3000m inserting 2004 slope with adjustment made to max depth and altitude=4.93679+(-0.000653571*C168)

Total Area = 11,592,123 square meters

284

Upper Limit Elevation Band (m)	z Elevation Band Midpoint (m)	Area sq m	Band specific bw	Band BW
1490	1485	7434	0.91	6761
1500	1495	7571	0.94	7091
1510	1505	7997	0.96	7706
1520	1515	9692	0.99	9599
1530	1525	17655	1.02	17956
1540	1535	22423	1.04	23398
1550	1545	20774	1.07	22223
1560	1555	20561	1.10	22533
1570	1565	22600	1.12	25353
1580	1575	28143	1.15	32295
1590	1585	32872	1.17	38562
1600	1595	31079	1.20	37248
1610	1605	24834	1.22	30388
1620	1615	32984	1.25	41186
1630	1625	45786	1.27	58310
1640	1635	49856	1.30	64723
1650	1645	53286	1.32	70480
1660	1655	79260	1.35	106761
1670	1665	73088	1.37	100211
1680	1675	58850	1.40	82098
1690	1685	59088	1.42	83833
1700	1695	93422	1.44	134749
1710	1705	112034	1.47	164217
1720	1715	87963	1.49	130977
1730	1725	76900	1.51	116276
1740	1735	87307	1.53	134007
1750	1745	65943	1.56	102712
1760	1755	59973	1.58	94762
1770	1765	55982	1.60	89705
1780	1775	76465	1.62	124221
1790	1785	81974	1.65	134969
1800	1795	85053	1.67	141893
1810	1805	91296	1.69	154278
1820	1815	89741	1.71	153574
1830	1825	92635	1.73	160494
1840	1835	104647	1.75	183509
1850	1845	102067	1.77	181116
1860	1855	88814	1.80	159438
1870	1865	68207	1.82	123843
1880	1875	65946	1.84	121080
1890	1885	59500	1.86	110444
1900	1895	55191	1.88	103548
1910	1905	50019	1.90	94835
1920	1915	48961	1.92	93789
1930	1925	48160	1.94	93191
1940	1935	44191	1.95	86362
1950	1945	39359	1.97	77670
1960	1955	30595	1.99	60953
1970	1965	34189	2.01	68755
1980	1975	37082	2.03	75258
1990	1985	32099	2.05	65735
2000	1995	28821	2.07	59546
2010	2005	41955	2.08	87437
2020	2015	43465	2.10	91360
2030	2025	34305	2.12	72711
2040	2035	29781	2.14	63642
2050	2045	33549	2.15	72274
2060	2055	31802	2.17	69055
2070	2065	30916	2.19	67652
2080	2075	32209	2.21	71022
2090	2085	31825	2.22	70703
2100	2095	35396	2.24	79215

Summer Balance: **BARE ICE** within 10-meter altitude bands.

altitudes1700-2810m bs=13.822Ln(x) - 112.34 R2 = 0.9933

altitudes 2810 to 4320m bs= 8.602Ln(x) - 70.956 R2 = 0.9949

263 Total Area = 9,035,935 square meters

Upper Limit Elevation Band (m)	Elevation Band Midpoint (m)	Area sq m	Band specific bs	Band BS
1700	1695	7246	-9.57	-69327
1710	1705	6559	-9.49	-62218
1720	1715	6416	-9.41	-60347
1730	1725	5818	-9.32	-54250
1740	1735	6514	-9.24	-60223
1750	1745	6752	-9.17	-61890
1760	1755	5832	-9.09	-52988
1770	1765	7519	-9.01	-67729
1780	1775	10057	-8.93	-89807
1790	1785	12776	-8.85	-113101
1800	1795	16368	-8.78	-143628
1810	1805	18758	-8.70	-163158
1820	1815	17876	-8.62	-154126
1830	1825	14996	-8.55	-128159
1840	1835	15919	-8.47	-134837
1850	1845	18597	-8.40	-156130
1860	1855	15080	-8.32	-125479
1870	1865	12585	-8.25	-103783
1880	1875	17385	-8.17	-142076
1890	1885	22626	-8.10	-183243
1900	1895	19566	-8.03	-157031
1910	1905	22602	-7.95	-179750
1920	1915	3172	-7.88	-24998
1930	1925	4008	-7.81	-31297
1940	1935	26558	-7.74	-205477
1950	1945	24035	-7.67	-184244
1960	1955	17601	-7.59	-133677
1970	1965	20325	-7.52	-152933
1980	1975	21421	-7.45	-159675
1990	1985	17330	-7.38	-127975
2000	1995	15654	-7.31	-114505
2010	2005	23520	-7.25	-170425
2020	2015	25988	-7.18	-186521
2030	2025	21163	-7.11	-150438
2040	2035	18119	-7.04	-127569
2050	2045	25025	-6.97	-174494
2060	2055	24387	-6.91	-168403
2070	2065	14682	-6.84	-100401
2080	2075	28191	-6.77	-190892
2090	2085	28413	-6.71	-190511
2100	2095	31022	-6.64	-205949
2110	2105	44846	-6.57	-294774
2120	2115	50151	-6.51	-326362
2130	2125	47816	-6.44	-308046
2140	2135	43903	-6.38	-279991
2150	2145	39572	-6.31	-249811
2160	2155	35152	-6.25	-219654
2170	2165	32121	-6.18	-198653
2180	2175	35558	-6.12	-217644
2190	2185	38484	-6.06	-233114
2200	2195	41684	-5.99	-249869
2210	2205	43628	-5.93	-258780
2220	2215	43367	-5.87	-254521
2230	2225	46291	-5.81	-268801
2240	2235	47475	-5.74	-272734
2250	2245	46857	-5.68	-266291
2260	2255	46748	-5.62	-262800
2270	2265	49023	-5.56	-272594
2280	2275	57692	-5.50	-317284
2290	2285	64805	-5.44	-352471
2300	2295	66248	-5.38	-356324
2310	2305	62403	-5.32	-331889

Summer Balance: **DEBRIS-COVERED ICE**

within 10-meter altitude bands.

bds = average bs of stakes 4A and 5

Total Area = 2,556,980 square meters

Upper Limit Elevation Band (m)	Elevation Band Midpoint (m)	Area sq m	Band specific bs	Band BS
1490	1485	7434	-3.53	-26205
1500	1495	7571	-3.53	-26687
1510	1505	7997	-3.53	-28191
1520	1515	9692	-3.53	-34165
1530	1525	17655	-3.53	-62233
1540	1535	22423	-3.53	-79040
1550	1545	22445	-3.53	-79119
1560	1555	20561	-3.53	-72478
1570	1565	20929	-3.53	-73774
1580	1575	28143	-3.53	-99203
1590	1585	32872	-3.53	-115873
1600	1595	31079	-3.53	-109554
1610	1605	24834	-3.53	-87538
1620	1615	32984	-3.53	-116267
1630	1625	45786	-3.53	-161396
1640	1635	49856	-3.53	-175742
1650	1645	53286	-3.53	-187832
1660	1655	79260	-3.53	-279390
1670	1665	73088	-3.53	-257637
1680	1675	58850	-3.53	-207447
1690	1685	59088	-3.53	-208284
1700	1695	86176	-3.53	-303769
1710	1705	105476	-3.53	-371801
1720	1715	81547	-3.53	-287452
1730	1725	71082	-3.53	-250565
1740	1735	80793	-3.53	-284794
1750	1745	59191	-3.53	-208648
1760	1755	54141	-3.53	-190848
1770	1765	48463	-3.53	-170831
1780	1775	66409	-3.53	-234090
1790	1785	69197	-3.53	-243920
1800	1795	68686	-3.53	-242117
1810	1805	72538	-3.53	-255697
1820	1815	71865	-3.53	-253324
1830	1825	77639	-3.53	-273676
1840	1835	88729	-3.53	-312768
1850	1845	83470	-3.53	-294231
1860	1855	73734	-3.53	-259912
1870	1865	55622	-3.53	-196066
1880	1875	48561	-3.53	-171179
1890	1885	36874	-3.53	-129982
1900	1895	35625	-3.53	-125578
1910	1905	27418	-3.53	-96647
1920	1915	45789	-3.53	-161405
1930	1925	44152	-3.53	-155635
1940	1935	17633	-3.53	-62157
1950	1945	15324	-3.53	-54018
1960	1955	12994	-3.53	-45803
1970	1965	13864	-3.53	-48871
1980	1975	15661	-3.53	-55204
1990	1985	14768	-3.53	-52058
2000	1995	13167	-3.53	-46414
2010	2005	18434	-3.53	-64981
2020	2015	17477	-3.53	-61606
2030	2025	13142	-3.53	-46327
2040	2035	11662	-3.53	-41109
2050	2045	8524	-3.53	-30047
2060	2055	7415	-3.53	-26137
2070	2065	16233	-3.53	-57222
2080	2075	4018	-3.53	-14164
2090	2085	4126	-3.53	-14545
2100	2095	4374	-3.53	-15420

Specific net balance
BARE ICE

within 10m altitude bands.

263 Total Area = square meters

Upper Limit Elevation Band (m)	Elevation Band Midpoint (m)	Band specific bn
1700	1695	-8.12
1710	1705	-8.02
1720	1715	-7.92
1730	1725	-7.81
1740	1735	-7.71
1750	1745	-7.61
1760	1755	-7.51
1770	1765	-7.41
1780	1775	-7.31
1790	1785	-7.21
1800	1795	-7.11
1810	1805	-7.01
1820	1815	-6.91
1830	1825	-6.81
1840	1835	-6.72
1850	1845	-6.62
1860	1855	-6.53
1870	1865	-6.43
1880	1875	-6.34
1890	1885	-6.24
1900	1895	-6.15
1910	1905	-6.06
1920	1915	-5.97
1930	1925	-5.87
1940	1935	-5.78
1950	1945	-5.69
1960	1955	-5.60
1970	1965	-5.51
1980	1975	-5.42
1990	1985	-5.34
2000	1995	-5.25
2010	2005	-5.16
2020	2015	-5.08
2030	2025	-4.99
2040	2035	-4.90
2050	2045	-4.82
2060	2055	-4.73
2070	2065	-4.65
2080	2075	-4.57
2090	2085	-4.48
2100	2095	-4.40
2110	2105	-4.32
2120	2115	-4.24
2130	2125	-4.16
2140	2135	-4.08
2150	2145	-4.00
2160	2155	-3.92
2170	2165	-3.84
2180	2175	-3.76
2190	2185	-3.68
2200	2195	-3.60
2210	2205	-3.53
2220	2215	-3.45
2230	2225	-3.37
2240	2235	-3.30
2250	2245	-3.22
2260	2255	-3.15
2270	2265	-3.07
2280	2275	-3.00
2290	2285	-2.92
2300	2295	-2.85
2310	2305	-2.78

Specific net balance
DEBRIS-COVERED ICE

within 10m altitude bands.

Total Area = square meters

Upper Limit Elevation Band (m)	Elevation Band Midpoint (m)	Band specific bs
1490	1485	-2.62
1500	1495	-2.59
1510	1505	-2.56
1520	1515	-2.53
1530	1525	-2.51
1540	1535	-2.48
1550	1545	-2.46
1560	1555	-2.43
1570	1565	-2.40
1580	1575	-2.38
1590	1585	-2.35
1600	1595	-2.33
1610	1605	-2.30
1620	1615	-2.28
1630	1625	-2.25
1640	1635	-2.23
1650	1645	-2.20
1660	1655	-2.18
1670	1665	-2.15
1680	1675	-2.13
1690	1685	-2.11
1700	1695	-2.08
1710	1705	-2.06
1720	1715	-2.04
1730	1725	-2.01
1740	1735	-1.99
1750	1745	-1.97
1760	1755	-1.94
1770	1765	-1.92
1780	1775	-1.90
1790	1785	-1.88
1800	1795	-1.86
1810	1805	-1.84
1820	1815	-1.81
1830	1825	-1.79
1840	1835	-1.77
1850	1845	-1.75
1860	1855	-1.73
1870	1865	-1.71
1880	1875	-1.69
1890	1885	-1.67
1900	1895	-1.65
1910	1905	-1.63
1920	1915	-1.61
1930	1925	-1.59
1940	1935	-1.57
1950	1945	-1.55
1960	1955	-1.53
1970	1965	-1.51
1980	1975	-1.50
1990	1985	-1.48
2000	1995	-1.46
2010	2005	-1.44
2020	2015	-1.42
2030	2025	-1.41
2040	2035	-1.39
2050	2045	-1.37
2060	2055	-1.35
2070	2065	-1.34
2080	2075	-1.32
2090	2085	-1.30
2100	2095	-1.29

Figure SOP 5.6. Example of 10-meter Elevation Band Balance worksheet for the Emmons Glacier, 2006. Only the first page of three is shown here.

As new glacier maps are made at ~ 10-year intervals, mass balance will be integrated using two different map sets as per Elsberg et al. (2001). Annual winter, summer, and net balances are calculated on the original maps made from 1994 air photos for correlation with climatic variations. Annual balances that are calculated on the map most current to the year in question, are used for annual and cumulative runoff calculations.

The calculation of winter and summer glacier mass balances requires the following data:

1. Winter or summer balance at each stake

2. Winter or summer balance error at each stake

3. The altitude of each stake from the latest map

4. Ten-meter elevation band areas, mass balance (B), and glacier area averaged balances ($\bar{b}$) determined using b(z) function and 10-meter elevation bands. Surface area (not two-dimensional map area) for the 10-meter elevation bands are determined by GIS analysis (See SOP 8. Watershed-Wide Glacier Runoff Calculations for GIS Directions).

5. Snow density observed on glacier

6. Snow density and snow depth observed at Paradise SNOTEL

7. Average mean freezing altitude for the months of July and August

Balance versus altitude (b(z)) functions are generated with regressions. Regressions are fit using graphing software i.e. Excel or Origin 7 (Origin 7 curve fitting procedure detailed below). The regression used can be linear, exponential, logarithmic. The b(z) functions determined by regression for b_w and the individual functions for b_s, for regular (b_R) and debris-covered ice (b_D) are applied to the mid-point altitude of each band, b(mid-point altitude). The mass balances are then integrated for the glacier by summing the mass balances of the 10-meter bands.

Procedures

Data management activities are listed below by seasons.

Post-Spring Visit

1. Enter the probed snow depths for each location into the “Stake and Probe Comparison” worksheet (Figure SOP 5.1). Enter the date, stake elevation, and the height of each stake below the snow surface into the “Stake Data” worksheet (Figure SOP 5.3). Plot the GPS coordinates for each stake on the most current map to retrieve stake altitudes.

2. Consider all the snow probes near each stake and disregard any individual probes that are not within 1.0 meter of the mean of all probes near the stake. This new mean depth will be used to calculate the provisional b_w at each stake. The mean depth from the probes at each stake is the provisional b_w at each stake.

3. If less than five probes were taken at site location, probes are inconsistent, or there is a persistent mid-winter layer, do not include stake probe data in remaining calculations below. Wait for summer probes and add mid season melt to summer probe depths.

4. Determine the snow density at each site following the “Snow Density” worksheet; see SOP 3 (Snow Density Determination) for worksheet. Use data from the Paradise SNOTEL to find lowest elevation density.
   a. Download the snow water equivalent (SWE) from Paradise SNOTEL for the day that the snow depth was measured in the field (~early April). Data can be found at http://www.wrcc.dri.edu/cgi-bin/snoMAIN.pl?AFSW1.
   b. Convert SWE from inches into meters.
   c. Divide SWE meters by the field measured meters snow depth.
   Find the altitude gradient for snow density by fitting the best fit line.

5. The provisional b_w at each stake is the product of the mean depth from the probes and the measured or calculated snow density at that stake. This operation is done in “Stake Data” worksheet (for example, see Figure SOP 5.3).

6. Calculate the b_w error at each stake in the “Uncertainty” worksheet. Balance errors are discussed in the protocol narrative and summarized in SOP 9 (Mass Balance Error Calculations and Determinations.)

7. Find the best-fit for the $b_w(z)$ function using regression for each glacier. Display the results in the “Balance Charts” worksheet (Figure SOP 5.4). Use this function at each elevation band midpoint along with the elevation band data to find the summation of the b_w for the glacier in the “Band Balance” (Figure SOP 5.5) worksheet.

8. Enter regression equation used in finding B_W into the “Summary Report” worksheet (Figure SOP 5.4) and include any other valuable information pertaining to B_W calculations.

9. Write the “Glacier Page” and send to Scott Pattee at the NRCS and distribute throughout the park. See SOP 13 (Products and Reporting) for an example.

Post-Summer Visits

1. Enter the probed snow depths for each location into the “Stake and Probe Comparison” worksheet (Figures SOP 5.1 and SOP 5.2). Enter the date and the height of each stake above the surface into the “Stake Data ” (Figure SOP 5.3) worksheet.

2. Consider all the snow probes for each stake and disregard any individual probes that are inconsistent with the others (not within 1.0 meter of the mean).

3. Determine if the summer probe depths are consistent with the spring probe depth by comparing the difference between spring probes and ablation stake height. Use the “Stake and Probe Comparison” worksheet (Figures SOP 5.1 and SOP 5.2). The sum of ablation (from the stake measurements) and probed snow depth at each stake in the summer

should equal the spring snow depth. If the spring probe depths appear suspect then the calculated spring depth (from summer probes and ablation stake heights) should be used instead.
Possible causes for this include:
   a. Probe penetrated through the previous years' summer surface into firn, which can be a problem following a positive mass balance year.
   b. Probes didn't penetrate deeply enough because of significant ice layers above the summer surface. Compare the data with ice layers recorded during probing in the spring.

4. If b_w or B_W is updated to account for any new information provided by the summer visit, change the b_w and B_W in the "Summary Report" worksheet (Figure SOP 5.5).

5. Record in the Stake and Data worksheet (Figure SOP 5.3) any "winter melt" at stakes which were left in ice from previous year, usually only at lower stakes.

6. Repeat steps 3 through 8 in the above section if data was collected on the upper mountain above the highest placed stake, 3,100 m (also see SOP 7. Balance Determination Above 3,100 Meters).

Post-Fall Visit

1. Enter the probed snow depths (if any) for each location into the "Stake and Probe Comparison" worksheet (Figures SOP 5.1 and SOP 5.2). Enter the date and the height of each stake above the surface into the "Stake Data" worksheet (Figure SOP 5.3).

2. If there is snow left at stakes on the glacier then probing the depth of the remaining snow is a useful check on depth determinations earlier in the season. Check this in the "Stake and Probe Comparison" worksheet. In this case, consider all the snow probes for each stake and throw out any individual probes that are inconsistent with the others (not within 1.0 meter of the mean of all probes).Compare the sum of ablation (from the stake measurements) to the probed snow depth at each stake.

3. If there is snow left and if crevasse stratigraphy was noted in the field, compare stratigraphy with fall probes as a confirmation of probing.

4. Using the final values for b_w at each stake calculate the final mass and area averaged B_W values using steps 4 through 8 in the section "Post spring visit" above.

5. Calculate b_s at each stake in the "Stake Data" worksheet (Figure SOP 5.3) by breaking down the summer season surface melt down into its snow, firn, and ice melt components. If there is an unrecovered stake, see below for reconstructing melt.

6. Calculate the b_s error at each stake in the "Uncertainty" worksheet (see SOP 9).

7. Calculate the average mean freezing altitude for the months of July–August (see SOP 7). Input freezing altitude into "Stake Data" worksheet (Figure SOP 5.3) as an additional b_s

point.

8. Generate an elevation vs. b_s curve (may be broken up into two parts, higher and lower altitudes see SOP 7 for details). Use only stake data 1–4, exclude debris covered ice stakes 4a and 5; see SOP 6 (Ablation Measurement of and Summer Mass Balance Estimation of Debris-Covered Ice). Calculate b_s for each 10-meter elevation band for each type of ice; regular (b_R) and debris-covered ice (b_D). Determine B_S for the glacier (in "Balance Charts" [Figure SOP 5.4] and "Band Balance" worksheets [Figure SOP 5.6]).

9. Enter equation used in finding B_S into the "Summary Report" worksheet (Figure SOP 5.5). Include any other valuable information pertaining to B_S calculations.

10. Enter $\overline{b_w}$, $\overline{b_s}$, B_W, B_S, into the "Summary Report" worksheet (Figure SOP 5.5) and calculate $\overline{b_n}$ and $\overline{B_N}$.

11. Enter other calculations into "Summary Report" worksheet (Figure SOP 5.5):
    a. Equilibrium Line Altitude (ELA): this altitude occurs where the net balance is zero and can be determined graphically from a plot of bn vs. altitude, site visit, and/ or aerial photograph.
    b. Accumulation Area: calculated by summing all elevation band areas above the ELA.
    c. Ablation Area: calculated by summing all elevation band areas below the ELA.
    d. Accumulation area ratio (AAR): Accumulation area/Total glacier area.

    End of Balance Year snow, firn, and ice boundaries can be seen on aerial photographs, if available. This provides a good check on ELA altitudes and residual snow but is neither always necessary nor are photographs available on an annual basis. The ELA can be determined from these photographs with the aid of a current topographical glacier map.

    e. On the photograph, determine snow, firn, and ice coverage.
    f. Look at past photos to see trends in remaining snow cover.
    g. Decide where the most continuous snow line of current year is located.
    h. Overlay a contour map and find the elevation of where it meets the bottom of the snow line.

    In any case, site visit information, a photo/map, and a bn vs. altitude plot should be used in conjunction if possible to compare elevations and provide a data quality control measure.

12. After entering data into the excel workbook, data should be reviewed for any red flags or unusual trends. In each glacier Excel workbook, charts are preprogrammed to plot bw, bs, and bn to visually see any problems. Always compare stake final melt with mid-season melt. If one stake measurement looks out of line there are several ways to render the problem.
    a. Consider a data entry error. Check all data input and linked calculated workbook cells.
    b. Consider a field note taking error. If the stake seems extremely low in comparison to other stake data the field note recorder could have wrote down the wrong stake

label and /or section number. Add on one full stake segment (1.5 m) to total recorded stake height and compare to other final melt data. Revised field datasheets are now used to limit this problem.

Managing Unrecovered Stakes

Over the years collecting data on maximum melt and locating crevasse zones have guided stake length (and depth at which the stake is placed) and the best location of stake placement. Even with this information a stake may not be recoverable during the fall visit. Reasons for this can include:

1. Stake melted out. In years with extreme hot and dry summers, melt can exceed the stake burial depth. If stake melt out occurs, usually only the lowest elevation stakes are a problem.

2. Stake swallowed by crevasse. The predetermined locations for the stakes are away from heavily crevassed areas but some locations still have crevasses in vicintity especially the highest stakes. It is possible during the spring visit when locating the stake position by GPS, the GPS can have an error of ~10 m. This error can position the stake closer to a crevasse field occuring in higher probality of hitting a crevasse or having one open during a warm summer. Even though probing at the site in the spring should detect a crevasse, probing does not always register one. A stake may be placed on the very edge of the crevasse and melt can occur not only in the vertical plane but also in the horizontal of the crevasse walls.

3. Stake "popped" out of hole. This is hard to detect and rare, but possible. In the fall, the melt can be so great that the stake is barely remaining inserted into the hole. With gravity lean and a low profile of remaining hole, the stake can "pop" out prematurely.

4. Stake removed. Stakes are purposely placed in areas where public visitatation is minimal (except the highest stake on both glaciers) but it is possible that a stake can be removed by a passing climber.

5. Stake buried by new (early fall) snow. As in the case of the fall of 2007, ~1.0m new (2008) snow buried several stakes and were unrecovered.

It is important to keep the above possibilities in mind in the event of trying to reconstruct the final stake height and final melt of a missing stake. The combination of using four or five data points (stakes) on a glacier and making a mid-summer visit allows for reconstructing melt from unrecovered stakes. There are several options listed in order of reliability below. It is suggested to use multiple options to single out the best one. Regardless, look at past data and compare current data to glacier trends.

1. Melt ratio. The melt ratio is based on the assumption that the difference of the mid-season melt between two different stake locations is similar to the difference of the end season melt. The only factor that changes is the additional melt from mid-summer to fall. Use the mid-season melt ratio between the missing stake and the next closest stake and multiply the ratio by the closest stake final melt.
2. Best fit curve. Plot available b_s stake data with altitude and find a best-fit function with a R^2 of $\geq$0.7. Interpolate or extrapolate regression from the line to the missing stake

altitude.

3. Compare best fit curve, step two, with the mid-season melt of all the stake data.

4. Find minimum melt. This is used for comparison and only at melt out stakes, typically on the lower part of the glacier. Add the stake length with the depth of placement below snow surface in the spring. Method chosen should be at least ≥ to this minimum melt.

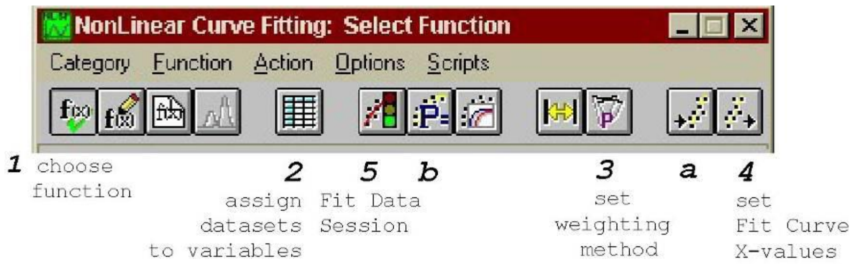
Glacier Data Check Procedure

This procedure is designed as a final check of data every year after all data is collected and calculations are made.

- Assemble and organize ALL information (hard copy and electronic) for each glacier.
- Go through data for each glacier year-by-year; follow the history of each glacier.
    - Work from annual data summary sheets to record all changes.
    - Check the following:
        - Stake elevations and locations against those recorded on the mylar and paper maps. Make sure feet and meters are equivalent.
        - Spring, summer, and fall stake heights on data sheet against field notes.
        - Snow depth data; compare with original spring probe data. Make sure to note in Changes Log if spring snow depth was reconstructed from later season probes and stake height.
        - Spring Probe Confidence Spreadsheets
        - Snow density
    - Investigate inconsistencies and discrepancies
    - Record all errors in changes in the Changes Log
    - Make sure all data changes carry through all applicable spreadsheets.
    - Check each and every calculation for the old stake-area method.
    - Apply new mass balance calculation method.

Curve Fitting Procedure in Origin 7

- Compile all the data that you want to fit the curve to in a table in the Excel worksheet including <u>elevation</u>, <u>balance</u>, and <u>balance error</u>.
- Bring data into an Origin worksheet from the Excel workbook for the glacier.
- Designate each column as X, Y, and Yerror (no Xerror used).
- Highlight/Select the Ycolumn.
- In the upper menu bar choose “Analysis” then “Non-linear Curve Fit” then “<u>Advanced Fitting Tool</u>”.
- Once in the “Advance Fitting Tool” make sure you have the dialog box maximized. This is the box with all the different buttons near the top. If you get the small box click the “More…” button.
- The buttons at the top of the box are different options and parameter settings. It is best to follow steps 1–5 with the buttons indicated below:



1. Choose Function: Category: Polynomial
   - Functions: Typically "Line" is the best choice however "Cubic" often fits the data quite well between the stakes but not above and below the stakes (In this case use a constant value or line above and below the stakes.

2. Assign datasets to variables.
   - Y dependent – bw or bs
   - X independent – elevation

3. Choose weighting method (bottom half of window).
   - Choose "Direct Weighting" and set Yerror as dataset. Make sure to click the check box: "Scale errors with sqrt (reduced chi^2).

4. Generate Fit Curve.
   - This option specifies how many points in what range to plot the curve. This also generates the results that can be used back in the Excel workbook in the "Band Balance" spreadsheet.
   - To set the range, choose the maximum and minimum elevations (to the nearest mid-point) and the number of elevation bands used in the "Band Balance" calculations. Enter these values into the dialog box.

5. Fitting Session
   a. If there are no values in the Parameter boxes you will have to click button (a) and click the "Execute" button to initialize the parameters.
   b. Once everything above is set, click on the "100 Iter." box until the chi-sqr is not reduced
   c. At this point you are done, click the "Done" button.
   d. The graph and results will automatically pop up in new windows.

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SOP 6. Ablation Measurement and Summer Mass Balance Estimation of Debris-Covered Ice

Version 1/24/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview and Explanation

Quantifying the effect that debris-covered ice has on summer balance is important because substantial areas of most of the large valley glaciers on Mount Rainier are covered by debris: 22% on Emmons and 18% on Nisqually and are in the ablation zones. Most of the debris cover has sufficient thickness so that the primary effect is decreased ice melt rates. However, debris cover on ice tends to enhance melting up to a certain thickness called the “effective thickness” which is between 1–2 cm in most empirical studies (Lundstrom et al. 1993; Nakawo and Rana 1999; Mattson et al. 1993; Khan 1989; Loomis 1970; Ostrem 1959). The “critical thickness” is defined as the debris thickness in which ice melt is equal to that of bare ice. This occurs between 2 and 4 cm in the studies cited above. When the debris cover is thicker than the critical thickness, ice change in melt rates decrease quickly then follow an asymptotic curve where the curve approximately stabilizes at a thickness of 15 to 20 cm. We refer to this thickness informally as the “minimum stagnant thickness”. Stagnant ice with a debris thickness of greater than one meter on the lower Eliot Glacier on Mount Hood showed ablation rates of 0 to 1 m/year over the five-year period of study (Lundstrom et al., 1993). Further research is currently being conducted on the lower Eliot Glacier by Keith Jackson, a grad student at Portland State University (http://web.pdx.edu/~kjack/eliotresearch.html).

Debris thicknesses are highly variable across these areas on the scale of a few meters and affect the morphology and evolution of the surface throughout the ablation season. The morphology of the surface is also affected by crevassing and flow, which in turn will affect debris thickness as the ice breaks up or compresses (Lundstrom et al., 1993).

Debris cover accumulates in the ablation area of the glaciers from supra- and englacial transport of debris from above (Small, 1987) and from direct deposition of rock avalanches (Crandell and Fahnestock, 1965).

Procedures

Our approach to measuring debris covered ice ablation in the field is three-fold:

1. Compare melt rates of clean ice verse debris covered ice: Adjacent ablation stakes are located at approximately the same elevation in debris covered ice and bare ice (see Figures 3 and 4 in Protocol Narrative).

2. Construct melt verses altitude linear functions: At least two stakes with different altitudes are situated in debris covered ice (two stakes in Emmons, and two in Nisqually; see Figures 3 and 4 in Protocol Narrative).

3. Compare debris thickness to surrounding stake location: Debris thickness is measured at the stake location and in the vicinity. Debris thickness is measured at four to five equally spaced points on either side and on contour with the stake (10 points total) along a 30-meter long transect. This data indicates how representative the thickness is at the stake location with the adjacent debris covered area.

Mass balance for debris covered ice areas (B_D) are estimated using the following approach:

1. Debris covered ice areas are delineated from orthorectified imagery every 10 years.

2. The debris covered area polygons are subdivided into 10-meter elevation bands (the debris covered area for each band is subtracted from the original total).

3. Either a best fit line is regressed between the summer balances of debris covered stakes 4a and 5 OR if a poor inverse correlation exists between altitude and b_D for the stakes, then the average b_D is used for the whole area.

4. Mass balance for debris covered ice, B_D, is calculated in the same “Band Balance” procedure as detailed in SOP 5 (Mass Balance Calculations).

Note for MORA glaciers that B_S is the sum of all the summer mass balances of all applicable surface types by area:

$$B_S = B_R + B_D \qquad \text{(Eq. 5)}$$

Where B_R is mass balance for bare ice and snow, and B_D is debris-covered ice mass balance (see SOP 5 (Mass Balance Calculations) for current surface cover delineations and band balance areas.).

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SOP 7. Balance Determination above 3,100 Meters

Version 6/9/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures

Overview and Explanation

On the upper mountain, above approximately 3100 m on both Emmons and Nisqually glaciers, the characteristics of the glaciers and climate become very different from below. Slopes steepen dramatically and the surface is extremely broken by large crevasses, toppling serac zones, and icefalls. Access is limited by these factors and safety is a major concern. This area falls into a relatively unique climate zone for the Cascade Range in which only the upper portions of some of the Cascade volcanoes occupy. Measurements of winter balance in the last several years indicate that accumulation decreases above approximately 3100m on the Emmons Glacier and 2100m on the Nisqually Glacier. Further, the ablation season does not typically begin until July and ends in late August. Strong winds also re-distribute snow on the exposed summit. These regions of the glaciers are very important, however, as they comprise approximately half of the accumulation area, and 21% and 25% of total glacier area on Emmons and Nisqually, respectively.

Due to practical considerations of accessibility, data uncertainty, time, personnel, and budget, the highest stakes are only placed at 3100 m on the Emmons and 3300 m on the Nisqually glaciers. The distinction between “higher” and “lower” altitude data in this SOP refers to the areas generally above and below stake 1, the highest in altitude placed stake. We have found it is very difficult to detect the previous year’s summer surface above this stake altitude with the snow depth probe. The underlying firn layers are not always denser than the snowpack, and ice layers within the snowpack are not always easily distinguishable from previous year’s summer surfaces.

Methods have been developed to calculate both winter and summer balance using the probed snow depth and melt at each of the stake locations and extrapolating up to the summit. This SOP describes the current methods and detailed procedures, but methods are subject to change in the future when more data become available. Figure SOP 7.1 shows relationship between the “higher” and “lower” altitude data for 2005 Emmons Glacier.

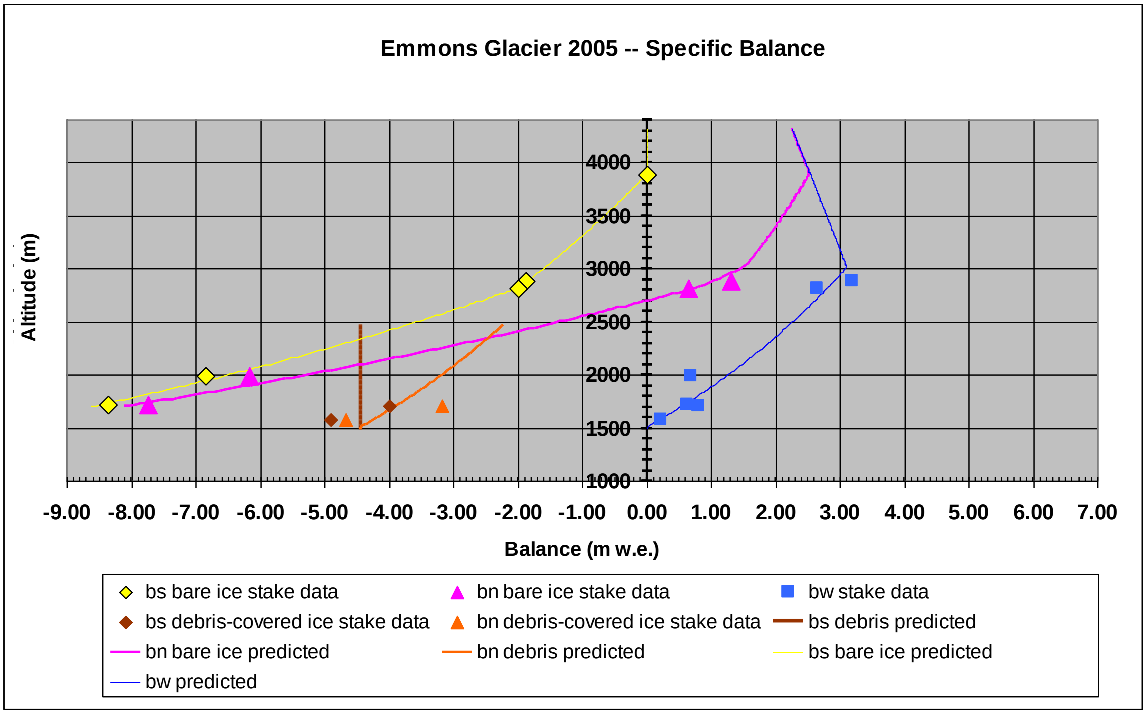

Figure SOP 7.1. Emmons Glacier specific balance chart for 2005 showing collected and predicted depths m w.e. at altitude for b_w, b_s, and net mass balance (b_n). Both b_w and b_s use two trend lines; one to represent the "higher" and the other the "lower" mountain. The upper b_w predicted trend line was generated using collected data on the upper mountain in 2004 and applying it to near the maximum accumulation altitude point for 2005. The upper b_s trend line was generated by using 1) the highest elevation stake data and 2) the estimated zero b_s altitude created by using a local summer lapse.

There are two methods for calculating winter balance (b_w) on the upper mountain. They are based on past observations that constrain the b_w verses elevation curve. In some years when ease of logistics and weather prevails, a visit above the highest stake locations may be made in early to mid-July, at the approximate time of maximum balance on the summit (Appendix C. Timing of Glacier Visits). If additional probe depths are made above the highest stake locations (possibly including the summit) these probes are analyzed for their consistency. If probe data are considered reliable; see SOP 2 (Snow Depth Probing) and SOP 5 (Mass Balance Calculations) winter balance (b_w) is estimated from snow these data.

In years without reliable higher altitude data, b_w is assumed to follow the same pattern of change with elevation as observed in 2004. In 2004, a traverse of the entire mountain was made collecting snow depth above stake location altitudes on the Nisqually and Emmons glaciers, including in the summit crater. Data was determined to be dependable and now provides a baseline of upper altitude snow accumulation for years lacking reliable data. Winter balance (b_w) on the upper mountain is based on the assumptions:

1. b_w decreases above a certain elevation on the glacier (Figure SOP 7.2)

2. annual b_w will always have different trend lines representing conditions above and below the near maximum snow depth altitude

3. the slope of b_w is consistent from year to year

4. b_w is always positive

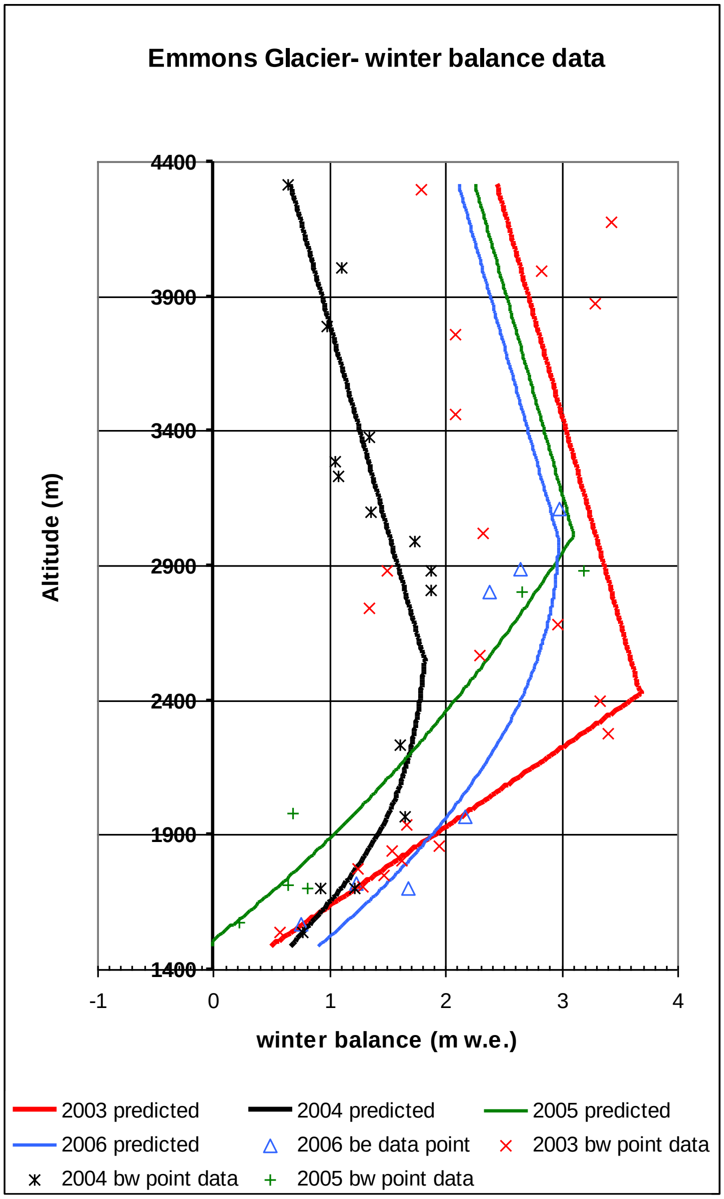

Figure SOP 7.2. Point data and predicted (b_w) for all years on record. Note b_w decreases above a 2,400 and 3,000 m elevation on the glacier.

Specific winter balance (b_w) is measured annually as high on the mountain as possible. Specific winter balance (b_w) is then extrapolated above this altitude point so that the line is parallel to the 2004 b_w slope (i.e. shift in entire curve) (Figure SOP 7.3). The data required to determine b_w above the highest measurement point are:

1) Upper mountain linear equation for 2004 glacier data:

$$y = a + b = x \qquad \text{(Eq. 1)}$$

Where: a = snow depth at 0 m altitude
b = slope of line
x = altitude at any given point on the slope.

2) Measured maximum accumulation depth and altitude for current year. Altitude may be directly derived from a measurement point on the glacier or generated from a trend line

3) 2004 depth at the current years' max depth altitude point.

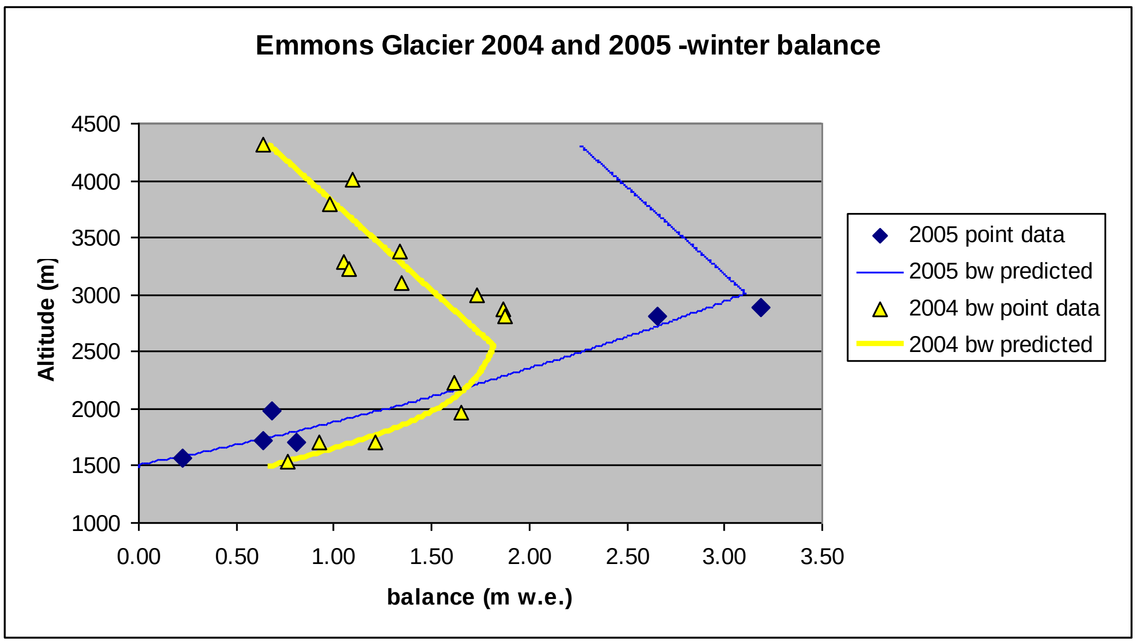

Figure SOP 7.3. Comparison of the Emmons Glacier b_w for 2004 and 2005. Note the same b_w slope for the upper mountain with 2005 maximum depth accounted for. Note the "lower" and "higher" 2005 altitude trend lines intersect at ~3,005 m instead of maximum recorded depth at 2,882 m.

As more b_w data becomes available above approximately 3100 m, this procedure may have to be adjusted. By changing the pattern of the b_w verses altitude curve.

LiDAR could also improve our understanding of b_w on the upper mountain. With LiDAR it would be possible to calculate the surface change, or snow depth change, between the previous fall and the current spring across the glacier surface. Currently, this program is unable to secure continuous funding to purchase images on the necessary biannual schedule. If LiDAR is used in the future methods will be updated to reflect this change.

Summer balance (b_s) higher on Mount Rainier is estimated from the highest measurement point to the elevation of the average July–August freezing isopleth. The freezing temperature is interpreted to have zero summer balance and provides an anchor to the balance versus altitude (b(z)) functions generated with regressions (see SOP 5). There are two options for finding the freezing temperature; interpolate data from NCEP-NCAR reanalysis grid point or create an annual lapse rate from two nearby weather stations. Collecting on site temperature data with small data loggers, hobos, at a series of glacier stations would be useful and preferred for glacier melt modeling. Experience has shown without constant attention and maintenance throughout the melt season, mounted hobos to ablation stakes become top-heavy, fall over, and land on the snow. These temperatures are less than accurate.

Using data collected from the local Longmire and Paradise weather stations and summarized by the Western Regional Climate Center (WRCC) at http://www.wrcc.dri.edu/summary/climsmwa.html, a summer (July and August) lapse rate was calculated for a 30 year average (1971–2000) to be 5.04 ºC/km. The zero degree elevation of the 30 year average was approximately 3,918 m which is currently located above our highest placed stake. Lapse rates and freezing altitudes can vary substantially on an annual basis. For example, 1999 and 2005 lapse rates were 4.42 ºC/km and 5.5 ºC/km, respectively with corresponding freezing altitudes of 4,237 m and 3,886 m.

Stake data is used in conjunction with this additional higher elevation data point to interpolate b_s above 3100m. Summer balance (b_s) decreases with altitude and usually fits an exponential curve. If data does not fit the curve, several trend lines may be used to split the “lower” and “higher” elevation stake data. Determining when to use one or more trend lines is discussed below.

Procedures

Office Procedure

Finding winter balance above ~3,100 m:
The procedure for determining b_w above approximately 3,100m as based on the 2004 b_w verses elevation curve is shown below (Figure SOP 7.2). The Emmons Glacier b_w 2005 data is used as an example below. All accumulation depths are in meters water equivalent (m w.e.) and altitudes are in meters (m).

1. Find the maximum snow depth and altitude for the current year.

2. Find the difference between the 2004 and the current years’ maximum depth at the current years’ maximum depth altitude.

3. As necessary, add or subtract depth to variable *a* in Eq. 1 above.

4. Find the altitude where the “higher and lower” mountain b_w data trend lines intersect, usually occurring between stakes 1 and 2. For additional detail see SOP 5 for curve fitting “lower” altitude b_w data. The intersection should be near but can be above or below the actual maximum snow depth (as recorded in step 1 above) for the current year by ~50 meters altitude depending on the trend line intersection. Whereas the intersection point from year to year and vary by 100m in elevation or more.

5. Replace the new snow depth for variable *a* into Eq. 1 above.

6. Insert the new equation into each 10 meter elevation band cell in the "Band Balance Worksheet" (see SOP 5 for worksheet example) at ≥ to the intersection altitude found in step 4 of this list, above.

7. Continue with calculations detailed in SOP 5.

Winter balance ($b_{w)}$ is always represented by two trend lines and is split near the maximum accumulation altitude. See steps 4 and 6 above.

2005 Emmons Glacier Example:
The upper mountain curve using Emmons Glacier 2004 b_w data is:

$$y = 3.48679 + (-0.000653571x)$$

1. Emmons Glacier 2005
   Max depth 3.19 m w.e. @ 2882 m

2. Shift b_w verse elevation curve:
   3.19 m w.e. (max depth in 2005)
   \- <u>1.61 m w.e. (2004 depth at the 2005 max depth altitude=2882 m)</u>
   1.58 m w.e. difference

   3.48679 m (variable a in 2004 slope equation)
   \+ <u>1.58 m (difference in max depth between 2005 and 2004)</u>
   5.06679 m (becomes the new snow depth at 0 m in the slope equation)

3. Using the trend line from b_w 2004 data (with adjustments made for the maximum snow depth for 2005) and the lower mountain b_w trend line (for stakes 2–4 on the lower mountain, see SOP 5), the altitude in which they intersect is 3005 m (see Figure SOP 7.1).

4. Insert the new equation
   (y = 5.06679 + -0.000653571x)
   for b_w on the upper mountain into the "Band Balance Worksheet" for bands ≥3005 m to find estimated snow depth per band (see SOP 5 for worksheet example).

Finding summer balance above ~3,100 m:
Calculate the annual average mean freezing altitude for the months of July and August. There are two options for finding the freezing altitude:

1. Create an annual lapse rate from two nearby weather stations. This is the simplest approach with data easily accessible for download off the internet.
   a) Download monthly average temperature for July and August from Paradise (1,655 m) and Longmire (841 m) weather stations at http://www.wrcc.dri.edu/cgi-bin/cliMONtavt.pl?wa6898 and http://www.wrcc.dri.edu/cgi-

bin/cliMAIN.pl?wa4764, respectively. These have the two longest running weather records in the vicinity of Mt. Rainier and are located on the south/southwest flank. These lapse rates are extrapolated to higher altitudes and assumed to represent conditions above the highest stake stations.

Using the lapse rate between Longmire and Paradise may underestimate temperatures at higher elevations on the mountain. This lapse rate is used currently because it is the best data available and the closest in proximity to the mountain.

A weather station at Camp Muir (3105 m) was installed in the fall of 2006 and has not yet collected enough data to use in finding a lapse rate at the time of writing this protocol. The Muir station is near to the Nisqually Glacier and higher than the weather stations currently used for calculating a lapse rate. Once the data becomes reliable and accessible, the Paradise to Muir lapse rate will be more accurate then what is currently calculated. As of the time of writing, weather data is accessible from the website http://www.nwac.us/products/archive/osomur_archive.htm and only for a 10 day archive. Also, a protocol will soon become available describing the archival procedures and locations of future data sets. Until then, contact MORA Resource Management staff for data.

b) Determine the linear relationship with altitude (dependent variable) and temperature (independent variable) between the two sites. Freezing level is extrapolated from the linear equation. Input freezing altitude location into stake data worksheet as an additional b_s point.

c) Continue with calculations detailed in SOP 5 (Mass Balance Calculations).

2) Interpolate data from NCEP-NCAR reanalysis grid point. This is a more sophisticated approach which uses upper atmospheric weather conditions collected by a nearby radiosonde (Rasmussen and Conway, 2003). Models calculate the weather data to estimate conditions at defined gridpoints across the country. Uploaded data to the internet may have a delay of a year or greater, limiting vitality of this approach.

a. Find grid point closest to Mount Rainier using the 4 km resolution data on the NCAR NOAA website at www.cdc.noaa.gov/cgi-bin/NARR/plotmonth.pl. At the time of writing, a separate program needs to be installed to sift through and read the large volume of downloadable weather data. Directions for downloading the program can be found at a link through the above website.
b. Download the upper atmospheric monthly average temperature for 450 mb to 700 mb for selected grid point.
c. Determine the linear relationship with altitude (dependent variable) and temperature (independent variable) between sites.
d. Find the freezing altitude.
e. Input freezing altitude into stake data worksheet as an additional b_s data point.
f. Continue with calculations detailed in SOP 5.

Glacier-wide summer balance ($B_{S)}$ estimations can follow two or three regression functions. Splitting the b_s trend line relies on three rules:

1. If R2 ≥ 0.90 and the intersection of zero b_s is within 100 m of the freezing altitude point using all stake data points including the freezing altitude data point, then one single line can be used to represent b_s.

2. If R2 < 0.90 and the intersection of zero b_s is > 100 m of the freezing altitude point using all stake data points including the freezing altitude data point, then break the trend line at stake 1, the highest stake altitude.

3. Specific summer balance (b_s) is always zero m w.e. at elevations above the trend line intersection with zero m w.e.

For the last rule, summer balance cannot be positive therefore is assumed to be zero above the trend line intersection of zero m w.e. This can occur below the summit by as much as 700 m.

Field Procedures

Winter Balance:
If a field visit is made above the highest stake locations in summer, the following should be considered. The trip is made in early to mid-July and the upper mountain is traversed in one day from Camp Muir up the Disappointment Cleaver Route to the summit crater and then down the Emmons Glacier Route to Camp Schurman. See SOP 1 (Field Season Time Line, Preparations, and Procedures) for details of tasks, time commitment, personnel, and equipment required for this visit. When time permits take a snow core to determine the depth of the summer surface. Take a snow core at stake 1 on both glaciers and locate the summer surface sediment marker placed the previous fall. SOP 1 and SOP 3 (Snow Density Determination with Snow Core) provides more sediment marker details. Crevasse wall stratigraphy also provides a potential means to measure b_w. When available however, use these observations with caution. Choose to measure depth in vertical walled crevasses in relatively stable areas of the glacier and not in toppling serac zones or other places where significant surface deformation from crevassing/flow occurs. Also compare the uphill and downhill walls of the crevasse.

During the time of this visit it is common that the snowpack temperature below the surface is below freezing which can make probing and coring difficult when the probe and corer freeze into the snowpack. If this is the case and probing is taking too much time on the ascent bypass any further probing until the summit and use the time that you have on snow coring in the summit crater. Obtaining the snow core or digging a snow pit at the summit takes priority.

Summer Balance:
There are no additional field procedures for collecting summer balance measurements above 3,100 m.

References

Rasmussen, L. A., and H. Conway. 2003. Using upper-air conditions to estimate South Cascade Glacier (Washington, U.S.A.) summer balance. Journal of Glaciology 49(166):456–462.

SOP 8. Watershed-wide Glacier Runoff Calculations

Version 6/10/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures and Tables

Overview and Explanation

Determining the watershed-wide glacial contribution to summer streamflow is a measurable objective of this protocol. Glacial contributions to summer streamflow are estimated using summer balance data from the index glacier in each watershed and the area-altitude distribution of all glaciers in each of two watersheds. Estimates are made annually for the White River watershed and the Nisqually watershed to the furthest up valley gauging station (Figure SOP 8.1). Runoff from bare ice areas and debris-covered ice areas are determined separately.

Procedures

Area-elevation distributions of glacierized areas for each of the two selected watersheds are determined using GIS analysis. This analysis determined glacierized area in 50 m elevation bands for each watershed. Glacier extents from the most recent GIS inventories are used. The GIS procedure is in the last section of this SOP.

The glacierized area for each 50m band in the watershed is multiplied by the summer balance for that elevation band to determine summer glacial runoff. Values from each 50m band are summed to determine total glacier runoff for a given watershed. These estimates are compared as a percentage of the total summer runoff for USGS river gages as reported in the Water Resources Data Report Washington.

Required data

1. Annual summer balance (b_s) versus altitude (z) functions of bare ice and debris-covered ice for Nisqually and Emmons Glacier.

2. Annual total Summer Mass Balance (B_S) for Nisqually and Emmons glaciers.

3. Watershed-wide glacier area by 50-meter elevation band for Nisqually and White River watersheds. Generated from GIS analysis (see GIS procedure below) using the latest glacier inventory data.

4. USGS stream runoff data as reported in the Water Resources Data Report, Washington from:
    a. Nisqually River near National, WA; USGS #12082500 (Watershed area of gage = 340 km^2): http://nwis.waterdata.usgs.gov/wa/nwis/dv?format=html&period=550&site_no=12082500
    b. White River above Boise Creek at Buckley, WA USGS Gage #12099200 (Watershed area of gage = 1064 km^2) http://nwis.waterdata.usgs.gov/nwis/dv?site_no=12099200

    Download “Discharge” (tab separated) from this site for the Water Year (October 1-September 31) of interest. Note whether this data is “published” or “provisional” and use “published” data if possible. If you use “provisional” data make sure to update it with the “published” data the following year.

5. The existing Excel Workbooks
    - MORA_glacier_runoff.xls”

- "*Glacier*YYYYRunoff.xls" from the previous year

6. The Excel Workbook you'll be creating:
   - "*Watershed*YYYYRunoff.xls" for the current year

Procedure

Tip: Link all data between worksheets and workbooks rather than copying and pasting so that when changes are made all values are automatically updated.

1. First import into Excel, the .txt files of data for each USGS stream gauging station you downloaded of the daily mean streamflow. Call this worksheet USGSYYYY (example USGS2000) and insert this worksheet into the current year watershed workbook "*Watershed*YYYYRunoff.xls" (for example "White2000Runoff.xls"). Data is given in cubic feet per second and will need to be converted to cubic feet per day (multiplier 86400, seconds in a day), to acre feet (af) (multiplier 0.000022957), to cubic meters (m3) (multiplier 1,233.49).

2. Determine the monthly sum of the streamflow gage daily values, then determine the water year (October 1– September 31st) and May through September sums. These are the values that you will link into the "MORA_glacier_runoff.xls" workbook to compare with the glacial contribution to watershed runoff.

3. Each watershed workbook (*Watershed*YYYYRunoff.xls) has a worksheet titled "*Glacier*YYYYBands" in which the runoff by 50-meter band calculations are carried out.

4. Insert/link the b_s vs. z functions determined for each glacier into the applicable worksheet (see step 3 of this list).

5. Apply the b_s vs. z function at the midpoint altitude for each 50-meter elevation band ("ablation from glaciers" columns: "bare ice" and "debris-cover"). See Tables SOP 8.1–2 for current 50-meter elevation band "GlacierYYYYBands" worksheet. These are placed next to the column of area values for each 50 m altitude band ("glacier area"). The product of "ablation from glaciers" and "glacier area" of each band is calculated in the adjacent column ("glacier runoff"). At the bottom of both "bare-ice" and the "debris-cover" ice columns, sum the "glacier runoff" values for all elevation bands. To determine the total watershed-wide glacier contribution to runoff, add both of these quantities together and place the sum at the top of the worksheet beside the cell labeled "Total Glacier Watershed Runoff".

6. Link Total Glacier Watershed Runoff into the appropriate column in the summary worksheet of the "MORA_glacier_runoff.xls" workbook.

7. Summarize and compare the values from step 5 and actual watershed runoff values (from USGS "actual" reports) in the "MORA_glacier_runoff.xls" workbook.

8. Plot results in existing charts in the watershed worksheets. Copy the previous year's, "Glacier Page Table YYYY" worksheet and link the appropriate values in this table.

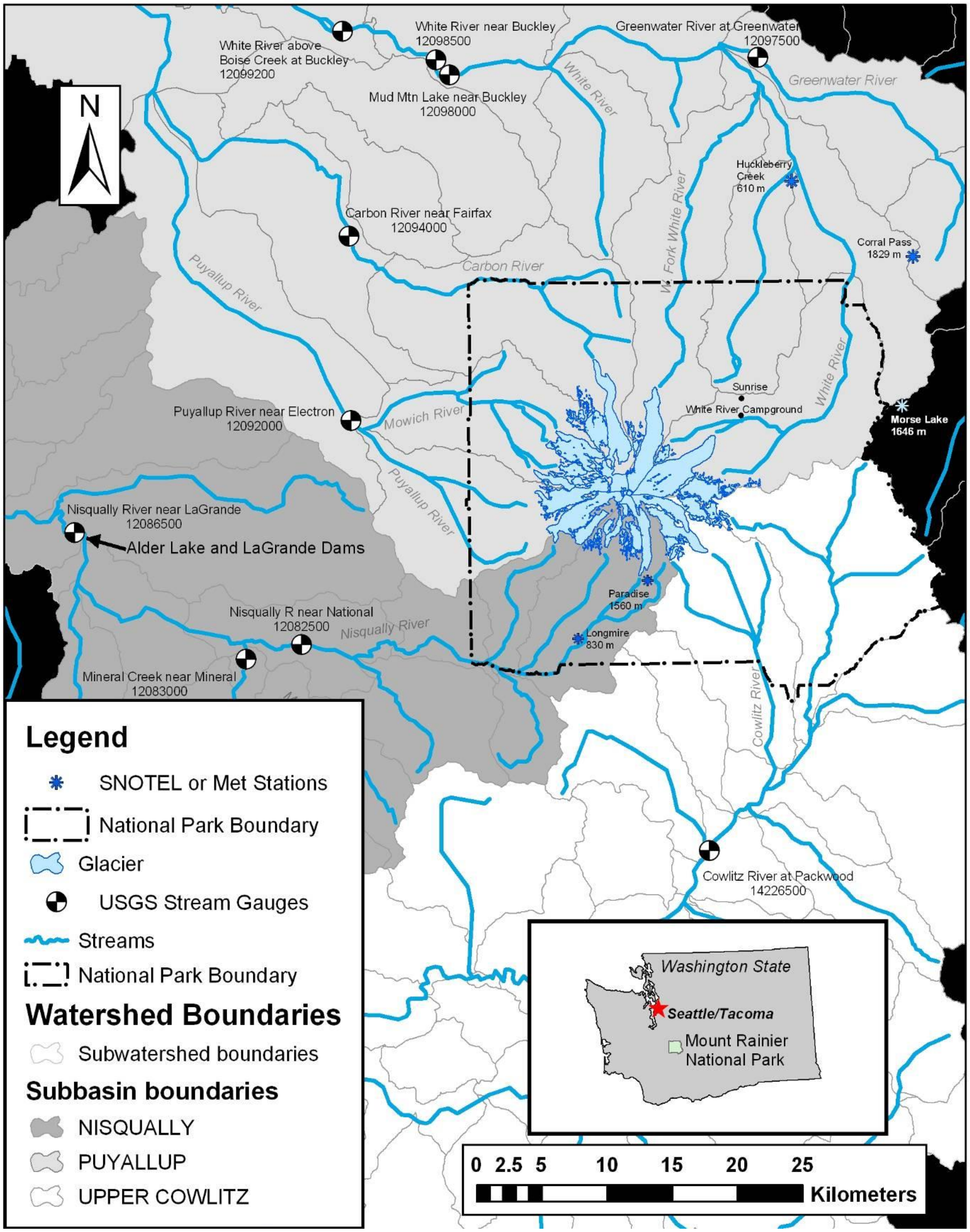

Figure SOP 8.2. Watersheds of Mount Rainier and USGS stream gage and SNOTEL site locations.

Table SOP 8.1 White River Watershed band areas broken down by 50-meter elevations.

White River Watershed-2007

All glacier areas within the White River Drainage system to be included in runoff Caculations

Created 2007- JMW

Data exported from shapefile= White_debris_50mBand and White_bareice50mband

Debris boundary created using Ikonos image and overlaying it on glacier boundary

Bare ice bands

Upper Contour	2006 Ablation from Glacier (m.w.e.)	Glacier Area m2	Glacier Runoff
1700		2352.0215	
1750		37223.3033	
1800		63051.4152	
1850		148282.6403	
1900		175540.5339	
1950		298261.5410	
2000		343575.0123	
2050		398788.9002	
2100		475084.7278	
2150		458928.7088	
2200		447508.4666	
2250		506643.6198	
2300		689744.8874	
2350		815682.2919	
2400		840340.9532	
2450		930405.9006	
2500		1034813.5301	
2550		1075925.1883	
2600		983900.5008	
2650		874649.8694	
2700		760108.3722	
2750		658942.6356	
2800		656191.2721	
2850		624503.4063	
2900		639414.3698	
2950		511078.1194	
3000		503860.7091	
3050		401543.1229	
3100		348761.2736	
3150		322794.2858	
3200		300234.7737	

Debris covered bands

Upper Contour	2006 Ablation from Glacier (m.w.e.)	Glacier Area m2	Glacier Runoff
1450		17656.4165	
1500		139582.4908	
1550		156887.4928	
1600		400294.9996	
1650		492065.4799	
1700		853502.2780	
1750		650470.7980	
1800		523822.6902	
1850		522516.0880	
1900		465607.8600	
1950		267336.7845	
2000		275554.7782	
2050		204496.0791	
2100		177336.6251	
2150		228303.0199	
2200		186669.8042	
2250		152707.9969	
2300		85699.8465	
2350		36414.0184	
2400		27795.2426	
2450		15263.3337	
2500		8792.9392	
2550		11884.9861	
2600		3319.4597	
2650		2866.7666	
2700		5430.2242	
2750		432.2761	

White River Bare ice bands

Upper Contour	2006 Ablation from Glacier (m.w.e.)	Glacier Area m2	Glacier Runoff
3250		255554.4517	
3300		235881.1313	
3350		226406.4321	
3400		211839.9146	
3450		184813.7116	
3500		187296.6314	
3550		178710.846	
3600		188974.494	
3650		159268.9471	
3700		164791.2973	
3750		156800.3829	
3800		159162.1257	
3850		145106.4676	
3900		136950.6548	
3950		143603.5132	
4000		133663.7397	
4050		115427.72	
4100		112425.9741	
4150		80629.479	
4200		67644.9764	
4250		67205.9444	
4300		51368.9441	
4350		13846.2116	

Table SOP 8.2 Nisqually River Watershed band areas broken down by 50-meter elevations.

Nisqually Watershed-50m bands

All glacier areas within the Nisqually River Drainage system to be included in runoff Caculations
Created 2007- JMW
Bare ice data exported from shapefile= UprNis50mbands_bareice
Debris boundaries are as follows:

Nisqually Glacier debris boundary from 2001:	Nsqdebris01_50mbands
Tahoma Glacier debris boundary from Nylen 1994:	Tahomadebris94_50mbands
South Tahoma Glaicer debris boundary from Nylen 1994:	STahomadebris94_50m

Nisqually Watershed Bare Ice 50-meter bands

Upper Contour	Mid Contour	Ablation from Glacier (m.w.e.)	Area m2	Glacier Runoff
1650	1625		6361.2836	
1700	1675		7355.8389	
1750	1725		12852.1552	
1800	1775		26384.4431	
1850	1825		43900.6531	
1900	1875		51434.8345	
1950	1925		40922.7953	
2000	1975		72508.7649	
2050	2025		71555.7361	
2100	2075		123112.8584	
2150	2125		182064.6819	
2200	2175		260913.5870	
2250	2225		360750.2807	
2300	2275		460955.5433	
2350	2325		469088.9810	
2400	2375		527090.6291	
2450	2425		576970.0772	
2500	2475		654584.4315	
2550	2525		497953.8852	
2600	2575		571697.4472	
2650	2625		540308.2701	
2700	2675		532338.9258	
2750	2725		521781.2158	
2800	2775		520558.5113	
2850	2825		535802.1894	
2900	2875		522989.2819	
2950	2925		531371.7111	
3000	2975		434639.8707	
3050	3025		349692.0519	
3100	3075		274575.4833	
3150	3125		242373.4593	
3200	3175		234737.9905	
3250	3225		185517.8200	
3300	3275		134369.1906	
3350	3325		126964.9338	
3400	3375		108762.3430	
3450	3425		87317.5089	
3500	3475		80464.0715	
3550	3525		98693.8795	
3600	3575		96568.1438	
3650	3625		96441.4544	
3700	3675		105040.3852	
3750	3725		108151.4414	
3800	3775		125226.0623	
3850	3825		128126.8964	
3900	3875		111740.8496	
3950	3925		126793.3753	
4000	3975		129419.8674	
4050	4025		129757.5000	
4100	4075		145896.1432	
4150	4125		160064.7820	
4200	4175		185837.1811	
4250	4225		252667.2826	
4300	4275		348421.0512	
4350	4325		96562.6590	
4400	4375		33173.4372	

Nisqually Watershed Debris Covered 50-meter bands

Upper Contour	Mid Contour	Ablation from Glacier (m.w.e.)	Area m2	Glacier Runoff
1500	1525		8183.5041	
1550	1575		26591.5432	
1600	1625		45500.3867	
1650	1675		49541.2541	
1700	1725		59538.9811	
1750	1775		144168.9492	
1800	1825		160609.8604	
1850	1875		150314.0910	
1900	1925		150754.6079	
1950	1975		109376.1620	
2000	2025		114417.0036	
2050	2075		89531.7488	
2100	2125		93265.3259	
2150	2175		141414.3997	
2200	2225		154863.6458	
2230	2275		111325.0174	
2240	2325		125266.3130	
2250	2375		98214.4552	
2300	2425		63963.6260	
2350	2475		78188.2738	
2400	2525		43762.4285	
2450	2575		40628.0160	
2500	2625		27146.5458	
2550	2675		20367.7468	
2600	2725		29174.9823	
2650	2775		17321.9132	
2700	2825		7647.0624	
2750	2875		7821.4455	
2800	2925		7223.0050	

Creating Elevation Band Contours and Calculating Area using GIS

Getting Started:

In an ArcMap session, add polygon layer of glacier boundaries within the watershed of interest and a TIN of the mountain (or glaciers of interest).

1. Create 50-meter contours
    - Start 3D Analyst:
        - Tools
        - Extensions
        - Make sure “3D Analyst” is check-marked.
    - Insert the 3D Analyst toolbar:
        - View
        - Toolbars
        - Choose 3D Analyst
    - Click the 3D Analyst drop down menu on the toolbar
        - Surface Analysis
        - Contour
            - Choose 50 meter elevation contour
            - Choose an output file path and name
            - Leave other settings as they are.

2. Clip contour lines based on glacier margin
    - Tools
    - Geoprocessing Wizard
    - Check “Clip one layer based on another”
        - 1- Input Layer to Clip: (select contour layer)
        - 2- Polygon Clip Layer: (select glacier boundary)
        - 3- Specify the output shapefile or feature class: (Select folder to save in)
    - (Recommend saving and working on hard drive, in a single folder (folder name should have *no* spaces), as opposed to multi-layered folders, example: C:\Temp).
        - Click OK.
        - Click finish

3. Create new polygon shapefile (to use as recipient feature class in next step)
    - In ArcCatalog, navigate to a location for new layer (C:\Temp)
    - File
    - New
    - Shapefile
    - Name: (type a name) eleband
    - Feature Type: Polygon
    - Edit Spatial Reference
    - Click Import. Navigate to a file with appropriate projections/coordinate system (UTM, Zone 10, NAD 83)
    - Click Add
    - Click OK
    - Click OK

4. Add Fields in Attribute Table

Add new shapefile (from step #2) in to ArcMap
Right click on layer in Table of contents
Select Open Attribute Table
Click on Options in the lower right hand corner
Select Add Field (if grayed out, the correct layer is not added to your map or you are in an “edit session”.
Under Name: (type) Area
Under Type: (select) Double
Click OK
Repeat steps to add second field. For second filed type the following:
Under Name: (type) Uppercont
Under Type: (select) Shortinterger

5. Create Polygons from Geometry

In ArcMap, select the Select Features Tool
Select the layers to use. Using the tool, hold down the mouse and draw a box around area (glacier margin and contour lines should be highlighted).
Under Editor, select Start Editing
Under Task: select Create New Feature
Under Target: select new shapefile (created in step #2)
On topology toolbar, click the Construct Features button (if topology toolbar is not displayed, right click and add/activate it in extensions)
Click OK

(If there are any missing contours in the new shapefile, try again and adjust to a larger tolerance. Try 0.0001)

6. Calculate Area Field

Click on Editor Tool bar
Select Start Editing
Open Attribute Table for elevation band polygon layer (new shapefile created in step #2)
Select the Area column
Right click the top and choose Field Calculator
Click Advanced
Type the following in the first box:

```
Dim dblArea as double
Dim pArea as IArea
Set pArea = [shape]
dblArea = pArea.area
```

In the second box below, type: `dblArea`
Click OK

(If the script has an error, try copying script in the help menu under “area”)

Depending on the version of Arc in use, instead of choosing “Field Calculator” “Calculate Geometry” may be an option. Select this option, it is quicker.

7. Adding Contours by hand

    In an Edit Session:
    Open attribute table
    Under Area field, click each row and manually type in each upper elevation contour
    Spot check entry by highlighting polygon and map simultaneously

(Beware that bands may be broken up. There may be several polygons for a single band elevation.) Save edits once complete.

8. Export Table

    With Attribute Table open (for elevation band shapefile)
    Select the Upper Contour column
        Select Summarize
        Box 1- Select upper contour field
        Box 2- Choose Area- Sum
        Box 3- Output table: (click on browse folder)
        Name: Select folder name
        Save as type: Select .txt file
        Save
        OK

9. Create Excel table

    Open a blank excel file.
    Click on File on main tool bar
        Select Open
        Look in: Navigate to storage space
        Name: Type in name
        Save as type: Select Excel File
        Save
        OK

There may be several polygons for a single band elevation, so you'll have to sum these and consolidate the final results into another table for use in the runoff calculations.

SOP 9. Mass Balance Error Calculations and Determination

Version 6/9/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures and Tables

Overview and Explanation

For quality assurance and quality control of measurable objectives, this SOP describes procedures for estimating field measurement error. The field measurements that are subject to uncertainty and error are snow depth, stake height, snow density, stake/probe position and altitude, and non-synchronous measurements with actual maximum and minimum balances. Positional error associated with measurement locations is discussed in the protocol narrative but not used in determining error on a glacier-wide basis. Other factors such as internal accumulation, superimposed ice, internal melt, and basal melt are considered insignificant compared to errors in surface balance measurements and are therefore ignored (Mayo et al., 1972). Base map errors are also ignored as they are extremely difficult to quantify.

When the data is published in a ten-year report the data are checked for errors and consistency.

Procedures

We estimate error for each measurement or set of measurements collected in the field. These errors are discussed in the protocol narrative and summarized in Table SOP 9.1. Errors must be calculated on an annual, stake-by-stake, glacier-by-glacier basis. Mount Rainier Glacier monitoring protocol design similarly follows the North Cascades methods which includes North Klawatti Glacier. This SOP has example calculations for North Klawatti Glacier in 2002 using the values and equations outlined in Figures SOP 9.1 and SOP 9.2. Errors for b_w, b_s, and b_n at each stake or other probe location are calculated using propagation equations (Bevington and Robinson, 1992; Rasmussen, Personal Comm., 2003).

The uncertainty or error for balance at each measurement location (stake and probe locations where multiple measurements are taken) is calculated from the error determined or estimated from each variable used to calculate balance. What follows is a general explanation of equations that are applied to winter, summer, and net balance errors. The general error propagation equations for multiplication of variables (Eq. 7) and addition of variables (Eq. 8) are derived. The “Uncertainty Calculations” worksheets are where these general equations are applied. To understand how they are applied one should study the “Uncertainty Calculations Formulas” worksheet in the glacier workbook. The references in this worksheet refer to the left-most row labels, 3 to 29, and the top-most column labels, A to J, on the “Uncertainty Calculations” worksheet. The formulas for Stakes 1 and 4 only are included in this worksheet as examples.

Table SOP 9.1. Summary of error values for variables measured in the field.

Variable	Estimated Error	Comments
Single probe measurement	± 0.03 meter depth	
Multiple probe measurements	Standard deviation	Calculated from measurements at location
Single stake measurement	± 0.03 meter depth	
Stake sinking	NA	Ignored on an annual basis. Assessed in decadal surface elevation change analysis.
Snow density	0.50 ± 0.03	No direct measurement
Snow density	± 0.02	One measurement on glacier
Snow density	± 0.01	Two measurements on glacier
1-yr-old firn density	± 0.05	estimated error
2-yr-old firn density	± 0.05	estimated error
ice density	± 0.05	estimated error
Stake position (z)	± 10 meters	Not used in error determination.
Stake position (x-y)	± 10 meters w/GPS ± 30 meters wo/GPS	Not used in error determination.
Non-synchronous measurements with actual minimum and maximum balances	See comments.	If significant adjusted with South Cascade Glacier b vs. z data.

Estimated Error at Each Measurement Location

Variances (σ^2) for each variable are used and carried through the error propagation equations. Standard Deviations (σ) are easily determined once all variables are considered and carried through.

The general error propagation equation (Bevington and Robinson, 1992) is:

$$\sigma_x^2 = \sigma_u^2(\delta x/\delta u)^2 + \sigma_v^2(\delta x/\delta v)^2 + \ldots + 2\sigma_{uv}^2(\delta x/\delta u)(\delta x/\delta v)\ldots \qquad \text{(Eq. 5)}$$

In all cases for application for glacier error calculations the errors are assumed to be uncorrelated therefore the covariances, $\sigma_{uv}^2 = 0$ and the equation is simplified. Below this equation is applied for multiplication and addition operations involving two or more variables with an assigned error for each one.

In the case where two variables are multiplied together for example at a stake: $b = h * \rho$ where b = balance, h = snow, firn, or ice depth, and ρ = snow, firn, or ice density. Errors determined for h and ρ are assumed to be standard deviations and the variances are easily calculated. The partial derivatives are functions of the other variables:

$$(\delta b/\delta h) = \pm a\rho \text{ and } (\delta b/\delta \rho) = \pm ah \qquad \text{(Eq. 6)}$$

In this case we set a = 1 because the variables are unweighted and the error propagation equation becomes:

$$\sigma_b^2 / b^2 = \sigma_h^2/h^2 + \sigma_\rho^2/\rho^2 \qquad \text{(Eq. 7)}$$

In the case where two or more variables are added together, for example

$$b_s = b_{snow} + b_{firn} + b_{ice} \qquad \text{(Eq. 8)}$$

where b_s = summer balance (water equivalent), b_{snow} = snow ablation, b_{firn} = firn ablation, b_{ice} = ice ablation. Again the covariances = 0.

$$\sigma_{bs}^2 = \sigma_{bsnow}^2 + \sigma_{bfirn}^2 + \sigma_{bice}^2 \qquad \text{(Eq. 9)}$$

To continue the example through, the combined error for b_s at stake is the combination of Equations 8 and 9:

$$\begin{aligned}\sigma_{bs}^2 = {} & (\sigma_{hsnow}^2/h_{snow}{}^2 + \sigma_{\rho snow}{}^2/\rho_{snow}{}^2)/\ \sigma_{bsnow}^2 \\ & + (\sigma_{hfirn}^2/h_{irn}{}^2 + \sigma_{\rho firn}{}^2/\rho_{firn}{}^2)/\ \sigma_{bfirn}^2 \\ & + (\sigma_{hice}{}^2/h_{ice}{}^2 + \sigma_{\rho ice}{}^2/\rho_{ice}{}^2)/\ \sigma_{bice}^2\end{aligned} \qquad \text{(Eq. 10)}$$

Propagation of Uncertainties in Glacier-wide Mass Balance Calculations

To come up with an overall estimate of error for a balance value (associated with a set of measurements) the variances for each measurement location are averaged.

$$\sigma_b^2 = (\sigma_{stk1}^2 + \sigma_{stk2}^2 + ... + \sigma_{prb1}^2 + \ldots + \sigma_n^2) / n \qquad \text{(Eq. 11)}$$

This is perhaps not the most statistically rigorous method but it yields a relative error estimate that is comparable between balance years and glaciers. An example calculation sheet is included below for North Klawatti Glacier, 2002. Error estimates for this glacier from this year are σ_{bw} = 0.29, σ_{bs} = 0.22, and σ_{bn} = 0.32. For comparison estimated errors for Emmons Glacier, 2003, are σ_{bw} = 0.54, σ_{bs} = 0.85, and σ_{bn} = 1.00. All quantities are meters water equivalent. Variances (σ^2) for each variable are used and carried through the error propagation equations. Uncertainties are reported in the Summary worksheet (for an example, see Figure SOP 5.3 Balance Calculations).

Cumulative Error Comparison

An independent means of testing mass balance measurements cumulatively is with ~10 year surface mapping. Every 10 years a DEM of each glacier will be generated from aerial photography. This will allow a direct comparison of cumulative balance change from the map with cumulative balance measured annually at the surface.

	A	B	C	D	E	F	G	H	I	
3	Station:	1	2	3	4	5	4B		**Averages**	
4	Elevation	2337	2236	2110	1988	1902	1997			
5	Snow Depth(d):	7.20	7.27	7.35	6.49	6.18	6.25			
6	Variance of d:	0.0276	0.013	0.053	0.012	0.05	0.88			
7	Density(p):	0.50	0.50	0.50	0.50	0.50	0.50			
8	Variance of p:	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009			
9										
10	Ice melt (hi):	na	na	na	1.78	1.33				
11	Std Dev hi:	na	na	na	0.11	0.22				
12	variance of hi:	na	na	na	0.013	0.047				
13	bsi:	na	na	na	1.60	1.20				
14	Density(p):	na	na	na	0.9	0.9				
15	Variance of p:	na	na	na	0.0025	0.0025				
16	**Variance of bsi:**	**na**	**na**	**na**	**0.018**	**0.042**				
17										
18	bw:	3.60	3.63	3.67	3.24	3.09	3.12			
19	Variance of bw:	0.054	0.052	0.063	0.041	0.046	0.25			
20	**Std Dev of bw:**	**0.23**	**0.23**	**0.25**	**0.20**	**0.21**	**0.50**		**0.29**	**bw**
21	Std Dev of depth:	0.17	0.11	0.23	0.11	0.21	0.94			
22										
23	bs:	-2.80	-3.27	-3.14	-4.84	-4.29				
24	Variance of bs:	0.028	0.039	0.036	0.059	0.088				
25	**Std Dev of bs:**	**0.17**	**0.20**	**0.19**	**0.24**	**0.30**			**0.22**	**bs**
26										
27	bn:	0.80	0.36	0.53	-1.60	-1.20				
28	Variance of bn:	0.083	0.090	0.099	0.10	0.13				
29	**Std Dev of bn:**	**0.29**	**0.30**	**0.31**	**0.32**	**0.37**			**0.32**	**bn**

Figure SOP 9.1. Example of uncertainty calculations for the North Klawatti Glacier 2002. Lettered and numbered rows and columns refer to equations in Figure SOP 9.2.

Station:	1	2	3	4	5	4b		**Averages**	
Elevation	2337			1988					
Snow Depth(d):	7.20			6.49					
Variance of d:	0.0276			0.012					
Density(p):	0.50			0.50					
Variance of p:	=0.03^2			=0.03^2					
Ice melt (hi):	na			1.78					
Std Dev hi:	na			=SQRT(E12)					
variance of hi:	na			=E6+0.03^2					
bsi:	na			=E10*E14					
Density(p):	na			0.9					
Variance of p:	na			=0.05^2					
Variance bsi:	**na**			**=((E12/E10^2)+(E15/E14^2))*E13^2**					
bw:	=B5*B7			=E5*E7					
Variance bw:	=(((B6/B5^2)+(B8/B7^2))*B18^2)+0.03^2			=(((E6/E5^2)+(E8/E7^2))*E18^2)					
Std Dev bw:	**=SQRT(B19)**			**=SQRT(E19)**				**=SQRT(SUM(B19:G19)/COUNT(B19:G19))**	**bw**
StdDevDpth	=SQRT(B6)			=SQRT(E6)					
bs:	-2.80			-4.84					
Variance of bs:	=((0.03^2/'Data and Stk-Area Balance'!C27^2)+(0.03^2/0.5^2))*B23^2			=E16+E19					
StdDev of bs:	**=SQRT(B24)**			**=SQRT(E24)**				**=SQRT(SUM(B24:F24)/COUNT(B24:F24))**	**bs**
bn:	=B18+B23			=E18+E23					
Variance bn:	=B19+B24			=E19+E24					
Std Dev of bn:	**=SQRT(B28)**			**=SQRT(E28)**				**=SQRT(SUM(B28:F28)/COUNT(B28:F28))**	**bn**

Figure SOP 9.2. Example of uncertainty calculation formulas for North Klawatti Glacier, 2002. Letters and numbers in equations refer to rows and columns in Figure SOP 9.1.

References

Bevington, P. R., and D. K. Robinson. 1992. Data reduction and error analysis for the physical sciences, Second Edition. McGraw-Hill, Inc, NY.

Mayo, L. R., M. F. Meier, and W. V. Tangborn. 1972. A system to combine stratigraphic and annual mass-balance systems: A contribution to the International Hydrological Decade. Journal of Glaciology 11(61):3–14.

SOP 10. Vertical Aerial Photography Specifications

Version 1/24/2009

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures and Tables

Explanation and Overview

Vertical aerial photographs are taken ten years of each index glacier as a record of decadal change in area, surface elevation, equilibrium line altitude, and snow, firn, and ice coverage. These color photographs are taken in stereo-pairs at 1:12,000 scale late in the ablation season, around mid to late September, before the first winter snow covers the glacier. It is extremely important that no significant cover of new snow overlies the surface of the glacier at the time of photography. The photo prints are archived at the NPS office for reference and future use, and negatives are retained by the contractor.

Mount Rainier Glaciers

- Flight lines designed to maintain ~1:12,000 scale over altitude ranges of glaciers (see Figure SOP 10.1 and Table SOP 10.1 for photo centers locations and coordinates).
- 6-inch focal length lens.
- See attached maps for target areas (Emmons and Nisqually). The target areas should have good stereo coverage (see "General" section for specifics).
- Use flight lines most appropriate for photogrammetric construction of a DEM with 30-meter grid spacing.

General

- In the future, center coordinates of photos from airborne GPS will be provided in Universal Trans Mercator (UTM) grid system, Zone 10, horizontal datum: NAD83, vertical datum: NGVD 1988 using meters for units.
- NPS receives a single set of color contact prints.
- NPS receives digital images of the film diapositives which need to be scanned at 15 micron resolution and stored in .tiff format on a CD or DVD (depending on the size of the files).
- Stereo pairs (60% overlap minimum)
- Photos will have NORTH indicated on photos.
- Contrast between bare glacier ice (blue/gray) and snow on upper part of glacier must be visible.
- Exposures made with the optical axis of the camera in a vertical position are desired. Tilt or departure from vertical on any exposure exceeding four degrees, or relative tilt between any two successive exposures exceeding six degrees, may be cause for rejection of any or all of the flight lines.
- Any series of two or more photographs crabbed in excess of five degrees, as measured between photographs in the same flight line and between adjoining flight lines, may be cause for rejection of any or all of the flight lines.
- Desired endlap is 65%. Minimum allowable endlap is 60% per photo; maximum is 70%.
- Desired sidelap is 31%. Minimum allowable sidelap is 20% per photo;maximum is 40%.

Table SOP 10.1. Aircraft GPS photo center coordinates. Prepared by Orion GPS, Inc, air photos by Bergman Photographic Services, Portland, OR. UTM Zone 10; Horizontal datum: NAD 1927 (CONUS); Vertical datum: NGVD 1929; Geoid model: Geoid03 (CONUS).

Photo Label	Photo Center ID	Northing (m)	Easting (m)	Aircraft Altitude (m)	UTC Time	Date Taken
Nisqually 1-1	1001	5183176.41406	593786.11072	3837.375	20:24:18	10/2/2004
Nisqually 1-2	1002	5183191.13683	594813.48977	3836.256	20:24:30	10/2/2004
Nisqually 1-3	1003	5183203.98507	595874.63843	3839.880	20:24:43	10/2/2004
Nisqually 1-4	1004	5183214.60184	596895.00210	3843.544	20:24:56	10/2/2004
Nisqually 1-5	1005	5183229.75538	597856.16538	3848.134	20:25:08	10/2/2004
Nisqually 2-1	2001	5185912.21830	593513.01965	4768.306	20:18:08	10/2/2004
Nisqually 2-2	2002	5185952.86504	594178.39078	4762.121	20:18:00	10/2/2004
Nisqually 2-3	2003	5185986.15209	595285.89750	4759.030	20:17:47	10/2/2004
Nisqually 2-4	2004	5185971.52907	596449.95693	4756.734	20:17:32	10/2/2004
Nisqually 2-5	2005	5185950.13534	597589.72964	4753.173	20:17:19	10/2/2004
Nisqually 3-1	3001	5188653.84588	593462.28496	6024.249	19:53:25	10/2/2004
Nisqually 3-2	3002	5188696.88211	594509.15925	6022.328	19:53:37	10/2/2004
Nisqually 3-3	3003	5188726.47351	595714.49857	6028.810	19:53:51	10/2/2004
Nisqually 3-4	3004	5188736.90323	597224.79314	6038.113	19:54:08	10/2/2004
Nisqually 3-5	3005	5188746.18158	598830.27611	6044.347	19:54:26	10/2/2004
Emmons 4-1	4001	5186976.01321	598308.62222	5952.490	20:00:39	10/2/2004
Emmons 4-2	4002	5188301.02268	597210.64771	5953.047	20:01:00	10/2/2004
Emmons 4-3	4003	5189448.95905	596266.55887	5948.574	20:01:18	10/2/2004
Emmons 4-4	4004	5190446.78455	595418.87195	5951.425	20:01:33	10/2/2004
Emmons 4-5	4005	5191428.21901	594623.02841	5964.820	20:01:49	10/2/2004
Emmons 4-6	4006	5192684.62539	593641.42048	5959.973	20:02:08	10/2/2004
Emmons 5-1	5001	5189094.66131	600064.61317	4747.795	20:11:27	10/2/2004
Emmons 5-2	5002	5189878.99386	599387.38613	4752.866	20:11:16	10/2/2004
Emmons 5-3	5003	5190688.87772	598692.63577	4756.236	20:11:04	10/2/2004
Emmons 5-4	5004	5191564.35434	597976.83650	4752.341	20:10:52	10/2/2004
Emmons 5-5	5005	5192403.94560	597292.29000	4743.950	20:10:40	10/2/2004
Emmons 6-1	6001	5190995.91660	602025.34389	3843.426	20:28:42	10/2/2004
Emmons 6-2	6002	5191794.89395	601388.06883	3844.682	20:28:54	10/2/2004
Emmons 6-3	6003	5192582.53405	600737.06111	3839.557	20:29:07	10/2/2004
Emmons 6-4	6004	5193364.78191	600105.14192	3838.369	20:29:19	10/2/2004
Emmons 6-5	6005	5194145.05124	599482.89006	3840.537	20:29:31	10/2/2004

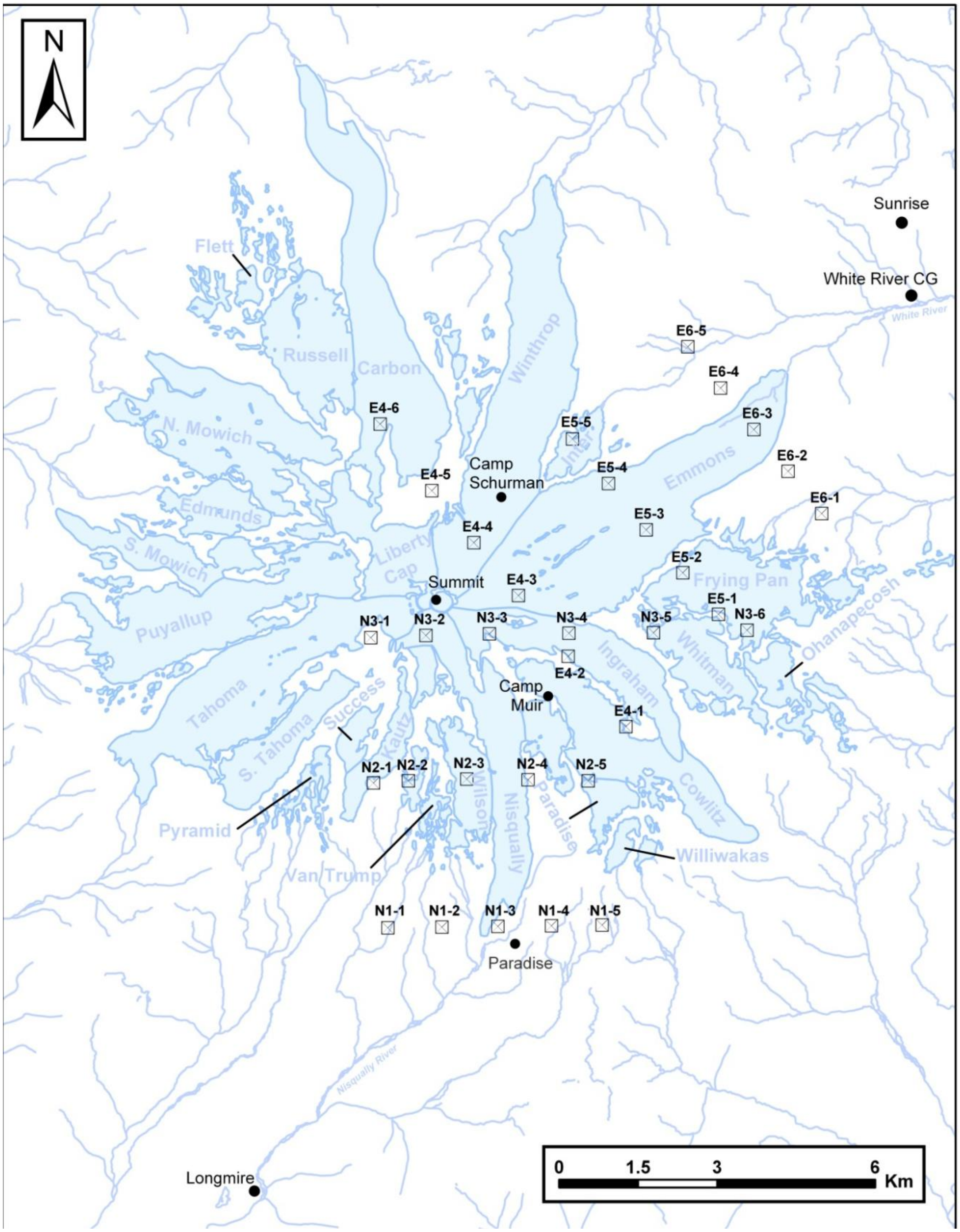

Figure SOP 10.1. Location of air photo centers and flightlines from 2004 flights for Nisqually and Emmons glaciers. Each flightline is at a different elevation to maintain a scale of approximately 1:12,000. The labels in this figure refer to the Photo Labels in Table SOP 10.1 (N is for Nisqually, E is for Emmons).

SOP 11. Ten-Year Glacier Mapping and Volume Change Determination Specifications

Version 6/25/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures and Tables

Overview and Explanation

Glacier contour maps and digital terrain models (DTMs) have important functions in this monitoring program. First, contour maps provide the basis for planning and executing field work. They allow planning of stake placement and for navigation in the field. They also supply the stake altitudes for generating balance vs. altitude curves. Second, DTMs provide a record of glacier surface elevations and conditions (debris and crevasse coverage) for the date of the air photos from which they were derived. They provide a basis for periodic comparison of changes in area, surface elevation, and volume, as well as derivative surface changes such as slope, aspect, surface roughness, and curvature (Etzelmuller and Sollid, 1997).

Vertical aerial photographs are taken at least every ten years (or more frequently when funding allows) of the index glaciers to assess extent/margin and terminus position, debris cover, crevassed area, equilibrium line altitude, and to measure the area of the glacier covered by snow, firn, and ice. These color photographs are taken in stereo-pairs at 1:12,000 scale late in the ablation season (September), before the first winter snow covers the glacier (for detailed specifications see SOP 10. Glacier Vertical Aerial Photography). The photo prints are archived at the NPS office for reference and future use, and negatives are retained by the contractor. For years in which maps are made by “softcopy”, the film diapositives need to be scanned at 15 micron resolution and stored in .tiff format on a CD or DVD (depending on the size of the files).

The glaciers are remapped every 10 years to assess area changes, advance/retreat of termini, surface elevation/volume changes, and to provide accurate base maps for mass balance calculations. Glaciers are mapped and the area and volume change is quantified by photogrammetry, high precision GPS survey, or LiDAR analysis. In addition the analysis compares changes in altitude, slope, and curvature, which are key indicators in longer term changes in glacier mass balance (Etzelmuller and Sollid, 1997; Jacobsen and Theakstone, 1997).

In order to take advantage of minimal snow conditions that make for more useable images for photogrammetry and aiding in precision GPS survey methods, the 10-year cycle may be adjusted by one or two years, provided suitable photography is taken. Mapping should be done in years of minimal snow because anomalously high snow can (1) obscure the terminus and make it impossible to derive significant terminus change results and (2) make the surface elevation change comparison less meaningful because the amount of snow remaining is anomalously high. Plus the high albedo of snow can make mapping difficult and less accurate.

Accurate results from the photogrammetric analysis rely on attention to detail in three different areas:

1. Vertical air photos must meet the specifications outlined in SOP 10 (Glacier Vertical Aerial Photography). This is important for good image quality, glacier surface condition, and sufficient stereo coverage of the glacier and surrounding photo identifiable, geodetically constrained, ground control points (photo ID points). In addition, the party that will undertake the photogrammetric mapping should have input into the configuration of the vertical air photos (i.e. flight lines and altitudes).

2. A network of well constrained and internally consistent photo ID points that are repeatedly identifiable from air photos taken in different years. See Tables SOP 11.1–2

and Figures SOP 11.1–2 for the coordinates and locations of photo ID points for each glacier.

3. Finally, comparable and compatible photogrammetric methods should be employed for each air photo year that is analyzed. Ideally, this analysis is done by the same photogrammetric operator, however this is not necessarily realistic when obtaining government contracts and in long term monitoring. For this reason, the methods should be documented in detail as well as for long term institutional memory. It is imperative that a close working relationship be maintained during the project with NPS staff, particularly if the photogrammetrist is not familiar with glaciers. Another way to handle this consistency problem is to have one operator create the photogrammetric models for two or more air photo years. This will allow for maximum accuracy.

When these three issues are addressed, the results can produce very low errors of ± 0.40 m in the horizontal and ± 0.75 m in the vertical (Ostrem and Haakensen, 1999).

To ensure mapping precision for GPS survey method defined ground control locations, transects, and profile points are visited each mapping year with a real-time kinematic (RTK) survey. This requires a base station, rover unit, and a radio connection between the two.

When using photogrammetry or high precision GPS survey methods, it is imperative that bedrock areas outside of the glacier boundaries be mapped to provide comparison of DTMs of different vintages.

Affordability and technology improvement in LiDAR may make surface mapping by this method viable in the future. However, good photo identifiable ground control points are still necessary.

Previous Topographic Mapping of Mount Rainier Glaciers

The first accurate map of the glaciers of Mount Rainier was completed by the USGS in 1955 from regional surveys done over 40 years earlier in 1910, 1911, and 1913 (Matthes, 1912; 1913; 1914a; 1914b; 1915). In 1971 the USGS revised this map from air photos taken in 1970 (USGS Project GS-VCHN). These air photos and other project materials are stored at the USGS Mapping Division Office at the Denver Federal Service Center.

Between 1931 and 1946, the USGS, the NPS, and the Department of Public Utilities of the City of Tacoma mapped the lower third of the glacier five times to evaluate the hydroelectric potential of the Nisqually River (Bender and Haines, 1955). After that most of or all of Nisqually Glacier was mapped periodically by the USGS. In 1951 the glacier was mapped to approximately 3350 m (11,000 feet). In 1956, 1961, and 1966 the glacier was mapped to approximately 3960 m (13,000 feet). In 1971 and 1976 the entire glacier was mapped from summit to terminus. All maps were published by the USGS. Nisqually Glacier was mapped to approximately 3950 feet by the USGS from 1980 air photos but this data was never published. All of the USGS maps have been digitized and analyzed by Nylen (2002).

More recently, Malone (1994) mapped topography and termini of the lowermost Emmons, Carbon, Nisqually, and Tahoma glaciers using photogrammetry of 1990 air photos. Most recently, the termini of Carbon, Emmons, Cowlitz/Ingraham, Nisqually, South Tahoma and Tahoma glaciers were updated from 1994 air photography by Andrew Fountain at Portland State University and the Digital Line Graph, DLG, for the glaciers was updated by the USGS (Nylen, Personal Comm., 2003). The most recent DEM from the USGS has updated topography (since the 1971 mapping) for the lower glaciers, but it is not clear at this time, which photography this most recent update is from.

Photo ID Points

The network of control points around the glaciers of Mount Rainer has developed as a result of terrestrial surveying and photogrammetrical mapping needs. The network of points for each glacier listed in Table SOP 11.1 were used for the 1971 Mount Rainier map and the Nisqually Glacier maps of 1951 through 1980. A network of survey points was established by Hodge (1972) for the Nisqually Glacier, many of those were approved by the USGS as 3rd Order Control. Control point locations are identified on 2001 air photos in Figures SOP 11.3–17.

Procedure

Mapping and Surface Elevation Change Approaches

Options for stereographic model and map generation:

1. Grid-of-points-DTM, directly from stereographic model as in Krimmel (1996, 1999). Then generate contours from elevations at these points.

2. Softcopy DTM as by SAM, Inc. (2003)

Options for surface elevation change comparison:

1. Use volume change comparison method of Krimmel (1999) which compares surface change at each grid point. If previous grid-of-points DTM does not exist then if time and resources are available do photogrammetry on all available stereo air photos in same “session” with same photogrammetric operator, as in Krimmel’s study. Otherwise if only old contour maps are available use a grid-of-points generated from a TIN generated from those past maps, as in Andreassen (1999).

2. Produce a raster grid from a TIN generated from either option 1 or 2 above. Then use 10 meter cell size for comparison of surface elevation change as by SAM, Inc. (2003).

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Table SOP 11.1. Photo ID point coordinates for Emmons Glacier.

Point Name	Suggested Control	Survey Method	USGS Source	DATE	Easting (X)	Northing (Y)	Elevation (Z)	USE?	Vertical Datum	Horizontal Datum
pt4822	full	unknown	spot elevation	1971	602064.095	5194311.074	1469.763	yes	NGVD1929	NAD27
pt6491	vert	unknown	spot elevation	1971	601036.891	5191017.890	1978.481	yes	NGVD1929	NAD27
pt6714	full	unknown	spot elevation	1971	601390.495	5191663.751	2046.452	yes	NGVD1929	NAD27
pt6723	full	unknown	spot elevation	1971	599778.750	5193028.630	2049.195	yes	NGVD1929	NAD27
pt6735	full	unknown	spot elevation	1971	599489.560	5192800.890	2052.853	yes	NGVD1929	NAD27
pt6772	full	unknown	spot elevation	1971	601891.798	5193090.654	2064.131	yes	NGVD1929	NAD27
pt7746	full	unknown	spot elevation	1971	599870.070	5190480.050	2361.010	yes	NGVD1929	NAD27
Whitman	full	Triangulation	3rd Order	1971	600525.225	5188070.531	2574.494	no	NGVD1929	NAD27
pt8690	full	unknown	spot elevation	1971	597919.380	5192019.990	2648.744	yes	NGVD1929	NAD27
pt8886	full	unknown	spot elevation	1971	599252.179	5190057.908	2708.486	yes	NGVD1929	NAD27
pt9323	full	unknown	spot elevation	1971	600177.819	5188938.721	2841.685	yes	NGVD1929	NAD27
LttleTahoma		Intersected	supplemental horizontal	1971	598300.528	5189043.159	3394.782	no	NGVD1929	NAD27
LT_RVSD	full	adjusted to DEM	10-meter DEM	1971	598310.345	5189060.156	3394.782	yes	NGVD1929	NAD27

Table SOP 11.2. Photo ID point coordinates Nisqually Glacier.

Point Name	Suggested Control	Survey Method	USGS Source	DATE	Easting (X)	Northing (Y)	Elevation (Z)	USE?	Vertical Datum	Horizontal Datum
MtRainier	full	Triangulation	USGS 3rd Order	1956	594630.474	5189412.895	4386.888	yes	NGVD1929	NAD27
Swat	Full	Triangulation	USGS 3rd Order	1976	595665.990	5182043.260	1596.500	yes	NGVD1929	NAD27
Nunatak	Full	Triangulation	USGS 3rd Order	1976	595851.500	5183070.549	1615.306	yes	NGVD1929	NAD27
Burp	Full	Triangulation	USGS 3rd Order	1976	596156.994	5183181.389	1706.800	yes	NGVD1929	NAD27
Fuzzy	Full	Triangulation	USGS 3rd Order	1976	596361.180	5183713.630	1842.300	yes	NGVD1929	NAD27
Cheek		Triangulation	USGS 3rd Order	1976	596548.980	5184239.260	1918.400	no	NGVD1929	NAD27
Stoned	Full	Triangulation	USGS 3rd Order	1976	596575.774	5183667.617	1931.332	yes	NGVD1929	NAD27
Toenail	Full	Triangulation	USGS 3rd Order	1976	596661.630	5183912.520	1971.300	yes	NGVD1929	NAD27
Chipmunk	Full	Triangulation	USGS 3rd Order	1976	596860.304	5184189.146	2068.789	yes	NGVD1929	NAD27
Cornice	Full	Triangulation	USGS 3rd Order	1976	595724.560	5184655.660	2082.150	yes	NGVD1929	NAD27
Hangover		Triangulation	USGS 3rd Order	1976	595517.550	5184227.450	2115.900	no	NGVD1929	NAD27
HR_Rvsd	full	adjusted to DEM	USGS 10-m DEM	1971	595484.404	5184243.593	2115.900	yes	NGVD1929	NAD27
Boomerang	Full	Triangulation	USGS 3rd Order	1976	596536.610	5185154.490	2145.200	yes	NGVD1929	NAD27
Stab	Full	Triangulation	USGS 3rd Order	1976	597037.910	5184686.510	2150.000	yes	NGVD1929	NAD27
McClure		Triangulation	USGS 3rd Order	1961	597534.189	5184492.206	2250.923	no	NGVD1929	NAD27
pt2307	full	unknown	USGS spot elevation	1976	596687.140	5185319.250	2307.000	yes	NGVD1929	NAD27
pt2552	full	unknown	USGS spot elevation	1976	596466.950	5186280.140	2552.000	yes	NGVD1929	NAD27
pt2792	full	unknown	USGS spot elevation	1976	595582.500	5186586.520	2792.000	yes	NGVD1929	NAD27
pt3064	full	unknown	USGS spot elevation	1976	595387.650	5186913.100	3064.000	yes	NGVD1929	NAD27
CmpMuir	full	unknown	USGS spot elevation	1976	596738.740	5187463.330	3073.000	yes	NGVD1929	NAD27
pt3334	full	unknown	USGS spot elevation	1976	595343.069	5187308.567	3334.000	yes	NGVD1929	NAD27
pt3869	full	unknown	USGS spot elevation	1976	595737.697	5188600.288	3869.000	yes	NGVD1929	NAD27

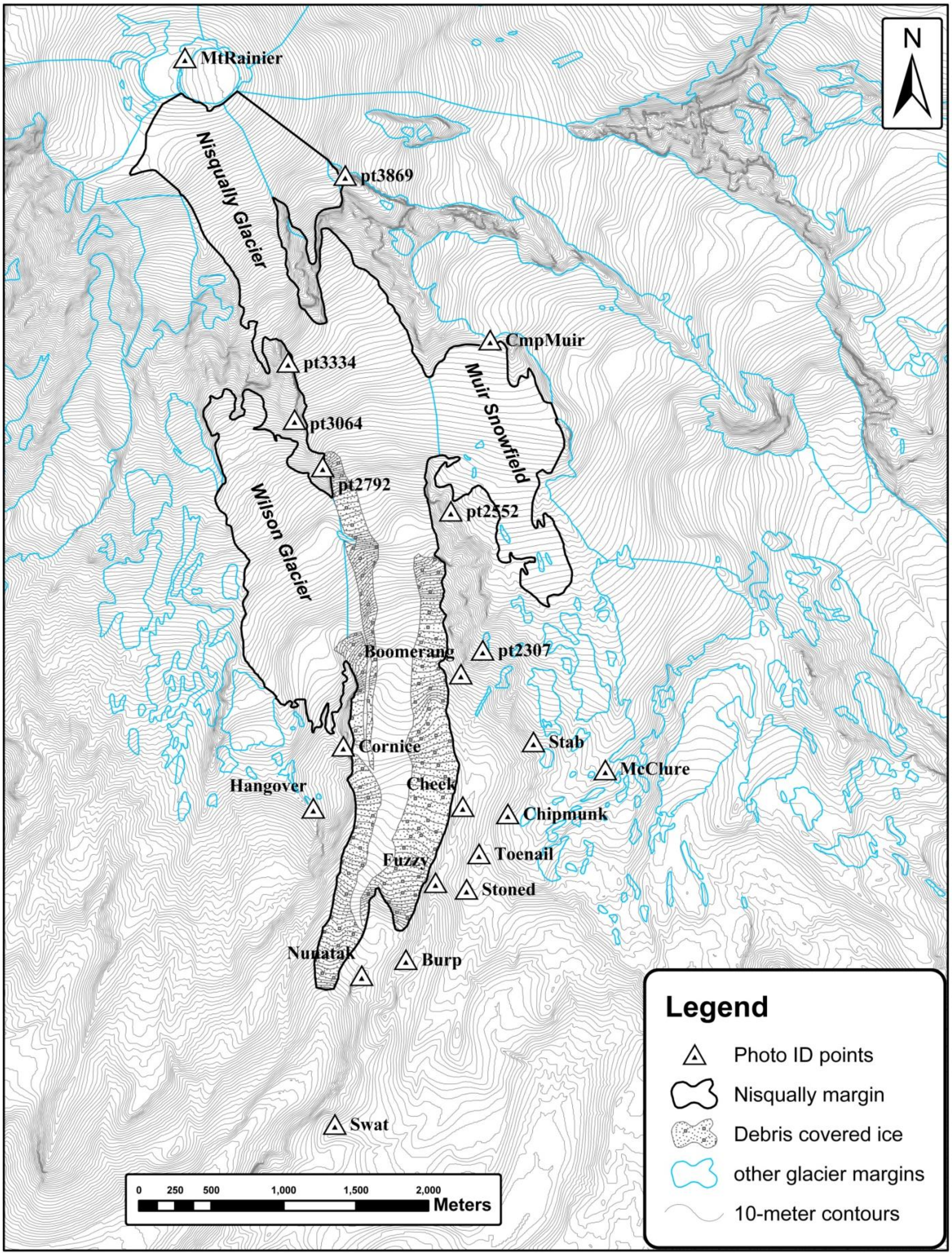


Figure SOP 11.1. Photo identifiable ground control points surrounding Nisqually Glacier.

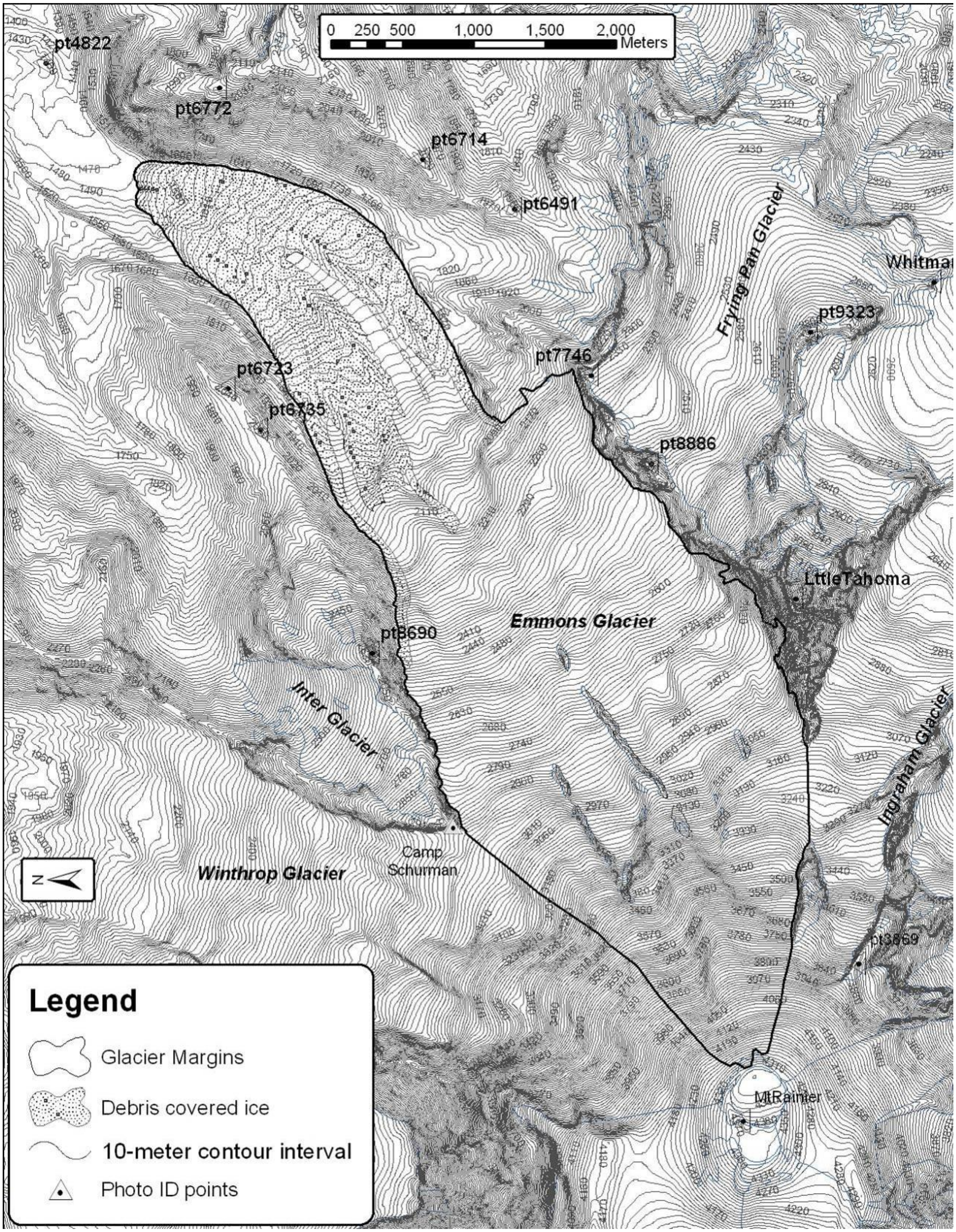


Figure SOP 11.2. Photo identifiable ground control points surrounding Emmons Glacier.

Figure SOP 11.3. Photo identifiable ground control points surrounding Nisqually Glacier.

Figure SOP 11.4. Photo identifiable ground control points surrounding Nisqually Glacier.

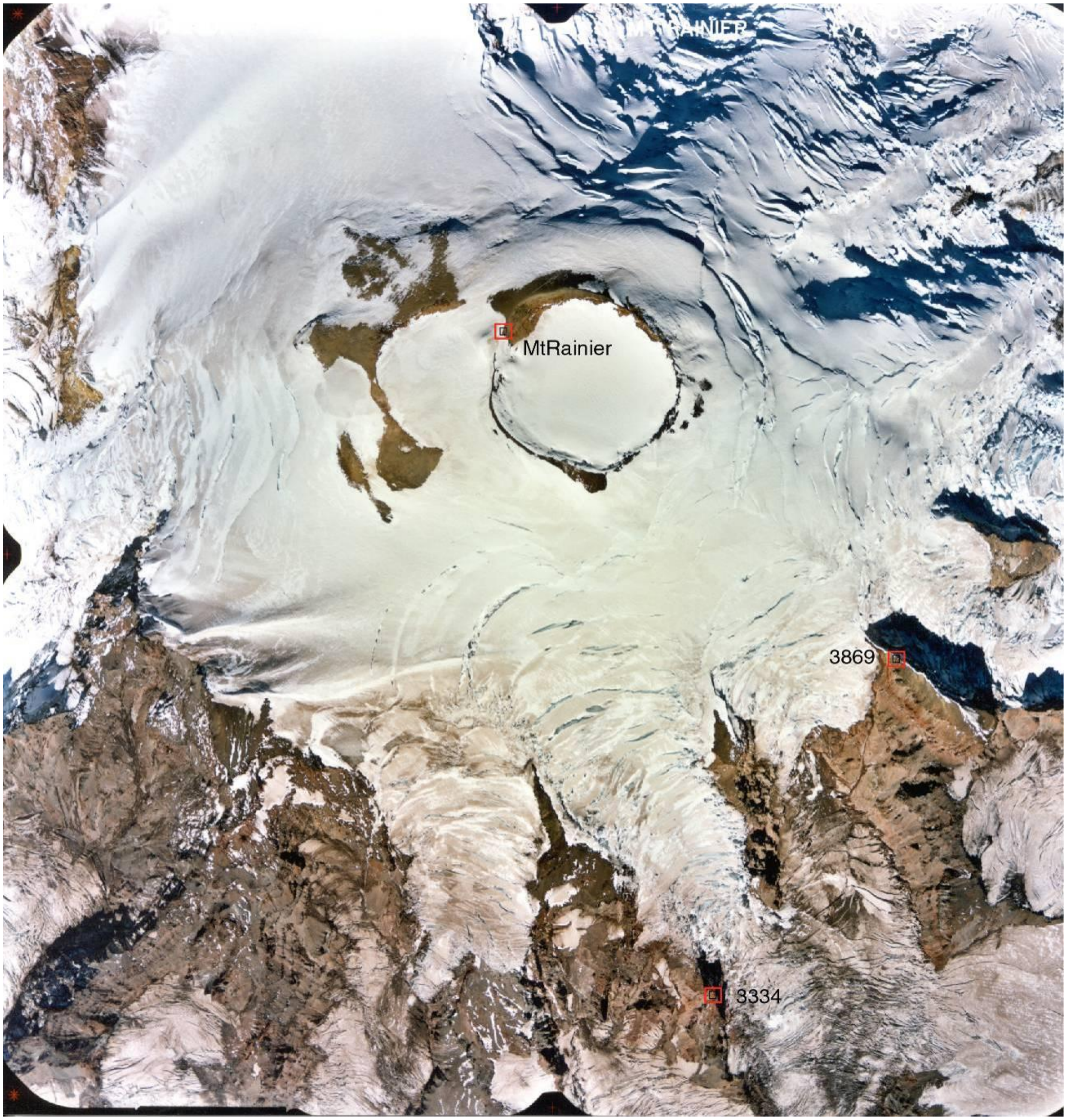


Figure SOP 11.5. Photo identifiable ground control points “Mt Rainier” and “3334” surrounding Nisqually Glacier.

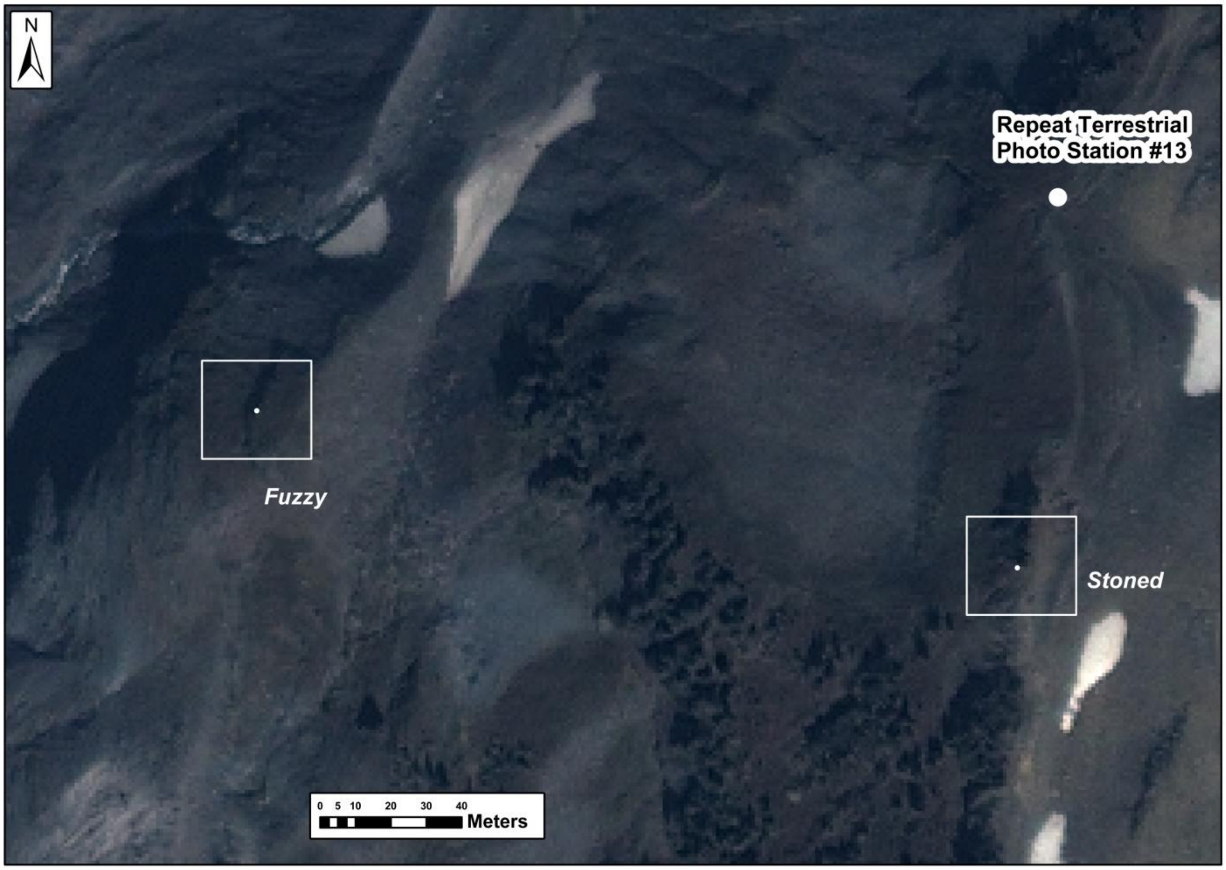


Figure SOP 11.6. Photo identifiable ground control points “Fuzzy” and “Stoned” and the repeat terrestrial photo station #13 surrounding Nisqually Glacier.

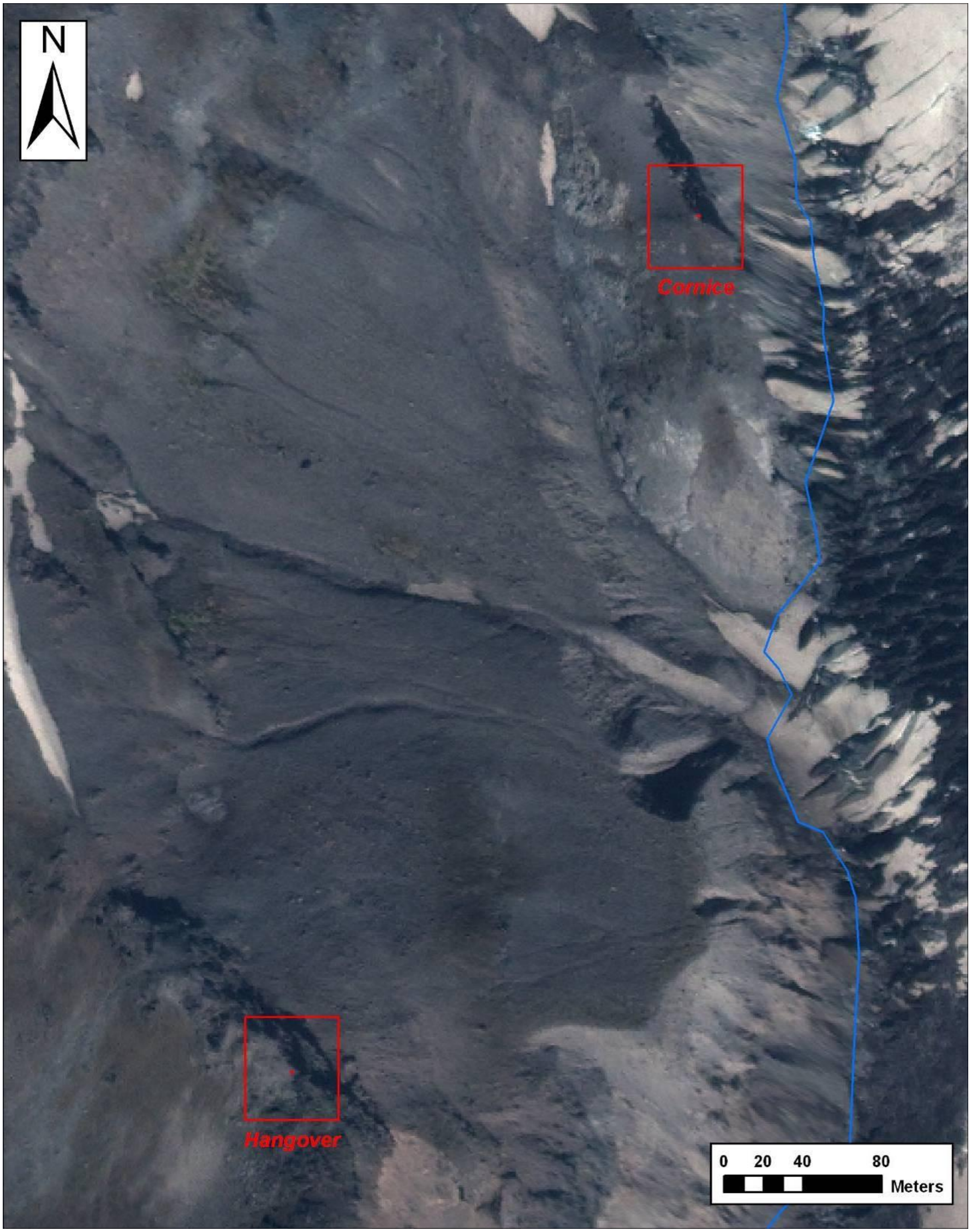


Figure SOP 11.7. Photo identifiable ground control points “Hangover” and “Cornice” surrounding Nisqually Glacier.

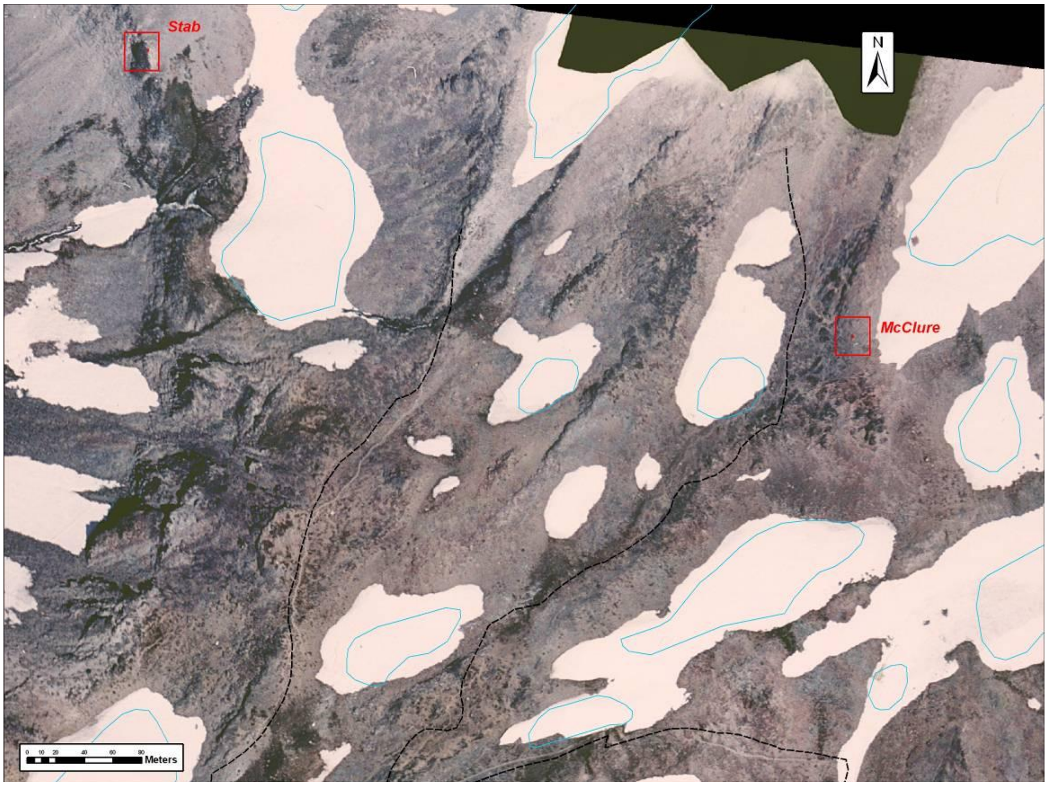


Figure SOP 11.8. Photo identifiable ground control points “Stab” and “McClure” surrounding Nisqually Glacier.

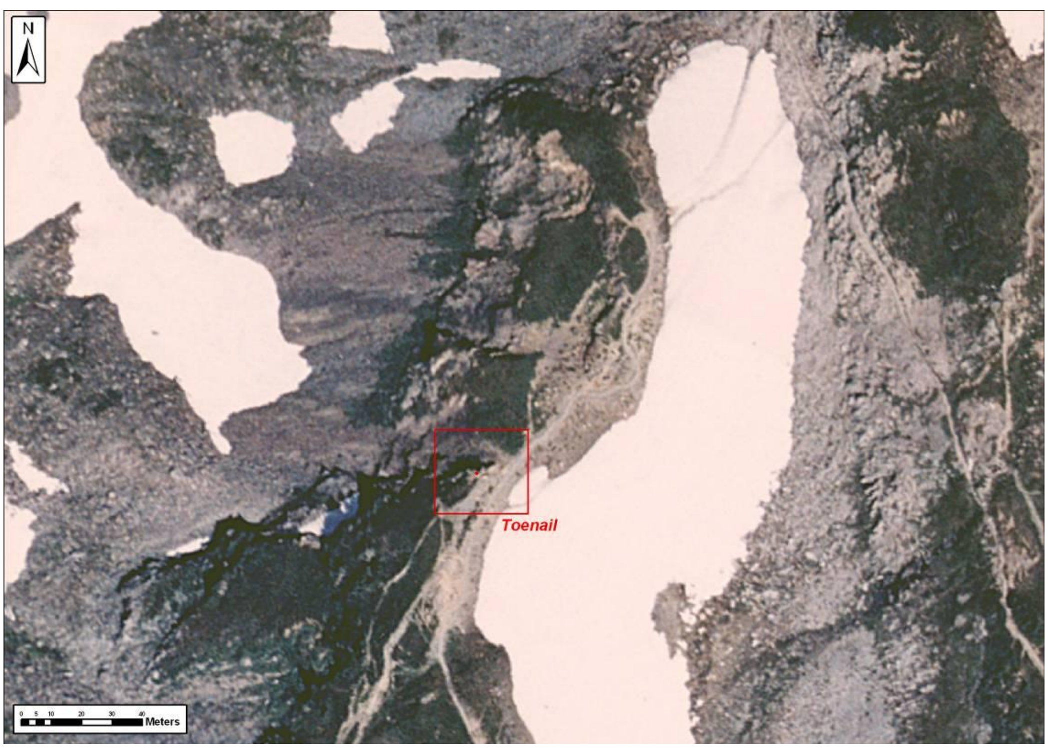


Figure SOP 11.9. Photo identifiable ground control point “Toenail” surrounding Nisqually Glacier.

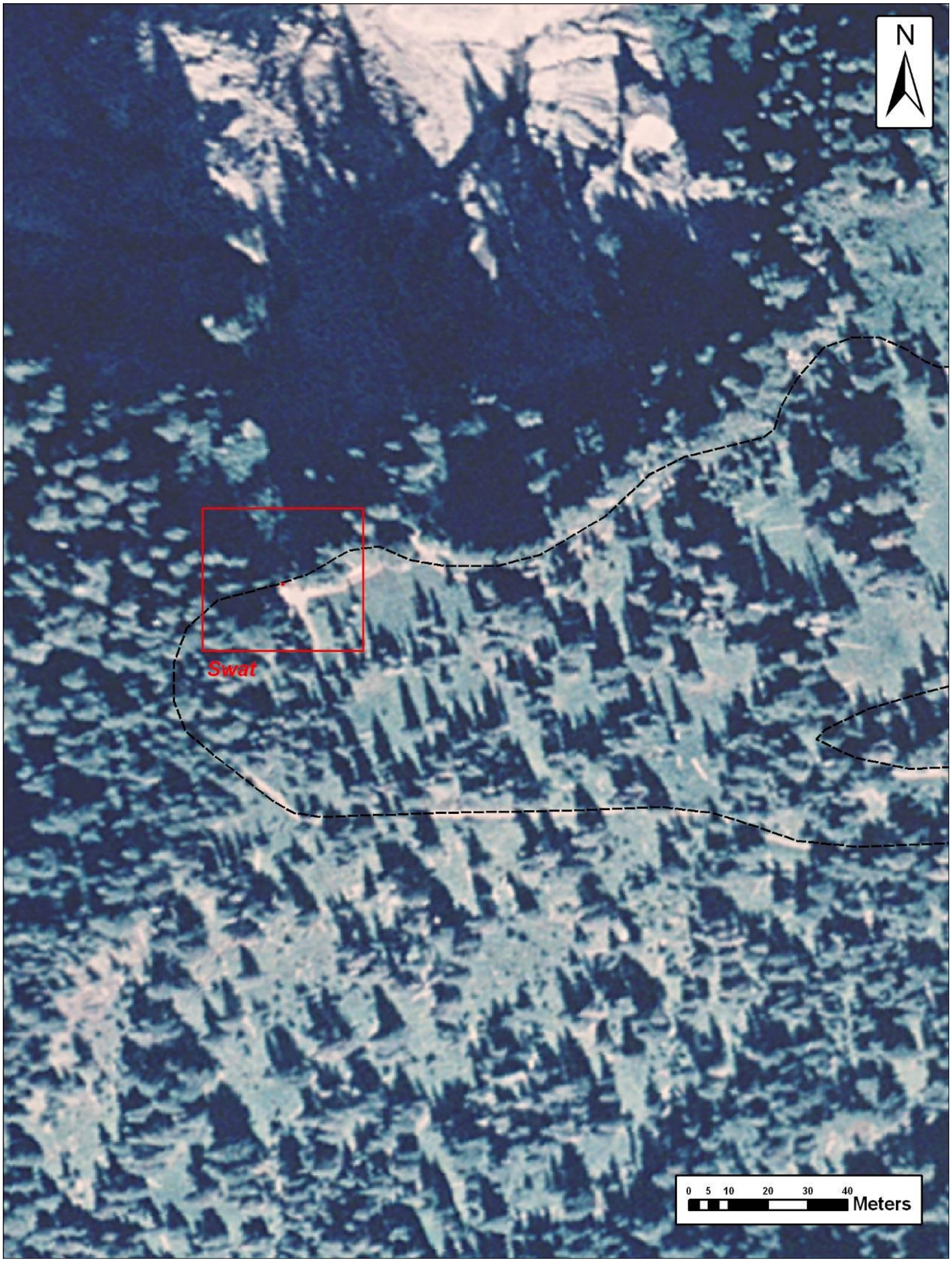


Figure SOP 11.10. Photo identifiable ground control point “Swat” surrounding Nisqually Glacier.

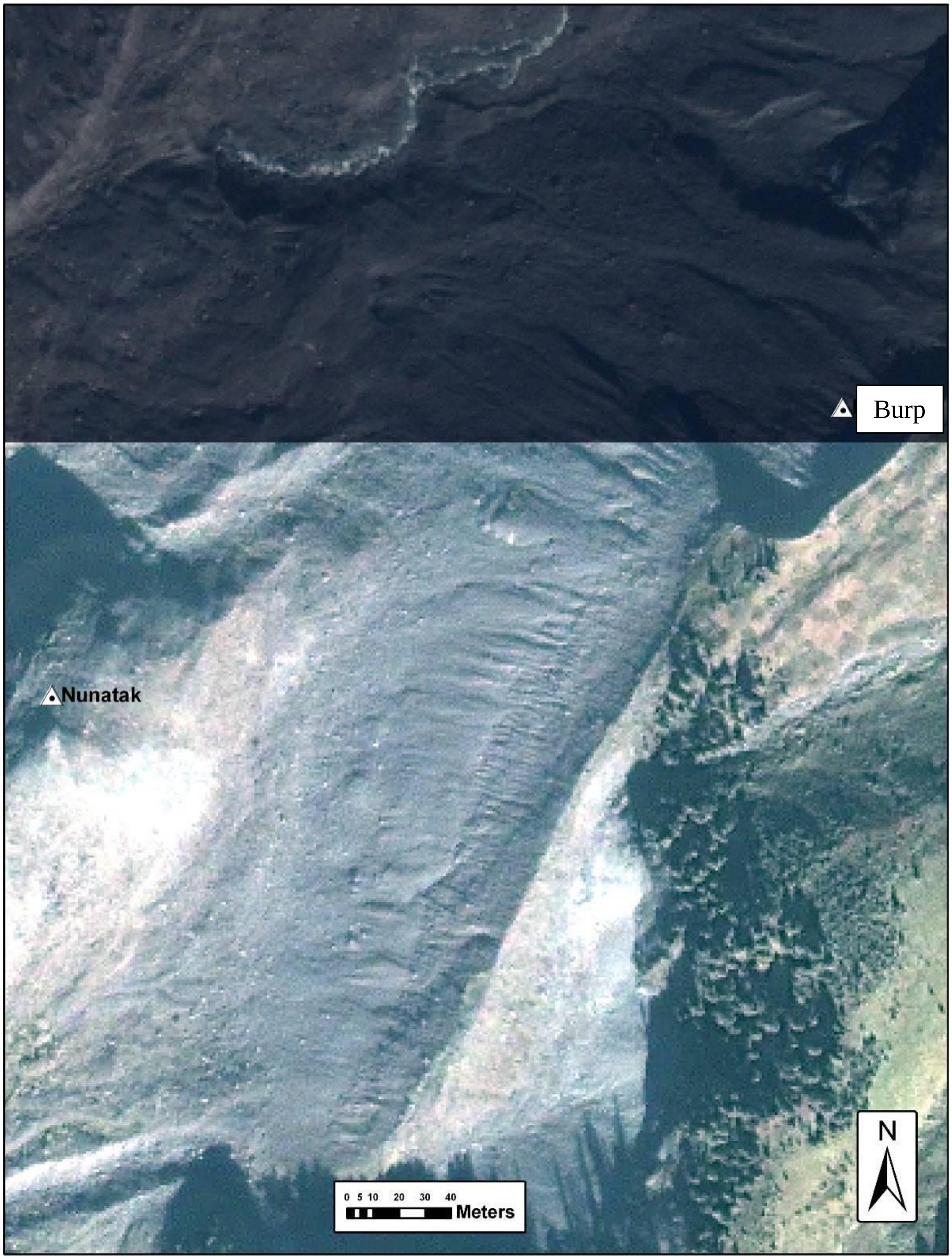


Figure SOP 11.11. Photo identifiable ground control points “Burp” and “Nunatak” surrounding Nisqually Glacier.

Figure SOP 11.12. Photo identifiable ground control point “Y2K” surrounding Nisqually Glacier.

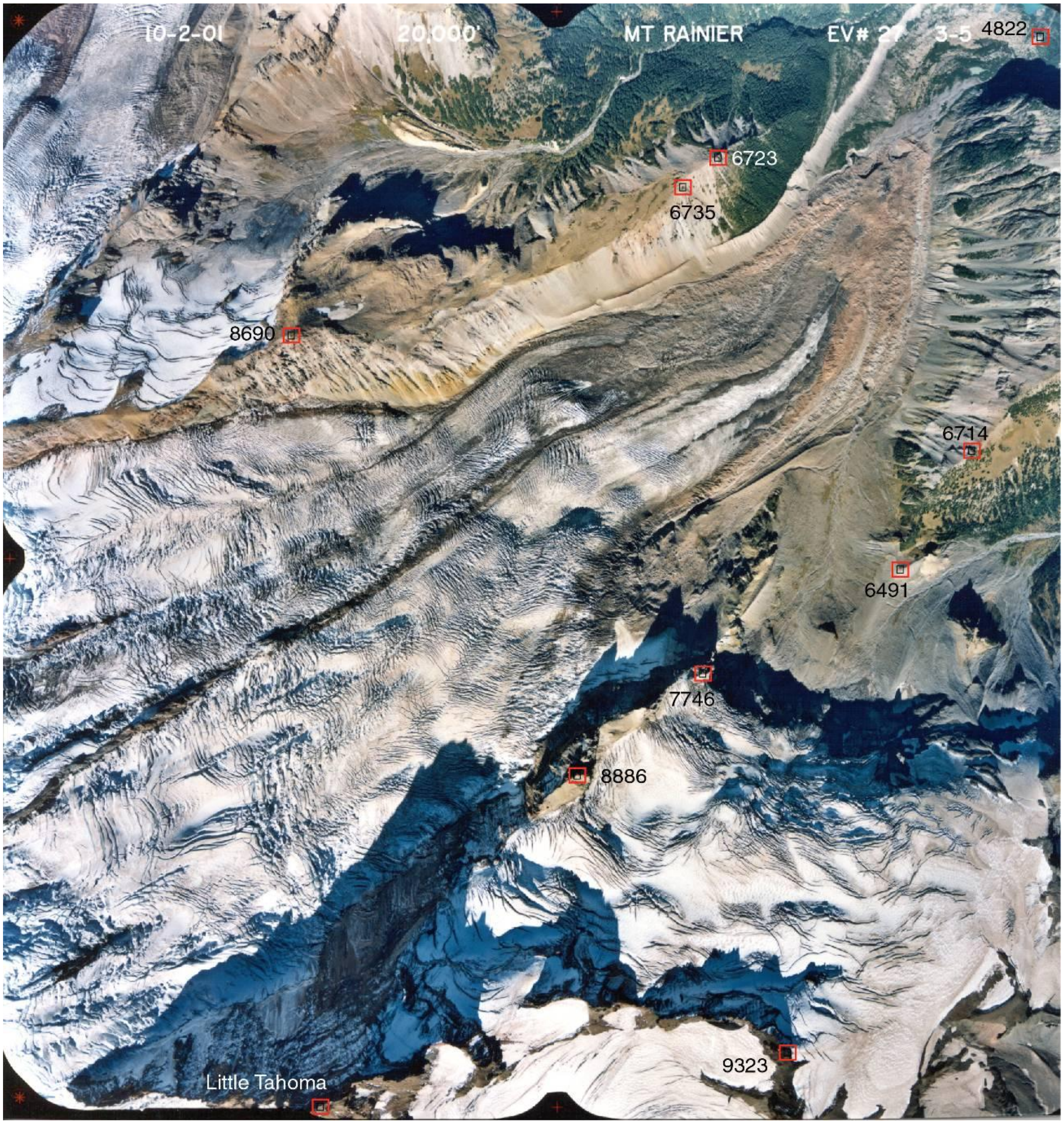


Figure SOP 11.13. Photo identifiable ground control points surrounding Emmons Glacier.

Figure SOP 11.14. Photo identifiable ground control points “6735” and “6723”surrounding Emmons Glacier.

Figure SOP 11.15. Photo identifiable ground control point “4822”surrounding Emmons Glacier.

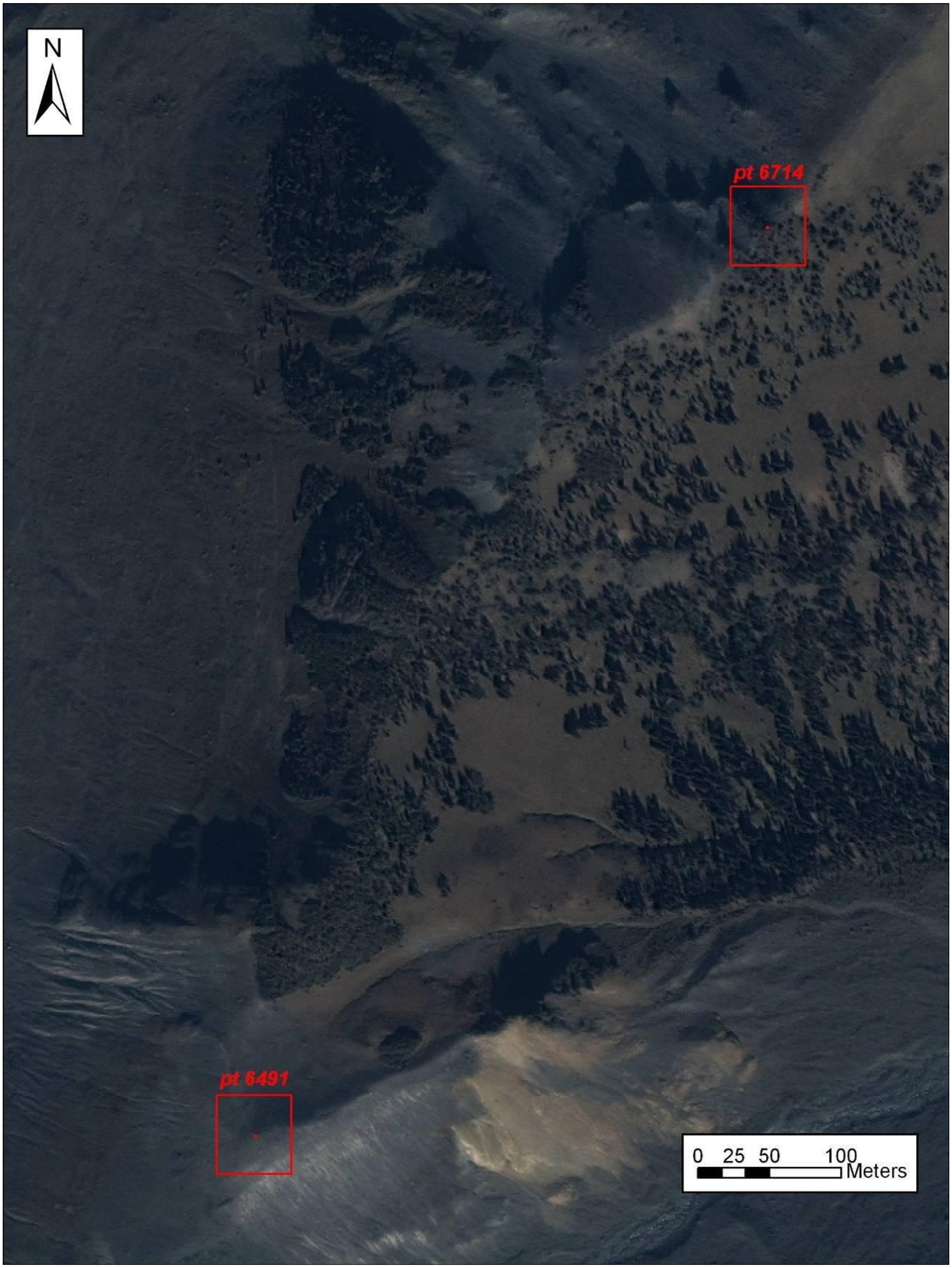


Figure SOP 11.16. Photo identifiable ground control points “6714” and “6491”surrounding Emmons Glacier.

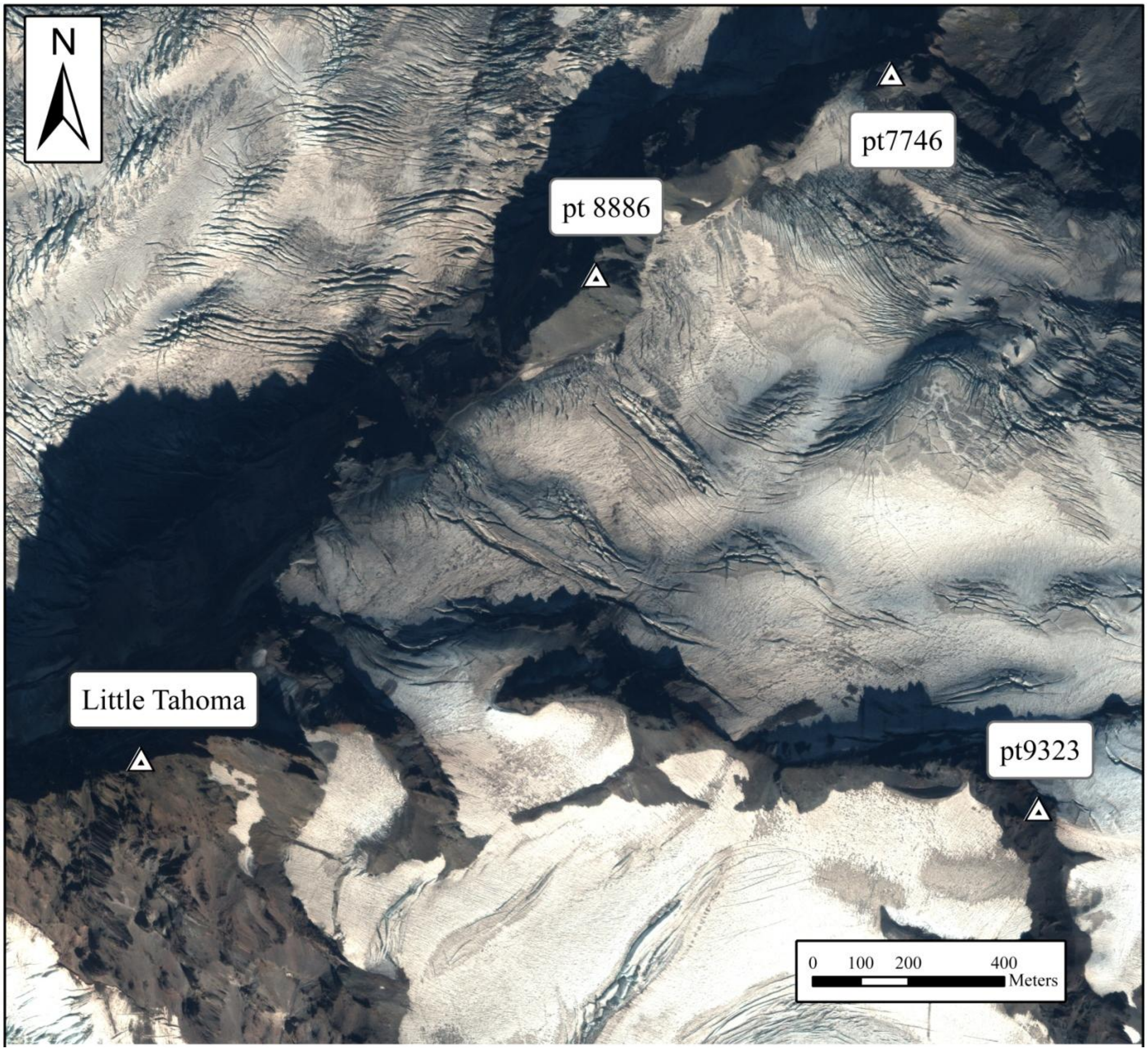


Figure SOP 11.17. Photo identifiable ground control points “7746”, “8886”, “9323” and “Little Tahoma” surrounding Emmons Glacier.

Figure SOP 11.18. Photo identifiable ground control points “6772”surrounding Emmons Glacier.

SOP 12. Twenty-Year Glacier Inventory

Version 1/28/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview and Explanation

This Standard Operating Procedure explains the basic procedures for conducting a 20-year inventory of all glaciers at Mount Rainier National Park. Glacier margins are mapped from orthorectified imagery to monitor change in area of all glaciers. Mass changes are estimated using area change. These results help monitor impact of glacier changes on aquatic and terrestrial ecosystems by relating glacier area to runoff and creation or destruction of terrestrial habitat.

The latest inventory and analysis was done by Nylen (2002). See his thesis for more details.

Procedures

1. At the present time there are two options for obtaining images of sufficient resolution to conduct a glacier inventory: (1) large scale (1:24,000 scale or greater) stereo, color aerial photographs and satellite imagery (IKONOS). No matter what type of image is used, it is essential that the images be taken late in the melt season of a negative mass balance year. In other words, the photos should be taken in late August –early September during a dry year when little or none of the glacier surfaces are covered by snow from the previous winter.

2. Arrange for extra staff time (or graduate student) to assess glacier changes from the remotely sensed images, to digitize changes into a geographic information system, and to report changes in a technical report (or M.S. thesis).

3. Add data on change in area of each individual glacier to database. Data from glacier inventories are currently stored on an Access database and in Arc Info GIS software. As the NCCN develops a relational database, the Access database will be eliminated.

References

Nylen, T. 2002. Spatial and temporal variations of glaciers on Mt. Rainier between 1913 and 1994. Master’s Thesis, Department of Geology, Portland State University, Portland, Oregon.

SOP 13. Products and Reporting

Version 4/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures

Overview and Explanation

This Standard Operating Procedure explains how staff will share information on glacier and climate change with the public, NPS staff, and professionals. To meet this goal, specific products and reporting schedule, and media include:

Procedures

1. Annual posting of Field Season report:
   The North Coast and Cascades Network have websites where glacier monitoring data is posted. These sites should be updated with new cumulative mass balance data and glacier runoff data (at a minimum) each fall. Annual reports follow the Natural Resource Technical Report template and can be found at http://www.nature.nps.gov/publications/NRPM/index.cfm. For more details, refer to SOP #22 (Workspace Setup and Project Records Management).

2. Annual posting of Digital photographs:
   See SOP 18 (Metadata Development) for specifications on naming, organizing, and maintaining digital photographs.

3. Annual posting of Certified data:
   The primary goal for reporting data is to make it available to other aspects of our monitoring program. At the writing of this protocol the North Coast and Cascades Network is developing a relational database. Once developed this will be the primary reporting site for all certified database materials, geospatial data, and reports. See SOP 22 for specifics on reporting schedule and format.

4. Metadata
   For reporting on GIS themes in ESRI coverage or shapefile formats, refer to NCCN GIS Development Guidelines (NCCN, 2006) and NCCN GIS Product Specifications (NCCN 2005) for more information. The three page metadata interview form and Full metadata reporting specifications are available on the NCCN website at: http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm. For more details, refer to SOP 19 (Data Entry and Verification) and SOP 22.

5. Spring publishing of winter balance and glacier runoff data in the Washington State Snow Survey Report “Glacier Page”:
   http://www.wa.nrcs.usda.gov/snow/data/NPS_Glacierpage_2009.pdf
   Glacier monitoring data from this program provide key high elevation winter precipitation information tom water resource managers in Washington State. Data from winter balance measurements taken in April and the previous summer’s glacial runoff data are published in the June Washington State Snow Survey report, which is prepared by the Natural Resource Conservation Service. Data is electronically transferred to the Mt. Vernon NRCS office and Mr. Scott Pattee. Users include fisheries managers, aquatic ecologists and the hydroelectric industry, among others. An example of the “Glacier Page” can be found in Figure SOP 13.1.

The “Glacier Page” will also be available for educational purposes and can be included in any local newsletter type publications for park staff and visitors. MORA resource management staff (a direct glacier staff contact) will organize educational outreach.

6. Annual data submittal to the World Glacier Monitoring Service:
   Glacier monitoring at MORA has regional and global significance as part of larger efforts to monitor glaciers. Data is sent annually to the World Glacier Monitoring Service (WGMS). Data include per glacier the specific balance, Equilibrium Line Altitude, Accumulation Area Ratio, and glacier area. In years when the WGMS is publishing a more comprehensive report, such as their five year report, more information may be requested.

7. Annual I&M report
   This annual report is a concise summary of both the field report and “glacier page”.

8. Decadal publishing of 10-year analysis report:
   Following decadal remapping of glaciers, which provides an independent check on cumulative mass balance, a technical report will be prepared. The reports will include discussion of data on variation and trends in winter, summer, and net mass balance, and glacial runoff for four watersheds. Reports will use the NPS Natural Resource Publications template, which is based on current NPS formatting standards; the pre-formatted Microsoft Word template can be found at http://www.nature.nps.gov/publications/NRPM/index.cfm.

9. Other Publications:
   When staff expertise and time allow, analysis of glacier monitoring data with respect to pertinent research questions will be published in peer-reviewed journals. Results from the inventory of glacierized area including all MORA glaciers will be published in a technical reports or M.S. thesis. The most recent inventory was published as a M.S. Thesis at Portland State University (Nylen, 2002). This type of additional reporting will be submitted to the Park Curator for archival. Digital files that are slated for permanent retention should be uploaded to the NCCN Digital Library. Retain or dispose of records following NPS Director’s Order No. 19

10. Annual field data forms:
   Scan original, marked-up field forms as PDF files and upload these to the NCCN Digital Library [1] submissions folder. Originals go to the Park Curator for archival. See SOP 16 (Field Form Handling Procedures) for further specifications and procedures.

Other Outreach

1. Presentations at professional society meetings, including annually at the Northwest Glaciologists Meeting
   Glacier monitoring data is presented annually to professionals at the Northwest Glaciologists Meeting. The meeting location rotates between the University of British

Columbia (Vancouver), the University of Washington (Seattle) and Portland State University. Other professional meetings where data is presented have included the Geological Society of America, the Canadian Association of Geographers, and the American geophysical Union.

2. Annual training of NPS interpreters.
   Annual training of NPS interpretive staff allows for wide dissemination of glacier monitoring data to the public. By training the interpretive staff early in the visitor use season, we are able to relate the importance of glaciers and climate change to the public as staff develop nature walks, campfire programs, and other public presentations.

3. As time and resources permit during the winter, presentations to local schools and community events

References

National Park Service. Director’s order 19. National Park Service,2003. Washington, D.C. Online. (http://home.nps.gov/applications/npspolicy/DOrders.cfm).

North Coast and Cascades Network – National Park Service. 2006. GIS development guidelines. USDI National Park Service, North Coast and Cascades Network, Ashford, Washington. Online. (http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm).

North Coast and Cascades Network – National Park Service. 2005. GIS product specifications. USDI National Park Service, North Coast and Cascades Network, Ashford, Washington. Online. (http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm).

Nylen, T. 2002. Spatial and temporal variations of glaciers on Mt. Rainier between 1913 and 1994. Master’s thesis, Department of Geology, Portland State University, Portland, Oregon.

MOUNT RAINIER GLACIER PAGE 2004

This year the National Park Service continues to collect snow depth and ablation data for monitoring mass balance annually on Mount Rainier glaciers. This program is a cooperative venture between Mount Rainier National Park, the US Geological Survey, and North Cascades National Park. The program includes field measurements on Nisqually Glacier and Emmons Glacier, annual air photography, and 10-year remapping of the glaciers below 10,000 feet.

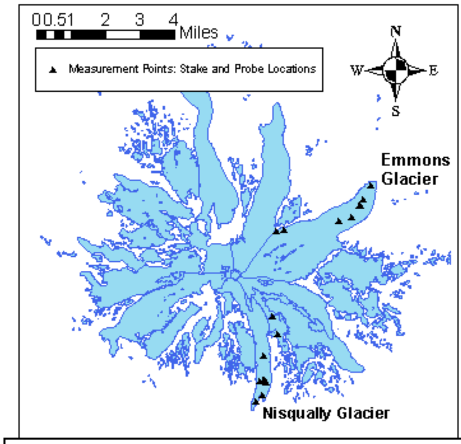


Figure 1. Glacier cover of Mount Rainier, monitored glaciers, and measurement locations on Muir Snowfield, Emmons, and Nisqually Glaciers.

Between March 30 and May 2 we measured bulk density of the snowpack, probed snow depths, and placed ablation stakes on the Nisqually and Emmons glaciers below 10,000 feet. Accumulation on the south side of the mountain (Muir Snowfield and Nisqually Glacier) may show an increasing trend with elevation to ~7200 feet and decreasing trend above (Table 1). However, the snow depth measurement at 7200 feet is based on one measurement that could be an overestimate. Depth measurements in June will help clarify this uncertainty. Accumulation on Emmons Glacier generally increases with altitude to the ceiling of our spring measurements at ~9500 feet (Table 1). Nearby SNOTEL sites (Morse Lake, Corral Pass, and Paradise) indicate glacier measurements were taken near the time of maximum snowpack at these sites. Ablation stakes were placed at 7200, 6200, and 5500 feet on Nisqually Glacier, at 9840 and 8640 feet on the Muir Snowfield, and at 9470, 7300, 6460, and 5570 feet on Emmons Glacier. We will return in mid June to check ablation stakes, probe snow depths, and place additional stakes in debris covered ice on the lowermost part of each glacier. In addition we will probe snow depth above 10,000 feet on the mountain. On a fall visit (late September/early October) we will record final ablation measurements from the stakes. For more information contact Jon_Riedel @nps.gov or Rob_Burrows@nps.gov.

Table 1	Elevation feet	Accumulation (inches w.e.) 2003	2004
Emmons Glacier	9470	56	90
	9200	na	102
	7300	134	64
	6460	65	63
	5575	58	47
	5590	na	35
	5050	22	29
Muir Snowfield and Nisqually Glacier	9840	71	87
	8640	na	92
	7180	125	154*
	6200	106	99
	6150	100	84
	5500	48	67
	5280	68	74
	5120**	61	72

*one measurement near crevasse depression, probably overestimate
** Paradise SNOTEL site.

Table 1. Accumulation on Mount Rainier Glaciers, Spring 2003 and 2004. Determined from probing snow depth at 1 to 11 points on each elevation contour. Provisional Data.

Table 2. 2004 spring snow density measured on Mt. Rainier. Although the density was measured a month apart on the upper and lower Emmons Glacier we believe this represents the density at near maximum snow accumulation at each point.

Glacier	Snow Density	Altitude (feet)	Snow Depth (inches)	Date
Emmons	0.43	9470	219	5/2/04
Emmons	0.38	7300	118	3/31/04
Emmons	0.40	6460	152	3/30/04
Emmons	0.43	5575	93	3/30/04
Emmons	0.47	5575	77	5/2/04
Muir Snowfield	0.41	9800	198	4/9/04
Nisqually	0.53	6820	271	4/8/04
Nisqually	0.47	5700	155	4/8/04
Paradise SNOTEL	0.50	5120	146	4/8/04

Figure SOP 13.1. Example of the reporting document "Glacier Page", Mount Rainier, 2004.

SOP 14. Revising the Protocol

Version 4/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview
This document explains how to make and track changes to the Mount Rainier Glacier Monitoring Protocol, including its accompanying SOPs. Project staff should refer to this SOP whenever edits are necessary, and should be familiar with the protocol versioning system in order to identify and use the most current versions of the protocol documents. Required revisions should be made in a timely manner to minimize disruptions to project planning and operations.

This protocol attempts to incorporate the best and most cost-effective methods for monitoring and information management. As new technologies, methods, and equipment become available, this protocol will be updated as appropriate, by balancing current best practices against the continuity of protocol information. All changes will be made in a timely manner with the appropriate level of review.

All edits require review for clarity and technical soundness. Small changes to existing documents – e.g., formatting, simple clarification of existing content, small changes in the task schedule or project budget, or general updates to information management handling SOPs – may be reviewed in-house by project cooperators and NCCN staff. However, changes to data collection or analysis techniques, sampling design, or response design will trigger an outside review to be coordinated by the Pacific West Regional Office.

Procedures
1. Discuss proposed changes with other project staff prior to making modifications. It is important to consult with the Data Manager prior to making changes because certain types of changes may jeopardize data set integrity unless they are planned and executed with data set integrity in mind. Also, because certain changes may require altering the database structure or functionality, advance notice of changes is important to minimize disruptions to project operations. Consensus should be reached on who will be making the changes and in what timeframe.

2. Make the agreed-upon changes in the current, primary version of the appropriate protocol document (i.e., not the most recent versioned copy – see below). Note that the protocol is split into separate documents for each appendix and SOP. Also note that a change in one document may necessitate other changes elsewhere in the protocol. For example, a change in the narrative may require changes to several SOPs; similarly renumbering an SOP may mean changing document references in several other documents. Also, the project task list and other appendices may need to be updated to reflect changes in timing or responsibilities for the various project tasks.

3. Document all edits in Change History at the front of this document and in the Change History(s) in each SOP. Log changes only in the document being edited (i.e., if there is a change to an SOP, log those changes only in that document). Record the date of the changes (i.e., the date on which all changes were finalized), author of the revision, describe the change and cite the paragraph(s) and page(s) where changes are made, and briefly indicate the reason for making the changes.

4. Circulate the changed document for internal review among project staff and cooperators.

5. Upon ratification and finalizing changes:
    a. Ensure that the version date (last saved date field code in the document header) and file name (field code in the document footer) are updated properly throughout the document.
    b. Make a copy of each changed file to the protocol archive folder (i.e., a subfolder under the Protocol folder in the project workspace).
    c. The copied files should be renamed by appending the revision date in YYYYMMDD format. In this manner, the revision date becomes the version number, and this copy becomes the 'versioned' copy to be archived and distributed.
    d. The current, primary version of the document (i.e., not the versioned document just copied and renamed) does not have a date stamp associated with it.
    e. To avoid unplanned edits to the document, reset the document to read-only by right-clicking on the document in Windows Explorer and checking the appropriate box in the Properties popup.
    f. Inform the Data Manager so the new version number(s) can be incorporated into the project metadata.
6. As appropriate, create PDF files of the versioned documents to post to the internet and share with others. These PDF files should have the same name and be made from the versioned copy of the file.

7. Post the versioned copies of revised documents to the NCCN Digital Library and forward copies to all individuals who had been using a previous version of the affected document.

Example of Document Revision

1. SOP_2_Records_Mgmt.doc is revised on October 31, 2008, and circulated for review.

2. Changes are accepted by the group and changes are finalized on November 6, 2008.

3. The revised SOP is:
    a. Copied into the Archive folder.
    b. That versioned copy is renamed as SOP_2_Records_Mgmt_20081106.doc.
    c. Both the current, primary version and the versioned copy are set to read-only.
    d. A PDF of the document is created from the versioned copy and named SOP_2_Records_Mgmt_20081106.pdf.
    e. Both the PDF and the versioned document are uploaded to the NCCN Digital Library.
    f. The PDF is sent to any cooperators.

SOP 15. Repeat Terrestrial-Based Photography

Version 6/25/2008

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures

Explanation and Overview

Terrestrial-based photographs are taken annually of each index glacier as a record of annual change of the terminus, relative surface elevation against bedrock, equilibrium line altitude, and snow, firn, and ice coverage. These color photographs are taken during field visits at the same locations and of the same views of the glaciers every year. This photographic record is especially important in years when no vertical imagery of the glaciers is obtained.

The locations and views of the glaciers were selected based on two criteria:

1. Convenient and safe stopping points on the routes used to access glacier stakes during field visits.

2. Historically established locations for photography (i.e. Veatch, 1969).

Photo point locations (Figures 1 and 2) and view descriptions (Figures 3–8) are listed below. The stations for Nisqually glacier were established by Veatch (1969).

Procedure

1. The photos should be taken *at least* once a year in the late summer or early fall (August–October). However, photographs in the spring or early summer provide an excellent record of snow cover and should be taken when weather permits. Early to mid summer photographs of the lower, debris-covered areas of the glaciers are important for recording the amount of snow cover in these areas at the time of stake placement. In addition, photographs of the lower glaciers are important during winters of extremely low snowfall, such as the winter of 2004/05.

2. The photographs may be either digital or on film, though digital are preferable because they are easier to organize and archive. Use a lens/camera with a variable focal length zoom lens (recommended 28–80 mm for a 35-mm format film camera) or equivalent digital camera (NOCA currently has a Canon PowerShot A300 with a 5 mm lens and a digital zoom feature). Most of the photo stations require multiple frames to photograph the entire view of the glacier (see Figures 4–8 below). Make sure there is some overlap of the frames. These frames can later be pasted together into a panorama.

3. Photograph zoomed in views of the terminus of each glacier as well as the entire view.

4. Download (or scan) the photographs from the camera (or print/slide).

5. Name each photo. Photos are arranged within photo point named folders. Each photo name includes abbreviated glacier name Emm (Emmons) Nis (Nisqually), full year (2007, (-), abbreviated location (stat5, stat13, etc), and sequence number (a,b,c, etc). See below for name example and folder structure.

   Photo name example: Nis2007_stat13a

   Folder structure:
   Folder [Glacier]

Folder [Year]
Folder [Photo point location]

6. Link/insert the images with/into the database and fill out all pertinent metadata (date, glacier, station, photographer, etc).

Photo Point Locations

Nisqually Glacier

All coordinates are in UTM zone 10, NAD 83.

Station #5: First viewpoint on the Nisqually Vista Trail

- Route Description: West of Jackson Visitor Center, hike along the Nisqually Vista Trail. Take a left at the first fork. Follow the trail down around a few switchbacks until you reach the first viewpoint.
- View Description: Straight on view of terminus area and above (Figure 3).
- Easting: 595665 Northing: 5182049 Altitude: 1590m

Station #13: Bedrock point near Glacier Vista

- Route Description: Off of the Skyline Trail, this is a point on bedrock beside the trail past the Glacier Visa Viewpoint.
- View Description: Enough frames to cover a full panorama of the Nisqually and Wilson Glaciers from the summit to the lower Nisqually Glacier (Figures 4a–4b). The lowermost view (no photo in this SOP) should look straight down the Nisqually Glacier valley toward the terminus but the terminus itself will not be in view.
- Easting: 596588 Northing: 5183770 Altitude: 1935 m

Note: Additional photo locations may be established on or around the Muir Snowfield as indicated on Figure 1.

Emmons Glacier

Station #1: Crest of Little Ice Age Moraine next to Moraine Trail

- Route Description: Follow the Glacier Basin Trail from White River Campground. About 1 mile up the trail turn left onto the Moraine Trail and cross Glacier Creek. Follow the trail for ~ ¼ mile and gain the actual crest of the moraine at the second major bare area/side trail. Look for a large boulder with a “seat” like a chair. Stand on this seat to take the photographs.
- View Description: Straight on of terminus area and above. (Figures 5a and 5b)
- Easting: 601738 Northing: 5194605 Altitude: 1480 m

Station #2 Saddle on ridge NE of Mt. Ruth:

- Route Description: From Glacier Basin ascend the climbers trail SW on the Mt. Ruth Route. The route gains the ridge at the major saddle in the ridge, which has a spectacular view of Emmons Glacier. The station is located in a pile of rocks (weathered rock

outcrop). Stand on a boulder toward the west edge of the ridge that offers a good platform (Figure 6a).
- View Description: Panorama of glacier from summit to lower, debris covered portion. (Figures 6b–6f).
- Easting: 599227 Northing: 5192629 Altitude: 2070 m

Station #3 Steamboat Prow:
- Route Description: On climber's trail that goes up and over Steamboat Prow to Camp Schurman. The photo station is at high point of the route on Steamboat Prow with a view down on Camp Schurman and up to the upper mountain.
- View Description: View encompasses where Steamboat Prow Cleaves Emmons/Winthrop Glacier (Camp Schurman) to the upper mountain above this point (Figures 7a and 7b).
- Easting: 596743 Northing: 5191465 Altitude: 2940 m

Station #4 Camp Schurman:
- Route Description: At Camp Schurman, on north side of "patio" in front of Ranger Hut.
- View Description: Panorama of Emmons Glacier from this station (Figures 8a–8h).
- Easting: 596680 Northing: 5191353 Altitude: 2890 m

References
Veatch, F. M. 1969. Analysis of a 24-year photographic record of Nisqually Glacier, Mount Rainier National Park, Washington. U.S. Geological Survey Professional Paper 631, 52 p.

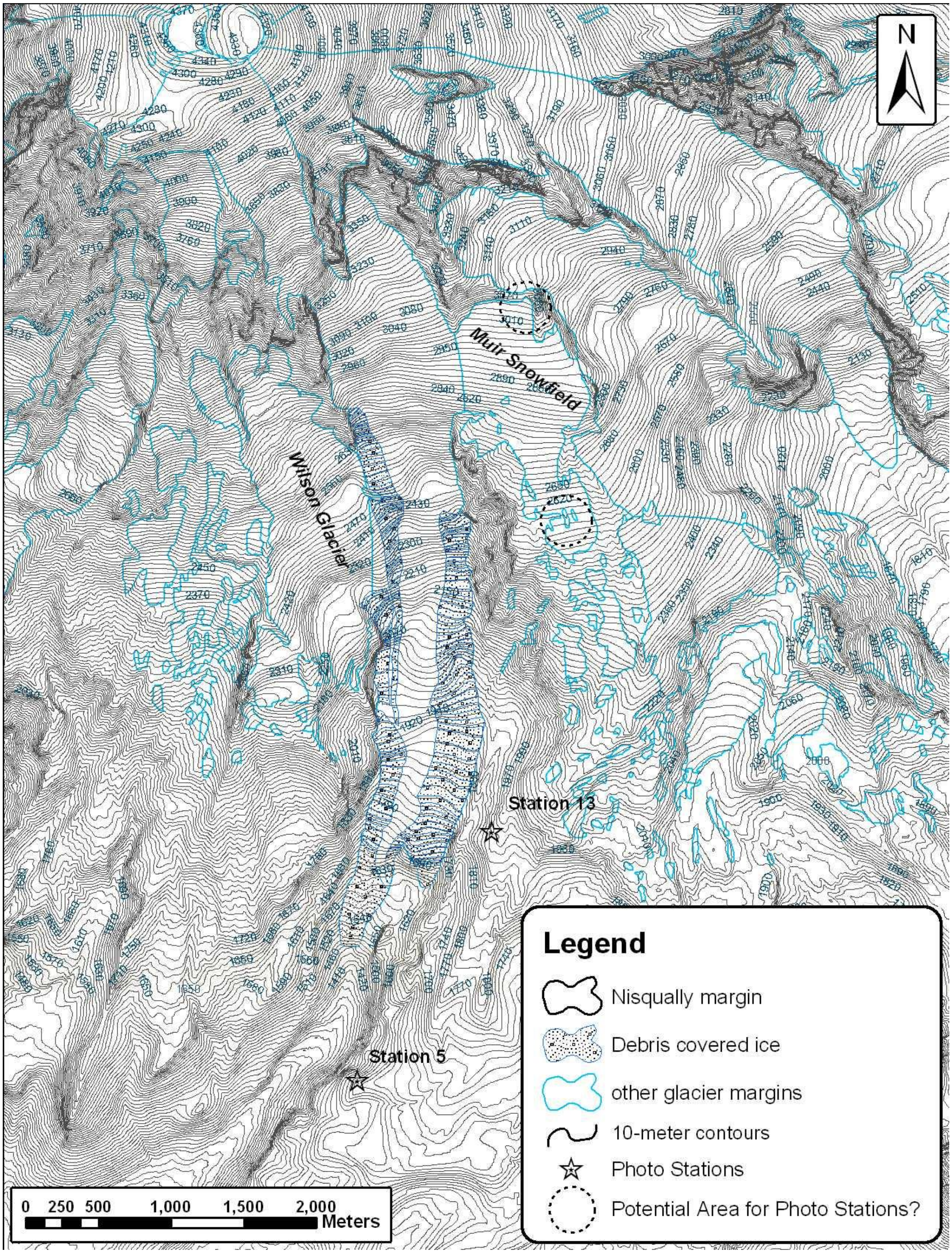


Figure SOP 15.1. Terrestrial-based photography stations for Nisqually Glacier. Stations 5 and 13 are based on locations established by Veatch (1969).

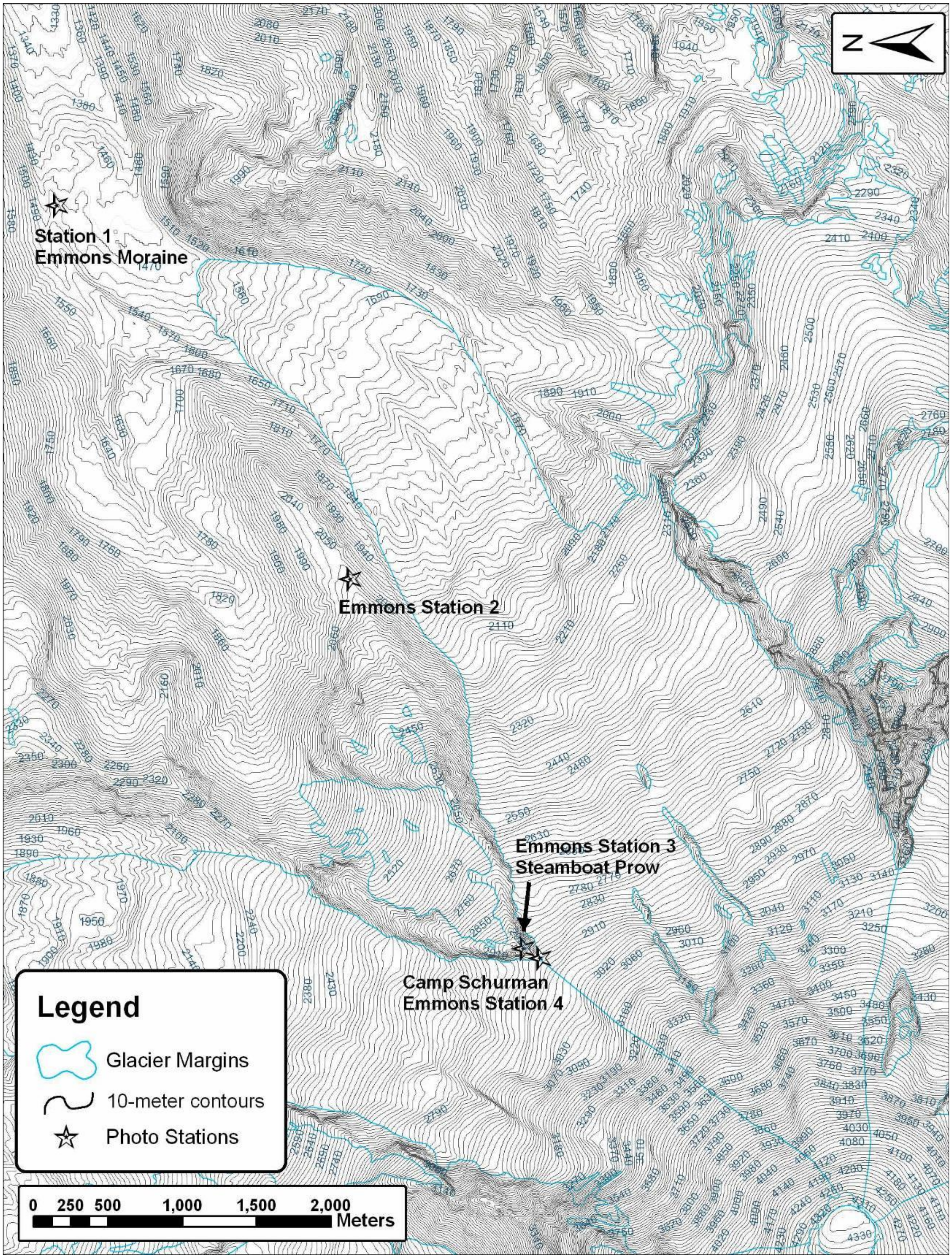


Figure SOP 15.2. Terrestrial-based photography stations for Emmons Glacier.

Figure SOP 15.3. The view from Nisqually photo Station 5 shows the terminus position and characteristics. Photo taken in August 1986.

Figure SOP 15.4a. The view from Nisqually photo Station 13 shows the mid and upper Nisqually/Wilson Glacier system. Photo taken on August 12, 2004.

Figure SOP 15.4b. The view from Nisqually photo Station 13 shows the lower Nisqually glacier. This includes the locations of Stakes 3, 4, 4A, and 5 as well as the surface elevation profiles.
Photo taken August 12, 2004.

Figure SOP 15.5a. View of the boulder with the “seat” that serves as the photo station from Emmons photo Station 1 showing the terminus of the Emmons Glacier. Photo taken on May 10, 2005.

Figure SOP 15.5b. Zoomed view of the glacier terminus from Emmons Photo Station 1. Photo taken in mid June, 2002.

Figure SOP 15.6a. The rock pile that serves as Emmons Glacier Photo Station 2. Photo taken mid June, 2005.

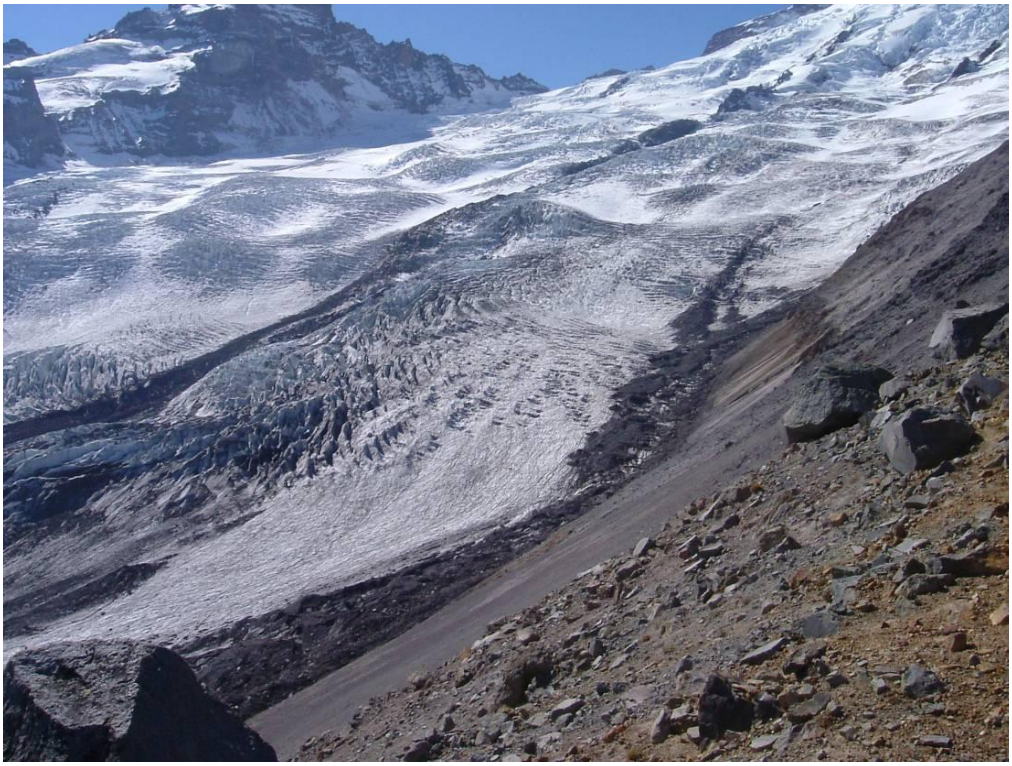


Figure SOP 15.5b. View of the upper Emmons Glacier from Photo Station 2. Photo taken on September 30, 2004.

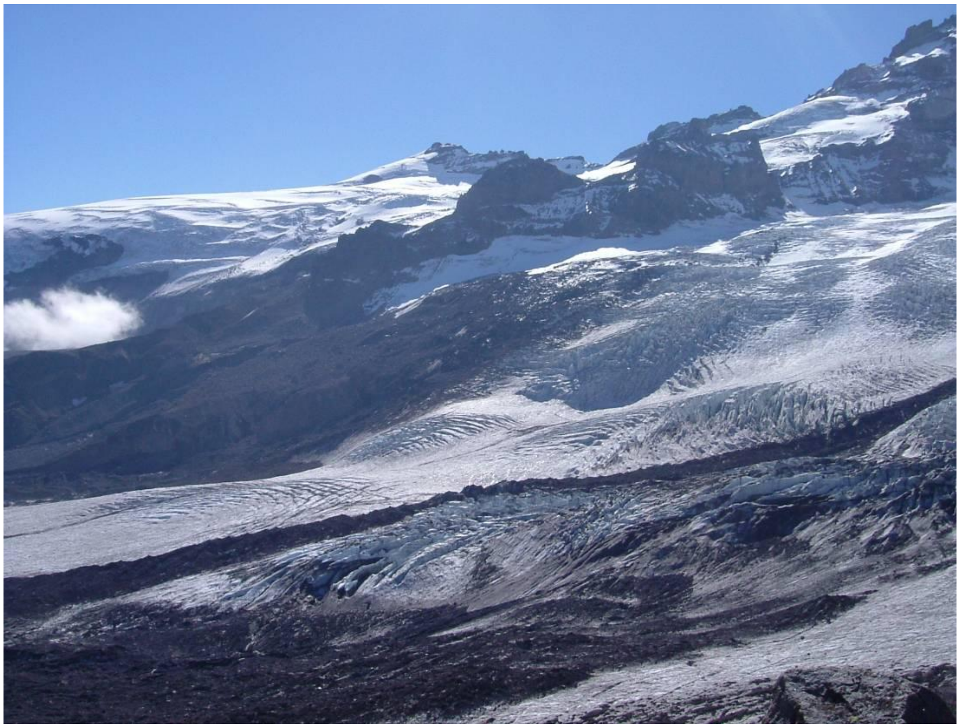


Figure SOP 15.6c. View of the mid-Emmons Glacier from Photo Station 2. Photo taken on September 30, 2004.

Figure SOP 15.6d. View of the mid-Emmons Glacier from Photo Station 2. Photo taken on September 30, 2004.

Figure SOP 15.6e. View of the lower Emmons Glacier from Photo Station 2. Photo taken on September 30, 2004.

Figure SOP 15.6f. View of the lowermost Emmons Glacier from Photo Station 2. Photo taken on September 30, 2004.

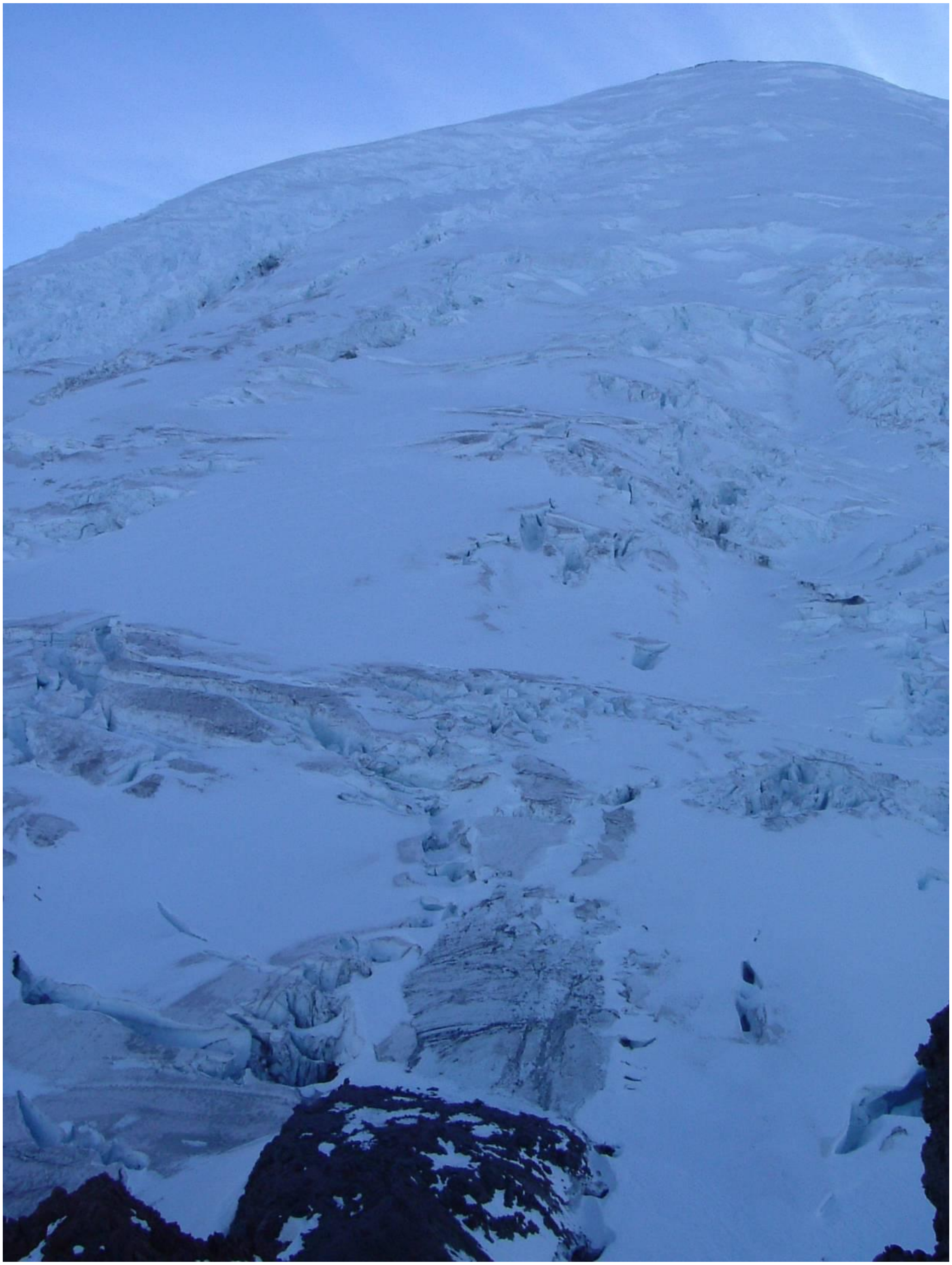


Figure SOP 15.7a. View of the upper Emmons Glacier from Photo Station 3. Photo taken on October 1, 2004.

Figure SOP 15.7b. View of the Camp Schurman area and adjacent glacier from Photo Station 3. Photo taken on October 1, 2004.

Figure SOP 15.8a. View of the upper Emmons Glacier from Photo Station 4, Camp Schurman. Photo taken on October 1, 2004.

Figure SOP 15.8b. View looking SE from Photo Station 4 across the middle and upper Emmons Glacier. Photo taken on October 1, 2004.

Figure SOP 15.8c. View looking SE from Photo Station 4 across the middle and upper Emmons Glacier. Detail of the glacier next to the cleaver on which Camp Schurman is located. Photo taken on October 1, 2004.

Figure SOP 15.8d. Detail of the glacier next to the cleaver on which Camp Schurman is located. Note the trail of footsteps in the snow, this is the normal route onto the cleaver for the route ascending from the glacier. Photo taken on October 1, 2004.

Figure SOP 15.8e. Detail of the glacier next to the cleaver on which Camp Schurman is located. Directly below Figure SOP 15.8d. Photo taken on October 1, 2004.

Figure SOP 15.8f. Detail of the glacier next to the cleaver on which Camp Schurman is located. The view is directly below Figure SOP 15.8e. Photo taken on October 1, 2004.

Figure SOP 15.8g. View of the glacier from Emmons Photo Station across the glacier to Little Tahoma. Directly up from the view shown in Figure SOP 15.8f. Photo taken on October 1, 2004.

Figure SOP 15.8h. Detail of the glacier next to the cleaver on which Camp Schurman is located. Directly below Figures 15.8f–g. Photo taken on October 1, 2004.

SOP 16. Field Form Handling Procedures

Version 4/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Field Form Handling Procedures

As the field data forms are part of the permanent record for project data, they should be handled in a way that preserves their future interpretability and information content. If changes to data on the forms need to be made subsequent to data collection, the original values should not be erased or otherwise rendered illegible. Instead, changes should be made as follows:

- Draw an “X” through the original value then, in the appropriate “Notes” section on the field form, write the original value (“X” out) and the new value adjacent with the date and initials of the person making the change. Note: An “X” is used instead of a horizontal line, which indicates that the value was “discarded” during data collection.
- All corrections should be accompanied by a written explanation in the appropriate notes section on the field form. These notes should also be dated and initialed.
- If possible, edits and revisions should be made in a different color ink to make it easier for subsequent viewers to be able to retrace the edit history.
- Edits should be made on the original field forms and on any photocopied forms.

These procedures should be followed throughout data entry and data revision. On a five-year basis, data sheets are to be scanned as PDF documents and archived (see protocol narrative Section 4K, and SOP 21 (Project Delivery Specifications). The PDF files may then serve as a convenient digital reference of the original if needed.

SOP 17. Managing Photographic Images

Version 4/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview

This document covers photographic images collected by project staff or volunteers during the course of conducting project-related activities. Images that are acquired by other means – e.g., downloaded from a website or those taken by a cooperating researcher – are not project records and should be handled separately.

Care should be taken to distinguish data photos from incidental or opportunistic photos taken by project staff. Data photos are those taken for at least one of the following reasons:

- An opportunistic overview photo that is not part of the standard Repeat Terrestrial Photograph (SOP 15. Repeat Terrestrial-based Photography) sites which captures glacier surface characteristics (snow, firn, ice), crevasse (distribution and locations), new features (termini retreat, exposed bedrock, fresh rock falls, new surficial ponds) and avalanche deposition areas.
- An on site photo to document a particular feature or perspective for the purpose of site relocation, crevasse stratigraphy, snow core stratigraphy, new glacier feature, or abnormal ablation stake melt.

Data photos are linked to specific records within the database, and are stored in a manner that permits the preservation of those database links. Other photos – e.g., of field crew members at work, or photos showing glacier morphology – may also be retained but are not necessarily linked with database records.

Effectively managing hundreds of photographic images requires a consistent method for downloading, naming, editing and documenting. The general process for managing data photos proceeds as follows:

1. File Structure Setup – Set up the file organization for images prior to acquisition

2. Image Acquisition

3. Download and Process
    a. Download the files from the camera
    b. Rename the image files according to convention
    c. Copy and store the original, unedited versions
    d. Review and edit or delete the photos
    e. Move into appropriate folders for storage

4. Establish Database Links

5. Deliver Image Files for Final Storage

1. File Structure Setup

Prior to data collection for any given year, project staff will need to set up a new folder under the Images folder in the project workspace as follows:

[Glacier]	Name of glacier – (Nisqually), (Emmons)
[Year]	The appropriate year – (2006, 2007, etc.)
_Processing	Processing workspace
_Originals	Renamed but otherwise unedited image file copies
Data_near_stakes	Data images taken at or near stake locations
[Stake location]	Arrange by stake location number (1, 2, 3, 4, 4a, 5)
Other_misc_data	Data images not taken at or near stake locations
[Feature name]	Arrange by abbreviated name of captured feature and altitude if applicable – crevasse_strat (crevasse stratigraphy)
[Altitude]	Arrange by altitude in meters
Non-NPS	Images acquired from other sources

This folder structure permits data images to be stored and managed separately from non-record and miscellaneous images collected during the course of the project. It also provides separate space for image processing and storage of originals. Note: For additional information about the project workspace, refer to SOP 22: (Workspace Setup and Project Records Management).

Folder Naming Standards

In all cases, folder names should follow these guidelines:

- Use full name of glacier
- Use full year as 2007
- No spaces or special characters in the folder name
- Use the underbar ("_") character to separate words in folder names
- Try to limit folder names to 20 characters or fewer

2. Image Acquisition

Capture images at an appropriate resolution that balances space limitations with the intended use of the images. Although photographs taken to facilitate future navigation to the site do not need to be stored at the same resolution as those that may be used to indicate gross environmental change at the site, it may be more efficient to capture all images at the same resolution initially. A recommended minimum raw resolution is 1600 x 1200 pixels (approximately 2 megapixels).

3. Download and Processing Procedures

a. Download the raw, unedited images from the camera into the appropriate "_Processing" folder.

b. Rename the images according to convention (refer to the image naming standards section). If image file names were noted on the field data forms, be sure to update these to reflect the new image file name prior to data entry. See SOP 16 (Field Form Handling

Procedures).

c. Process images as follows:
    - Copy the images to the 'Originals' folder and set the contents as read-only by right clicking in Windows Explorer and checking the appropriate box. These originals are the image backup to be referred to in case of unintended file alteration or deletion.
    - Delete any poor quality photos, repeats, or otherwise unnecessary photos. Low quality photos might be retained if the subject is highly unique, or the photo is an irreplaceable data photo.
    - Rotate the image to make the horizon level.
    - Photos of people should have 'red eye' glare removed.
    - Photos should be cropped to remove edge areas that grossly distract from the subject.

d. When finished, move the image files that are to be retained and possibly linked in the database to the appropriate year/season folder. Photos of interest to a greater audience should be copied to the park Digital Image Library. To minimize the chance for accidental deletion or overwriting of needed files, no stray files should remain in the processing folder between downloads.

e. Depending on the size of the files and storage limitations, contents of the Originals folder may be deleted if all desired files are accounted for after processing.

Large groups of photos acquired under sub-optimal exposure or lighting can be batch processed to enhance contrast or brightness. Batch processing can also be used to resize groups of photos for use on the web. Batch processing may be done in ThumbsPlus, Extensis Portfolio or a similar image software package.

Image File Naming Standards

In all cases, image names should follow these guidelines:

- No spaces or special characters in the file name
- Use the underbar ("_") character to separate file name components
- Try to limit file names to 30 characters or fewer, up to a maximum of 50 characters
- Park code and year should either be included in the file name or conclusive by the directory structure

The image file name should consist of the following parts:

a. Abbreviated glacier name: Nis (Nisqually), Emm (Emmons)
b. Date: 20070701 (1st of August, 2007) if full date is unknown, just use full year or abbreviate month Oct, Nov, etc
c. Optional: a sequential letter if multiple images were captured (a, b, c, etc.)
d. Optional: the number of the ablation stake that the photo was taken at or near (stk1, stk2, stk3, stk4, stk4a, stk5)
e. Optional: abbreviated name that image is featuring
f. Optional: altitude in meters from where the photo was taken from

Examples:

- Nis_20060401_2100m.jpg: Nisqually Glacier at 2100m on April 1, 2006
- Emm_2004_summer_stk1.jpg: Stake 1 of Emmons Glacier in the year of 2004
- Emm_Oct2005_surf_pond_stk3b.jpg: The second picture of a surficial pond near stk3 of Emmons Glacier in October 2005.

In cases where there are small quantities of photos it is practical to individually rename these files. However, for larger numbers it may be useful to rename files in batches. This may be done in ThumbsPlus, Extensis Portfolio or a similar image software package. A somewhat less sophisticated alternative is to batch rename files in Windows Explorer, by first selecting the files to be renamed and then selecting File > Rename. The edits made to one file will be made to all others, although with the unpleasant side effect of often adding spaces and special characters (e.g., parentheses) which will then need to be removed manually.

Renaming photos may be most efficient as a two part event – one step performed as a batch process which inserts the date and transect number at the beginning of the photo name, and a second step in which a descriptive component is manually added to each file name.

4. Establish Database Links

During data entry and processing, the database application will provide the functionality required to establish a link between each database record and the appropriate image file(s). To establish the link, the database prompts the user to indicate the root project workspace directory path, the specific image folder within the project workspace, and the specific file name. This way, the entire workspace may be later moved to a different directory (i.e., the NCCN Digital Library) and the links will still be valid after changing only the root path. Refer to SOP 19 (Data Entry and Verification) for additional details on establishing these links.

Note: It is important that the files keep the same name and relative organization once these database links have been established. Users should not rename or reorganize the directory structure for linked image files without first consulting with the Data Manager.

5. Deliver Image Files for Final Storage

Note: Please refer to SOP 21 (Product Delivery Specifications).

At the end of the season, and once the year's data are certified, data images for the year may be delivered along with the working copy of the database to the Data Manager on a CD or DVD. To do this, simply copy the folder for the appropriate year(s) and all associated subfolders and images onto the disk. These files will be loaded into the project section of the NCCN Digital Library, and the database links to data images will be updated accordingly.

Prior to delivery, make sure that all processing folders are empty. Upon delivery, the delivered folders should be made read-only to prevent unintended changes.

SOP 18. Metadata Development

Version 4/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview

Data documentation is a critical step toward ensuring that data sets are usable for their intended purposes well into the future (Boetsch et al., 2005). This involves the development of metadata, which can be defined as structured information about the content, quality, condition and other characteristics of a given data set. Additionally, metadata provide the means to catalog and search among data sets, thus making them available to a broad range of potential data users. Metadata for all NCCN monitoring data will conform to Federal Geographic Data Committee (FGDC) guidelines and will contain all components of supporting information such that the data may be confidently manipulated, analyzed and synthesized.

Updated metadata is a required deliverable that should accompany each season's certified data. For long-term projects such as this one, metadata creation is most time consuming the first time it is developed, after which most information remains static from one year to the next. Metadata records in subsequent years then only need to be updated to reflect changes in contact information and taxonomic conventions, to include recent publications, to update data disposition and quality descriptions, and to describe any changes in collection methods, analysis approaches or quality assurance for the project.

Procedures

Specific procedures for creating, parsing and posting the metadata record are found in NCCN Metadata Development Guidelines (http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm) (NCCN, 2006). The general flow is as follows:

1. After the annual data quality review has been performed and the data are ready for certification, the Project Lead (or a designee) updates the metadata interview form.
    a. The metadata interview form greatly facilitates metadata creation by structuring the required information into a logical arrangement of 15 main questions, many with additional sub-questions.
    b. The first year, a new copy of the NCCN Metadata Interview (http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm) form should be downloaded. Otherwise the form from the previous year can be used as a starting point, in which case the Track Changes tool in MS Word should be activated in order to make edits obvious to the person who will be updating the XML record.

   c. Complete the metadata interview form and maintain it in the project workspace. Much of the interview form can be filled out by cutting and pasting material from other documents (e.g., reports, protocol narrative sections, and SOPs).
   d. The Data Manager can help answer questions about the metadata interview form.

2. Deliver the completed interview form to the Data Manager according to the **SOP 21** (Product Delivery Specifications).

3. The Data Manager (or GIS Specialist for spatial data) will then extract the information from the interview form and use it to create and update an FGDC- and NPS-compliant metadata record in XML format. Specific guidance for creating the XML record is contained in NCCN Metadata Development Guidelines (NCCN, 2006).

4. The Data Manager will post the record and the certified data to the NPS Data Store, and maintain a local copy of the XML file for subsequent updates. The NPS Data Store has help files to guide the upload process.

5. The Project Lead should update the metadata interview content as changes to the protocol are made, and each year as additional data are accumulated.

References

Boetsch, J. R., B. Christoe, and R. E. Holmes. 2005. Data management plan for the North Coast and Cascades Network Inventory and Monitoring Program. USDI National Park Service. Port Angeles, WA. Available at: http://www1.nature.nps.gov/im/units/nccn/datamgmt.cfm

NCCN (North Coast and Cascades Network – National Park Service). 2006. Metadata development guidelines. USDI National Park Service. Available at: http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm

SOP 19. Data Entry and Verification

Version 4/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview Guidelines for Data Entry and Verification

This document describes the general procedures for entry and verification of field data in the working project database. Refer also to protocol Section 4C – Overview of Database Design, and Section 4D – Data Entry and Processing for related guidance and a clarification of the distinction between the working database and the master database. The following are general guidelines to keep in mind:

1. Data entry should occur as soon after data collection as possible so that field crews keep current with data entry tasks, and catch any errors or problems as close to the time of data collection as possible.

2. The working database application will be found in the project workspace. For enhanced performance, it is recommended that users copy the front-end database onto their workstation hard drives and open it there. This front-end copy may be considered "disposable" because it does not contain any data, but rather acts as an interface with data residing in the back-end working database.

3. Each data entry form is patterned after the layout of the field form, and has built-in quality assurance components such as pick lists and validation rules to test for missing data or illogical combinations. Although the database permits users to view the raw data tables and other database objects, users are strongly encouraged only to use the pre-built forms as a way of ensuring the maximum level of quality assurance.

4. As data are being entered, the person entering the data should visually review each data form to make sure that the data on screen match the field forms. This should be done for each record prior to moving to the next form for data entry.

5. At regular intervals and at the end of the field season the Field Lead should inspect the data that have been entered to check for completeness and perhaps catch avoidable errors. The Field Lead may also periodically run the Quality Assurance Tools that are built into the front-end working database application to check for logical inconsistencies and data outliers (this step is described in greater detail in Section 4E and also in SOP 20 (Data Quality Review and Certification).

Database Instructions

Getting Started

The first action to be taken is to make sure the data entry workspace is set up properly on a networked drive. If you are unclear about where this should be, contact either the local park wildlife biologist or the Data Manager.

- Store the back-end database file on the server so that others can enter data into the same back end file. The back-end file has "_be_" as part of its name. Upon saving this back-end, the user may want to append the local park code to distinguish it from other back-end files associated with other crews (e.g., Glaciers_HYa01_be_2007_OLYM.mdb).
- The crew's copy of the front-end database may also be stored in the same folder.

- If it doesn't already exist, also create a folder in the same network folder named "backups" or "backup_copies" for storing daily backups of the back-end database file.

Prior to using the database:

- Open the front-end database. The first thing it will do is to ask to update the links to the back-end database file. This will only need to be done once for each new issue of the front-end database.

Important Reminders for Daily Database Use

- A fresh copy of the front-end will need to be copied to your workstation every day. Do not open up and use the front-end on the network as this 'bloats' the database file and makes it run more slowly.
- Backups should be made consistently at some point every day that data entry occurs. Normally the front-end application will automatically prompt you to make a backup either upon initially opening or upon exiting the application. Backups can also be made on demand by hitting the "Back up data" button on the main menu and storing the backup file in the "backups" folder.
- To save drive space and network resources, backup files should be compacted by right-clicking on the backup file in Windows Explorer and selecting the option: "Add to Zip file". Older files may be deleted at the discretion of the project crew lead.
- New issues of the front-end application may be released as needed through the course of the field season. If this happens, there should be no need to move or alter the back-end file. Instead, the front-end file may be deleted and replaced with the new version, which will be named in a manner reflecting the update (e.g., Glaciers_2007_v2.mdb).
- If the front-end database gets bigger and slower, compact it periodically by selecting Tools > Database Utilities > Compact and Repair Database.

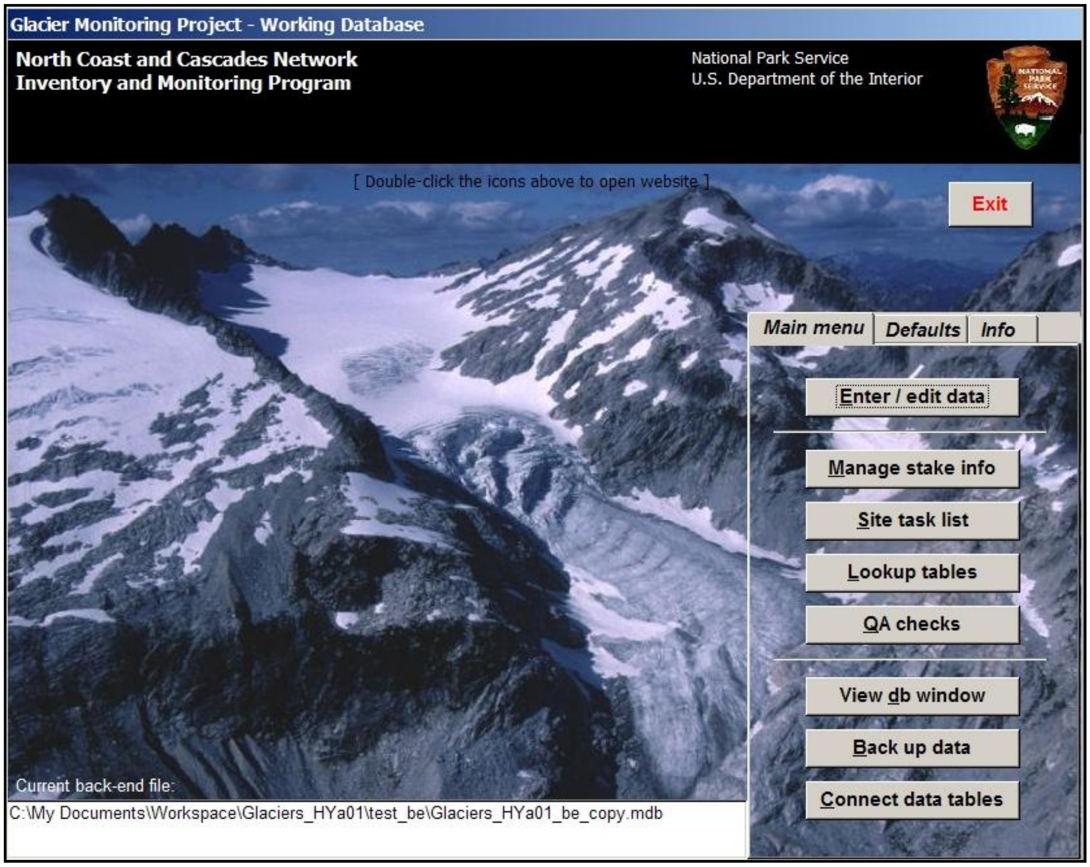
Database Components

The working front-end application has the following functional components, which are accessed from the main application switchboard form that opens automatically when the application starts:

- Enter / edit data – Opens a form to confirm default settings (e.g., park, coordinate datum) prior to continuing to the project-specific data entry screens.
- Manage stake info – Opens a form for entering coordinates and other information about each sampling stake.
- Site task list – Keeps track of unfinished tasks associated with sample locations (e.g., forgotten equipment, unfinished data collection) that one field crew can use to communicate with a future field crew.
- Lookup tables – Opens a tool for managing the lookup values for the project data set (e.g., species list, list of project personnel, etc.).
- QA checks – Opens the data validation tool, which shows the results of pre-built queries that check for data integrity, missing data, and illogical values, and allows the user to fix these problems and document the fixes. See SOP 20 (Data Quality Review and Certification).
- View db window – Allows the user to view database objects (tables, queries and forms).
- Back up data – Creates a date-stamped copy of the back-end database file.

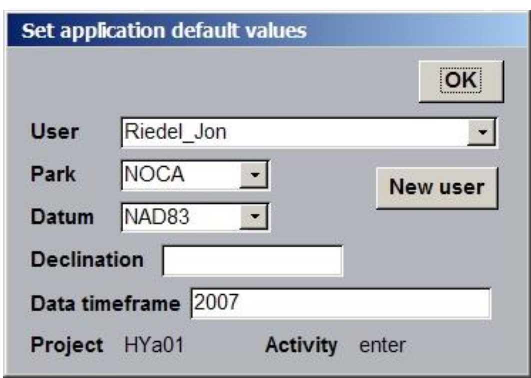
- Connect data tables – Verifies the connection to the back-end working database file, and provides the option to redirect or update that connection.

Here is a view of the main menu / switchboard form.



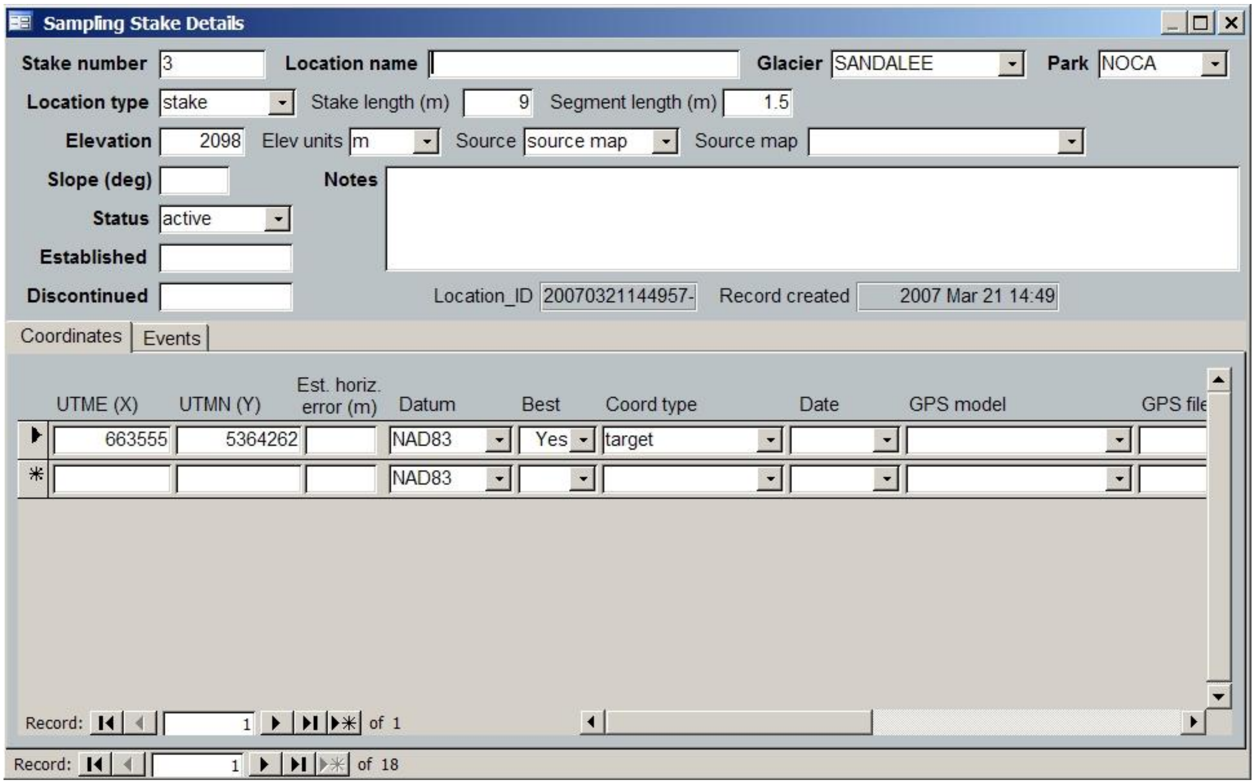
The second tab shows the current application default settings.

To set defaults, hit the ‘Change’ button. This will open up a new window where the user can enter the park, datum and user name. This window also appears each time the user selects the path for data entry or review to ensure that the correct user and park are indicated.



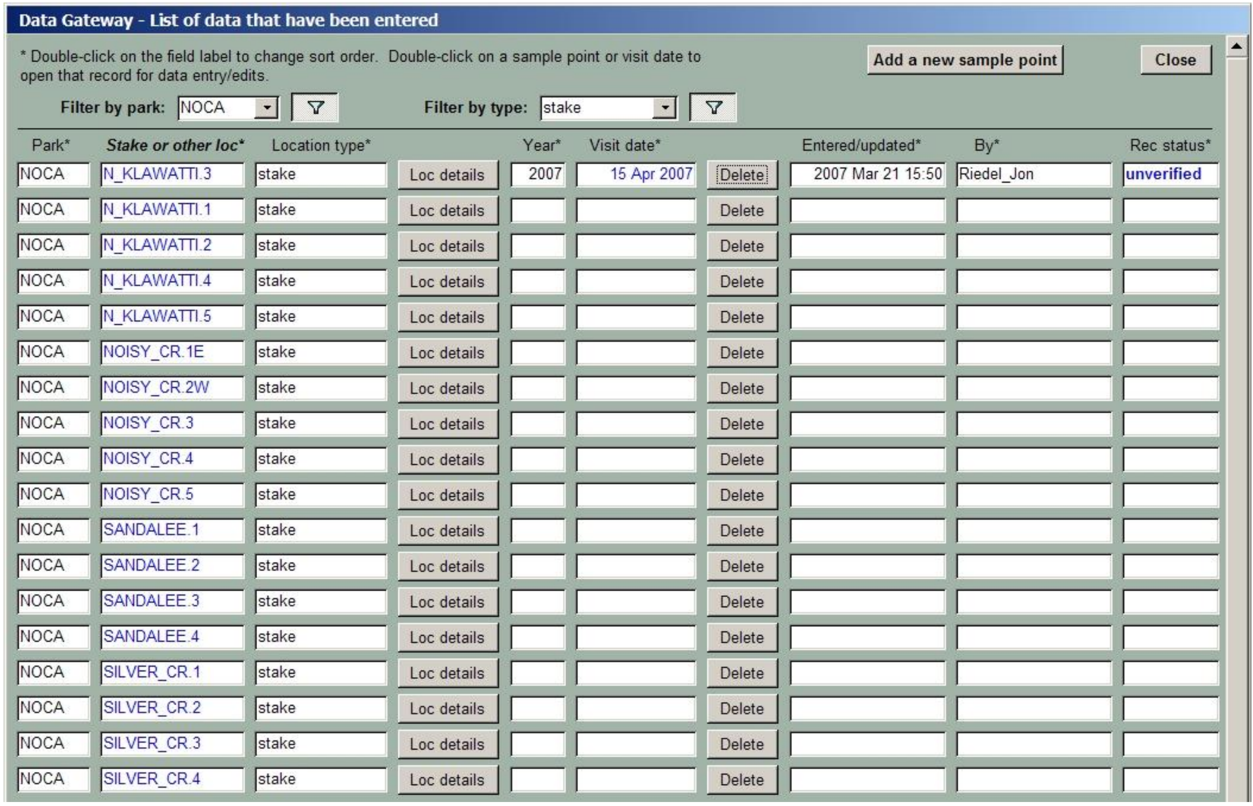
Entering Data

Upon hitting the "Manage stake info" button, you will be able to enter or view coordinate information and a list of sampling events associated with each sampling stake.



When you select the "Enter / edit data" button, you will have a chance to change the default user name, park and declination. Make sure this information is correct each time you go to enter data.

Next you will see the Data Gateway, which is where you will see a list of stakes, benchmarks and other incidental sample locations that are already present in the back-end database. This list is automatically filtered by the selected park (upper left corner), and to show only transect origins. Filters can be changed at any time, and records can be sorted by double-clicking on the field label above each column.



Data Gateway - List of data that have been entered

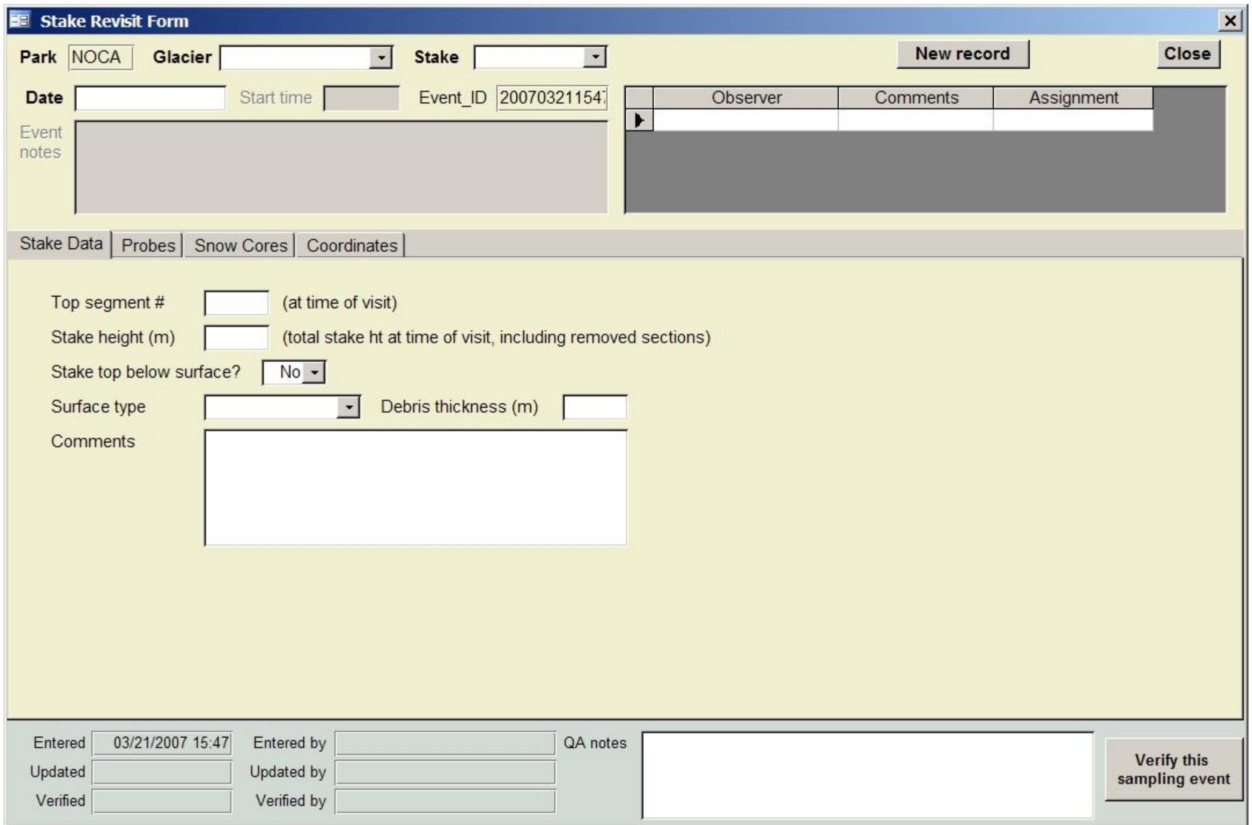
* Double-click on the field label to change sort order. Double-click on a sample point or visit date to open that record for data entry/edits.

Add a new sample point | Close

Filter by park: NOCA **Filter by type:** stake

Park*	*Stake or other loc**	Location type*		Year*	Visit date*		Entered/updated*	By*	Rec status*
NOCA	N_KLAWATTI.3	stake	Loc details	2007	15 Apr 2007	Delete	2007 Mar 21 15:50	Riedel_Jon	unverified
NOCA	N_KLAWATTI.1	stake	Loc details			Delete			
NOCA	N_KLAWATTI.2	stake	Loc details			Delete			
NOCA	N_KLAWATTI.4	stake	Loc details			Delete			
NOCA	N_KLAWATTI.5	stake	Loc details			Delete			
NOCA	NOISY_CR.1E	stake	Loc details			Delete			
NOCA	NOISY_CR.2W	stake	Loc details			Delete			
NOCA	NOISY_CR.3	stake	Loc details			Delete			
NOCA	NOISY_CR.4	stake	Loc details			Delete			
NOCA	NOISY_CR.5	stake	Loc details			Delete			
NOCA	SANDALEE.1	stake	Loc details			Delete			
NOCA	SANDALEE.2	stake	Loc details			Delete			
NOCA	SANDALEE.3	stake	Loc details			Delete			
NOCA	SANDALEE.4	stake	Loc details			Delete			
NOCA	SILVER_CR.1	stake	Loc details			Delete			
NOCA	SILVER_CR.2	stake	Loc details			Delete			
NOCA	SILVER_CR.3	stake	Loc details			Delete			
NOCA	SILVER_CR.4	stake	Loc details			Delete			

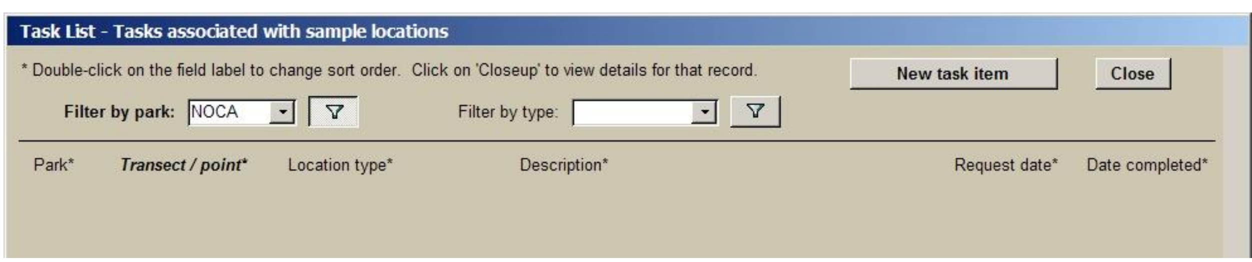
Clicking the “Add a new sampling point” button (upper right corner) will open the Sampling Stake Details form to a blank record. To open an existing record for edits or to complete data entry, click on the “Loc details” button associated with the desired record.



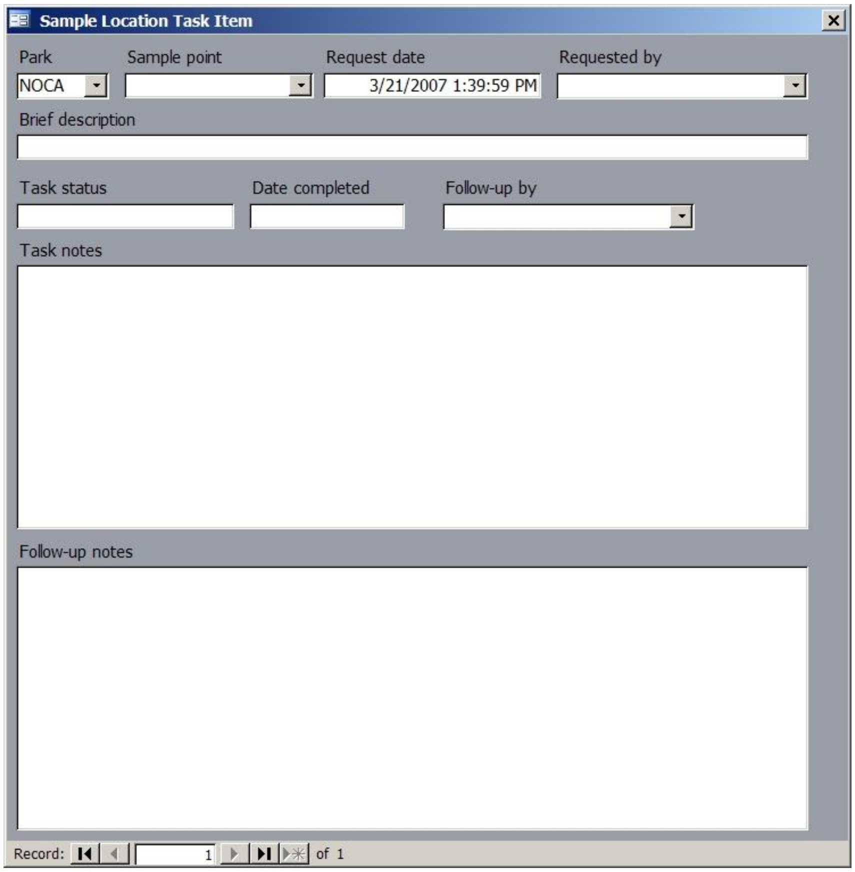
Upon finishing data entry for each stake, the database entries should be compared against the original field forms. When all of the data for the sampling event have been entered, hit the button that says "Verify this sampling event" to indicate that the event record is complete and accurately reflects the field forms.

Task List

The task list browser functions in much the same way as the Data Gateway form, and can be sorted or filtered by park or location type. Hit the "Closeup" button to view or edit information for that record.

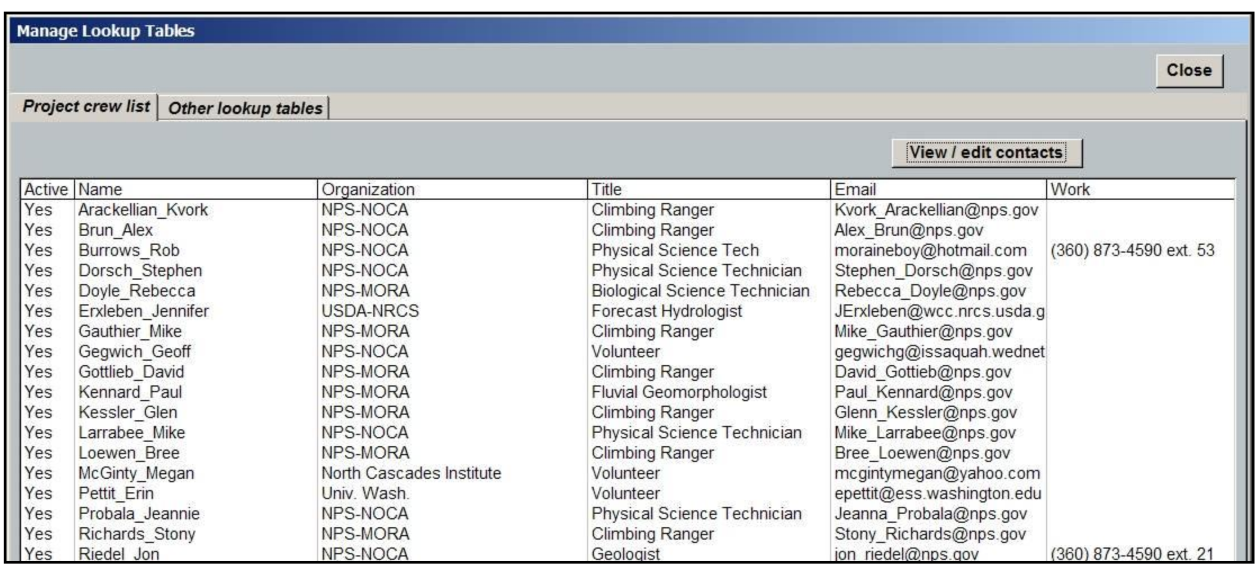


Close-up view for entering/editing location task items:

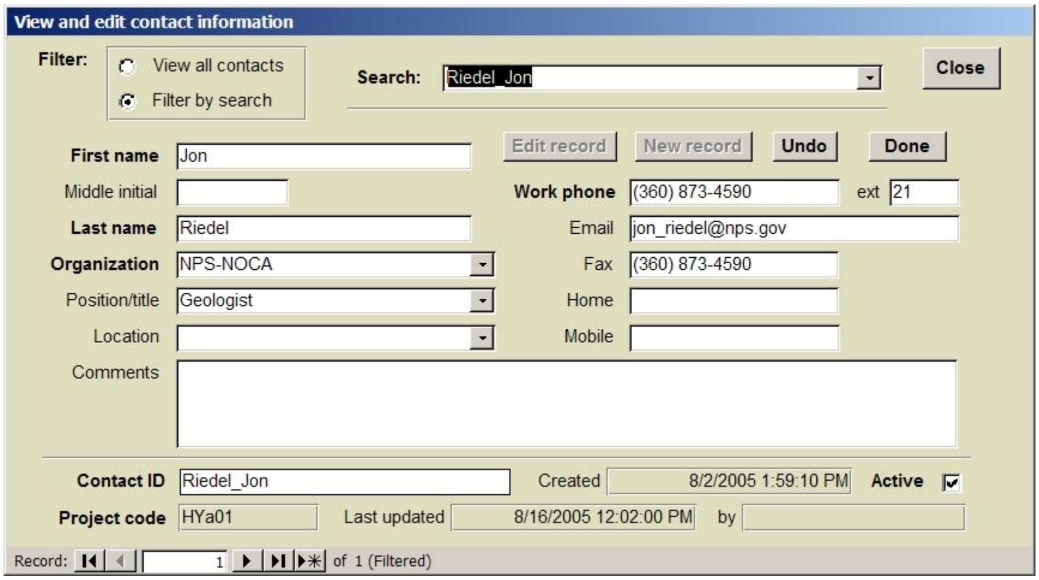


Manage Lookups

From the main menu, hit ‘Lookup tables’ to open the lookup tool. This tool has 2 tabs – one for the project contacts list, and another for viewing the contents of all other lookup tables. The first tab of the lookups module is a list of contacts for the project.

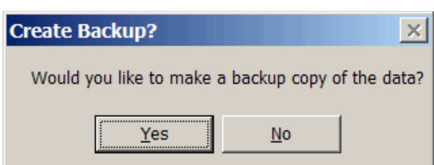


By selecting a contact record and hitting the “View / edit” button, or by double-clicking on a contact record, the following popup is opened in edit mode. Once edits are accepted with the “Done” button, the user may either page through the records using the record navigator at the bottom of the form, or may search for a particular name in the drop-down pick list.

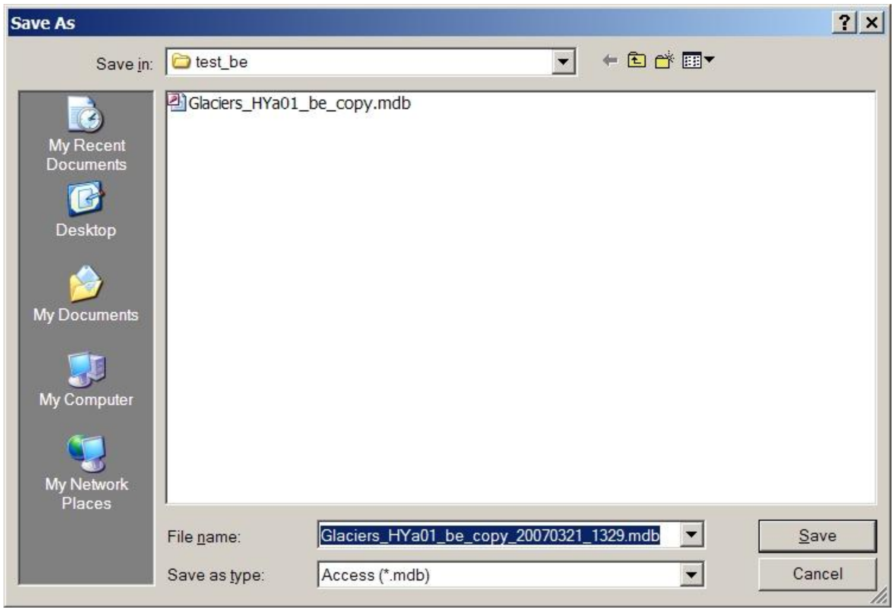


Database Backups

It is recommended that data backups be made on a regular basis – perhaps every day that new data are entered – to save time in case of mistakes or database file corruption. Depending on application defaults, you will be prompted upon opening or closing the application as to whether or not you want to make a backup. If you choose not to make a backup at this time, you may make one at any point by hitting the “Back up data” button on the main menu.

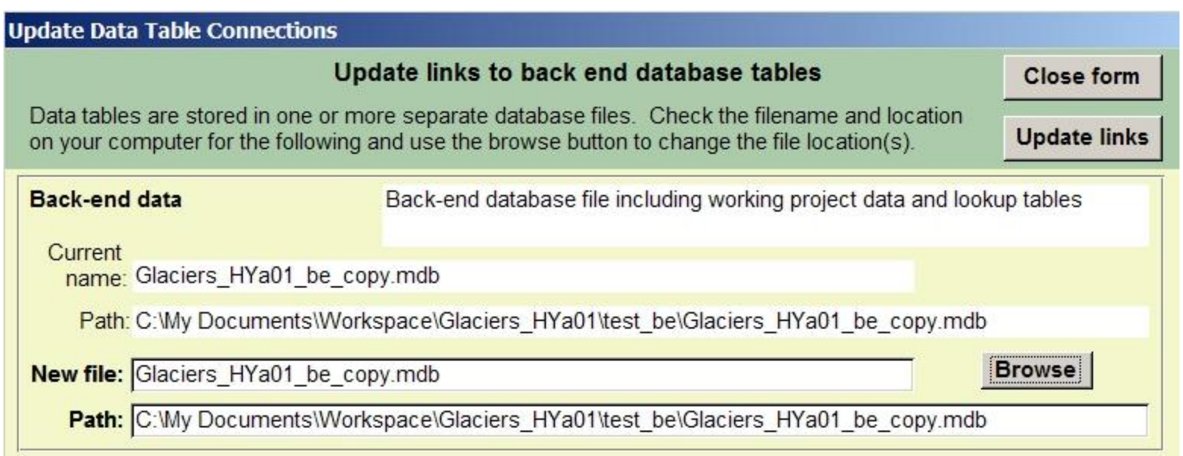


If you respond 'Yes' to the backup prompt, a window will open to allow you to indicate where to save the file. The default path is the same as the back-end database file, and the default name is that for the back-end file with a date stamp appended to the end. It is recommended that backups be made in a subfolder exclusively for backups in order to clearly separate the working back-end database file from the backups. These periodic backup files should be compressed to save drive space, and may be deleted once enough subsequent backups are made. All such backups should be deleted after the data have passed the quality review and been certified.



Link Back-End Data File

When first installing the front-end application, the user will need to establish the table links to the back-end database. Users may also need to refresh the links if the back end path changes or if a user wants to connect to a different back-end data file. Table links can be updated using the Data Table Connections tool, available by hitting the ‘Connect data tables’ button on the main menu. Browse to the desired back-end file and then hit ‘Update links’ to refresh the connection.



SOP 20. Data Quality Review and Certification

Version 4/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Tables

Overview

This document describes the procedures for validation and certification of data in the working project database. Refer also to protocol narrative Section 4C – Overview of Database Design, Section 4E – Quality Review, and Section 4G – Data Certification and Delivery for related guidance and a clarification of the distinction between the working database and the master database.

After the season's field data have been entered and processed, they need to be reviewed and certified by the Project Lead for quality, completeness and logical consistency. Data validation is the process of checking data for completeness, structural integrity, and logical consistency. The working database application facilitates this process by showing the results of pre-built queries that check for data integrity, data outliers and missing values, and illogical values. The user may then fix these problems and document the fixes.

Once the data have been through the validation process and metadata have been developed for them, they are to be certified by completing the NCCN Project Data Certification Form, available on the NCCN website (http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm). The completed form, certified data and updated metadata may then be delivered to the NPS Lead and the Data Manager according to the timeline in Appendix B (Yearly Project Task List).

Data Quality Review

The following table (SOP 20.1) shows the automated validation checks that are performed on the data prior to certification. These queries are designed to return records that need to be fixed, so ideally – once all data checks have been run and any errors have been fixed – none of the queries will return records. However, not all errors and inconsistencies can be fixed, in which case a description of the resulting errors and why edits were not made is then documented and included in the metadata and certification report.

The queries are named and numbered hierarchically so that high-order data – for example from tables on the parent side of a parent-child relationship such as sample locations – should be fixed before low-order data (e.g., individual species observations). The rationale for this is that one change in a high-order table affects many downstream records, and so proceeding in this fashion is the most efficient way to isolate and treat errors.

In addition to these automated checks, the person performing the quality review should remain vigilant for errors or omissions that may not be caught by the automated queries. Another task that cannot be automated is the process of making sure that all of the data for the current season are in fact entered into the database. This will often involve manual comparisons between field forms or other lists of the sites visited and the results of queries showing the sites for which data exist. The Data Manager is also available as needed to help construct new database queries or modify existing ones as needed.

Table SOP 20.1 Automated validation checks performed on data prior to certification

Query_name	Returns records meeting the following criteria
qa_1a_Strata_missing_critical_info	Missing park code, project code, stratification date, stratum name, stratum definition
qa_1b_Strata_illogical_dates	Stratum record updated date prior to created date
qa_2a_Sites_missing_critical_info	Missing site code, park code, or stratum ID
qa_2b_Sites_park_inconsistencies	Park code inconsistent with strata table
qa_2c_Sites_duplicates_on_code_and_park	Duplicate records on site code and park code
qa_2d_Sites_missing_evaluation_codes	Established or rejected sites without evaluation codes
qa_2e_Sites_site_status_inconsistencies	Missing site status, 'retired' sites without discontinued dates, discontinued dates on status other than 'retired', or discontinued dates without establishment dates
qa_2f_Sites_illogical_dates	Discontinued date prior to establishment date, or updated date prior to created date
qa_2g_Sites_missing_panel_type	Active sites without a panel type
qa_2h_Sites_missing_site_name	Missing site name (no remedy required)
qa_3a_Locations_missing_critical_info	Missing site ID (except where loc_type = 'incidental'), location code, location type, or park code
qa_3b_Locations_park_inconsistencies	Park code inconsistent with sites table
qa_3c_Locations_duplicates_on_site_and_loc_code	Duplicate records on site ID and loc code
qa_3d_Locations_duplicates_on_site_and_loc_name	Duplicate records on site ID and loc name
qa_3e_Locations_duplicates_on_loc_name_and_park	Duplicate records on loc name and park code

Table SOP 20.1 Automated validation checks performed on data prior to certification (continued).

Query_name	Returns records meeting the following criteria
qa_3f_Locations_missing_sampling_events	Location type <> 'origin' and missing an event; or event is null and features, markers or images were entered
qa_3g_Locations_missing_establishment_dates	Locations with sampling events or field coordinates or discontinued dates, but without with location establishment dates
qa_3h_Locations_loc_status_inconsistencies	Missing loc status; sampled locations with loc status = 'rejected' or 'proposed'; locs with establishment dates or field coords and loc_status = 'proposed'; 'retired' locs without discontinued dates; discontinued dates on status other than 'retired'
qa_3i_Locations_unclassified_new_points	Newly sampled locations with an undetermined location type (location_type = 'new')
qa_3j_Locations_loc_type_and_loc_code_inconsistent	Locations where loc code = 'TO' and loc type <> 'origin' or vice versa, or where loc code = 'rare' and loc type <> 'incidental' or vice versa
qa_3k_Location_illogical_dates	Discontinued date prior to establishment date, or updated date prior to created date
qa_3l_Locations_without_coordinates	Locations without coordinates
qa_3m_Locations_without_field_coords	Locations that have sampling events but no field coordinates (no remedy required)
qa_3n_Locations_with_more_than_one_coord	Locations with more than one coordinate record; verify that these are intended
qa_3o_Locations_missing_travel_info	Sampled locations missing azimuth to point, travel notes, or reason for azimuth direction changes where direction changed = 'yes'
qa_3p_Locations_missing_env_values	Missing elevation, slope or aspect values

Table SOP 20.1 Automated validation checks performed on data prior to certification (continued).

Query_name	Returns records meeting the following criteria
qa_3q_Locations_elev_source_inconsistencies	Sampled locations where elevation source = 'GIS theme'
qa_3r_Locations_missing_elev_metadata	Missing elevation units or elevation source where elevations are present
qa_3s_Locations_elev_unit_inconsistencies	Elevation units = 'm' but elevation source = 'GIS theme'; units = 'm' but elevation values over 4419
qa_3t_Locations_without_markers	Locations that have sampling events but no markers
qa_3u_Locations_no_best_coord_assigned	For GIS specialist: locations without best coordinates
qa_4a_Coordinates_missing_critical_values	Records missing location ID or coord creation date
qa_4b_Coordinates_incomplete_field_UTMs	A portion of the field coordinate pair is missing, or the field datum is missing
qa_4c_Coordinates_missing_field_UTMs	Field UTMs are missing, but where there is either a coordinate collection date, a coordinate label, a field error, field offsets, field sources, GPS file or model type, or a source map scale filled in
qa_4d_Coordinates_missing_field_coord_date	Field coordinates without a coordinate collection date
qa_4e_Coordinates_inconsistent_field_source_info	Field coordinate source = 'map', however there is a GPS file name, a field horizontal error, or GPS model filled in to suggest that the source is GPS
qa_4f_Coordinates_final_UTM_inconsistencies	Final UTM coordinates are incomplete; or they are present and the coordinate type or datum is missing; or coord type or an estimated error value is present and the coordinates are missing
qa_4g_Coordinates_public_UTM_inconsistencies	Public UTM coordinates are incomplete; or they are present and the public coord type is missing; or public coord type or public coord scale is present and the public coordinates are missing
qa_4h_Coordinates_illogical_dates	Coordinates with updated dates before creation dates

Table SOP 20.1 Automated validation checks performed on data prior to certification (continued).

Query_name	Returns records meeting the following criteria
qa_4i_Coordinates_target_coord_inconsistencies	Target UTM coordinates are incomplete; or they are present and the target datum is missing
qa_4j_Coordinates_without_final_or_public_coords	For GIS specialist: records missing final UTMs and/or public coordinates
qa_5a_Sample_period_errors	Missing start or end dates; start date/time after end date/time; or updated dates prior to created dates
qa_6a_Events_missing_critical_info	Missing location ID, project code, or start date
qa_6b_Events_duplicates_on_location	Duplicate records on location ID - also shows how many records exist in related tables
qa_6c_Events_missing_start_times	Start times missing where location type is missing or <> 'origin'
qa_6d_Events_without_observers	Events without associated observers
qa_6e_Events_without_point_count_data	Events without associated point count data where location type <> 'incidental'
qa_6f_Events_without_habitat_data	Events without associated habitat data where location type <> 'incidental'
qa_6g_Events_missing_obs_records	Events at incidental sampling locations without associated rare bird or nesting observations
qa_6h_Events_inconsistent_coord_info	Events at locations where coordinates_updated = True but missing associated coordinate records, or having associated coordinates where coordinates _updated = False, or where coord_date is different from the date of the event
qa_6i_Events_inconsistent_feature_info	Events at locations where features_updated = True but missing associated feature records, or having associated features where features_updated = False

Table SOP 20.1 Automated validation checks performed on data prior to certification (continued).

Query_name	Returns records meeting the following criteria
qa_6j_Events_inconsistent_marker_info	Events at locations where markers_updated = True but missing associated marker records, or having associated markers where markers_updated = False, or where marker_installed is different from the date of the event
qa_6k_Events_inconsistent_image_info	Events at locations where photos_taken = True but missing associated image records, or having associated images where photos_taken = False, or where image_date is different from the date of the event
qa_6l_Events_missing_conditions	Point count events with missing environmental conditions - noise level, wind_cond, precip_cond, cloud_cover, temperature
qa_6m_Events_illogical_dates	Events with start date/times occurring after end date/times; or records that have update or verified dates prior to the record creation date
qa_7a_Observers_missing_critical_info	Missing event ID or contact ID
qa_7b_Observers_missing_role	Observer role is missing (no remedy required)
qa_7c_Markers_missing_critical_info	Missing marker code, location ID, marker type, marker status, or marker updated values
qa_7d_Markers_missing_measurements	Missing marker height, substrate, or having only partial offset information (distance without azimuth or vice versa)
qa_7e_Markers_status_inconsistencies	Marker status = 'removed' but no removal date, or with a removal date and status <> 'removed'
qa_7f_Markers_illogical_dates	Marker updated or marker removed date before marker installed date
qa_7i_Features_missing_measurements	Missing distance or azimuth values
qa_7j_Features_missing_critical_info	Location ID, feature type, or feature status is missing
qa_8a_Habitat_missing_critical_info	Missing event ID or habitat num

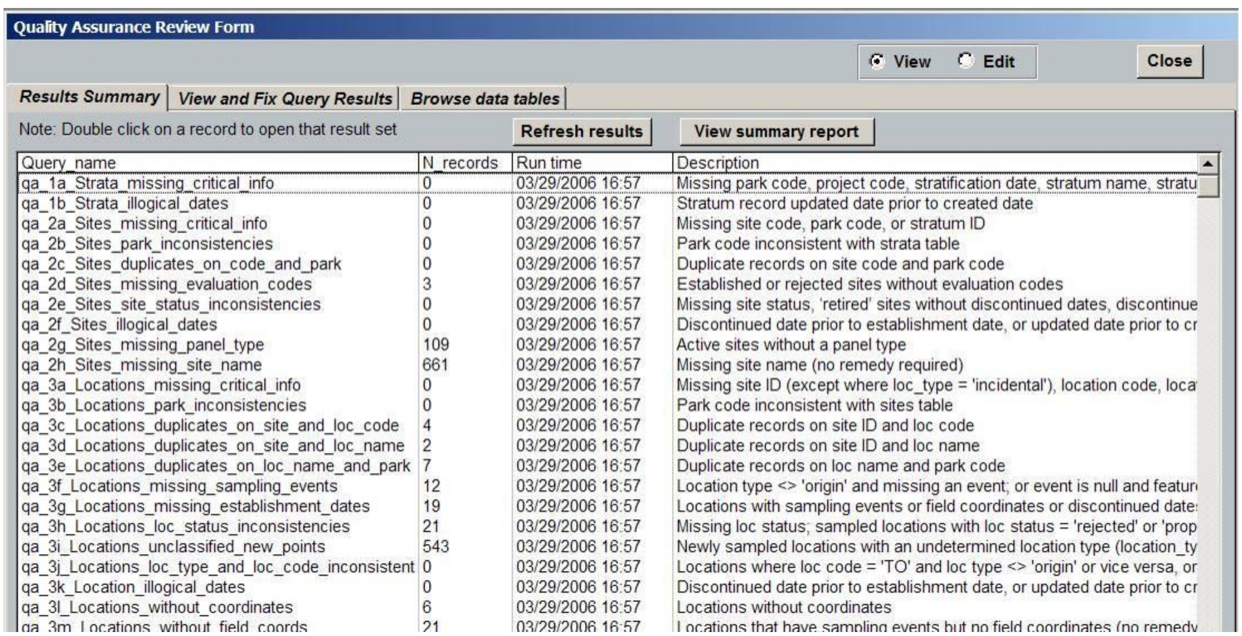
Table SOP 20.1 Automated validation checks performed on data prior to certification (continued).

Query_name	Returns records meeting the following criteria
qa_8b_Habitat_missing_values	Missing PMR code, canopy cover, or tree size class
qa_8c_Nesting_obs_missing_values	Missing event ID, taxon ID, or nest activity
qa_8d_Point_counts_missing_critical_info	Missing event ID, taxon ID, time interval, or group size
qa_8e_Point_counts_missing_values	Missing observation distance, seen first, ever sang, prev observed, or flyover
qa_8f_Rare_bird_obs_missing_critical_info	Missing event ID or taxon ID
qa_8g_Rare_bird_obs_missing_values	Missing observation distance, group size, or nest activity

Using the Database Quality Review Tools

Open the working copy of the database application and hit the button labeled "QA Checks". This will open the quality review form. Upon opening, the quality review form automatically runs the validation queries and stores the results in a table built into the front-end database (tbl_QA_Results). Each time the queries results are refreshed, or the quality review form is re-opened, the number of records returned and the run times are rewritten so that the most recent result set is always available; any remedy description and the user name for the person making the edits is retained between runs of the queries. These results form the basis of documentation in the certification report output as shown below.

The first page of the quality review form has a results summary showing each query sorted by name, the number of records returned by the query, the most recent run time, and the description. There is also a button for refreshing the results, which may need to be done periodically as changes in one part of the data structure may change the number of records returned by other queries.



Quality Assurance Review Form

View Edit Close

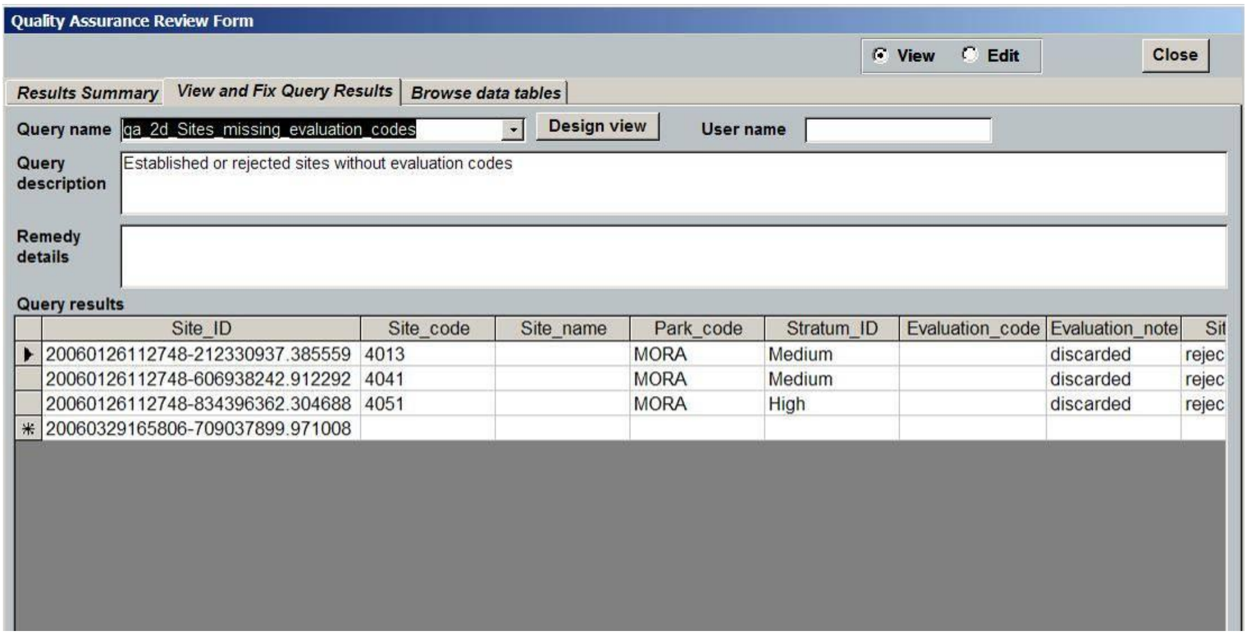
Results Summary | View and Fix Query Results | Browse data tables

Note: Double click on a record to open that result set

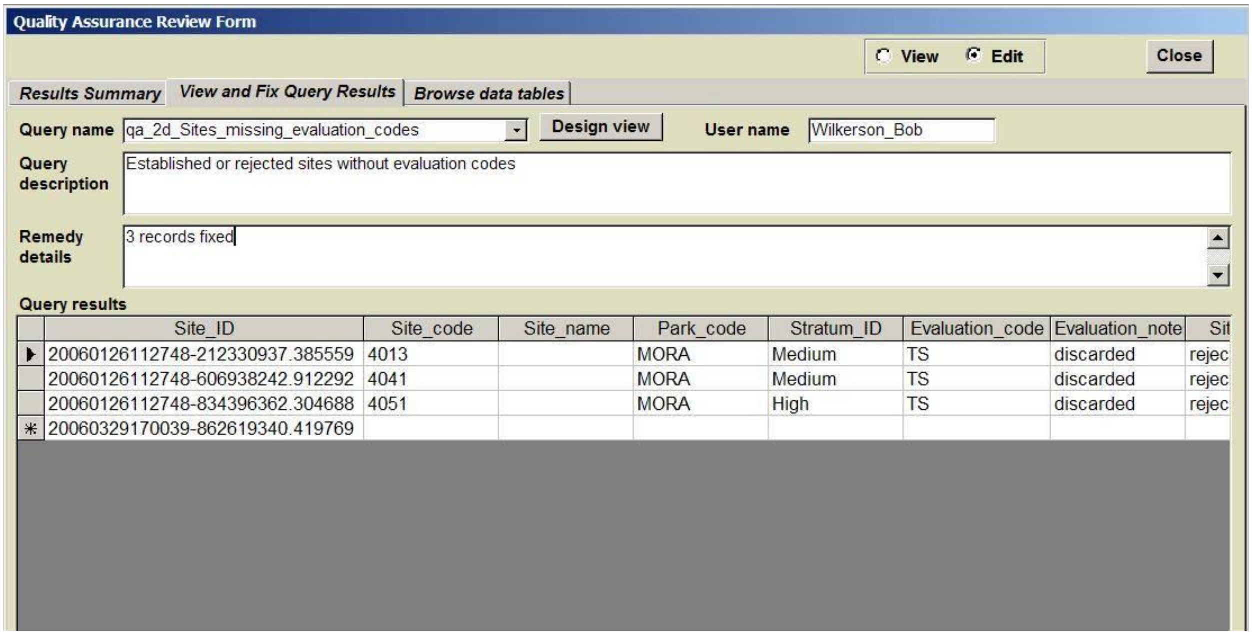
Refresh results | View summary report

Query_name	N_records	Run time	Description
qa_1a_Strata_missing_critical_info	0	03/29/2006 16:57	Missing park code, project code, stratification date, stratum name, stratu
qa_1b_Strata_illogical_dates	0	03/29/2006 16:57	Stratum record updated date prior to created date
qa_2a_Sites_missing_critical_info	0	03/29/2006 16:57	Missing site code, park code, or stratum ID
qa_2b_Sites_park_inconsistencies	0	03/29/2006 16:57	Park code inconsistent with strata table
qa_2c_Sites_duplicates_on_code_and_park	0	03/29/2006 16:57	Duplicate records on site code and park code
qa_2d_Sites_missing_evaluation_codes	3	03/29/2006 16:57	Established or rejected sites without evaluation codes
qa_2e_Sites_site_status_inconsistencies	0	03/29/2006 16:57	Missing site status, 'retired' sites without discontinued dates, discontinue
qa_2f_Sites_illogical_dates	0	03/29/2006 16:57	Discontinued date prior to establishment date, or updated date prior to cr
qa_2g_Sites_missing_panel_type	109	03/29/2006 16:57	Active sites without a panel type
qa_2h_Sites_missing_site_name	661	03/29/2006 16:57	Missing site name (no remedy required)
qa_3a_Locations_missing_critical_info	0	03/29/2006 16:57	Missing site ID (except where loc_type = 'incidental'), location code, loca
qa_3b_Locations_park_inconsistencies	0	03/29/2006 16:57	Park code inconsistent with sites table
qa_3c_Locations_duplicates_on_site_and_loc_code	4	03/29/2006 16:57	Duplicate records on site ID and loc code
qa_3d_Locations_duplicates_on_site_and_loc_name	2	03/29/2006 16:57	Duplicate records on site ID and loc name
qa_3e_Locations_duplicates_on_loc_name_and_park	7	03/29/2006 16:57	Duplicate records on loc name and park code
qa_3f_Locations_missing_sampling_events	12	03/29/2006 16:57	Location type <> 'origin' and missing an event; or event is null and featur
qa_3g_Locations_missing_establishment_dates	19	03/29/2006 16:57	Locations with sampling events or field coordinates or discontinued date
qa_3h_Locations_loc_status_inconsistencies	21	03/29/2006 16:57	Missing loc status; sampled locations with loc status = 'rejected' or 'prop
qa_3i_Locations_unclassified_new_points	543	03/29/2006 16:57	Newly sampled locations with an undetermined location type (location_ty
qa_3j_Locations_loc_type_and_loc_code_inconsistent	0	03/29/2006 16:57	Locations where loc code = 'TO' and loc type <> 'origin' or vice versa, or
qa_3k_Location_illogical_dates	0	03/29/2006 16:57	Discontinued date prior to establishment date, or updated date prior to cr
qa_3l_Locations_without_coordinates	6	03/29/2006 16:57	Locations without coordinates
qa_3m_Locations_without_field_coords	21	03/29/2006 16:57	Locations that have sampling events but no field coordinates (no remedy

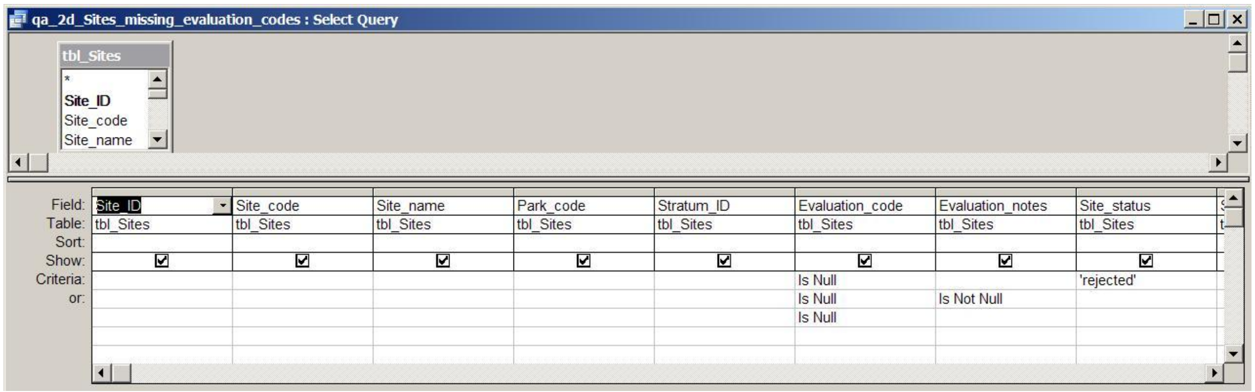
Upon double-clicking a particular query name, the second page will open up to show the results from that query.



In the upper-right is a switch that allows the user to put the form in either view mode (default) or edit mode. Upon changing to edit mode, the form changes color to provide a visual reminder that edits are possible. At this point the query results may be modified and the remedy details may be entered in the appropriate place. If certain records in a query result set are not to be fixed for whatever reason, this is also the place to document that. The user name is automatically filled in (if it was blank) once the user types in the remedy details.

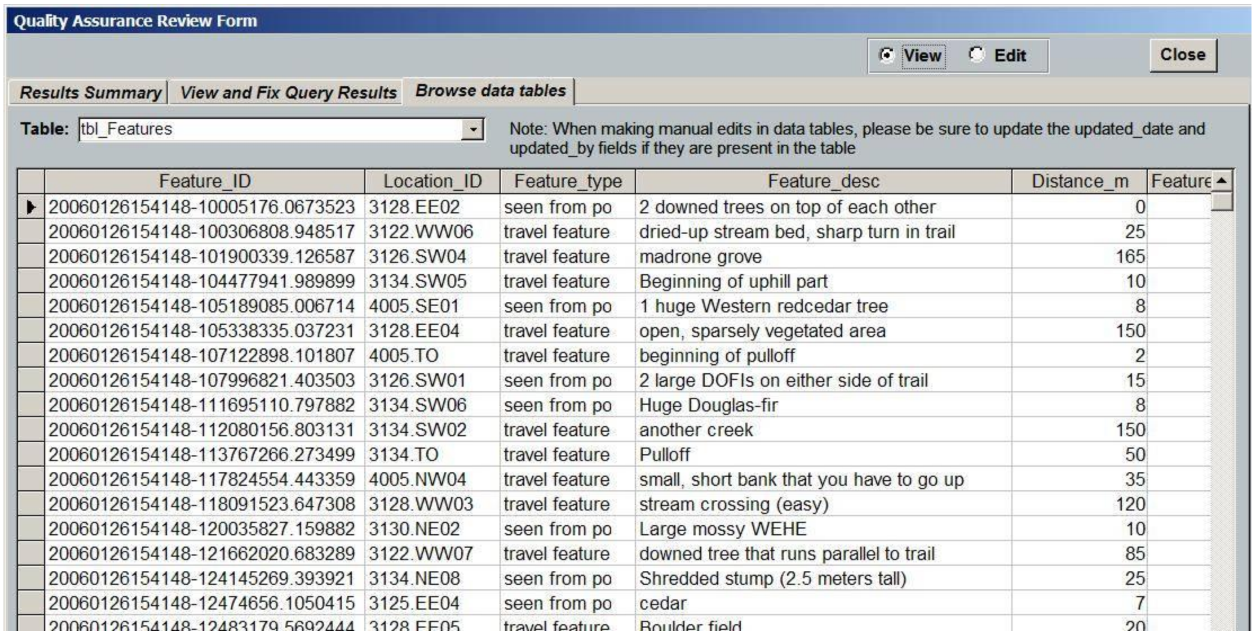


On this page is also a button labeled "Design view", which will open the currently selected query in the design interface in Access. In this manner, the user can verify that the query is in fact filtering records appropriately. Note: Any desired changes to query structure or names should be discussed with the Data Manager prior to making these changes.



Certain queries, due to their structural complexity, cannot be edited directly. Other queries may not contain all of the fields the user may want to see in order to make the best decision about whether and how to edit a given record. In such cases, the user may opt to view and/or edit data directly in the data tables. To facilitate this process, the "Browse Data Tables" page on the form can be used to open the table directly for viewing and editing as needed.

Important: As with all edits performed during the quality review, these types of direct edits in the data tables should be made with extreme care as the validation checks that are built into the front-end data entry forms are not present in the tables themselves. It is possible, therefore, to make edits to the tables that may result in a loss of data integrity and quality. While the automated queries are intended to check for these, it is not possible to check for every possible error combination.


Quality Assurance Review Form

View Edit Close

Results Summary | View and Fix Query Results | Browse data tables

Table: tbl_Features

Note: When making manual edits in data tables, please be sure to update the updated_date and updated_by fields if they are present in the table

Feature_ID	Location_ID	Feature_type	Feature_desc	Distance_m	Feature
20060126154148-10005176.0673523	3128.EE02	seen from po	2 downed trees on top of each other	0	
20060126154148-100306808.948517	3122.WW06	travel feature	dried-up stream bed, sharp turn in trail	25	
20060126154148-101900339.126587	3126.SW04	travel feature	madrone grove	165	
20060126154148-104477941.989899	3134.SW05	travel feature	Beginning of uphill part	10	
20060126154148-105189085.006714	4005.SE01	seen from po	1 huge Western redcedar tree	8	
20060126154148-105338335.037231	3128.EE04	travel feature	open, sparsely vegetated area	150	
20060126154148-107122898.101807	4005.TO	travel feature	beginning of pulloff	2	
20060126154148-107996821.403503	3126.SW01	seen from po	2 large DOFIs on either side of trail	15	
20060126154148-111695110.797882	3134.SW06	seen from po	Huge Douglas-fir	8	
20060126154148-112080156.803131	3134.SW02	travel feature	another creek	150	
20060126154148-113767266.273499	3134.TO	travel feature	Pulloff	50	
20060126154148-117824554.443359	4005.NW04	travel feature	small, short bank that you have to go up	35	
20060126154148-118091523.647308	3128.WW03	travel feature	stream crossing (easy)	120	
20060126154148-120035827.159882	3130.NE02	seen from po	Large mossy WEHE	10	
20060126154148-121662020.683289	3122.WW07	travel feature	downed tree that runs parallel to trail	85	
20060126154148-124145269.393921	3134.NE08	seen from po	Shredded stump (2.5 meters tall)	25	
20060126154148-12474656.1050415	3125.EE04	seen from po	cedar	7	
20060126154148-12483179.5692444	3128.EE05	travel feature	Boulder field	20	

Note: Whenever making quality review edits – whether through a query or directly in a table – the user should remember to update the Updated_date and Updated_by fields to the current date and the current user name.

Generating Output for the Certification Report

The first page of the quality review form has a button labeled “View summary report”. This button opens the formatted information for each query, the last run time, the number of records returned at last run time, a description and any remedy details that were typed in by the user. This report can be exported from the database and included as an attachment to the certification report by either hitting File > Export on the Access menu, or by right clicking on the report object and selecting Export. Select ‘Rich Text Format (*.rtf)’ to retain formatting to facilitate importing it into the certification report in Word.

tbl_QA_Results

Quality Assurance and Data Validation Results **Run time** 03/29/2006 17:02 **QA by**

Query name	Records	Query description	Remedy details
qa_1a_Strata_missing_critical_info	0	Missing park code, project code, stratification date, stratum name, stratum definition	
qa_1b_Strata_illogical_dates	0	Stratum record updated date prior to created date	
qa_2a_Sites_missing_critical_info	0	Missing site code, park code, or stratum ID	
qa_2b_Sites_park_inconsistencies	0	Park code inconsistent with strata table	
qa_2c_Sites_duplicates_on_code_and_park	0	Duplicate records on site code and park code	
qa_2e_Sites_site_status_inconsistencies	0	Missing site status, 'retired' sites without discontinued dates, discontinued dates on status other than 'retired', or discontinued dates without establishment dates	
qa_2f_Sites_illogical_dates	0	Discontinued date prior to establishment date, or updated date prior to created date	
qa_2g_Sites_missing_panel_type	109	Active sites without a panel type	
qa_2h_Sites_missing_site_name	661	Missing site name (no remedy required)	
qa_3a_Locations_missing_critical_info	0	Missing site ID (except where loc_type = 'incidental'), location code, location type, or park code	
qa_3b_Locations_park_inconsistencies	0	Park code inconsistent with sites table	
qa_3c_Locations_duplicates_on_site_and_lo	4	Duplicate records on site ID and loc code	
qa_3d_Locations_duplicates_on_site_and_lo	2	Duplicate records on site ID and loc name	
qa_3e_Locations_duplicates_on_loc_name_	7	Duplicate records on loc name and park code	
qa_3f_Locations_missing_sampling_events	12	Location type <> 'origin' and missing an event; or event is null and features, markers or images were entered	
qa_3g_Locations_missing_establishment_da	19	Locations with sampling events or field coordinates or discontinued dates, but without with location establishment dates	
qa_3h_Locations_loc_status_inconsistencies	21	Missing loc status; sampled locations with loc status = 'rejected' or 'proposed'; locs with establishement dates or field coords and loc_status = 'proposed'; 'retired' locs without discontinued dates; discontinued dates on status other than 'retired'	
qa_3i_Locations_unclassified_new_points	543	Newly sampled locations with an undetermined location type (location_type = 'new')	
qa_3j_Locations_loc_type_and_loc_code_in	0	Locations where loc code = 'TO' and loc type <> 'origin' or vice versa, or where loc code = 'rare' and loc type <> 'incidental' or vice versa	
qa_3k_Location_illogical_dates	0	Discontinued date prior to establishment date, or updated date prior to created date	

Wednesday, March 29, 2006 Page 1 of 4

Page: 1

Completing Data Certification

Data certification is a benchmark in the project information management process that indicates that: 1) the data are complete for the period of record; 2) they have undergone and passed the quality assurance checks; and 3) that they are appropriately documented and in a condition for archiving, posting and distribution as appropriate. Certification is not intended to imply that the data are completely free of errors or inconsistencies which may or may not have been detected during quality assurance reviews.

To ensure that only quality data are included in reports and other project deliverables, the data certification step is an annual requirement for all tabular and spatial data. The Project Lead is primarily responsible for completing a NCCN Project Data Certification Form, available on the NCCN website. This brief form and the certified data should be submitted according to the timeline in Appendix B (Yearly Project Task List). Refer to SOP 21 (Product Delivery Specifications) for delivery instructions.

SOP 21. Product Delivery Specifications

Version 4/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Tables

Page

Overview

This document provides details on the process of submitting completed data sets, reports and other project deliverables; see Table SOP 21.1 for an overview. Prior to submitting digital products, files should be named according to the naming conventions appropriate to each product type (see section on page SOP 21.6 on general naming conventions).

All digital file submissions that are sent by email should be accompanied by a product submission form, which briefly captures the following information about the products:

- Submission date
- Name of the person submitting the product(s)
- Name and file format of each product
- Indication of whether or not each product contains sensitive information

This form can be downloaded from the NCCN website or obtained from the Data Manager. People who submit digital files directly to the NCCN Digital Library will be prompted for the same information, and so a submission form is not required.

Upon notification and/or receipt of the completed products, the Data Manager or GIS Specialist will check them into the NCCN project tracking application.

Table SOP 21.1 Product Delivery Schedule and Specifications.

Deliverable Product	Primary Responsibility	Target Date	Instructions
Field season report	Field Lead	November 30 of the same year	Upload digital file in MS Word format to the NCCN Digital Library [1] submissions folder.
Digital photographs	Project Lead	January 31 of the following year	Organize, name and maintain photographic images in the project workspace according to SOP 18: (Managing Photographic Images).
Certified working database Certified geospatial data Data certification report Metadata interview form	Project Lead Project Lead with GIS Specialist Project Lead Project Lead and NPS Lead	November 30 of the same year	Refer to the following section on delivering certified data and related materials.
Full metadata (parsed XML)	Data Manager and GIS Specialist	December–January of the following year	Upload the parsed XML record to the NPS Data Store [2], and store in the NCCN Digital Library [1].
Washington State Snow Survey Report(“Glacier Page”)	Project Lead	May 31 of the same year	Refer to the following section on reports and publications.
World Glacier Monitoring Service Report	Field Lead	December–January of the following year	

Table SOP 21.1 Product Delivery Schedule and Specifications (continued).

Deliverable Product	Primary Responsibility	Target Date	Instructions
Annual I&M report	Project Lead	March 1 of the following year	
10-year analysis report	Project Lead	Every 10 years by April 30 of the following year	
Other publications	NPS Lead, Project Lead, Data Analyst	as completed	
Field data forms	NPS Lead and Project Lead	November 30 of the same year	Scan original, marked-up field forms as PDF files and upload these to the NCCN Digital Library 1 submissions folder. Originals go to the Park Curator for archival.
Other records	NPS Lead and Project Lead	review for retention every January	Organize and send analog files to Park Curator for archival. Digital files that are slated for permanent retention should be uploaded to the NCCN Digital Library. Retain or dispose of records following NPS Director's Order #194.

[1] The NCCN Digital Library is a hierarchical digital filing system stored on the NCCN file servers (Boetsch et al. 2005). Network users have read-only access to these files, except where information sensitivity may preclude general access.
[2] NPS Data Store is a clearinghouse for natural resource data and metadata (http://science.nature.nps.gov/nrdata). Only non-sensitive information is posted to NPS Data Store. Refer to the protocol section on sensitive information for details.
[3] NatureBib is the NPS bibliographic database (http://www.nature.nps.gov/nrbib/index.htm). This application has the capability of storing and providing public access to image data (e.g., PDF files) associated with each record.
[4] NPS Director's Order 19 provides a schedule indicating the amount of time that the various kinds of records should be retained. Available at: http://data2.itc.nps.gov/npspolicy/DOrders.cfm

Specific Instructions for Delivering Certified Data and Related Materials

Data certification is a benchmark in the project information management process that indicates that: 1) the data are complete for the period of record; 2) they have undergone and passed the quality assurance checks; and 3) that they are appropriately documented and in a condition for archiving, posting and distribution as appropriate. To ensure that only quality data are included in reports and other project deliverables, the data certification step is an annual requirement for all tabular and spatial data. For more information refer to SOP 20 (Data Quality Review and Certification).

The following deliverables should be delivered as a package:

- Certified working database: Database in MS Access format containing data for the current season that has been through the quality assurance checks documented in SOP 20.
- Certified geospatial data: GIS themes in ESRI coverage or shapefile format. Refer to NCCN GIS Development Guidelines (NCCN, 2006) and NCCN GIS Product Specifications (NCCN, 2005a) for more information.
- Data certification report: A brief questionnaire in MS Word that describes the certified data product(s) being submitted. A template form is available on the NCCN website at: http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm.
- Metadata interview form: The metadata interview form is an MS Word questionnaire that greatly facilitates metadata creation. It is available on the NCCN website at: http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm. For more details, refer to SOP 18 (Metadata Development).

After the quality review is completed, the Project Lead should package the certification materials for delivery as follows:

1. Open the certified back-end database file and compact it (in Microsoft Access, Tools > Database Utilities > Compact and Repair Database). This will make the file size much smaller. Back-end files are typically indicated with the letters "_be" in the name (e.g., MORA_Glaciers_HYa01_be_2007.mdb).

2. Rename the certified back-end file with the project code ("HYa01"), the year or span of years for the data being certified, and the word "certified". For example: HYa01_2007_certified.mdb.

3. Create a compressed file (using WinZip® or similar software) and add the back-end database file to that file. Note: The front-end application does not contain project data and as such should not be included in the delivery file.

4. Add the completed metadata interview and data certification forms to the compressed file. Both files should be named in a manner consistent with the naming conventions described elsewhere in this document.

5. Add any geospatial data files that aren't already in the possession of the GIS Specialist. Geospatial data files should be developed and named according to NCCN GIS Naming Conventions (NCCN, 2005b).

6. Upload the compressed file containing all certification materials to the new submissions folder of the NCCN Digital Library. If the Project Lead does not have intranet access to the NCCN Digital Library, then certification materials should be delivered as follows:
    a. If the compressed file is under 5 mb in size, it may be delivered directly to the NPS Lead and Data Manager by email.
    b. If the compressed file is larger than 5 mb, it should be copied to a CD or DVD and delivered in this manner. Under no circumstances should products containing sensitive information be posted to an FTP site or other unsecured web portal.

7. Notify the Data Manager and NPS Lead by email that the certification materials have been uploaded or otherwise sent.

Upon receiving the certification materials, the Data Manager will:

1. Review them for completeness and work with the Project Lead if there are any questions.

2. Notify the GIS Specialist if any geospatial data are submitted. The GIS Specialist will then review the data, and update any project GIS data sets and metadata accordingly.

3. Check in the delivered products using the NCCN project tracking application.

4. Store the certified products together in the NCCN Digital Library.

5. Upload the certified data to the master project database.

6. Notify the Project Lead that the year's data have been uploaded and processed successfully. The Project Lead may then proceed with data summarization, analysis and reporting.

7. Develop, parse and post the XML metadata record to the NPS Data Store.

8. After a holding period of 2 years, the Data Manager will upload the certified data to the NPS Data Store. This holding period is to protect professional authorship priority and to provide sufficient time to catch any undetected quality assurance problems. See SOP 23 (Product Posting and Distribution).

Specific Instructions for Reports and Publications

Annual reports and trend analysis reports will use the NPS Natural Resource Publications template, a pre-formatted Microsoft Word template document based on current NPS formatting standards. Annual reports will use the Natural Resource Technical Report template, and trend analysis and other peer-reviewed technical reports will use the Natural Resource Report template. The template and instructions for acquiring a series number and other information about NPS publication standards can be found at: http://www.nature.nps.gov/publications/NRPM/index.cfm. In general, the procedures for reports and publications are as follows:

1. The document should be formatted using the NPS Natural Resource Publications template. Formatting according to NPS standards is easiest when using the template from the very beginning, as opposed to reformatting an existing document.

2. The document should be peer reviewed at the appropriate level. For example, I&M Annual Reports should be reviewed by other members of the appropriate project work group. The Network Coordinator will also review all annual reports for completeness and compliance with I&M standards and expectations.

3. Upon completing the peer review, acquire a publication series number from the NPS Technical Information Center or the appropriate local or regional key official (currently

the Regional I&M Coordinator).

4. Upload the file in PDF and MS Word formats to the NCCN Digital Library submissions folder.

5. Send a printout to each Park Curator.

6. The Data Manager or a designee will create a bibliographic record and upload the PDF document to NatureBib according to document sensitivity.

Naming Conventions

In all cases, file names should follow these guidelines:

- No spaces or special characters in the file name.
- Use the underbar ("_") character to separate file name components.
- Try to limit file names to 30 characters or fewer, up to a maximum of 50 characters.
- Dates should be formatted as YYYYMMDD.
- Correspondence files should be named as YYYYMMDD_AuthorName_subject.ext.
- As appropriate, include the project code (e.g., "HYa01"), network code ("NCCN") or park code, and year in the file name.

Naming Examples

- NCCN_HYa01_2007_Annual_report.pdf
- NCCN_HYa01_2007_Field_season_report.doc
- NCCN_HYa01_2007_Certification_report.doc

References

North Coast and Cascades Network – National Park Service (NCCN). 2006. GIS development guidelines. USDI National Park Service. Available at: http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm

North Coast and Cascades Network – National Park Service (NCCN). 2005a. GIS product specifications. USDI National Park Service. Available at: http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm

North Coast and Cascades Network – National Park Service (NCCN). 2005b. GIS naming conventions. USDI National Park Service. Available at: http://www1.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm

SOP 22. Workspace Setup and Project Records Management

Version 4/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Figures

Setting Up the Project Workspace

A section of the networked file server at each host park is reserved for this project, and access permissions are established so that project staff members have access to needed files within this workspace. Prior to each season, the NPS Lead should make sure that network accounts are established for each new staff member, and that the Data Manager is notified to ensure access to the project workspace and databases.

The recommended file structure within this workspace is shown in Figure SOP 22.1. Certain folders – especially those for GPS data and images – should be retained in separate folders for each calendar year as shown in Figure SOP 22.1. This will make it easier to identify and move these files to the project archives at the end of each season.

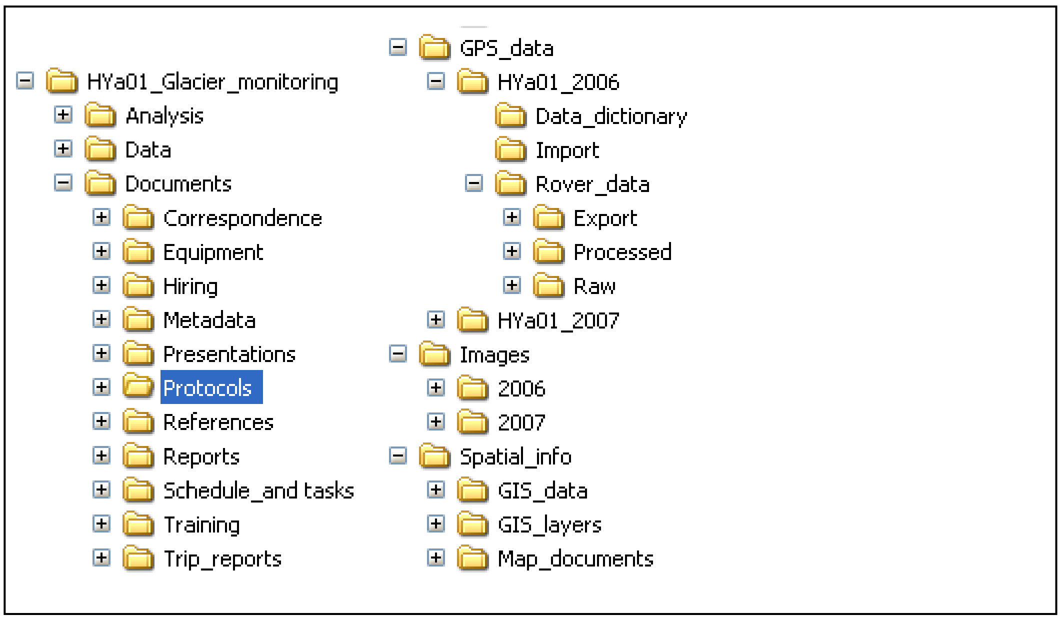


Figure SOP 22.1. Recommended file structure for project workspace. Note that the workspace folder name includes 'HYa01', the NCCN project code.

Each major subfolder is described as follows:

- Analysis – Contains working files associated with data analysis.
- Database – Contains the working database file for the season. The master database for the project is stored in the enterprise data management system (Boetsch et al., 2005).
- Documents – Contains subfolders to categorize documents as needed for various stages of project implementation.
- GPS data – Contains GPS data dictionaries, and raw and processed GPS data files. Note that this folder contains subfolders to arrange files by year. Each of these subfolders also contains the project code (i.e., 'HYa01') to make it easier to select the correct project folder within the GPS processing software.
- Images – For storing images associated with the project (refer to SOP 17. Managing Photographic Images). Note that this folder contains subfolders to arrange files by year.

- Spatial info – Contains files related to visualizing and interacting with GIS data.
    - GIS data – New working shapefiles and coverages specific to the project.
    - GIS layers – Pointer files to centralized GIS base themes and coverages.
    - Map documents – Map composition files (.mxd).

Naming Conventions

Folder Naming Standards

In all cases, folder names should follow these guidelines:

- No spaces or special characters in the folder name
- Use the underbar ("_") character to separate words in folder names
- Try to limit folder names to 20 characters or fewer
- Dates should be formatted as YYYYMMDD

File Naming Standards

In all cases, file names should follow these guidelines:

- No spaces or special characters in the file name
- Use the underbar ("_") character to separate file name components
- Try to limit file names to 30 characters or fewer, up to a maximum of 50 characters
- Dates should be formatted as YYYYMMDD
- Correspondence files should be named as YYYYMMDD_AuthorName_subject.ext

Archival and Records Management

All project files should be reviewed, cleaned up and organized by the Project Lead and NPS Lead on a regular basis (e.g., annually in January). Decisions on what to retain and what to destroy should be made following guidelines stipulated in NPS Director's Order 19 (available online at http://www.nps.gov/refdesk/DOrders/DOrder19.html), which provides a schedule indicating the amount of time that the various kinds of records should be retained. Many of the files for this project may be scheduled for permanent retention, so it is important to isolate and protect them, rather than lose them in the midst of a large, disordered array of miscellaneous project files. Because this is a long-term monitoring project, good records management practices are critical for ensuring the continuity of project information. Files will be more useful to others if they are well organized, well named, and stored in a common format.

To help ensure safe and organized electronic file management, NCCN has implemented a system called the NCCN Digital Library, which is a hierarchical digital filing system stored on the NCCN file servers (Boetsch et al., 2005). The typical arrangement is by project, then by year to facilitate easy access. Network users have read-only access to these files, except where information sensitivity may preclude general access.

As digital products are delivered for long-term storage according to the schedule in SOP 21 (Product Delivery Specifications), they will be catalogued in the NCCN project tracking database and filed within this the NCCN Digital Library. Analog (non-digital) materials are to be handled according to current practices of the individual park collections.

References

Boetsch, J.R., B. Christoe, and R.E. Holmes. 2005. Data management plan for the North Coast and Cascades Network Inventory and Monitoring Program. USDI National Park Service. Port Angeles, WA. Available at: http://www1.nature.nps.gov/im/units/nccn/datamgmt.cfm

SOP 23. Product Posting and Distribution

Version 11/07/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview

This document provides details on the process of posting and otherwise distributing finalized data, reports and other project deliverables. For a complete list of project deliverables, refer to SOP 21 (Project Delivery Specifications).

Product Posting

Once digital products have been delivered and processed, the following steps will be taken by the Data Manager to make them generally available:

1. Full metadata records will be posted to the NPS Data Store, which is the NPS clearinghouse for natural resource data and metadata that is available to the public at: http://science.nature.nps.gov/nrdata. Refer to the website for upload instructions.
2. A record for reports and other publications will be created in NatureBib, which is the NPS bibliographic database (http://www.nature.nps.gov/nrbib/index.htm). The digital report file in PDF format will then be uploaded and linked to the NatureBib record. Refer to the NatureBib website for record creation and upload instructions.

These applications serve as the primary mechanisms for sharing reports, data, and other project deliverables with other agencies, organizations, and the general public.

Holding Period for Project Data

To protect professional authorship priority and to provide sufficient time to complete quality assurance measures, there is a 2-year holding period before posting or otherwise distributing finalized data. This means that certified data sets are first posted to publicly accessible websites (i.e., the NPS Data Store) approximately 24 months after they are collected (e.g., data collected in June 2006 becomes generally available through the NPS Data Store in June 2008). In certain circumstances, and at the discretion of the NPS Lead and Park Geologists, data may be shared before a full 2 years have elapsed.

Note: This hold only applies to raw data; all metadata, reports or other products are to be posted to NPS clearinghouses in a timely manner as they are received and processed.

Responding to Data Requests

Occasionally, a park or project staff member may be contacted directly regarding a specific data request from another agency, organization, scientist, or from a member of the general public. The following points should be considered when responding to data requests:

- NPS is the originator and steward of the data, and the NPS Inventory and Monitoring Program should be acknowledged in any professional publication using the data.
- NPS retains distribution rights; copies of the data should not be redistributed by anyone but NPS.
- The data that project staff members and cooperators collect using public funds are public records and as such cannot be considered personal or professional intellectual property.
- For quality assurance, only the certified, finalized versions of data sets should be shared with others.

The NPS Lead will handle all data requests as follows:

1. Discuss the request with other Park Geologist as necessary to make those with a need to know aware of the request and, if necessary, to work together on a response.

2. Notify the Data Manager of the request if s/he is needed to facilitate fulfilling the request in some manner.

3. Respond to the request in an official email or memo.

4. In the response, refer the requestor to the NPS Data Store (http://science.nature.nps.gov/nrdata), so they may download the necessary data and/or metadata. If the request cannot be fulfilled in that manner – either because the data products have not been posted yet, or because the requested data include sensitive information – work with the Data Manager to discuss options for fulfilling the request directly (e.g., burning data to CD or DVD). Ordinarily, only certified data sets should be shared outside NPS.

5. If the request is for a document, it is recommended that documents be converted to PDF format prior to distributing it.

6. After responding, provide the following information to the Data Manager, who will maintain a log of all requests in the NCCN Project Tracking database:
    a. Name and affiliation of requestor
    b. Request date
    c. Nature of request
    d. Responder
    e. Response date
    f. Nature of response
    g. List of specific data sets and products sent (if any)

All official FOIA requests will be handled according to NPS policy. The NPS Lead will work with the Data Manager and the park FOIA representative(s) of the park(s) for which the request applies.

NPS 105/100950 January 2010

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