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Long Term Monitoring of Small Glaciers at North Cascades National Park :

A Prototype Park Model for the North Coast and Cascades Network

Natural Resource Report NPS/NCCN/NRR—2008/066

ON THE COVER
North Klawatti Glacier Spring and Fall, staff probing with Forbidden Peak in the background, author operating steam drill, and staff measuring an ablation stake.
Photograph by: NPS staff.

Long Term Monitoring of Small Glaciers at North Cascades National Park :

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Abstract

The purpose of this document is to explain the background, monitoring need, and protocols for glacier monitoring in North Cascades National Park Service Complex (NOCA). Four sampling protocols are outlined in this report: annual mass balance, annual summer glacier meltwater discharge, decadal index glacier re-mapping, and standards for park-wide glacier inventories at 20 year intervals. Standardized instructions for field access, data handling, reporting, and data storage is presented as well as field form and reporting document examples.

The primary focus of this program is on detailed annual mass balance monitoring of a small sample of the entire population of the NOCA glacier population. Within NOCA, North Klawatti, Silver, and Noisy glaciers have been monitored since 1993 and Sandalee glacier was added in 1994. Already each glacier shows signs of area and volume loss.

Acknowledgements

Creation of this protocol took much longer than we anticipated and involved many more people than we first would have imagined. Dr. Andrew Fountain of Portland State University and Dr. Robert Krimmel of the USGS (retired) assisted with development of the original study plan in 1992. Krimmel provided the first field lesson in glacier monitoring in 1992, and guided early development of this program. Fountain provided the most detailed and thorough peer review of this document. Other reviewers included Dr. David Peterson (University of Washington), Andrea Woodward (USGS), Jesse Kennedy (NPS), and Jack Oelfke (Chief Resource Management - NPS). Al Rasmussen and Howard Conway (University of Washington) assisted with our analysis of measurement error. Three anonymous reviewers for the Earthwatch Institute also helped develop this document. Finally, NOCA staff members who contributed countless hours to this endeavor in the field and in the office include Joanie Lawrence, Mike Larrabee, and Roger Christophersen. We also want to thank the many volunteers who made this project possible, including the first two field assistants, Bill Shaffner and Tom Hammond. Finally, we want to acknowledge the contribution of data managers John Boetsch and Ron Holmes for their patient assistance with development of the data management portion of this protocol.

I. Introduction

Glaciers are integral components of the region's hydrologic, ecologic, and geologic systems, and they are retreating rapidly. At NOCA, geologic mapping data and a 1998 inventory (Granshaw, 2001) indicate that glacier area has declined 44% in the last 150 years. Glacier changes are driven primarily by climate, and in special cases, debris cover from landslides, topographical factors, and tectonic drivers such as geothermal ablation.

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 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).

In 1991 a meeting between government land managers and professionals resulted in identifying glacier mass balance monitoring as a key indicator of climate, glacier, and ecosystem change. Glacier monitoring selection and study plans began development in 1993. In 1998, the NCCN Network recognized glacier monitoring as an important environmental "vital sign" and resource at NOCA.

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.

A. Background

1. Geographic Setting

NOCA is located within the North Cascade Mountains of northwestern Washington and southwestern British Columbia. The North Cascades Physiographic Province extends from Snoqualmie Pass in the south to the Fraser River in the north, and from Puget Lowland in the west to the Columbia River in the east (McKee, 1972). A wide range of bedrock types, active volcanoes, rugged topography, and modern glaciation characterize the range. Local relief within the park averages 2000 meters, with the highest peaks exceeding 3000 meters above sea level (asl), and many west-slope valley floors within a few hundred meters of sea level near valley heads.

Two major regional hydrologic divides of the North Cascade Range define broad boundaries for the continental climate on the east slopes from a maritime climate on the west. The divides also separate flow between the Fraser River, Columbia River, and Puget Sound river basins. These divides also create the large interior drainage basin of the Skagit River (Figure 1), which has characteristics of both continental and maritime climates.

Climate is characterized by extreme spatial and temporal variability. Precipitation decreases markedly from west to east due to the orographic effect of the mountains on eastbound storms. Precipitation is highly seasonal, with approximately 80% of the total annual precipitation delivered between November and March. Most of this precipitation falls as snow, which typically exceeds a depth of 5 meters at altitudes above 1000 meters asl. The summer season (particularly July through September) is marked by persistent drought. Near the South Cascade Glacier (1500 meters asl), typical winter low temperatures are approximately –10 degrees C and typical summer high temperatures are around 20 degrees C (Krimmel, 2000).

2. History and Overview

The NOCA glacier monitoring program is part of a larger effort to monitor abiotic factors important to the stability and function of the North Cascades ecosystem. Abiotic ecosystem factors monitored include glacier hydrology and change, climate, solar radiation, geologic disturbance, and air quality. This data contributes to a larger body of climatic and hydrologic data in the North Cascades collected by the US Geological Survey (USGS), Natural Resource Conservation Service (NRCS), North Cascades Glacier Climate Project (NCGCP), the hydroelectric industry, and university researchers.

Indicator development for the NOCA glacier monitoring program began in 1991 at a meeting in Alaska between government agencies that manage lands which contain glaciers (NPS, US Forest Service, Bureau of Land Management, US Fish and Wildlife Service) and professionals involved in research and monitoring of glaciers (see **Appendix K: Administrative History**). The result of this meeting was a global change research proposal that identified glacier mass balance monitoring as a key indicator of climate, glacier, and ecosystem change.

The global change proposal was not funded, but became the basis for further development of a glacier monitoring program by NOCA staff as they prepared a “Prototype Park” proposal in 1993. Glacier monitoring was a key component of the NOCA plan, which competed successfully in the lakes and streams category. The prototype proposal recommends annual monitoring of the mass balance and volume of index glaciers and inventory of all glaciers every 20 years. In 1993, a detailed study plan was developed to begin monitoring the mass balance and area of four NOCA glaciers. This plan was peer-reviewed by Robert Krimmel and Andrew Fountain of the USGS Water Resources Division and has been the basis for glacier monitoring at NOCA. In this time we have refined methods, established a baseline of natural variation and trends, and developed strong cost and data sharing partnerships with Seattle City Light, North Cascades Institute, USGS, NRCS, Portland State University, University of Washington, and Nichols College.

The importance of glacier monitoring has been recently reaffirmed in the North Coast and Cascades Network (NCCN). Glaciers have been recognized as important Vital Signs at Olympic (OLYM), North Cascades, and Mt. Rainier National Park workshops. Their importance as ecological system drivers, geologic-hydrologic integrators, and as indicators of climate change was also recognized during the OLYM Geoindicators meeting in 2001, and during NCCN prioritization of monitoring questions in 2003.

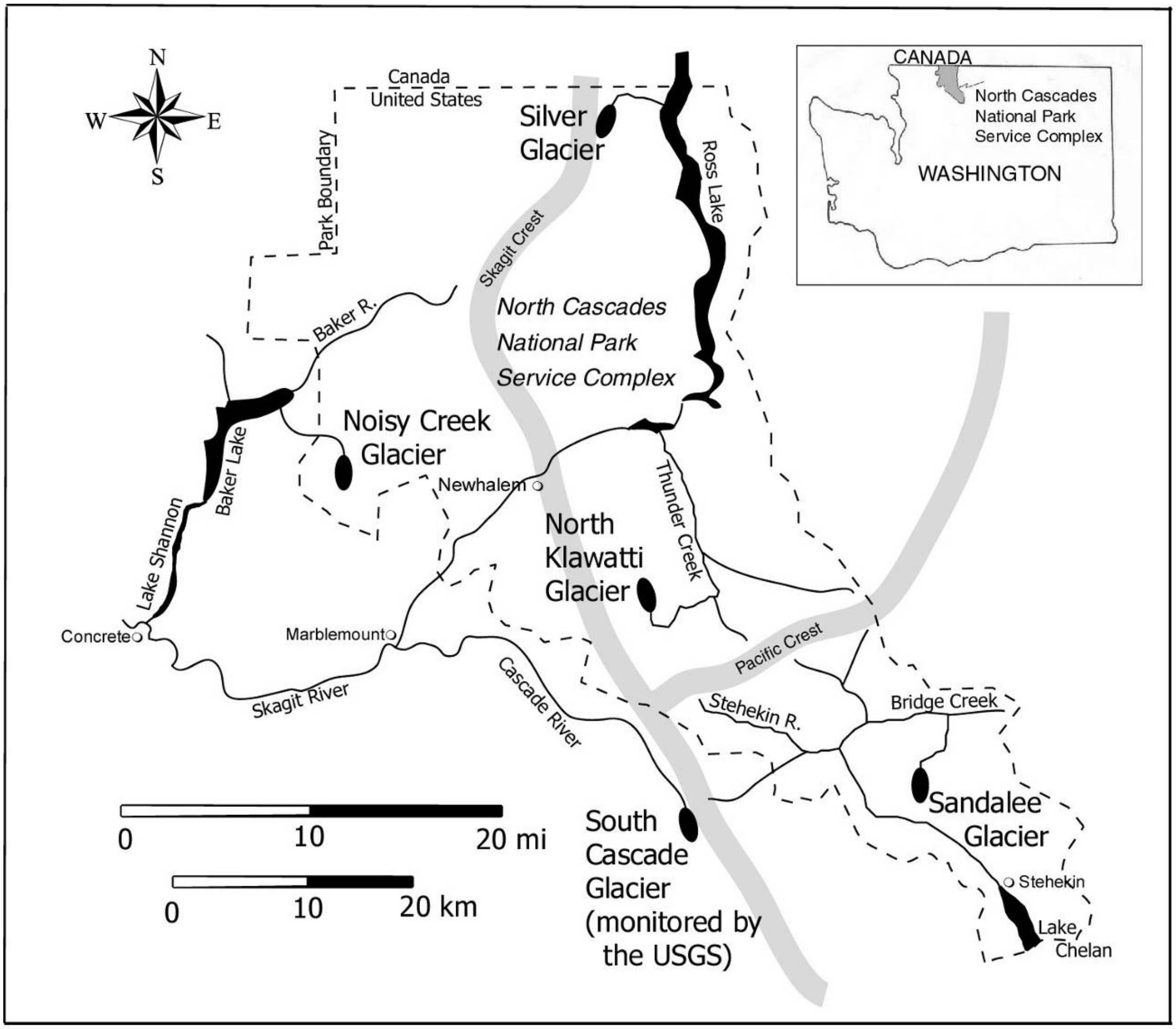

Figure 1. Locations of monitored glaciers and major hydrologic crests in the North Cascades.

B. Monitoring Need

Glaciers are a significant resource of many mountain ranges of the world including the three large parks in the NCCN. Combined, the glacial resources of this network are extensive, covering 235 km^2. They are integral components of the region's hydrologic, ecologic, and geologic systems, and they are retreating rapidly. At NOCA, geologic mapping data and a 1998 inventory (Granshaw, 2001) indicate that glacier area has declined 44% in the last 150 years.

The importance of glaciers to the North Coast and Cascades ecosystems is illustrated in a glacier-ecosystem conceptual model (Figure 2). Glacier changes are driven primarily by climate, and in special cases, tectonic drivers such as geothermal ablation and debris cover from landslides. Topographical factors interact with weather, climate, and glacier movement to influence glacier change. Glaciers integrate these factors and export landforms (soils and terrestrial habitat) and melt water (aquatic habitat, nutrient cycling, and water supply). Further, glaciers are habitat to a number of species, and are the sole habitat for ice worms (*Mesenchytraeus solifugus*) and certain species of springtails (Collembola) (Hartzell, 2003). 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 melt water and fine-grained sediment they release. 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 within the last century.

The influence of glaciers on NOCA and regional hydrology is immense in both the quantity and timing of discharge of glacial melt water. Post and others (1971) estimated that glaciers contribute 800 million cubic meters to streamflow annually in the North Cascades alone. In the Thunder Creek watershed (250 km^2 area) glaciers contribute as much as 45% of the total summer runoff (NOCA unpublished data). More importantly, glacial melt water delivery peaks during the hot, dry summers in the Pacific Northwest, buffering the region's aquatic ecosystems from seasonal and interannual droughts. Aquatic ecosystems, endangered species such as salmon, bull trout and western cutthroat trout, and the hydroelectric and agricultural industries benefit from the seasonal and interannual stability glaciers impart to the region's hydrologic systems.

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 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).

C. Goals and Objectives

Four broad goals are identified to monitor glaciers as important Vital Signs of the ecological health of NOCA, following the guidance of Davis (1993) and Silsbee and Peterson (1991):

1) Monitor range of variation and trends in volume of NOCA glaciers;
2) Relate glacier changes to status of aquatic and terrestrial ecosystems;
3) Link glacier observations to research on climate and ecosystem change; and
4) Share information on glaciers with the public and professionals.

To meet the primary goal of monitoring the range of variation and trends in the volume of more than 300 glaciers covering 300 km^2, monitoring must occur at multiple spatial and temporal scales, and at variable levels of intensity. Objectives identified to reach this goal include:

- Identify index glaciers to represent larger population of NOCA glaciers;
- Seasonally monitor the mass balance of index glaciers;
- Measure the geometry of index glaciers every 10 years; and
- Monitor extent and area of the entire population of NOCA glaciers with a comprehensive inventory every 20 years.

Mass balance is chosen as the primary indicator of glacier change for several reasons. First, it accounts for ~90% 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. Finally, measurement of this quantity allows for direct assessment of changes in glacier volume, climate, and glacial runoff.

To reach our second goal we identify three primary links between glaciers and mountain ecosystems: glacial melt water, glacial microclimate influences, and glacial landforms/soils (Figure 2). 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 at 10 year intervals at index glaciers and 20 year intervals at all glaciers. For aquatic ecosystems, annual variation in summer melt water discharge will be monitored in selected watersheds with gauging stations that represent a range in climate regime from west to east.

Linking glacier monitoring observations with ecosystem dynamics and past and future climate are considered as research questions. These questions have been and will continue to be addressed by professors and their graduate students from regional universities and by NOCA staff, and currently include:

1) Is glacier mass balance at NOCA related to cycles in trans-Pacific climate such as El Nino/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO)?
2) What was the distribution and extent of glaciers in NOCA during various phases of the Neoglacial period, including the Little Ice Age?
3) What are the hydrological and ecological impacts of modern and Little Ice Age glacier change at NOCA?

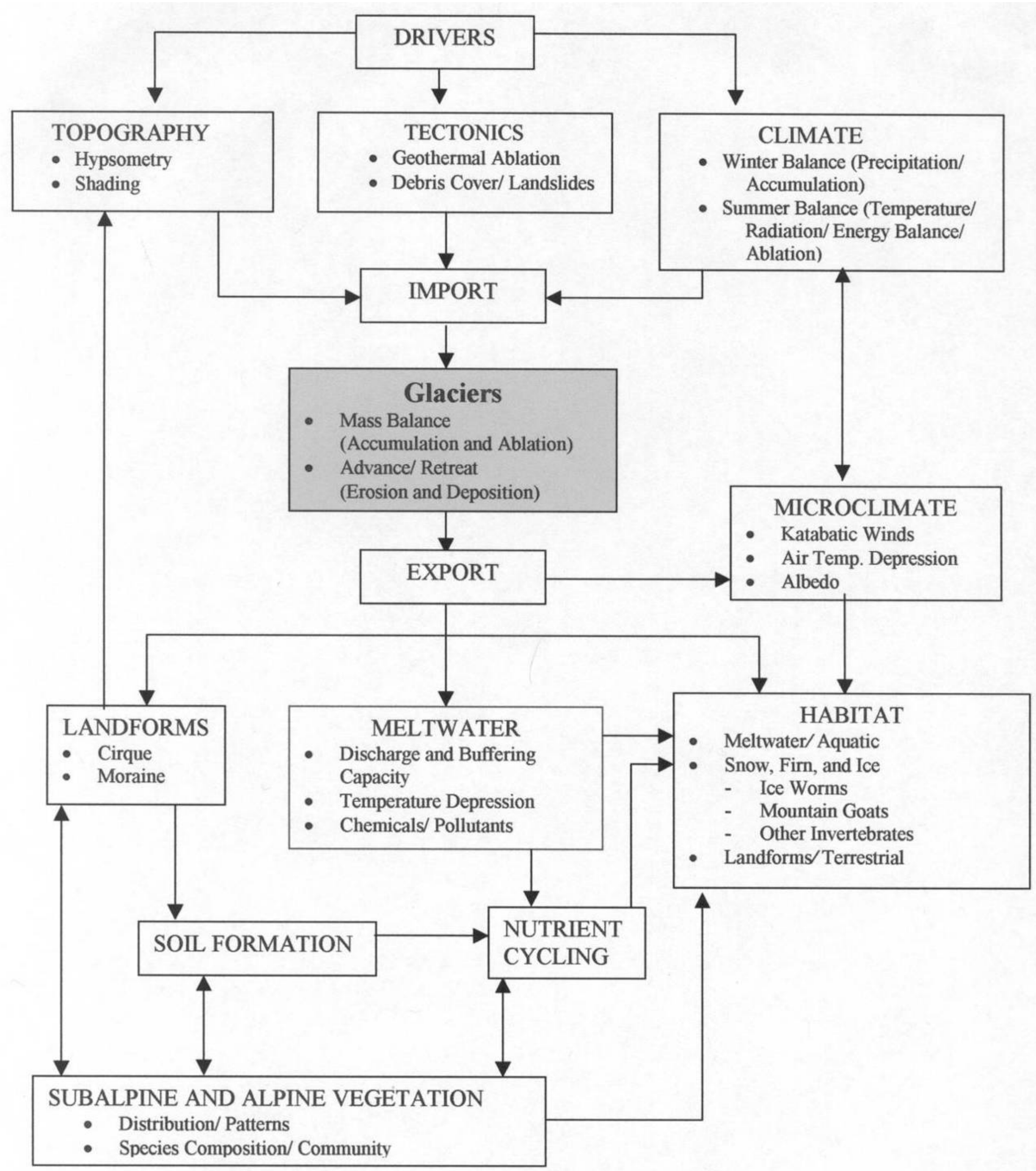

Figure 2. Glacier ecosystem conceptual model shows the relationship of monitored glacier characteristics (shaded box) to the surrounding landscape and ecosystem.

D. Measurable Objectives

Based on the broader goals and related objectives identified above, there are seven measurable objectives for the monitoring described in this protocol. Determined by the following:

- winter balance at index glaciers;
- summer balance at index glaciers;
- net mass balance at index glaciers;
- assess surface cover in late fall for each index glacier;
- glacier volume/area for index glaciers at 10-year intervals;
- glacier volume/area for all glaciers at 20 year intervals; and
- glacial contribution to summer runoff for four watersheds.

Mass balance measurement methods used in this program generally follow procedures (with some differences as discussed below) established on the South Cascade Glacier (SCG) by the USGS-Water Resources Division, Tacoma, WA (Meier, 1961; Meier and Tangborn, 1965; Meier et al., 1971; Tangborn et al., 1971; Krimmel, 1994, 1995, 1996, 1996a). Periodic mapping continues to be done and mass balance data collected on SCG. Thus, these data are directly comparable to NOCA data. South Cascade Glacier data are included for comparison and correlation with NOCA data in summary tables, graphs, and reports. In addition, SCG data is used along with NOCA data for estimating glacier contribution to summer runoff.

II. Sample Design

The sample design utilized in this project was developed in cooperation with USGS Water Resource Division, Portland State University, and the University of Washington. Sample design consists of a multi-scaled approach that incorporates different measurement frequencies for different indicators. Monitoring scales include individual glaciers, watersheds, and the entire population of NOCA glaciers. Sampling frequencies include seasonal, annual, decadal, and 20-year periods.

The primary focus is on detailed annual mass balance monitoring of a small sample of the entire NOCA glacier population. This "index glacier" approach has been used in most glacier monitoring programs, due to cost and logistical problems associated with sampling an extensive population in rugged terrain. USGS used this approach in designing its Benchmark Glacier Program, and in the selection of South Cascade Glacier (Figure 1 for location) to represent the larger population of glaciers in the North Cascades. Recent research has supported use of the index glacier approach (Fountain, 2001).

Glacier area changes provide a direct measure of the advance and retreat of NOCA glaciers, and the concomitant creation and destruction of terrestrial and aquatic habitat. Area changes can also be linked to mass balance data to understand hydrologic processes at watershed and park-wide scales.

Glacier area changes are directly related to changes in volume and are used to monitor the third indicator – glacier meltwater discharge. These measurements will provide a seasonal estimate of water accumulation, storage, and loss, as well as an estimate for extrapolation to the larger population of glaciers in the park, the region, and the planet.

A. Index Glacier Selection

Several criteria were used to select the four index glaciers for surface mass balance monitoring:

1) Geographic position - To understand spatial variation in climate and glacier mass balance, the glaciers were chosen to represent one of three climate zones in relation to the Skagit/Pacific Crests: west side, at the crest, and east side.
2) Glacier margin - Glaciers were chosen that did not have calving or hanging margins. Methods selected for mass balance measurement were not designed to accommodate this type of ablation.
3) Glacier altitude - Individual glaciers were chosen with varying altitudes to provide data on altitudinal control on mass balance.
4) Character of glacier surface - For accuracy of surface mass balance measurements and safety, accessible glaciers with few icefalls and/or heavily crevassed zones were chosen. Icefalls and heavily crevassed zones complicate mass balance calculations.
5) Overland access to glacier - All four glaciers are located in designated wilderness, and helicopter use is limited. Therefore, glaciers accessible by maintained trail or well established cross-country routes were preferred.
6) Glacier aspect - Glaciers were chosen with varying aspects.

7) Glacier drainage system – Glaciers were chosen that drain into a single basin with no multiple ice divides.

Four glaciers were chosen for this study based on these criteria and consultation with Dr. Robert Krimmel (retired USGS) and Dr. Andrew Fountain (Portland State University). The glaciers are in four major watersheds in NOCA and they represent a 1000 meter range in altitude from the bottom of the lowest glacier to the top of the highest (Figure 3). The glaciers and some of their characteristics from Post et al. (1971) and NOCA staff observations include:

Silver Creek Glacier (Figure 4)

USGS 7.5 minute Quadrangle: Mt. Spickard. – Inventory # Post et al. (1971) 2236-6
Glacier Type, Characteristics, and Location: This cirque glacier is northwest facing, steep, and moderately crevassed. It lies on the north-northwest side of Mt. Spickard at a major divide of the North Cascade Range west of the Pacific Crest.
Drainage Basin: Ross Lake Watershed.
Area: 0.49 km^2 in 1993
Altitude Range: 2090 to 2710 meters
Other: Silver Creek glacier underwent dramatic retreat in the 20^{th} century and before 1906 occupied the entire Silver Lake basin. As late as 1973, a portion of the terminus calved into Silver Lake.

Noisy Creek Glacier (Figure 5)

USGS 7.5 minute Quadrangle: Bacon Peak – Inventory # Post et al. (1971) 2219-1
Glacier Type, Characteristics, and Location: This cirque glacier is north facing, has gentle slopes, and not appreciably crevassed. It lies on the northwest flank of Bacon Peak
Drainage Basin: Baker Lake Watershed
Area: 0.58 km^2 in 1993
Altitude Range: 1680 to 1920 meters
Other: This glacier lies far to the west of the Pacific Crest and is directly in line of winter storms that come from the southwest. Ice radar measurements made in 1995 indicate the thickness of the upper part of the glacier is ~110 m.

North Klawatti Glacier (Figure 6)

USGS 7.5 minute Quadrangle: Forbidden Peak – Inventory # Post et al. (1971) 2253-10
Glacier Type, Characteristics, and Location: This valley glacier is southeast facing, has gentle and steep slopes, and is moderately crevassed with a large icefall. It is located south of Primus Peak and on the west side of the Pacific Crest.
Drainage Basin: Thunder Creek Watershed
Area: 1.48 km^2 in 1993
Altitude Range: 1740 to 2400 meters
Other: The glacier has been studied by the USGS (Tangborn, Fountain and Sikonia, 1990; Meier, 1966). Surface laser profiling was completed in 1996 by K. Echelmeyer, U of Alaska. Attempts to measure ice thickness with radar were unsuccessful.

Sandalee Glacier (Figure 7)

USGS 7.5 minute Quadrangle: McGregor Mtn. – Inventory # Post et al. (1971) 2448-10

Glacier Type, Characteristics, and Location: This small cirque glacier is north facing, has gentle and steep slopes, and is somewhat crevassed. It lies on the north face of McGregor Mtn. which is to the east of the Pacific Crest.

Drainage Basin: Stehekin River Watershed.

Area: 0.20 km^2 in 1994

Altitude Range: 1975 to 2350 meters

Other: Sandalee Glacier lies within a climate zone that is more continentally influenced than the other three glaciers.

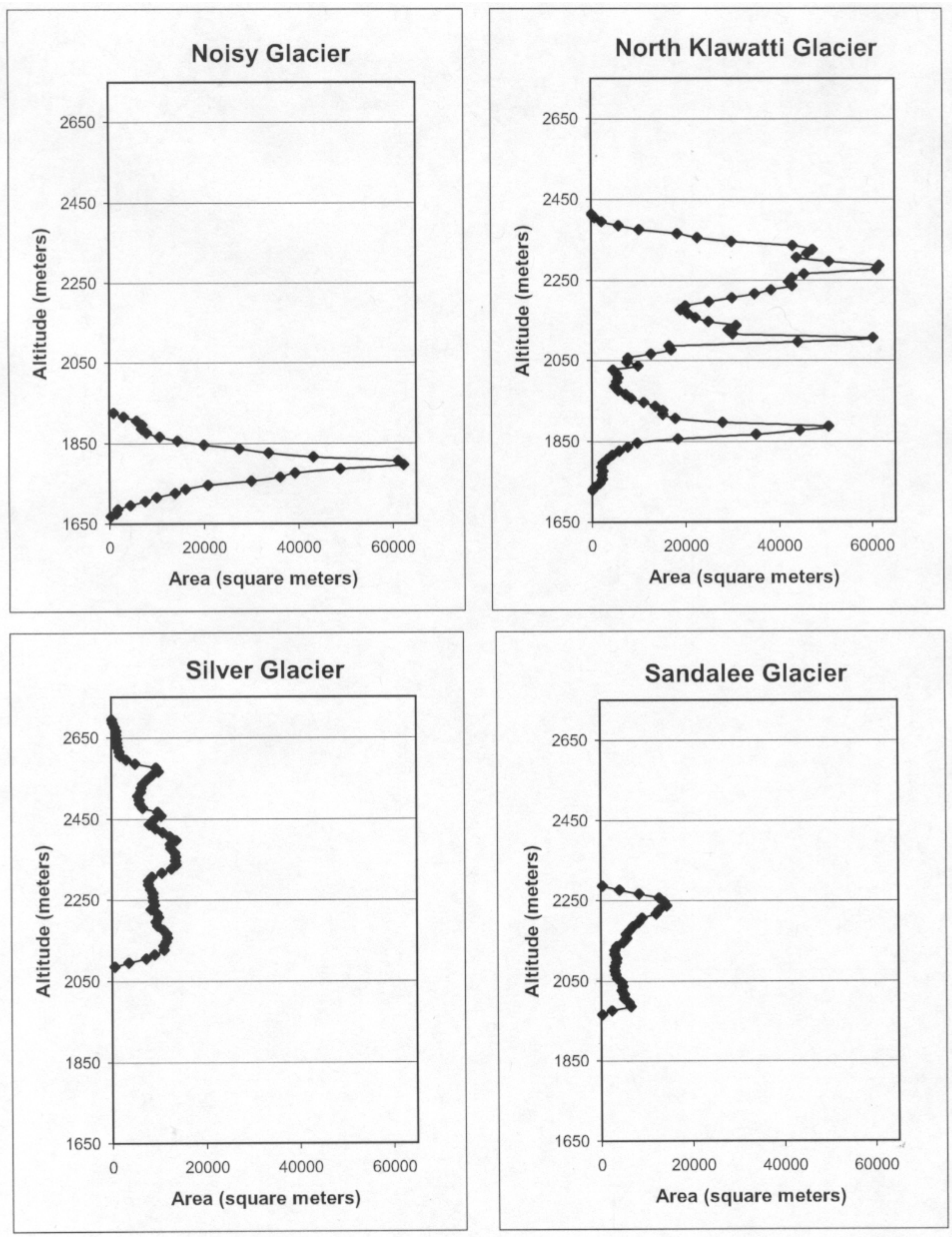

Figure 3. Area-altitude distributions for the four index glaciers. Area is per 10-meter altitude band from 1993 and 1996 (Sandalee) maps.

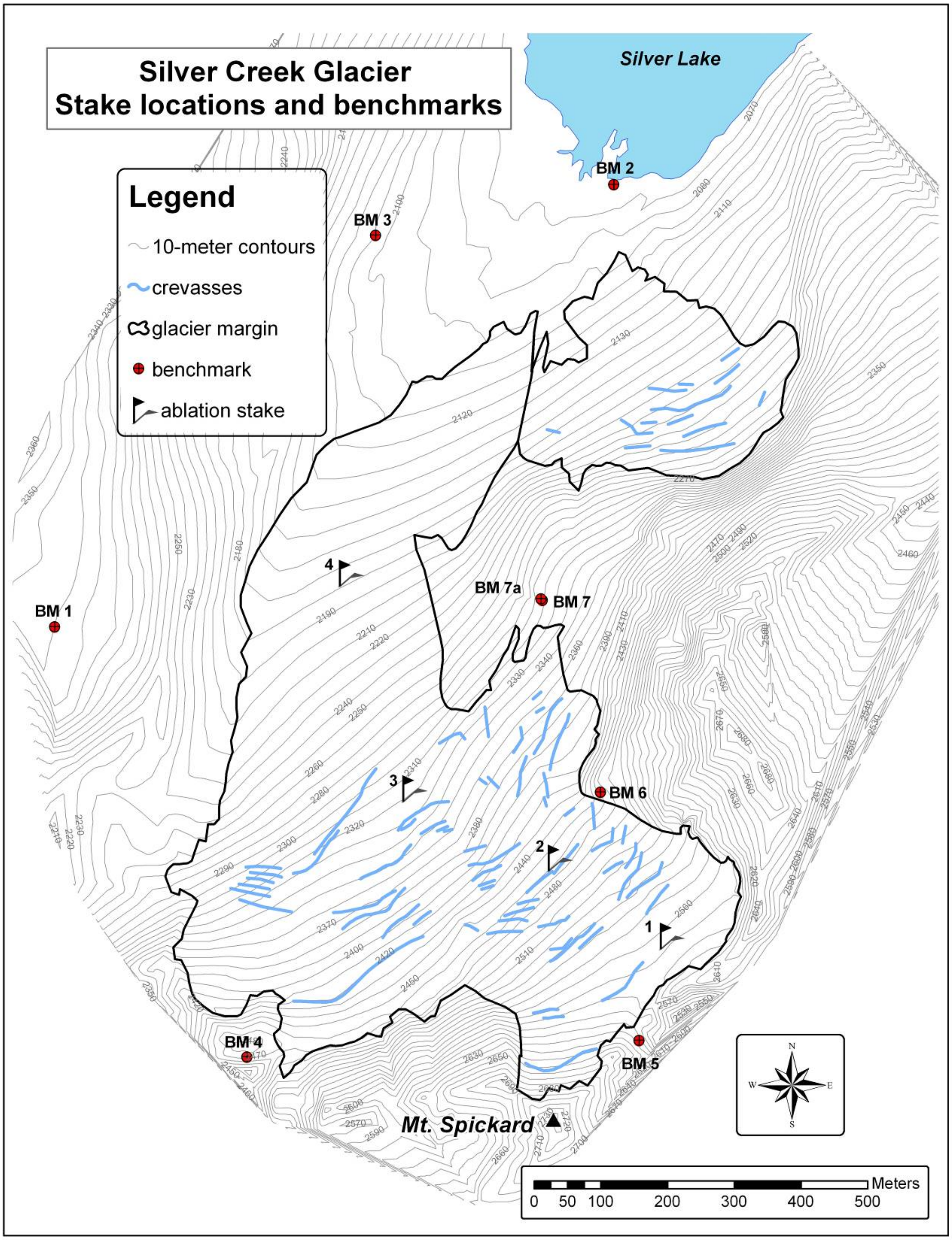

Figure 4. Silver Glacier. This map was generated from photogrammetry based on 1993 vertical air photos. The stake locations are approximate.

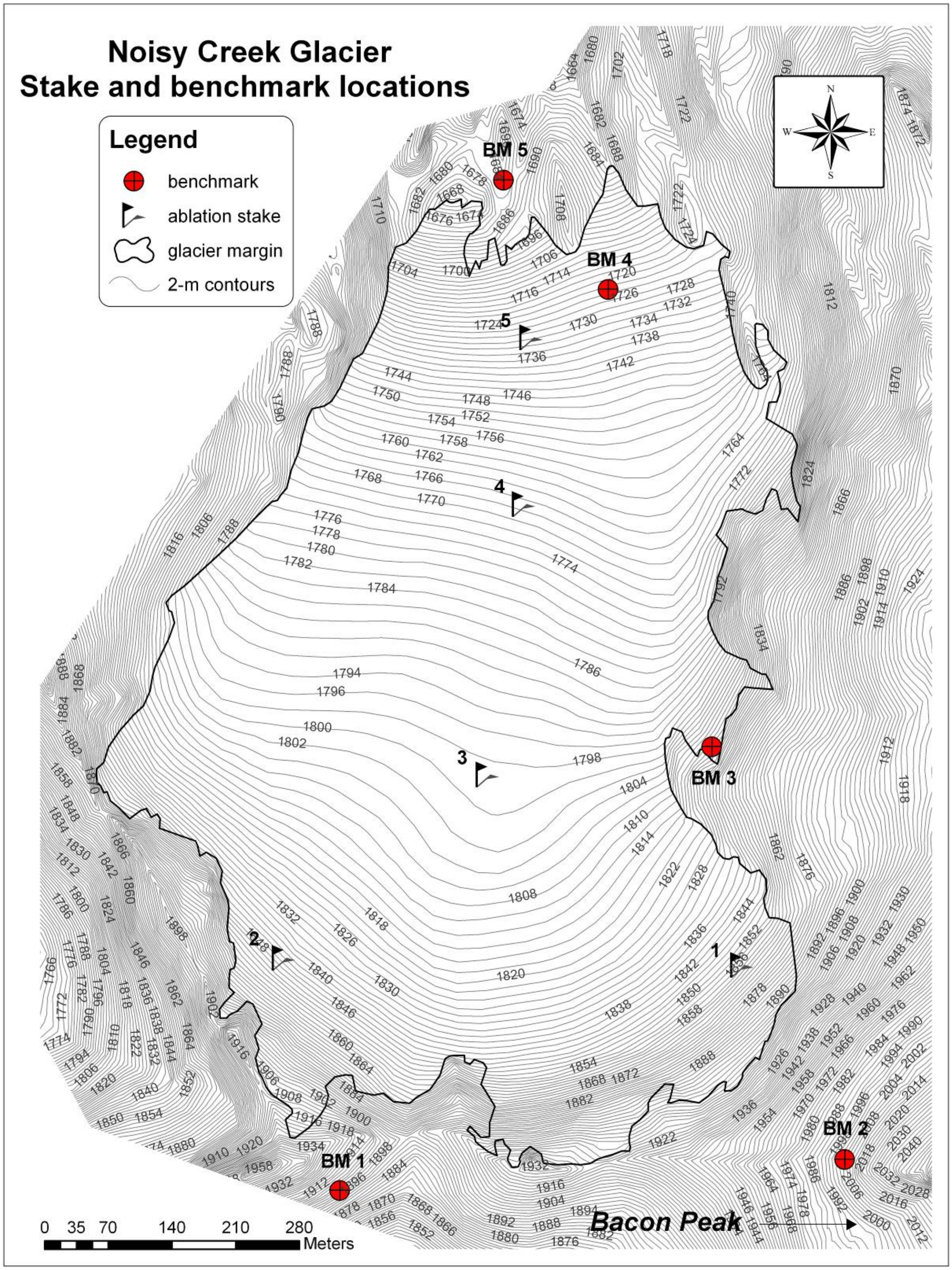

Figure 5. Noisy Creek Glacier. This map was generated from photogrammetry based on 1993 vertical air photos. The stake locations are approximate.

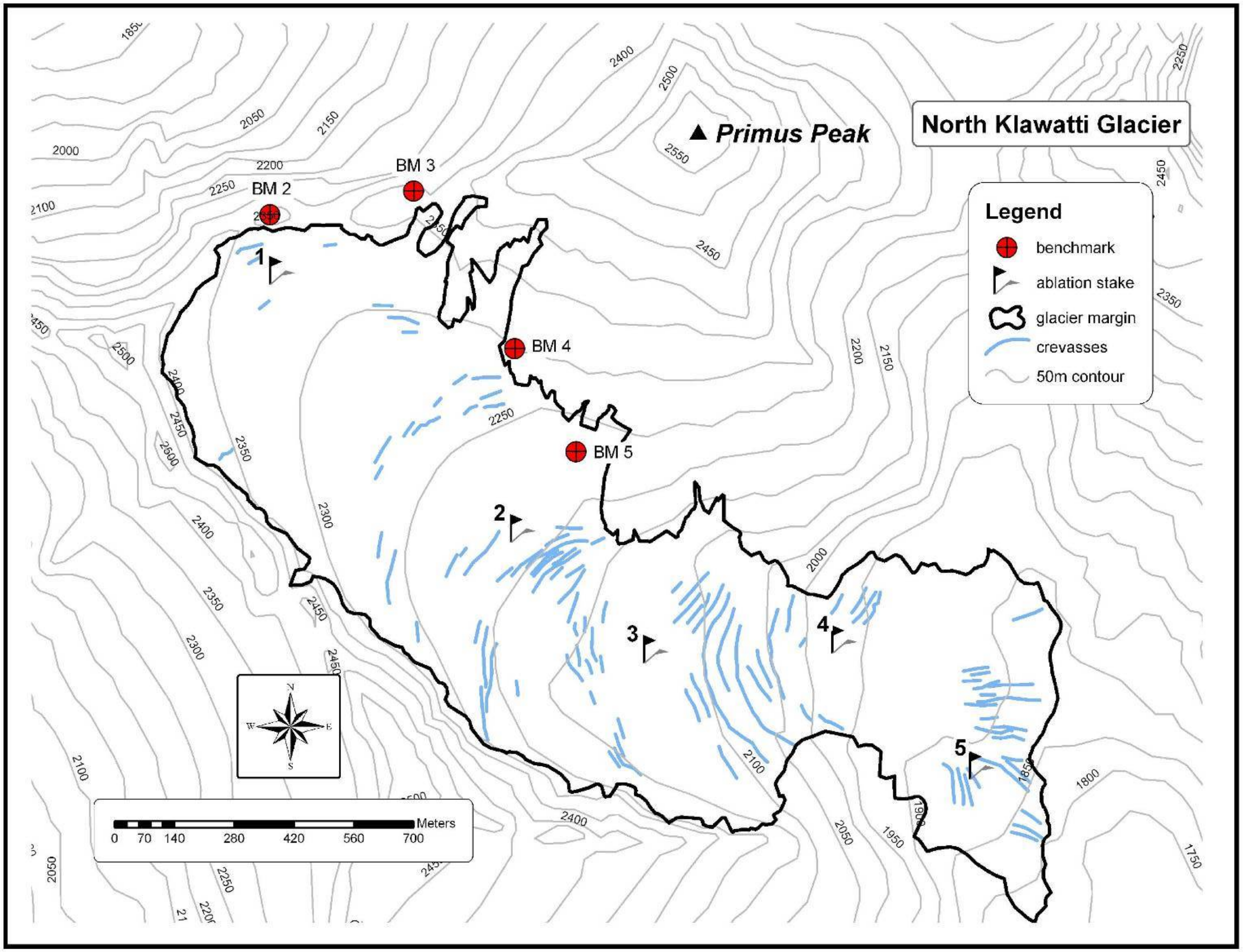

Figure 6. North Klawatti Glacier. This map was generated from photogrammetry based on 1993 vertical air photos. The stake locations are approximate.

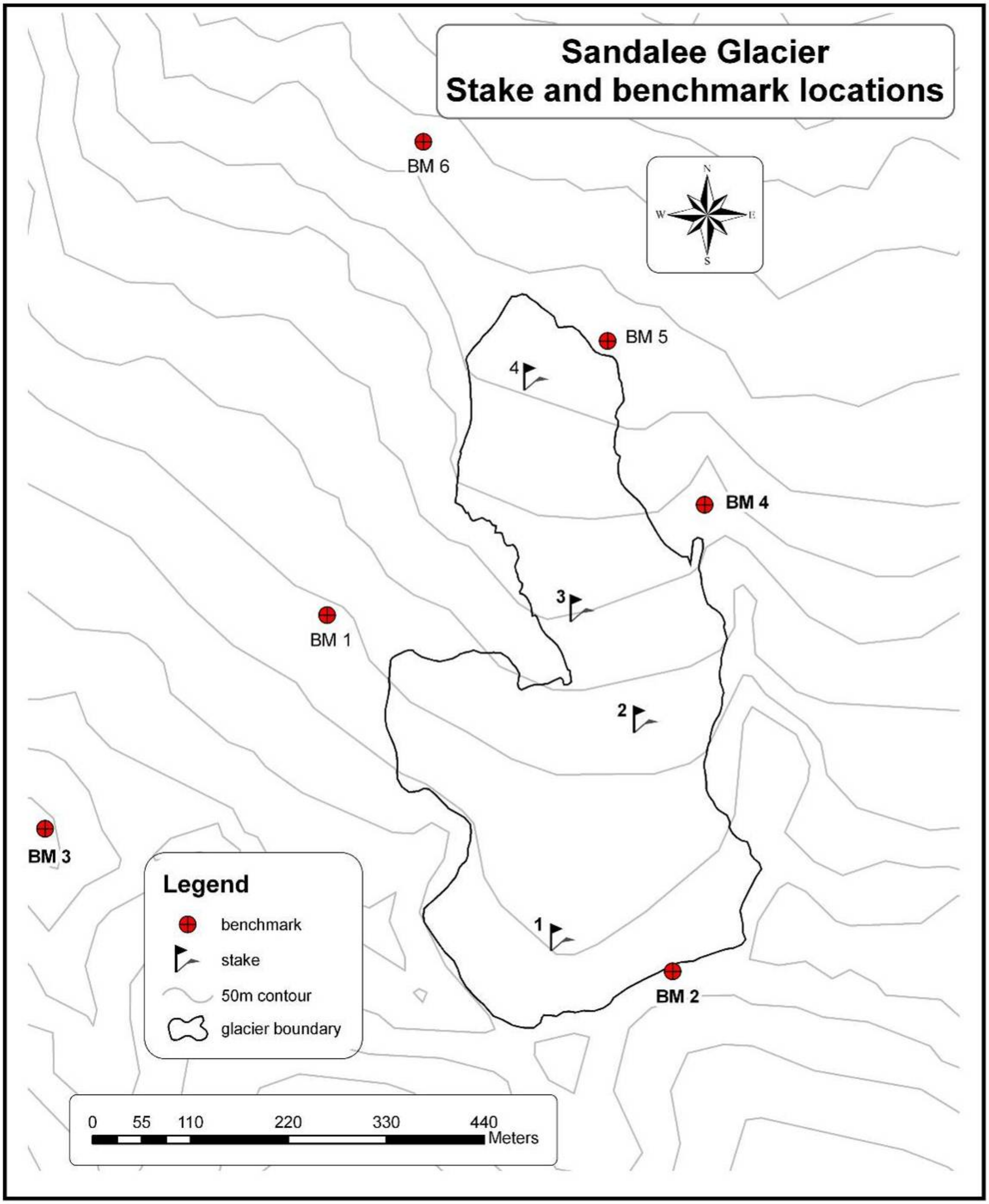

Figure 7. Sandalee Glacier. This map was generated from photogrammetry based on 1995 vertical air photos. The stake locations are approximate.

B. Glacier Mass Balance Monitoring

1. Methods Overview

Numerous options exist for monitoring glacier mass balance, but surface measurements are an accurate, relatively easy way to monitor most annual changes in winter balance, summer balance, and net balance. While an unknown subsurface change in mass is ignored by surface measurements, these quantities are assumed to be negligible. Mayo (1992) suggests that approximately 89% of the ablation of South Cascade Glacier (SCG) in a given year occurs on the glacier's surface, while the rest occurs at the bed and margins. Glaciers at NOCA are temperate, so internal accumulation is assumed to be negligible (Ostrem and Brugman, 1991). Likewise, the glaciers are small with low flow rates, and glacier flow is ignored in quantifying annual and cumulative mass balance changes.

Mass balance measurement methods used in this project generally follow procedures (with some differences as discussed below) established during 45 years of research on the SCG by the USGS-Water Resources Division (Meier, 1961; Meier and Tangborn, 1965; Meier et al., 1971; Tangborn et al., 1971; Krimmel, 1994, 1995, 1996, 1996a) and are very similar to those used around the world. Similar methodology is described in the literature by Ostrem and Stanley (1969), Paterson (1981), and Ostrem and Brugman (1991). Data reduction methods follow a modification of those outlined in Ostrem and Brugman (1991) and Krimmel (1994, 1995, 1996, 1997, 1998, 1999, 2000, and 2001). NPS staff helped apply USGS methods on SCG in 1992. These methods are applied with the assumption that mass balance maxima in the spring and minima in the fall occur simultaneously across the entire surface of the glaciers at these respective times. This assumption is likely valid because the glaciers are small and individually do not represent a large range in altitude.

2. Measurement system

Glacier mass balance terms and variables used in this report follow the convention of Ostrem and Brugman (1991). 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 successive times of minimum balance in late fall (Figure 8). The BY is designated by the calendar year in which it ends.

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). At elevation greater than 1700m in the North Cascades, the time of maximum winter balance typically occurs in late April to early May. The b_w is the product of accumulated snow depth or vertical height, (h_s) between the upper surface to the previous year's summer surface and the snow density (ρ) at a single point on the glacier surface.

$$b_w = h_s\rho \qquad \text{(eq. 1)}$$

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 identify it.

This shows the idealized relationship of balance variables to the physical minimum and maximum. Minima, maxima, and measurements occur near the dates of September 30 and May 1. Balance year 1 illustrated here as an example is a negative net balance year.

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 a stake or other measurement point. Likewise the local net balance (b_n) is the change in balance calculated at a measurement point during one BY (Figure 8). These balance values are expressed in meters water equivalent (m w.e.).

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

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 values have the same relationship as the local values and are expressed in cubic meters water equivalent (m^3 w.e.)

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

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

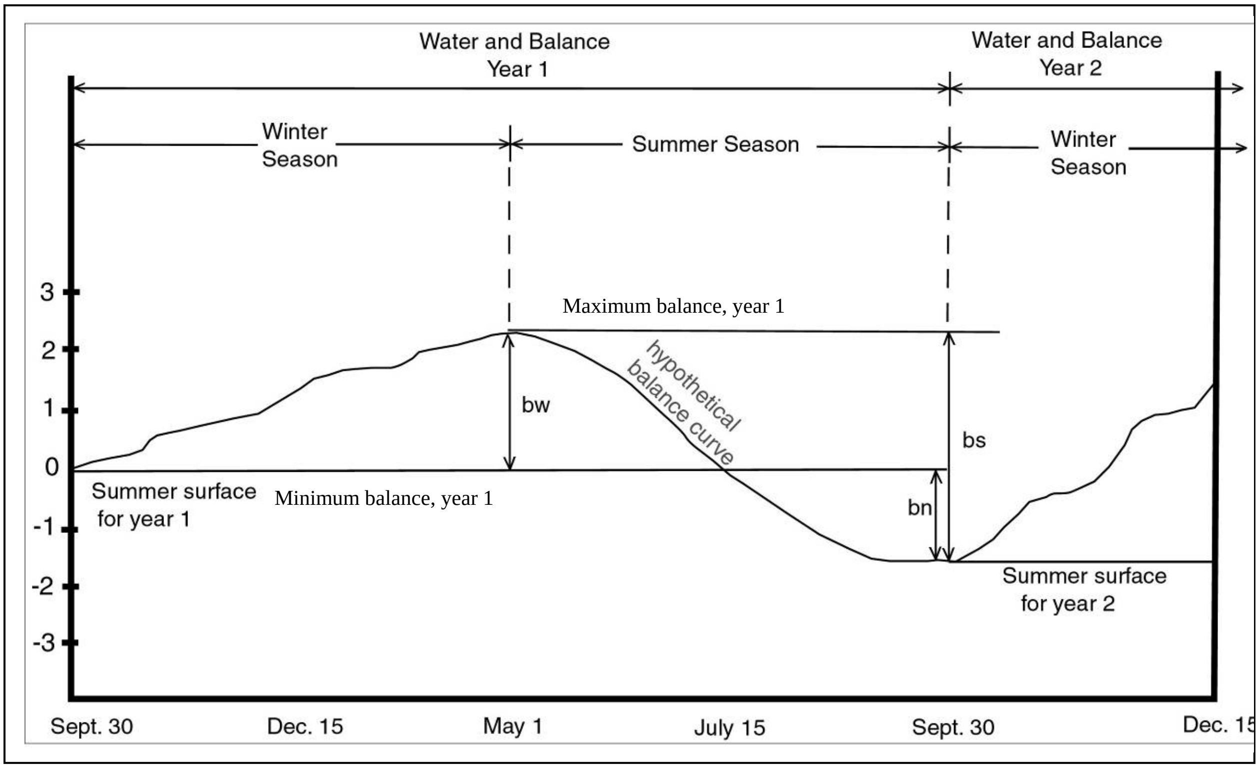

Figure 8. Glacier mass balance curve through time.

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 ρ_{ice} = 0.9 for glacier ice, ρ_{firn2} = 0.7 for two year old firn, and ρ_{firn} = 0.6 for one-summer-old and one-year-old firn. These estimates are based on research at South Cascade Glacier (SCG). Snow densities are discussed later.

This protocol uses a two-season stratigraphic approach to calculate mass gained (b_w) and mass lost (b_s) on a seasonal basis (Figure 8). Summation of these measurements allows for calculation of the net balance of a given glacier for a given balance year. Measurements of b_w and b_s are made at around the same time every year at approximately the same locations. Due to weather and logistical limitations, the actual events of maximum and minimum mass balance may not be recorded. Differences between actual events and the times of measurement are assumed to be negligible. The Water Year (WY) begins on October 1 and runs through September 30 of the following year. Experience shows that the BY typically begins and ends within two weeks of the WY and for comparative purposes the BY and WY are assumed to be the same.

Snow depth is measured at five to ten points near four to ten locations along the centerline of the glacier (ablation stakes) and other selected locations, resulting in 20-50 measurements per glacier. See **SOP #2: Snow Depth Probing** for detailed snow depth probing procedure. Measurement density ranges from 40 points/km^2 on North Klawatti Glacier to 100 points/km^2 on Noisy Creek Glacier. Snow depths range from 2 to 10 meters depending on point location, altitude, and the previous winter's weather. The snow depth probe cannot always reliably detect the previous year's summer surface, particularly at higher elevations, so a snow coring device is used to positively identify the previous summer's surface. This surface is recognized as either a dirty layer or a change in density between snow and firn. We use two different designs for 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 snow coring device mentioned above is also used to determine snow density. See **SOP #3: Snow Density Determination with Snow Core** for detailed snow coring procedures and snow density determination. Snow density (ρ_{snow}) on each glacier is measured at the ablation stake location which is closest to the mid-point altitude of the glacier. If there is time, density is measured at the top and bottom stakes on the 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. From past data, average density of the spring snowpack has been ~ 0.5 at SCG and NOCA glaciers (**Appendix C: Snow Densitites from South Cascade and North Cascade Glaciers**). Based on this data, when not directly measured, $\rho = 0.5 \pm 0.5$ is used for spring snow at all glaciers.

Ablation stakes are used to measure summer balance. Stakes are placed in late April/early May when snow depth is probed for winter balance. Measurements of surface level change against the stakes are made in early to mid-summer and in late September to early October on each glacier. The change in level against the stake indicates the mass lost 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.

Fountain and Vecchia (1999) recommend that a minimum of five ablation stakes be used per glacier. Five stakes are placed annually on Noisy Creek (Figure 5) and North Klawatti (Figure 6) glaciers. Four stakes are placed on Silver Creek and Sandalee glaciers due to their small size and limitations imposed by steep slopes, crevasses and icefalls (Figures 4 and 7). Depending on the glacier and the year, adjacent stakes are placed between 10 to 150 meters in elevation apart along an approximate centerline longitudinal profile. Noisy Creek Glacier has a unique stake pattern to record balance variation on the upper glacier due to topographic effects. The two upper stakes are placed laterally from the centerline of the glacier.

Noisy Creek Glacier has five stakes and a stake density of 8.6 points/km^2; North Klawatti has 5 stakes and a density of 3.4 points/km^2; Silver Creek has four stakes and a density of 8.2 points/km^2; and Sandalee has 4 stakes and a density of 20 points/km^2. Stake locations are determined and recorded using a handheld global positioning system (GPS) unit. Stakes are placed in holes using a backpack-mounted steam drill. See **SOP #4: Operation of the Steam Drills and Drilling** for instructions on how to use the steam drill safely and properly. The efficiency of the drill allows holes of 9 meters or more in depth to be drilled. Deep burial prevents the need to re-drill stakes during summers of particularly high melt.

C. Glacier Meltwater Discharge

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 seasonal summer drought (Fountain and Tangborn, 1985).

Glacier contribution to summer streamflow is calculated annually in four park watersheds: Baker River, Thunder Creek, Ross Lake, and Stehekin River. These watersheds were selected for several reasons. First, they represent a range in climatic and hydrologic conditions from wet west slope to dry east slope. Further, all four watersheds have gauging stations near their mouths with no diversions upstream, drain into large hydroelectric projects, and have long-term monitoring glaciers within them. Finally, information provided for these watersheds benefits other long-term monitoring programs.

The summer season is defined as the period between May 1 and September 30. These dates were chosen because they coincide with the approximate timing of measurement of winter balance and the beginning of the ablation season (May 1), and the measurement of summer balance and the beginning of the accumulation season/end of the water year (September 30). Defining the glacial runoff period as May 1- September 30 means that estimates of glacial runoff will include snow on the glacier surface as well as ice and firn buried beneath it. Further, due to the wide range in altitudes of glaciers it is problematic to pick a single date where runoff from only firn and ice begins on all glaciers. Glacier contributions to summer streamflow are estimated using summer balance data versus altitude from Silver, Sandalee, North Klawatti, and South Cascade glaciers and the area-altitude distributions of all glaciers in each watershed (Figure 9). Noisy Creek is not used because it has a different balance to altitude relationship from the other glaciers due to the small altitude range and low angle slopes.

In the future, it may be possible to establish a glacier runoff-altitude relationship specific to the Baker Watershed by combining NPS data from Noisy Creek Glacier with data from Easton Glacier collected by the North Cascades Glacier Climate Project.

D. Glacier Mapping and Volume Change

Glacier oblique area change is monitored at three temporal scales and two spatial scales. These include annual aerial photography, decadal mapping of each index glacier, and a 20-year inventory and area determination for all glaciers in NOCA.

Oblique aerial photographs are taken during the fall visit to the index glaciers to assess equilibrium line altitude, and to estimate the area of the glacier covered by snow, firn, and ice. These digital photographs are taken late in the ablation season (September), before the first winter snow covers the glacier. Images are archived at the NPS office for reference and future use (see **SOP #14: Managing Photographic Images** for specifications). Every 10 years maps are made from vertical 1:12,000 scale air photos and high-precision GPS surveys of the glacier surface. The aerial photos allow fast and accurate mapping of glacier margins, while surface GPS survey allow for adjustment of ice surface elevation changes.

Each glacier is mapped approximately every 10 years from the late season stereo-aerial photography. The glaciers are remapped every 10 years to assess area changes (advance/retreat), surface elevation/volume changes, and to provide accurate base maps for mass balance calculation. In order to take advantage of minimal snow conditions that make for more useable images for mapping and more accurate maps, the 10-year cycle may be adjusted by one or two years. 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.

A contractor is hired to make the ten-year maps of the glaciers. See **SOP #6: Glacier Mapping and Volume Change Determination Specifications** for instructions. Digital elevation models (DEMs) are produced by adjusting the ice surface elevation and glacier margin. Digital line graphs (DLGs) of glacier boundaries, 3 meter contours, crevasses, nearby permanent snowfields, and terminal hydrography including streams and ponds are mapped. Digital products are provided in the most suitable format to the parks current GIS software. Hard copy maps are plotted at 1:24,000 scale on mylar. The first base maps were generated from 1993 photography (1995 for Sandalee Glacier). The second set of maps were made from 2001 photography.

To make the original maps, elevation control was obtained from benchmarks and summit altitudes on nearby peaks from 7.5-minute USGS quadrangle maps. Altitudes were checked using GPS data with post processing for higher precision. The GPS data show fair agreement with the 1993 and 1996 maps. Benchmarks were placed around the four index glaciers in 2005 and 2006 (Figures 4-7 and **SOP #6**).

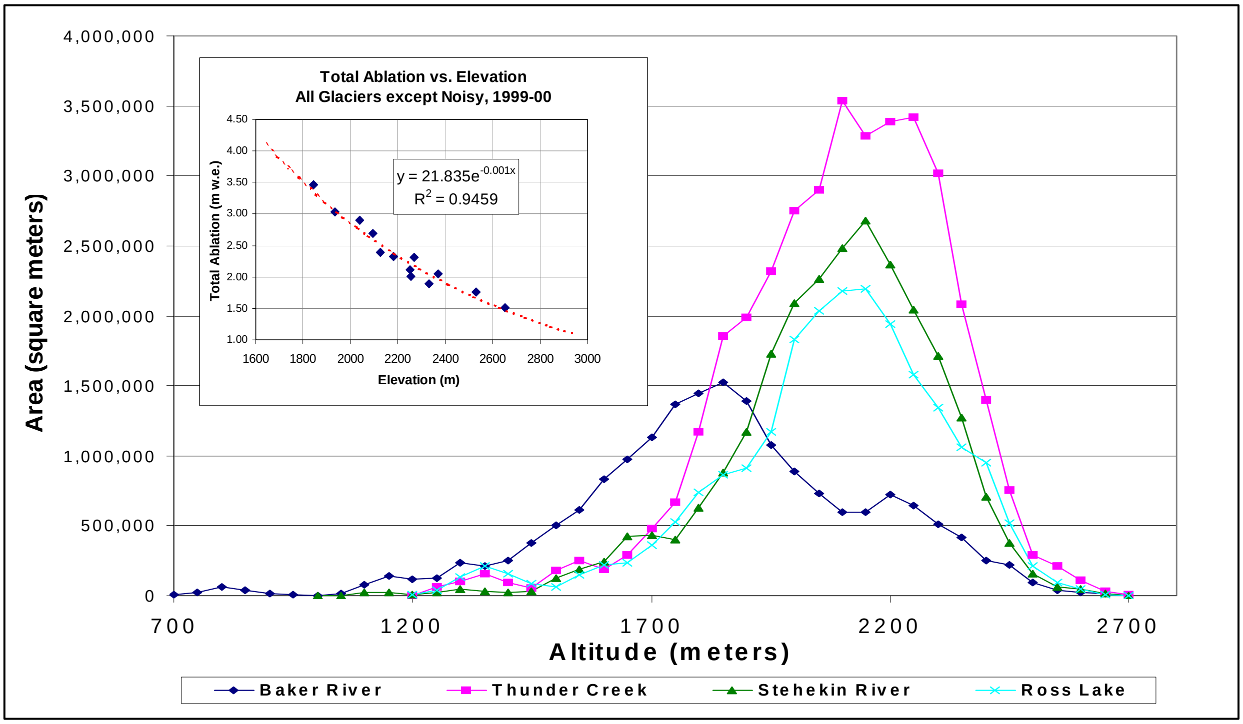

Figure 9. These graphs illustrate the altitude vs. summer balance curve (inset) and the glacier area vs. altitude for each watershed used to calculate glacier melt water discharge. Glacier areas are for 50-meter altitude bands. Noisy Glacier is in Baker River Watershed; Silver Glacier in

Ross Lake Watershed; North Klawatti in Thunder Creek Watershed; and Sandalee Glacier in Stehekin River Watershed.

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.

When new maps are made an area and volume change analysis is done to compare the new maps with all previous maps. This analysis compares changes in terminal positions, area, surface elevation, and volume. 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).

Area change for the entire population of NOCA glaciers is monitored every 20 years by completion of an inventory of all glaciers. See **SOP #11: 20-Year Glacier Inventory** for details. Volume change is estimated with the results of this inventory using methods outlined by Granshaw (2001). The first inventory of glaciers in the North Cascades was published by Post et al. (1971), and was based on data from large-scale topographic maps and aerial photographs. The latest inventory is derived from a manipulation of the NOCA snow and ice GIS Coverage based on 1:12,000 scale color aerial photography taken in 1998 (Granshaw, 2001).

III. Field Methods

Three field visits are made to each index glacier per year to collect winter and summer balance data. In the spring, ablation stakes are placed and snow depth and density are measured. In the early to mid summer, ablation stakes are measured to determine melt and more extensive snow depth measurements are made. In the fall, the final measurements of the ablation stakes are made and any residual snow is probed. Precise dates will be dictated by weather, staff availability, and by helicopter availability in the spring and fall. See **Appendix C: Snow Densities from South Cascade and North Cascades Glaciers** for dates of previous visits. All team members involved in field visits should review and discuss the SOPs including the Job Safety Hazard Analysis. See **SOP #1: Field Season Preparations and Task List** for details on preparations for and conducting of the field visits.

A. Spring Visit

Glaciers are accessed by helicopter in the spring because they are not safely accessible on foot due to avalanche danger and possible snow storms. In addition, the amount of equipment that needs to be transported to each glacier and the amount of time required would make each glacier trip a four day expedition. Helicopter flights to each glacier are made during the period from mid April to the first or second week of May, depending on weather conditions and helicopter availability. It is only possible to access the glaciers by helicopter in clear, sunny weather when shadows can assist landing on the glacier surface. Preparation to fly to all of the glaciers takes ~ 20 hours, using the Spring Equipment Checklist as a guide (see **SOP #1**). The timing of these visits generally coincides with the transition from accumulation season to ablation season. Spring visits have four objectives:

1) Measure snow depths.
2) Place ablation stakes.
3) Measure bulk snow density.
4) Photograph the glacier in oblique view from the helicopter.

Winter snow depth down to previous year's summer surface is determined using a 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, 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 snow pack because of the formation of ice layers that are created during winter freeze thaw cycles and/or precipitation events. Any distinct ice layers encountered while probing along with the interpreted summer surface depth are recorded on the data sheet. See **SOP #2: Snow Depth Probing** for details and example data sheets. **Appendix D: Blank Field Data Forms** has blank field data forms. These are referred back to if there is any doubt as to the level of the summer surface at subsequent site visits and when calculating winter balance.

Snow depth is probed at a minimum of three (but preferably ten) points along a 15 –30 meter long transect on 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.

Occasionally snow conditions and time constraints permit only one probe measurement to be taken. In these cases we rely on probing during the summer visit and depth loss from the stake measurement to fill in this data. Noisy Creek Glacier has an additional probing location between the upper two stakes. Additional locations on the glaciers are probed if time permits. Probe data can also be checked by examining the stratigraphy exposed in crevasse walls.

Ablation stakes are placed in the same approximate locations year after year. These locations were initially chosen to be on the approximate centerline of the glaciers and approximately evenly spaced from top to bottom (Figures 4 -7). See **SOP #1: Field Season Preparations and Task List** for specific coordinates. Noisy Glacier has two uppermost stakes placed across from each other on the upper glacier to record the ablation in different aspects (Figure 5). In the past, stakes were located by altitude and compass triangulation. Starting in 2001, the stakes were located by GPS with an accuracy of ± 10 meters. Altimeter and compass are probably as accurate, but GPS is easier, especially if visibility is poor. The altitude and position of the stake are recorded as accurately as possible on the field map. Holes for the ablation stakes are drilled vertically into the snow and ice at each location and not perpendicular to the surface (Paterson, 1981). The top of the stakes are placed 0.5 to 3.0 meters below the surface (depending on altitude). Stake lengths are typically 6.0 meters and 7.5 meters long and placed in 7 to 9 meter holes depending on the glacier and elevation. Typically, lower altitude stakes are placed at a greater depth below the surface because of higher ablation rates. 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. **Appendix D: Blank Field Data Forms** has blank field data sheets and **SOP #2: Snow Depth Probing** has forms filled out with stake data.

When approaching the glacier in the helicopter come in at such a height and angle as to be able to photograph the entire glacier. This procedure can be neglected in the spring if weather is marginal or time is short, but photos must be taken during fall visit.

The capabilities and contracting cost of the McDonnell Douglas (Hughes) 500D helicopter are optimal for the glacier flights. The pilot must be carded to fly for the Department of the Interior and certified in mountain flying and snow landing. The aircraft must have snow pads attached to the landing gear.

The ideal schedule for the spring is to complete two glaciers in a day, two days back to back (see sample flight/work plan, **SOP #1**). This is most efficiently accomplished by keeping the helicopter with the glacier team (helicopter shuts down and waits while the team works). This is not always practical for the helicopter company and other parties using the helicopter in the same period; however, every effort should be made to keep on the schedule of completing two glaciers in a day. If the team ends up waiting for the helicopter, this is the perfect opportunity to probe snow depth at more locations. The average number of flight hours for the spring flights is 5.3 with a range of 4.1 to 7.2 hours.

B. Summer Visit

Visits to the glaciers in mid-summer are primarily to check stakes, confirm spring probe measurements, and measure initial melt. Initially, visits were made in July and August. Because of deterioration in the previous summer surface throughout the summer, this visit is now made in early summer (late June to early July). The visits are made overland. For the uninitiated, routes into the glaciers are marked on large scale maps. Each trip requires two to three days. The heights of the stakes above the glacier surface are measured and recorded on the data sheet. Stake altitudes are also compared with spring values. Snow depth probing is done at ten points on contour with the stake as done in the spring. For an equipment list to prepare for this visit see **SOP #1: Field Season Preparations and Task List**.

We enlist the help of our staff, backcountry/climbing rangers, and volunteers for the summer trips. Four to six people on a glacier allows us to use two rope teams and probe more extensively. Additional probe locations are done between the stakes. Use the same probing procedure as at the stakes (**SOP #2: Snow Depth Probing**). Additional summer probe and stake height data can be used with spring probe data to construct a winter balance map.

C. Fall Visit

Helicopter flights are made to all the glaciers in one or two days between mid-September and mid-October. The average number of flight hours is 3.7, with a range of 2.2 to 4.8 hours. (See **SOP #1** for the Fall Visit Equipment Checklist). The timing of this visit more or less coincides with the minimum balance and the end of the balance year, but is subject to weather and helicopter availability. Each stake's height is measured and recorded and each stake is pulled out, broken down, and transported out for use the following year. The dowels and duct tape fastening the stake sections together are easily broken apart across the knee. Sections of stakes are sometimes left in the lower glacier when they have frozen in. In this case, the stake labels, number of sections left behind, and the GPS coordinates of the stake are recorded. Also, the stake labels are traced using a permanent marker to insure the label can be read the following year. Snow is probed following procedures used in spring and summer 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. When new snow has accumulated on the glacier prior to the fall visit, the depth of new snow at each stake is determined and noted and subtracted from the stake and probe measurements.

When approaching the glacier in the helicopter come in at such a height and angle as to be able to photograph the entire glacier. This procedure can be neglected if weather is marginal or time is short. Photography at this visit is particularly important.

IV. 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 also contains guidance documents on various information management topics (e.g., report development, GIS development, GPS use).

A. Information Management Overview

Project information management may be best understood as an ongoing or cyclic process, as shown in Figure 10. Specific yearly information management tasks for this project and their timing are described in **Appendix B: Yearly NOCA Task List**. Readers may also refer to each respective chapter section below for additional guidance and instructions.

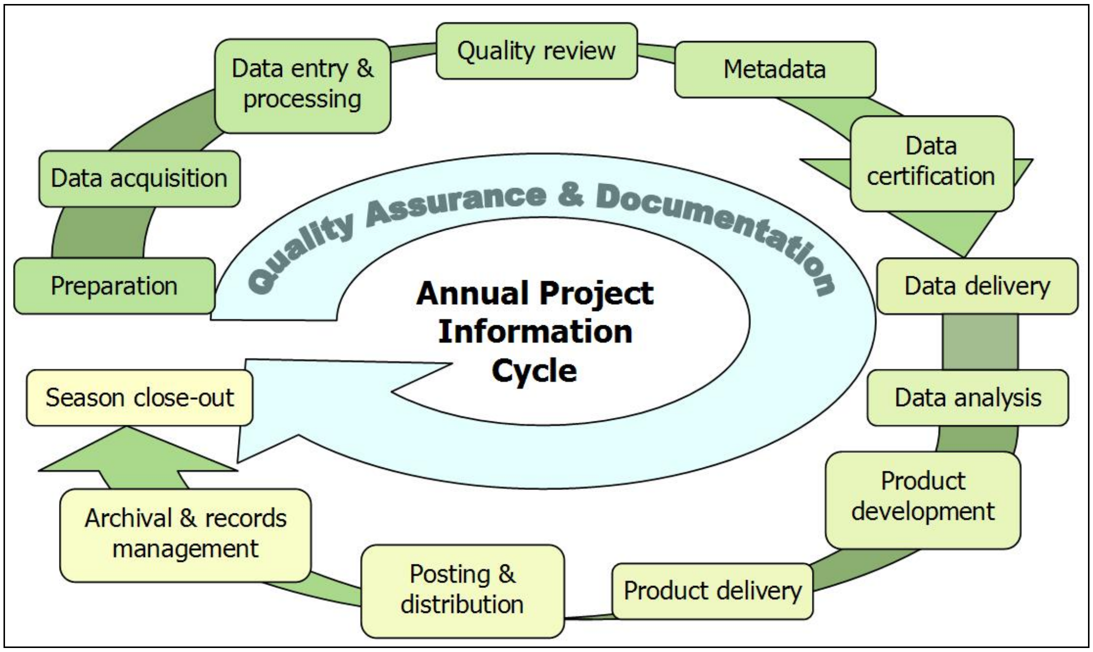

Figure 10. Diagram of the typical project information life cycle.

Figure 10 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 & 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 & distribution* – Distribute products as planned and/or post to NPS clearinghouses
- *Archival & records management* – Review analog and digital files for retention (or destruction) according to NPS Director's Order 19. 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

B. Pre-season Preparations for Information Management

1. Set Up 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 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 #19: Workspace Setup and Project Records Management**.

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 4C for additional information about the database design and implementation strategy.

C. 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: 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: Database Documentation**). 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 the next section and **SOP #16: 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.

D. 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 #16: Data Entry and Verification**. 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 #7: Mass Balance Calculations** 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 4E).

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: Field Season Preparations and Task List**, **SOP #2: Snow Depth Probing** and **SOP #7: Mass Balance Calculation**.

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 #7**).

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 #7**). 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 #16: Data Entry and Verification**). 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 4E and also in **SOP #17: Data Quality Review and Certification**).

2. Regular Data Backups
Upon opening the working database, the user will be prompted to make a backup of the underlying data (see **SOP #16**). 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.

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 #13: Field Form Handling Procedures**.

4. Image Handling Procedures

Photographic images should also be handled and processed with care. Refer to **SOP #14: Managing Photographic Images** for details on how to handle and manage these files.

E. 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 4F and 4G, and **SOP #17: Data Quality Review and Certification**).

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.

F. 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: Yearly NOCA Task List**), 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 #15: Metadata Development** for specific instructions.

G. 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 4E); 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 an 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: Yearly NOCA Task List**. Refer to **SOP #17: Data Quality Review and Certification** and **SOP #18: Product Delivery Specifications for Specific Instructions**.

H. Data Processing, Reduction and Analysis

1. Uncertainties and 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 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.

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. **SOP #9: Mass Balance Error Calculations** has example calculations for North Klawatti Glacier in 2002 using the values and equations outlined below. Error estimates for this glacier from this year are $b_w = 3.84 \pm 0.29$, $b_s = -3.62 \pm 0.22$, and $b_n = 0.22 \pm 0.32$. All quantities are meters water equivalent. The percent errors are 7.6%, 6.2%, and 142% respectively. Note that the percent error for b_n becomes inordinately large when $b_n \sim 0$. Thus percent error is only relevant for b_w and b_s.

Errors are calculated on an annual, stake-by-stake, glacier-by-glacier basis. 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). Errors in stake/probe position and altitude contribute to error but the complexity of determining these quantities in error propagation equations prohibits including them.

(a) Probe measurement: Snow probing is probably the greatest source for error in the winter balance measurements. The estimated error for a single probe measurement under ideal conditions is $\pm$ 0.03 m depth. 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.

In conditions in which residual snow and firn exists as the summer surface under the current years 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, such as 1998 and 2000. 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 (e.g., 1995) 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 (Table 2). The largest standard deviation (0.23 m water equivalent) is from Silver Creek Glacier in 1998 whereas the smallest (0.06 m water equivalent) is from Sandalee and Noisy Creek glaciers in 1995. While the differences are not systematic from glacier to glacier, they are useful in indicating the magnitude of this error. **Appendix F: Probe Error** has the full treatment of the data which are summarized in Table 2. In years in which 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.

Table 2. Average uncertainty (expressed as standard deviation) for probe data at all stakes for each glacier (additional data and more explanation in Appendix F). Balance year 1995 followed an extremely negative year, thus a firm summer surface underlay the 1994/95 snowpack for less variable probing results. Balance years 1998 and 2000 followed extremely positive balance years, with the snowpack overlying a less dense summer surface than in 1995, with more variability. These patterns are most apparent on Silver and Sandalee Glaciers.

		Balance Year					
		1995		**1998**		**2000**	
	Glacier	n	std dev	n	std dev	n	std dev
Average Uncertainty (m w.e.)	North Klawatti	34	0.09	46	0.08	43	0.12
	Sandalee	17	0.07	35	0.12	35	0.14
	Silver	21	0.14	37	0.27	18	0.23
	Noisy	39	0.07	52	0.07	50	0.07
	Average		**0.09**		**0.13**		**0.14**

Ice layers in the winter snow pack mistaken for the summer surface may cause an underestimate of winter balance, especially after a year such as 1999, which had an unusually large winter accumulation with development of several prominent ice layers within the winter snow pack. However, probing in the summer and fall will catch these errors because the ice layers generally disintegrate later in the season.

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.

(b) Stake measurement: The estimated measurement error for each stake measurement is ± 0.03 m depth, which is primarily from departure of the stake from being vertical. Uncertainty in interpreting stake data is primarily due to stake sinking (Ostrem and Brugman, 1991). Ostrem and Brugman (p. 29, 1991) documented sinking through a summer season for ~ 32 mm diameter wood, plastic, aluminum, and steel stakes whereas NOCA stakes are 22 mm diameter PVC plastic. After 200 days, which is comparable to a North Cascades summer season, a plastic stake sank ~0.25 m water equivalent 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. However, Krimmel (1999a) suggests more stake sinking may occur on the lower glacier in areas of extreme ice melt. Stake sinking results in underestimation of summer balance.

We attempted to quantify stake sinking at Sandalee Glacier in 2000 by comparing stake measurements and probe depths at each stake (see **Appendix G: Stake Sinking Assessment** for a full explanation). 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. This value is in the same range as the Ostrem and Brugman (1991) finding of 0.25 m water equivalent; however, this falls within the probe depth error at that stake and year, 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. Furthermore, cumulative snow probe and stake sinking errors can be quantitatively assessed during remapping (see below).

(c) Snow density: Snow density measurement precision and accuracy is primarily due to field measurement error of snow depth and weight. Error estimates for snow depth (± 0.03 m) and core push weight (± 0.05 kg) are used in error propagation equations (see below) for an estimate of snow density at each snow core location. Total measurement error estimates at the time of this writing range from ± 0.05g/ml to ± 0.15 g/ml, which is 10% to 30% error. See **SOP #3: Snow Density Determination with Snow Core** for calculation details.

When density is not directly measured, the spring snow density and error is assumed to be 0.50 g/ml ± 0.08 g/ml. This quantity is based on average snow density from several years at SCG and NOCA with a range in values from 0.41 g/ml to 0.55 g/ml (altitude and balance year dependent) and a standard deviation of 0.03 g/ml at measurement location P1 on SCG where density has been consistently measured mostly from snow pits. (**Appendix C: Snow Densities from South Cascade and North Cascades Glaciers**). The error estimate of ± 0.08 g/ml is derived from the average of ten snow core field measurements. Snow density does vary with altitude in the spring, but 0.50 g/ml is a reasonable estimate for the whole glacier.

(d) Stake position and altitude: Errors in recording stake position and altitude are not included in error calculations, but is estimated at ± 10 m. Estimated positional error is ± 30 m prior to and ± 10 m after the use of GPS to record locations.

(e) Non-synchronous measurements with actual maximum and minimum balances: Systematic error due to the non-synchronous timing of glacier visits to the actual timing of maximum and minimum balance can be compensated for by relying on SCG data and revisiting stakes left from the previous most season. South Cascade Glacier is used for comparison since the maximum and minimum balances occur nearly simultaneously to NOCA glaciers. Monthly visits are made to record the minimum and maximum balances at SCG, although visits often occur near the same time to NOCA glaciers (**Appendix C: Snow Densities from South Cascade and North Cascades Glaciers**). Minimum balances occurred on SCG between October 4 and 15 for balance years 1992 to 1999, whereas end of season measurements occurred on NOCA glaciers between September 14 and October 19, with most occurring earlier than the SCG minimum balances (**Appendix C**). Thus, many years summer balance may be underestimated at NOCA by ~0.05 to 0.20 m water equivalent. These discrepancies are adjusted for by relating summer season ablation rates between SCG and each NOCA glacier and applying this relationship between the period of time between the balance recorded at the NOCA glacier and that of minimum balance on SCG.

(f) 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. A detailed discussion of error calculations for each balance variable is not provided here, but rather 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: Mass balance error calculations**. 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:

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

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

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

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

$$\sigma_{bs}^2 = \sigma_{bsnow}^2 + \sigma_{bfirn}^2 + \sigma_{bice}^2 \qquad \text{(Eq. 8)}$$

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

$$\begin{aligned}\sigma_{bs}^2 = &(\sigma_{hsnow}^2/h_{snow}^{\ 2} + \sigma_{\rho snow}^{\ 2}/\rho_{snow}^{\ 2})/\ \sigma_{bsnow}^2 \\ &+ (\sigma_{hfirn}^2/h_{irn}^{\ 2} + \sigma_{\rho firn}^{\ 2}/\rho_{firn}^{\ 2})/\ \sigma_{bfirn}^2 \\ &+ (\sigma_{hice}^{\ 2}/h_{ice}^{\ 2} + \sigma_{\rho ice}^{\ 2}/\rho_{ice}^{\ 2})/\ \sigma_{bice}^2\end{aligned} \qquad \text{(Eq. 9)}$$

(g) Propagation of uncertainties in glacier-wide mass balance calculations: To come up with an overall estimate of error for a balance value (the variances for each measurement location are averaged.

$$\sigma_b^2 = (\sigma_{stk1}^2 + \sigma_{stk2}^2 + ... + \sigma_{prb1}^2 + \ldots + \sigma_n^2) / n \qquad \text{(Eq.10)}$$

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

(h) 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 and high-precision GPS surveys tied to benchmarks around glaciers. This will allow a direct comparison of cumulative balance change from the map with annual surface measurements. See **SOP #6: Glacier Mapping and Volume Change Determination Specifications** for more detail.

2. Data Reduction for Mass Balance

Once the balances at individual stakes and additional probe locations are determined from the snow depth, snow density, and stake height measurements then glacier-wide and area-averaged balances are determined. These data reduction methods are unique to this program; however, they follow the general principles from Ostrem and Brugman (1991) and Krimmel (1994, 1995, 1996, 1996a, 1997, 1998, 1999, 2000). Summaries of their methods follow as a basis for the description of our methods.

Ostrem and Brugman (1991) suggest a balance map approach to calculate balance. Based on field measurements winter and summer balance maps of the glaciers are generated. The respective balances are calculated for 50 to 100 meter elevation bands for plotting with elevation and summation for total mass balances. The average balance is calculated from the total mass balance divided by the area of the glacier. This is the preferred method of the World Glacier Monitoring Service.

Krimmel's (1996a) Grid-Index Method requires a digital elevation model (DEM) and elevation balance functions (b(z), where b is balance and z is elevation above sea level or altitude). The

DEM grid resolution is 100 meters. Krimmel constructs b(z) for maximum winter snow depth and net balance by hand drawing a curve to the plotted data. Balance values at each elevation grid point are determined from the respective b(z) plots. The mass balance is determined from summing balances at all the grid points and the average balance is the average value of all grid points.

Our primary method for calculating glacier-wide mass balance is termed the “best-fit” method. This relies on 10 meter elevation bands of which the areas are known from the most recent map of each glacier. The point balance data, elevation at each location (z), and error are used to determine a b vs. z weighted regression function. The b vs. z function is then applied to the mid-point elevation for each band. The mass balance for each band is the product of the band balance and the area of the band. The mass balance for the glacier is the sum of all the band mass balances. The second method is the “best-fit hybrid” which utilizes the stake area method to represent one stake while the rest of the glacier is represented by the “best-fit” method. Both are then inserted into a 10 meter elevation band spreadsheet and summed for the balance.

The third method for calculating glacier-wide mass balance is the “stake-area” method in which the glacier is divided into areas designed to be represented by each stake. For details see **SOP #7: Mass Balance Calculations**.

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 in 1993 (1995 for Sandalee) 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.

3. Glacier Meltwater Discharge

Glacier contributions to summer season stream flow are estimated using summer balance data from the index glaciers and the area-altitude distributions of all glaciers in each of four watersheds. Estimates are made annually for the Baker River, Thunder Creek, Stehekin River, and Ross Lake watersheds (Figure 11 and Table 2). Summer balance data for three index glaciers and SCG are plotted against altitude to create a park-wide relationship between altitude and ablation (Figure 9). This regression typically has correlation coefficient values (r^2) with a range from 0.72 to 0.95. Data from Noisy Creek Glacier are not used because the ablation for this glacier has a weak relationship to altitude. See **SOP #8: Watershed-Wide Glacier Runoff Calculations** for calculation procedures.

Area-elevation distributions of glacier areas for each of the three selected watersheds are determined using GIS analysis (Figure 9). This analysis determined glacier area in 50 m elevation bands for each watershed. Glacier extents from the most recent GIS inventory are used.

The glacier area for each 50 m band in the watersheds 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 gauges as reported in the Water Resources Data report Washington, Water Years 1993-2004. These gauges are: Thunder Creek near

Newhalem (site #12175500); Baker River at Concrete (site #12193500); and Stehekin River at Stehekin (site #12451000). Reservoir level and discharge at Ross Dam are available from Seattle City Light. Detailed calculation worksheets for each watershed in Water Year 2000 are included in **SOP #8: Watershed-Wide Glacier Runoff Calculations**.

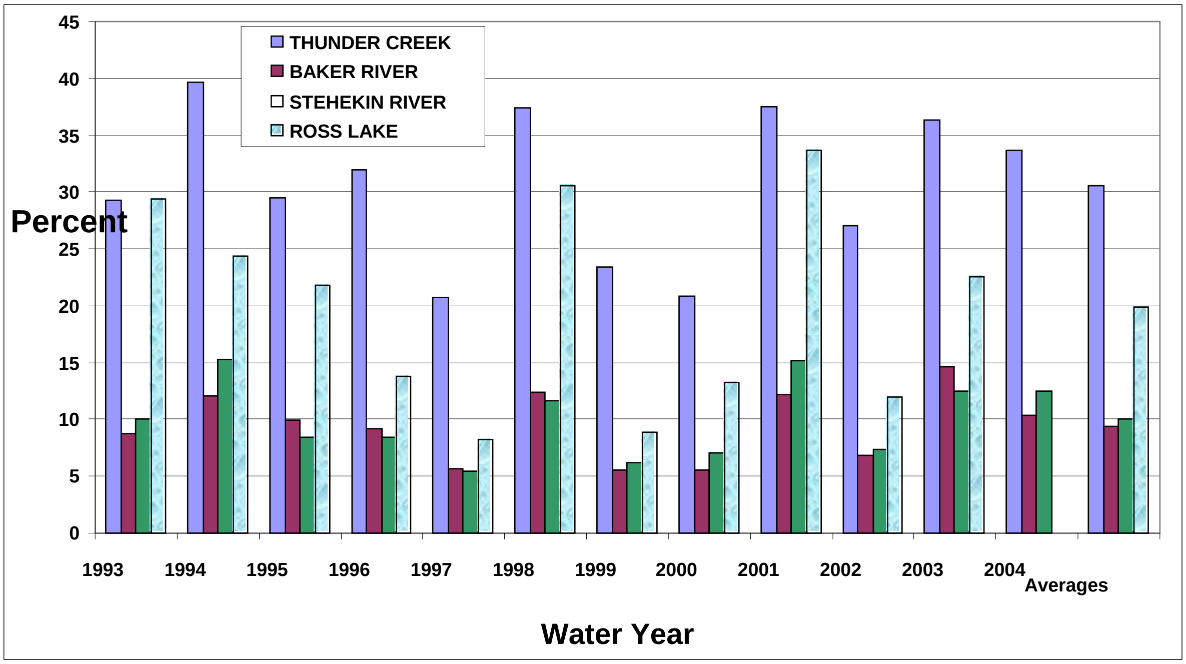

Figure 11. The percent of glacier contribution to total summer runoff by year and by watershed for three watersheds. Thunder Creek has 13% of its area covered by glaciers, one of the highest percentages in the park. Baker River, Stehekin River, and Ross Lake Watersheds are 3.2 %, 2.2 %, and 0.87% glaciated by area, respectively.

Table 3. Glacial contributions to summer stream flow for three watersheds. Runoff units are thousands of acre-feet. Data from 1993-2002 except the Sandalee Glacier and Stehekin River Watershed (1995-2004).

	May-September Runoff (thousands acre-feet)				Percent Glacial Runoff to Total Summer Runoff		
	Mean	2004	minimum	maximum	2004	minimum	maximum
Noisy Creek Glacier	1.5	1.7	1.1	1.9			
Baker River Watershed	69	78	50	87	10	6	15
North Klawatti Glacier	4.0	4.2	2.8	4.8			
Thunder Creek Watershed	95	105	72	119	34	21	40
Sandalee Glacier	0.5	0.5	0.4	0.6			
Stehekin River Watershed	70	78	52	88	13	5	15
Silver Glacier	1.0	1.0	0.7	1.2			
Ross Lake Watershed	64	71	47	81	N/A	N/A	N/A

I. Reporting and Product Development

Refer to **SOP #18: Product Delivery Specifications** for the complete list and schedule for project reports and other deliverables and the people responsible for them.

1. Recommended Reporting Schedule

We will produce 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).

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” and “Complex Issues”; reports on park 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, 2000); and the data is available annually to professional hydrologists and water resource managers in the NRCS Snow Survey Report, 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. This is included in the NRCS May Snow Survey Report and is typically distributed regionally. See **SOP #12: Products and Reporting** for full procedures.

Figures 12 and 13 are mass balance summaries that are included in most reports to all audiences. A location map of the glaciers (Figure 2) is included and if there is room, detailed maps of each glacier (Figures 4 – 7). Glacier meltwater discharge results are reported on the glacier page and in specific reports to Seattle City Light.

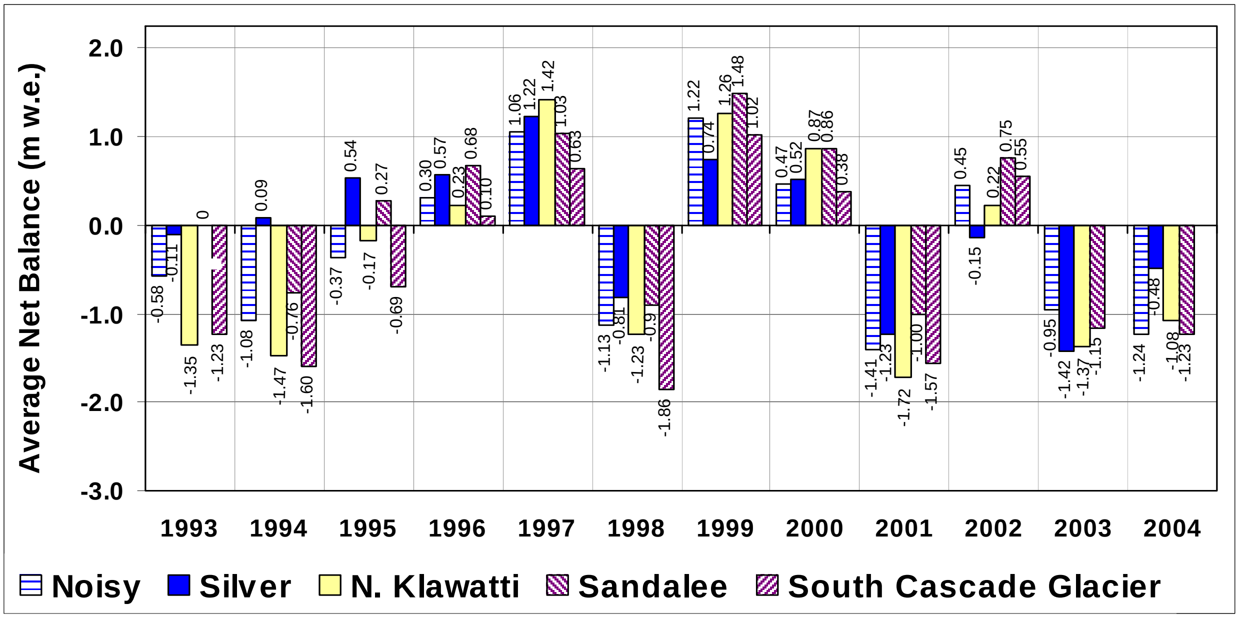

Figure 12. Average net balance for each glacier by balance year.

3. Recommended methods for long-term trend analysis (5-10 years)

Long-trend analyses are primarily conducted using cumulative net balance curves (Figure 13). 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.

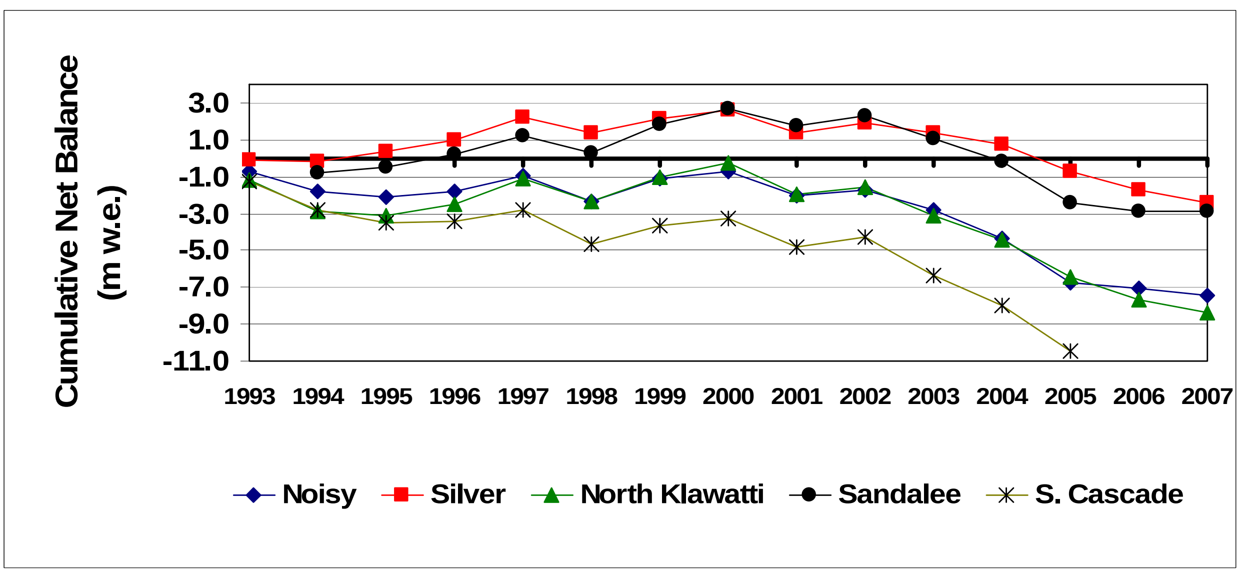

Figure 13. Cumulative net balance series for the four NOCA monitoring glaciers plus the SCG. The SCG follows the same annual trends as the NOCA glaciers but tends toward a more negative long term balance.

J. Product Delivery, Posting and Distribution

Refer to **SOP #18: Product Delivery Specifications** for the complete schedule for project deliverables and the people responsible for them. Upon delivery products will be posted to NPS websites and clearinghouses (e.g., NatureBib, NPSpecies, NPS Data Store) as appropriate.

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 2 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.

K. Archival 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 NPS Director's Order 19, which provides a schedule indicating the amount of time that the various kinds of records should be retained. Refer to **SOP #19: Workspace Setup and Project Records Management**.

L. 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 SOPs associated with the protocol.

This protocol will be tested 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.

V. Personnel and Training Requirements

Operation of the NOCA glacier monitoring program primarily relies on a minimum of three personnel: the Park Geologist, a Physical Science Technician-Permanent (PST-Perm), and a Physical Science Technician-Term (PST-Term). See **Appendix A: Roles and Responsibilities for Glacier Monitoring in NOCA** for roles and responsibilities of personnel. Other term and seasonal employees in the Physical Sciences Workgroup and volunteers may assist with fieldwork tasks as needed. In addition volunteers are used in the summer to assist with the mid-season overland field visits.

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

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

Physical Science Technician, GS-7 Permanent or Term – M.S. in Geology or related field or B.S. in geology with specific experience in glaciology.

Physical Science Technician, GS-5 Term – B.S. in Geology 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 Park Geologist is responsible for general oversight, budget, personnel, planning, data analysis, publication of results, and also arranges contracts. At the present time this position also contributes to field work as needed. The PST-Perm is primarily responsible for running field aspects of the program, by directing field operations and logistics, coordinating helicopter use, and directing and coordinating other employees and volunteers. This position is also responsible for data handling, and assisting with reporting in technical reports. The PST-Seasonal assists in field logistics and operations, data handling, and reporting as needed and is responsible for keeping the gear cache organized and inventoried. This position reports to the Park Geologist 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 training is required for compliant and safe execution of duties for each of the primary personnel. All personnel involved in helicopter operations need S-270 Interagency Helicopter Crewmember training. One member of the team needs S-271 Interagency Helicopter Project Manager training. The PST-Perm and Seasonal needs a background or training in using ESRI ARCGIS (ArcInfo8.3 at the time of this writing). The staff needs to review the Job Hazard Analysis (**Appendix I: Job Hazard Analysis**) once a year while going through the annual safety checklist with a supervisor.

VI. Operational Requirements

A. Annual Schedule

Date	Event
February 15	Paperwork to return STF employees to active status
March 15	Bring on Perm STF & Term/Seasonal
April 1	Schedule work, Reserve Helicopter and Submit Flight Request to Aviation Officer
April 1	Check equipment and supplies, buy and/or repair as needed
April 1	Hire seasonal employee
April 10	Organize field gear. Prepare Data Sheets
April 15 to May 15	Spring flights and field work as scheduled
May 15	Spring Data entry and initial analysis and archiving
Deadline: May 20	Produce and Submit Glacier Page to NRCS and Complex Issues
June	Budget programmed
Deadline: July 1	Submit aerial photography contract (and mapping contract every 10 years).
June 20 to July 15	Summer glacier hikes
Deadline: July 15	Purchases and Contracts complete (cutoff date for purchase credit card)
July 15 to August 1	Data entry and continuing analysis
August 28	Seattle City Light Agreement updated to accept $2000
September 10	Contribution to NCCN Annual Administrative Report and Work Plan
September 20 to Oct 5	Fall flights and field work as scheduled.
October 1 to December 15	Final data entry, verification, validation, analysis, and certification
early November	GSA Annual Meeting
Mid November	NW Glaciologists Meeting
Deadline: December 1	NCCN Budget Request
early December	AGU Annual Meeting
Dec. 15 to Feb. 15	Completion of Annual Report (date dependent on PST furlough) Completion of Annual Admin Report Work Plan

B. Annual Workload

- Spring Visit – 2 employees ~ 80 hours each
- Summer Visit – 4 employees ~ 80 hours each, 4 –8 volunteers ~ 80 hours each
- Fall Visit – 3 employees ~ 30 hours each
- Data handling and analysis – 2 employees ~120 hours each
- Reporting – 2 employees ~80-160 hours each, except in years in which the 10-year report is done additional 160 hours.

C. Facility and Equipment Needs

Minimum facilities include:

- Helipad with flight following (Comm Center or another team member).
- Storage for all equipment.
- Access to workshop or tools for stake fabrication.

- Offices for Park Geologist and Physical Science Technicians
- Computer with capability for GIS.
- Parking space for vehicle.
- Computer software:
    - ArcInfo8.3
    - MS Word
    - MS Excel
    - Origin or other scientific graphing program.
    - Adobe Illustrator or other graphics/drawing program.
    - Adobe Photoshop or other image processing program.

Equipment needed is listed in the spring, summer, and fall "Equipment Checklists" in **SOP #1: Field Season Preparations and Task List**. One car is needed to access trailheads and transport equipment, preferably a high clearance 4wd vehicle.

D. Budget Considerations

The cost of monitoring four glaciers at NOCA (Table 3) is well constrained after 15 years of data collection. Most support comes from the NPS but we have developed a strong partnership with Seattle City Light.

For FY 07 we requested $22,500 from the NCCN budget process. In the future, limited funds may force us to not monitor North Klawatti Glacier unless SCL support increases. This amount is essentially what is budgeted for NOCA glaciers in the Phase 3 plan for the North Coast and Cascades Network. Helicopter costs have also increased 50% in the past few years, and we anticipate requesting an additional $2,000 in FY09.

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.

Table 4. Costs and sources of annual support for the NOCA glacier monitoring program.

COSTS			SUPPORT		
FY2007 Annual Budget			ONPS	NCCN	Partners
Personnel		$30,500			
Park Geologist	$12,500		$12,500		
Phys.Sci.Techs	$18,000			$18,000	
Helicopter transport		$3,400		$3,200	$2,000
Equipment/travel expenses		$800		$800	
Annual Total		$34,700	$12,500	$22,000	$2,000
10-Year Intervals (2015, 2025, etc)					
Re-mapping and surface analysis		$10,000			
Ten-Year Summary Report		$2,000			
Total (includes annual costs)		$46,700			
20-Year Intervals (2020, 2040, etc)					
Glacier Inventory (does not include annual and ten-year costs)		$25,000			
(assumes park-wide air photos available)					

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Standard Operating Procedures

Long Term Monitoring of Small Glaciers at North Cascades National Park:
A Prototype Park Model for the North Coast and Cascades Network

SOP #1: Field Season Preparations and Task List

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview and Explanation

Field trips are made seasonally to each glacier to collect winter and summer balance data in support of goals 1 and 2 of this protocol. Three field trips a year must be planned and prepared for. Each visit also has a required list of data to collect once in the field. The first trip is in spring in late April to early May. The second trip is in summer occurring in late June to mid July and the third trip is made in the fall from late September to mid October. Precise dates will be dictated by weather, staff availability, and by helicopter availability in the spring and fall. See **Appendix C**: for dates of previous visits. All team members involved in field visits should review and discuss the SOPs including the Job Safety Hazard Analysis. Preparations for each visit are described as well as a set of tasks to accomplish below.

Refer to **Appendix B: Yearly NOCA Task Lis**t for a generalized overview of annual tasks.

Procedures

Spring Preparations
Glaciers are accessed by helicopter in the spring because they are not safely accessible on foot due to avalanche danger and bad weather. In addition, the large amount of equipment that needs to be transported and the amount of time needed to reach each glacier would make each glacier trip at least a four day expedition. Accessing the glaciers by helicopter allows us to both reach each site and accomplish the necessary work in half of a day. Helicopter flights to each glacier are made during the period of the last week of April to the first or second week of May, depending on weather conditions and helicopter availability. The timing of these visits generally coincides with the transition from accumulation season to ablation season. It is only possible to access the glaciers by helicopter in clear, sunny weather when shadows can assist landing on the glacier surface. Due to variable weather, teams should be prepared to spend the night on the glacier and to walk out and must bring all the necessary gear for these contingencies. It is also most cost effective to complete the spring visit to four glaciers in 2 days.

Successive steps are listed below to prepare for the logistically challenging spring field work:

1. Equipment check and preparation: Preparations for the spring field season should begin in mid-March to early April. A flight request (Figure 1) should be filed at this time. Preparing for this first round of field work requires approximately 20 hours of work for one person or more if equipment needs repair. All equipment is stored in the Resource Management building at the Marblemount Ranger Station. 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:

    a. Check the steam drill hoses, valves, and connections for damage and excessive wear. Repair if necessary.
    b. Fill all propane 2.5 gallon tanks.
    c. Test run the steam drills to confirm everything is operating properly. See **SOP #4** for detailed instructions and safety precautions.
    d. Clean and check probes for damage and excessive wear. Sharpen tips if necessary. Mark and tape one meter successive interval sections.
    e. Inspect ropes, glacier travel, and snowshoe 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 22mm or 7/8-inch outer diameter and 3mm or ¼-inch wall thickness: PVC 1120 schedule 40, 600 psi) along with new wooden dowel (50 to 70 mm sections or 2 to 3 inches of 16 mm or 5/8-inch) need to be purchased. Take the scissor-like PVC cutter to the hardware store to precut the PVC into 1.5 meter segments for easier transport. Note: Not all 5/8-inch wooden dowels are exactly the same diameter. Some sections can have too large of a diameter to fit into the PVC tubing. For this reason one should bring a small section of PVC tubing to the hardware store to test fit dowel. Darrington Hardware currently is the best vendor for dowels.
3. Ablation Stake Preparation: Ablation stakes are constructed on the glaciers from 1.5 meter sections of PVC. Bundle sections for each stake together and group for each glacier. Tables 1.1 – 1.4 detail the stake lengths and number of sections required for each glacier. Plug the bottom section of a stake with another wooden dowel flush with PVC (glued in) to prevent sinking. In addition, perforate the bottom one or two sections of a stake with 5 mm diameter holes to prevent floating when the hole fills with water. Assemble a small stuff sack that contains the required number of dowels plus some extras 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).
4. GPS Preparation: Locations of the stakes are determined on the glacier using a GPS. Make sure that the proper stake locations have been loaded into the GPS's memory. Most often these are the same as last year and can just be carried over. Tables 1.1 – 1.4 list the GPS coordinates for each stake for the four glaciers. Figures 4 -7 in the Protocol Narrative show approximate locations in map view.
5. Helicopter Request and Aviation Management: It is critical to begin preparing helicopter use plans in late March. For budget purposes the average number of flight hours for the spring flights is 5.3 with a range of 4.1 to 7.2 hours. A flight plan should be filed with the Project Helicopter Manager and the Communications Center who conducts the flight

following. Standard procedures should be followed for administrative helicopter use in the park (see NOCA Aviation Management Plan). The ideal schedule for the spring is to complete two glaciers in a day, two days back to back (see sample flight/work plan, below). This is most efficiently accomplished by keeping the helicopter with the glacier team (helicopter shuts down and waits while the team works). This is not always practical for the helicopter company and other parties using the helicopter in the same period, however, every effort should be made to keep on the schedule of completing two glaciers in a day. If the team ends up waiting for the helicopter, this is the perfect opportunity to probe snow depth at more locations.

Summer Preparations

Summer visits to the glacier are made on foot overland in two to four day trips. Helicopters are not used for summer trips because the use of helicopters in Wilderness between July 4 and Labor Day is restricted to Fire and SAR use only. The equipment needed for the summer visits is easily carried in on foot so it is difficult to argue for using a helicopter as a "minimum tool" in Wilderness. Backcountry permits are required for all overnight administrative use. Obtain these at the Wilderness Information Center in Marblemount. Prepare and pack using the "Summer Glacier Equipment List" below. Glacier travel equipment (ropes, harness kits, and snow anchors) should be carried to all glaciers with the exception of Noisy Glacier. Noisy Glacier has no appreciable crevasse hazards so this equipment is not needed. Ice axes and crampons should be carried and are used on all trips for steep snow and ice travel. Teams to each glacier should include at least two people (who are well trained in glacier rescue) or three if one person has lesser training for all glacier trips. North Klawatti requires a four-person team so that two can access the lower glacier while two access the upper. Access to the trailheads for Noisy, North Klawatti and Sandalee glaciers can be accomplished in a passenger sedan; however, access to Silver Glacier requires a high clearance vehicle and preferably 4WD.

Access to the Silver Glacier trailhead requires driving into British Columbia, Canada so all team members should carry photo identification and a birth certificate or a passport. See Cascade Alpine Guide volume three (Becky, 2000) for description on approach to Mount Spikard via the Depot Creek route. There is no official trail head at the time of this writing and the main Depot Creek road is subject to washouts. Camp is usually made near the small unnamed lake at the head of Depot Creek on glacial till, in some years camp is on snow.

Driving directions to Silver Glacier:
-Take 1E from the US Canadian Boarder.
-Take exit #119 to Vedder Rd.
-Continue through Sardis for several miles
-Take left before first main bridge (toward Chilliwack River/ fish hatchery)
-Drive ~1/2hr, ~40km (25 miles)
-Paved road turns into gravel road with potholes, Chilliwack Lake is to the right.
-Pass through "No Camping" sign near Provincial Park building.
-Pass Paleface River, currently signed but sign may not be maintained. This is the first major/only river crossing with a bridge
-Take the first left after bridge which is also before Depot Creek, and head up incline on a very rough and rocky road.

-*Currently, a low clearance vehicle can drive ~10minutes to a pull out on the right. A high clearance vehicle can drive ~20 minutes to where the road is washed out with little room to turn around.*

Sandalee Glacier requires special logistical considerations because it is accessed from the remote Stehekin Valley. This will require leaving Marblemount very early in the morning, ~4:30am (or the night before), to catch the morning ferry up Lake Chelan from Field's Point in Chelan to Stehekin. The Natural Resource Specialist as well as other staff in Stehekin are usually willing to provide a vehicle or help arrange a ride to and from the McGregor Mountain trailhead. One can reach the base camp (Heaton Camp) in a long, full day from Marblemount via car, ferry, car, and foot. See Cascade Alpine Guide volume three (Becky, 2000) for description on approach via McGregor Mountain trail.

To reach Noisy Glacier drive the Baker Lake highway for 22.4km (13.9 mi) to the dam. Take a right over the dam and follow road 1107 for 16km (10 mi) to the Watson Lakes trailhead. To reach the glacier, see Cascade Alpine Guide volume three (Becky, 2000) for a description of approach via Watson Lakes trail to the southwest climbers route for Bacon Peak. Camp is located on snow in ~6km (4mi), ~four hours, from trailhead at 1516m (5300') elevation.

The trail to North Klawatti Glacier is reached by driving from Marblemount on the Cascade River Road for ~29km (~18 miles) to the gravel parking lot at Eldorado Creek. See Cascade Alpine Guide volume three (Becky, 2000) for a description of approach via the climbers routes of Eldorado Creek, the Sowthwest route for Klawatti Peak, and finally the South Route of Primus Peak to reach North Klawatti Glacier. There are several options for camping locations. The lower camp at 1890m (~6200') is east of hammered ridge in the Eldorado Creek basin. If this camp is chosen, prepare for an extremely long glacier monitoring day, ~15hours. The middle camp is at 2255m (~7400') on the Eldorado Glacier below Eldorado Peak and has a large flat area for camping. The third option is to camp at the Inspiration/ McAllister Creek Glacier col, just below Klawatti Peak. This camp is wind exposed and has the least amount of sunlight but makes for the shortest glacier monitoring day. All three camps are on snow.

<u>Fall Preparations</u>
Helicopter flights are made to all the glaciers in one or two days between mid-September and mid-October. For budget purposes, the average number of flight hours is 3.7, with a range of 2.2 to 4.8 hours. See the "Fall Flight Plan" below for the recommended itinerary. The flight plan should be filed with the Project Helicopter Manager and the Communications Center who is doing the flight following. Standard procedures should be followed for administrative helicopter use in the park (see NOCA Aviation Management Plan).

The timing of this visit more or less coincides with the minimum balance and the end of the balance year, but is subject to weather and helicopter availability. Prepare and pack using the "Fall Glacier Monitoring Equipment Checklist" below. Due to variable weather, teams should be prepared to spend the night on the glacier and to walk out and must bring all the necessary gear for these contingencies.

Spring Tasks On Glacier

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**"). 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. Light steam drill and wait for pressure to build (25psi for the Taylor Scientific, and 1.5 bar for Heucke ice drills). See **SOP #4 "Operation of the steam dril**l".
5. Drill hole for stake. Once pressure is built, 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 ~0.3m before reaching desired hole depth. With 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 9 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 5mm 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 wooden dowel and duct tape. (ex. **06-1-5** which translates to the year 20**06 -** stake **1 –** segment **5**)
8. Place PVC stake in hole. One person stands above hole holding assembled stake with arms spread to balance stake upright. Second person pushes the end of the stake up into the air to create a vertical plane 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. Taken near the middle of the glacier (usually stake 3) unless time allows for two cores, one at the top and one at the bottom of the glacier. See **SOP#3 "Snow density determination with the snow core**".
11. Probe at location between stakes as time allows.
12. Take oblique digital photo. Use a three mega pixels or better camera to photograph entire glacier from helicopter. Include adjoining peaks and/or lakes (ex. Silver Lake below Silver glacier
13. Have field partner verify data collection.
    a. Calibration 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. Check each snow core push weight, length, and depth.
    d. Confirm distance from glacier surface to top of stake.

Summer Tasks On Glacier

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. 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.
3. Check mid season stake melt to mid season probes and probe melt. Make sure these numbers agree within 0.5m.
4. Measure other 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 section break and record the label off this section.
5. Probe snow for previous year summer surface and record measurements (see **SOP #2 "Snow depth probing").**
6. 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, and density.
7. Probe at locations between stakes as time allows.
8. 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 (ie. not falling seracs). Look for dirty layer of previous year and note both sides of crevasse walls (ie. South and North facing).
9. Have field partner verify data collection.
    a. Calibration 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 distance from glacier surface to top of stake.
    d. Check stake melt. Count segments and check label measurement was taken from.

Fall Task On Glacier

1. Measure height of stake from glacier surface. (see Summer Tasks 2 above) If stake is melted out (lower stakes) look for drill hole. If stake is missing look in nearby crevasse for stake segments.
2. Check end season stake melt to spring data. Make sure melt from stakes and probes agree.
3. Measure other 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.
4. Mark glacier surface. Use a black sharpie to mark a line on stake where the glacier surface is. Write "Fall" with current year and arrow pointing to line. Leave stake in glacier if ≥0.5m remains under the ice. Make a note as to how many sections are left behind.
5. Remove and break apart stake segments above "fall" marked line. Bundle these for helicopter transport with duct tape or bungee cord.
6. Probe remaining snow and record measurements (see **SOP #2 "Snow depth probing**")

7. 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, and density.
8. Look for and record crevasse stratigraphy. see above Summer Task 6 above)
9. Have field partner verify data collection.
    a. Calibration 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 distance from glacier surface to top of stake.
    d. Check stake melt. Count segments and check label measurement was taken from.
10. Take oblique digit photo. (see Spring Tasks #10)

Table 1.1. Silver Creek Glacier Stakes.

Stake	X UTM NAD83	Y UTM NAD83	Z Altitude	Stake Length	No. of Segments	Top depth below surface
1	628948	5425853	2567	6.0 m	4	0.5 m
2	628780	5425970	2460	7.5 m	5	0.5 m
3	628562	5426074	2319	7.5 m	5	0.5 m
4	628467	5426397	2177	9.0 m	6	0.5 m

Table 1.2. Noisy Glacier Stakes.

Stake	X UTM NAD83	Y UTM NAD83	Z Altitude	Stake Length	No. of Segments	Top depth below surface
1E	608607	5391856	1845	7.5 m	5	1.5 m
between 1E & 2W	608303	5391758	1840	NA	NA	NA
2W	608103	5391864	1857	7.5 m	5	1.5 m
3	608327	5392065	1799	9.0 m	6	1.5 m
4	608367	5392362	1766	9.0 m	6	1.5 m
5	608375	5392545	1750	10.5 m	7	1.5 m

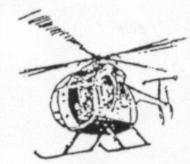
Table 1.3. North Klawatti Glacier.

Stake	X UTM NAD83	Y UTM NAD83	Z Altitude	Stake Length	No. of Segments	Top depth below surface
1	639769	5382399	2331	7.5 m	5	1.0 m
2	640333	5381795	2215	7.5 m	5	1.0 m
3	640645	5381512	2104	7.5 m	5	1.5 m
4	641086	5381535	1953	9.0 m	6	1.5 m
5	641409	5381240	1863	10.5 m	7	1.5 m

Table 1.4. Sandalee Glacier.

Stake	X UTM NAD83	Y UTM NAD83	Z Altitude	Stake Length	No. of Segments	Top depth below surface
1	663533	5363892	2242	7.5 m	5	0.5 m
2	663626	5364137	2172	6.0 m	4	1.0 m
3	663555	5364262	2098	9.0 m	6	1.5 m
4	663503	5364522	1995	9.0 m	6	2.0 m

FLIGHT REQUEST/AIRCRAFT PERMIT



NORTH CASCADES
NATIONAL PARK SERVICE COMPLEX

Note: Bold headings MUST be completed prior to submission for approval. Instructions for completing form on reverse.

Request Date: ______________________ **Requested by:** ______________________

Date of Flight: ______________________ **Day of Week:** ______________________

Flight Purpose & Justification: *Describe purpose (eg. snow survey, amphibian sampling, search). Justification needed for 4th of July through Labor Day holiday weekends; Friday, Saturday or Sunday flights; flights in the NRA's during Fall hunting seasons; special use flights (defined on reverse); and if wilderness: why this project cannot be accomplished on foot, by horse, or other non-mechanical means.*

____

____

____

____

Is this flight being combined with other flights/projects? ______________________

Loadmaster ______________________ Helibase/Helispot Manager ______________________

Flight Route and Landing Locations: ______________________

____

____

Activity: ☐ **Routine, shuttle personnel/equipment** ☐ **Non-Routine (Emergency)** ☐ **Special use**
☐ **Survey/overflight above 1,000 AGL** ☐ **Survey/overflight below 1,000 AGL**

Passengers

1. ______________________
2. ______________________
3. ______________________
4. ______________________
5. ______________________

Cargo: weight and description: ______________________

Company: ______________________ Helicopter Model: ______________________

Account Number	Est.Hrs.	Est.Cost	**Fund Manager Signature**

Estimated Flight Minutes over Wilderness: _______ **Estimated # of landings in Wilderness:** _______

For Administrative Use

OAS-23 Control Number: ______________ NOCA Flight Approval Number: ______________

Flight Approval Signature: Aviation Officer ______________________, or
Wilderness/Aviation Committee Chair ______________________

Figure 1. Flight Request/Aircraft Permit form used for helicopter use.

Spring Glacier Monitoring Equipment List
Group Equipment for 2 people. Preparation time for 1 person ~ 20 hours

Ablation Stakes
- __ 4 to 7, 1.5 m bundled segments per stake depending on glacier
  - __ 5 stakes – Noisy
  - __ 4 stakes – Silver
  - __ 5 stakes – North Klawatti
  - __ 4 stakes – Sandalee
- __ 4” dowels – 3 or 4 per stake and pack extras
- __ 2-rolls duct tape
- __ 2-10 meter measuring tapes

Snow depth Probe – make sure all segments are included and 1-m intervals are taped and marked.
- __ 2 – small vice grips
- __ leather or rubber palm gloves for probing
- __ wax, sunscreen, 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

Steam Drill and Accessories
- __ large propane tank __ filled
- __ small propane tank __ filled
- __ propane hose and regulator
- __ 2 large piezo electric starter torches
- __ 2 8inch crescent wrenches
- __ 2 pair pliers
- __ screwdriver and clamp kit
- __ 2gallon water container
  - __start with hot water

Other Equipment
- __GPS (make sure stake locations are loaded)
- __ altimeter – don’t forget to calibrate w/helicopter
- __ compass
- __ stake and probe field forms and glacier map on write in the rain paper
- __ snow core field form on write in the rain paper
- __ extra probe field form on write in the rain paper
- __ clipboard

- __ 3 pencils
- __ 2 sharpies
- __ radio charged
- __ extra radio battery
- __ camera and film charged
- __ extra batteries for GPS and camera (AA)
- __ flight suits with flight gloves
- __ helmets

Emergency Overnight and Group Gear
- __ 1 tent
- __ 2 sleeping bags
- __ 1 stove
  - __ filled fuel canister
  - __ 1 or 2 pots

__ dinner and breakfast for 2

Glacier Safety Equipment

- __ rope
- __ 2 pickets and runners
- __ ice axe
- __ harness and
  - __ prussiks
  - __ pulleys
  - __ extra carabiners
  - __ extra runner
- __ 2 avalanche transceivers (for Silver and Sandalee Glaciers)

Personal Equipment

- __ wear cotton or wool clothing only under flight suit
- __ fleece layer
- __ rain Gear
- __ gaiters
- __ boots and socks
- __ hat (warm and ball cap)
- __ sunglasses
- __ sunscreen
- __ first aid kit
- __ water and snacks

Summer Glacier Trip Equipment List

Based on 2 rope teams for each glacier trip.

Other Equipment

__ 2 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
__ 1 pair of pliers or leatherman
__ 1-2 pairs of probing gloves (not vital in shallow snow)
__ 2-4 pencils
__ 2 sharpies
__ duct tape
__ 2 GPS units and extra batteries
__ 2 radios and extra batteries
__ 2 vise grips

Emergency Overnight and Group Gear

See spring glacier Trip Equipment above

Glacier Safety Equipment

See spring glacier Trip Equipment above

Personal Equipment

See spring glacier Trip Equipment above

Fall Glacier Trip Equipment List

2 to 3 glacier workers plus pilot

Other Equipment

__ Data forms for each glacier
    2 forms for North Klawatti and Silver

__ Map of each glacier
__ 3 small measuring tapes – 1 for each person
__ 2 probes
__ 2 pairs of vice grips (for old probe if used)
__ 1 pair of pliers or Leatherman
__ 1-2 pairs of probing gloves (not vital in shallow snow)
__ PVC carrier tube (didn't use in 2000)
__ 6 pencils (2 per person)
__ 3 sharpies (1 per person)
__ 1-2 rolls duct tape
__ shovel
__ 2 radios and extra batteries

Emergency Overnight and Group Gear
See spring glacier Trip Equipment above

Glacier Safety Equipment
See spring glacier Trip Equipment above

Personal Equipment
See spring glacier Trip Equipment above

<u>Spring Flight Plan, Glacier Monitoring</u>

DATE____

HELICOPTER TYPE: Hughes 500D

HELICOPTER CALL NUMBER:

PILOT:

HELICOPTER CREWMEMBERS:

<u>Marblemount Helibase</u>

Day 1

7:30 a.m. = Ship, 2 crewmembers, and equipment depart Marblemount.

8:00 a.m. = Arrive Noisy Glacier. Ship drops off 2 crewmembers at the top of the glacier (~5900 ft). Ship lands on lower glacier (~5600 ft) and shuts engine down, waits for 2 crewmembers to descend and rendezvous with ship. Alternatively ship drops off crew and returns later to pick them up.

1:00 p.m. = Ship and crew depart Noisy Glacier for North Klawatti Glacier.

1:30 p.m. = Arrive North Klawatti Glacier. Ship drops off 2 crewmembers at the top of the glacier (~7750 feet). Ship lands at midway point on the glacier (~6890 feet, above large icefall), shuts down and waits for 2 crewmembers to descend glacier. After rendezvous ship and crew fly to lower glacier (~6100 feet). Ship shuts down while crew works.

6:00 p.m. = Ship and crew depart North Klawatti Glacier for Marblemount.

6:30 p.m. = Arrive Marblemount.

Day 2

7:30 a.m. = Ship, 2 crewmembers, and equipment depart Marblemount.

8:00 a.m. = Arrive Sandalee Glacier. Ship drops off 2 crewmembers at the top of the glacier (~7350 ft). Ship lands on lower glacier (~6490 ft) and shuts engine down, waits for 2 crewmembers to descend and rendezvous with ship. Alternatively ship drops off crew and returns later to pick them up. Alternatively ship drops off crew and returns later to pick them up.

1:00 p.m. = Ship and crew depart Sandalee Glacier for Silver Glacier.

1:30 p.m. = Arrive Silver Glacier. Ship drops off 2 crewmembers at the top of the glacier (~8400 feet). Ship lands on the lower glacier (~6850 ft) shuts down and waits for 2 crewmembers to descend glacier. Alternatively ship drops off crew and returns later to pick them up.
6:00 p.m. = Ship and crew depart North Klawatti Glacier for Marblemount.
6:30 p.m. = Arrive Marblemount.

Fall Flight Plan, Glacier Monitoring

DATE:
HELICOPTER TYPE: Hughes 500D
HELICOPTER CALL NUMBER:
PILOT:
HELICOPTER CREWMEMBERS:

Marblemount Helibase
7:30 a.m. = Ship and crew depart Marblemount for Silver Glacier.

8 a.m. = Ship and 3 crewmembers to Silver Glacier. Ship drops off two crewmembers on upper glacier (~8400 feet). Ship lands on lower glacier (shuts engine down) and waits for crewmembers to descend the glacier while the third crewmember works on the lower glacier (~6850 feet).

10:30 a.m. = Ship and crew depart Silver Glacier for Sandalee Glacier.

11:00 a.m. = Arrive Sandalee Glacier. Ship drops off 2 crewmembers at the top of the glacier (~7350 feet). Ship lands (shuts engine down) on lower glacier (~6490 feet) and waits for 2 crewmembers to descend glacier while third crewmember works on lower glacier.

12:30 p.m. = Ship and crew depart Sandalee Glacier for North Klawatti Glacier.

12:45 p.m. = Arrive North Klawatti Glacier. Ship drops off 2 crewmembers at the top of the glacier (~7750 feet). Ship lands on lower glacier (~6100 feet) and waits for third crewmember to work (shuts engine down). When third crewmember is done ship and crewmember takes off. Ship lands at midway point on the glacier (~6890 feet, above large icefall) and waits for 2 crewmembers to descend glacier (depending on their progress may or may not shut engine down).

3:45 p.m. = Ship and crew depart North Klawatti Glacier.

4:00 p.m. = Ship arrives Marblemount and lands for refueling

4:30 p.m. = Ship and crew depart Marblemount to Noisy glacier.

4:45 p.m. = Arrive Noisy Glacier. Ship drops off 2 crewmembers at the top of the glacier (~5900 feet). Ship lands on lower glacier (~5600 feet) and waits (shuts engine down) for third crewmember to work and for 2 crewmembers to descend and rendezvous with ship.

6:15 p.m. = Ship and crew depart Noisy Glacier.

6:30 p.m. = Arrive Marblemount Helibase.

Literature Cited:

Becky, F. 2000. Cascade Alpine Guide, vol.3. The Mountaineers, Seattle, WA.

Long Term Monitoring of Small Glaciers at North Cascades National Park :
A Prototype Park Model for the North Coast and Cascades Network

SOP #2: Snow Depth Probing

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview and Explanation

Measuring winter balance is a measurable of objective in support of goal 1 of this protocol. One of two key tasks for measuring winter balance is using a metal probe to measure snow depth across the glacier. Probing snow depth is fairly straight forward but there are important procedures to follow to insure safety, probe integrity, 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 spring visits.

Procedures

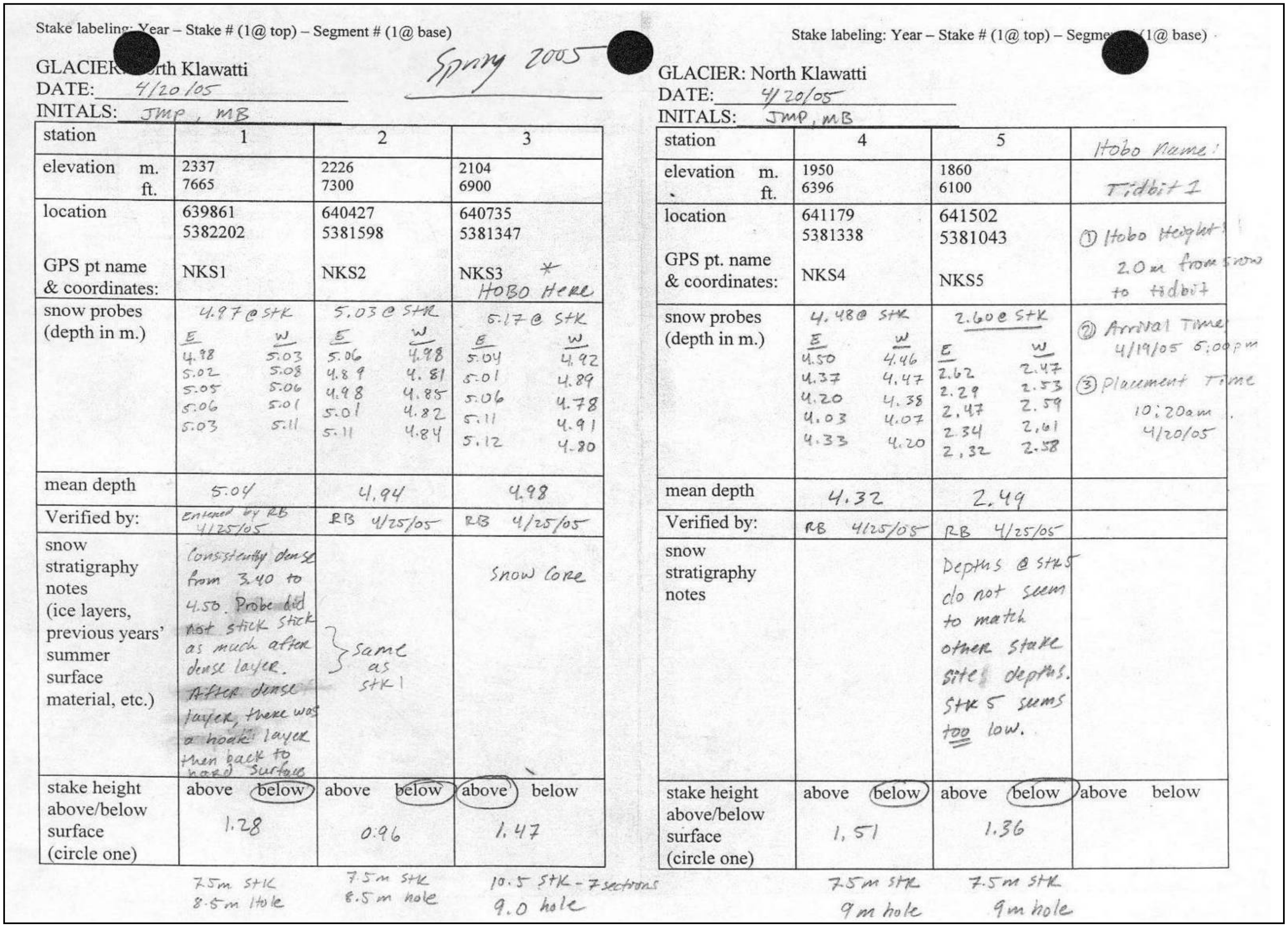
1. Probe packaging, transport, and coupling/decoupling – Always use the plastic carrying tubes for transport into the field. If these are not available then it is permissible to carry the probe segments in a bundle fastened with thick rubber bands. Do not use duct tape as the tape adhesive gums up the probe. Probes should be carefully screwed together completely until the sections ends are flush. Wax or grease 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 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, 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 snow pack because of the formation of ice layers that are created during winter freeze thaw cycles and/or precipitation events. 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**).

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.
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), and Black Diamond, lightweight insulated, nylon, 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 vertically 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 (Figure 1.1-1.3). 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 on the upper elevations of Silver, Sandalee, and North Klawatti Glaciers in the spring.
    i. First apply a small amount of lubricant (ie. 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, keep the probe moving. 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 most often frees it. 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.

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 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. Occasionally snow conditions and time constraints permit fewer probe measurements to be taken in the spring. In these cases we rely on probing during the summer visit and depth loss from the stake measurement to fill in this data. Additional locations on the glaciers are probed if time permits. Look at past years data to see where these additional probes were located.
4. Recording the data: Data are recorded on a standardized data sheet. See Figure 1.1-1.3 below for 2005 spring, summer, and fall completed datasheets. Individual probe measurements, including ice layers and location relative to the stake are recorded on these sheets along with other observations and notes.
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 to for repair or replacement.
   e. Keep an inventory/log of bent and broken probe sections


Stake labeling: Year – Stake # (1@ top) – Segment # (1@ base)

GLACIER: North Klawatti   Spring 2005
DATE: 4/20/05
INITALS: JMP, MB

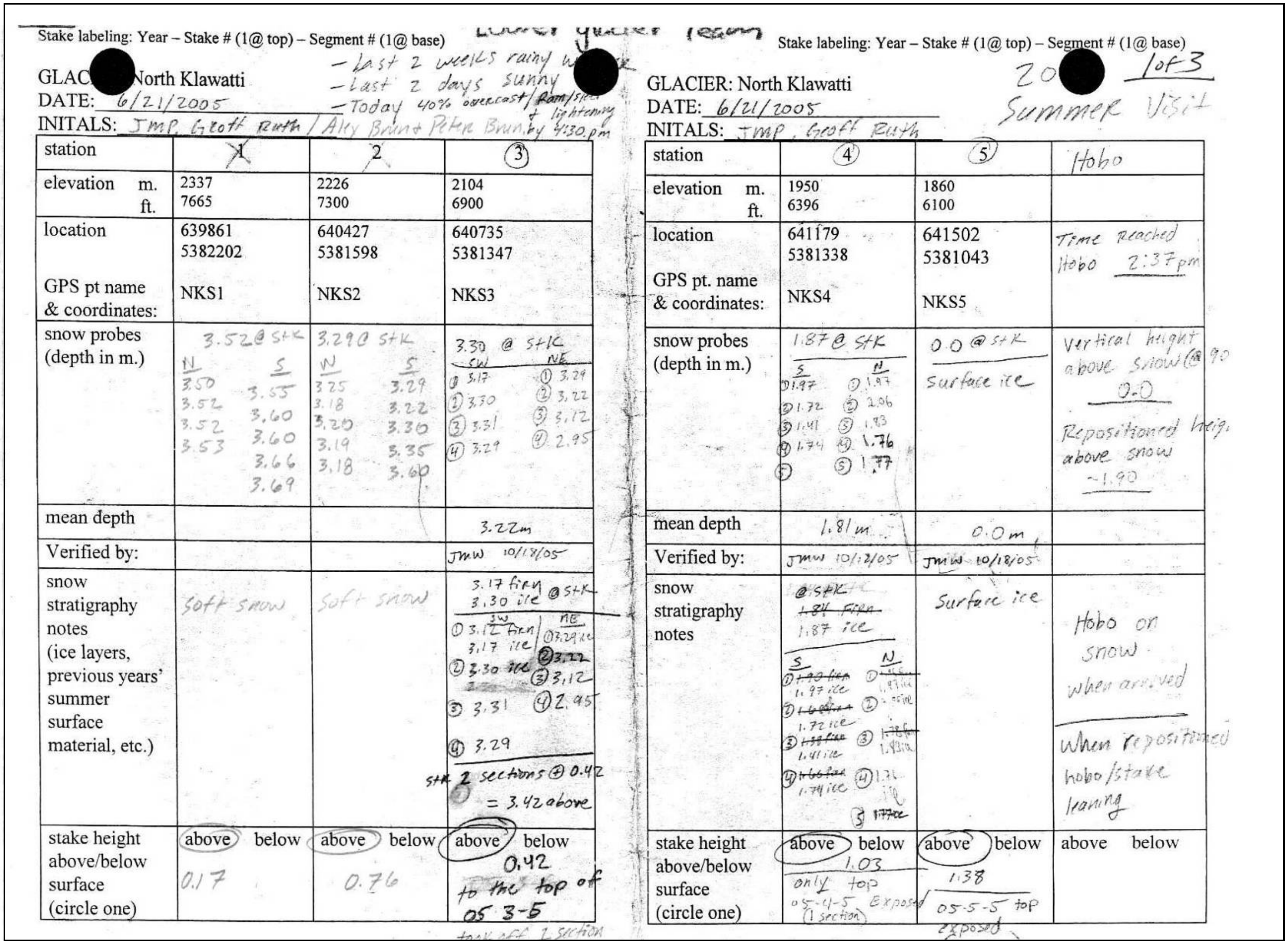
station	1	2	3
elevation m. / ft.	2337 / 7665	2226 / 7300	2104 / 6900
location	639861 5382202	640427 5381598	640735 5381347
GPS pt name & coordinates:	NKS1	NKS2	NKS3 * HOBO Here
snow probes (depth in m.)	4.97 @ Stk; E: 4.98, 5.02, 5.05, 5.06, 5.03; W: 5.03, 5.08, 5.06, 5.01, 5.11	5.03 @ Stk; E: 5.06, 4.89, 4.98, 5.01, 5.11; W: 4.98, 4.81, 4.85, 4.82, 4.84	5.17 @ Stk; E: 5.04, 5.01, 5.06, 5.11, 5.12; W: 4.92, 4.89, 4.78, 4.91, 4.80
mean depth	5.04	4.94	4.98
Verified by:	entered by RB 4/25/05	RB 4/25/05	RB 4/25/05
snow stratigraphy notes (ice layers, previous years' summer surface material, etc.)	Consistently dense from 3.40 to 4.50. Probe did not stick stick as much after dense layer. After dense layer, there was a hoar layer then back to hard surface	Same as stk 1	Snow Core
stake height above/below surface (circle one)	above (below) 1.28	above (below) 0.96	(above) below 1.47
	7.5m Stk 8.5m Hole	7.5m Stk 8.5m hole	10.5 Stk – 7 sections 9.0 hole

Stake labeling: Year – Stake # (1@ top) – Segment # (1@ base)

GLACIER: North Klawatti
DATE: 4/20/05
INITALS: JMP, MB

station	4	5	Hobo Name:
elevation m. / ft.	1950 / 6396	1860 / 6100	Tidbit 1
location	641179 5381338	641502 5381043	① Hobo Height: 2.0 m from snow to tidbit
GPS pt. name & coordinates:	NKS4	NKS5	
snow probes (depth in m.)	4.48 @ Stk; E: 4.50, 4.37, 4.20, 4.03, 4.33; W: 4.46, 4.47, 4.38, 4.07, 4.20	2.60 @ Stk; E: 2.62, 2.29, 2.47, 2.34, 2.32; W: 2.47, 2.53, 2.59, 2.61, 2.58	② Arrival Time 4/19/05 5:00 pm; ③ Placement Time 10:20 am 4/20/05
mean depth	4.32	2.49	
Verified by:	RB 4/25/05	RB 4/25/05	
snow stratigraphy notes		Depths @ stk 5 do not seem to match other stake sites depths. Stk 5 seems too low.	
stake height above/below surface (circle one)	above (below) 1.51	above (below) 1.36	above below
	7.5m stk 9m hole	7.5m stk 9m hole	

Figure 1.1. Sample field data sheets for North Klawatti Glacier, spring 2005.



Stake labeling: Year – Stake # (1@ top) – Segment # (1@ base)

Lower glacier region

– last 2 weeks rainy w[illegible]
– Last 2 days sunny
– Today 40% overcast / Rain/sleet + lightening

GLAC[illegible]orth Klawatti
DATE: 6/21/2005
INITALS: JMP, Geoff Ruth / Alky Brunt Peter Brun.by 4:30 pm

station	~~1~~	2	③
elevation m. / ft.	2337 / 7665	2226 / 7300	2104 / 6900
location / GPS pt name & coordinates:	639861 5382202 NKS1	640427 5381598 NKS2	640735 5381347 NKS3
snow probes (depth in m.)	3.52 @ stk; N: 3.50, 3.52, 3.52, 3.53; S: 3.55, 3.60, 3.60, 3.66, 3.69	3.29 @ stk; W: 3.25, 3.18, 3.20, 3.19, 3.18; S: 3.29, 3.22, 3.30, 3.35, 3.60	3.30 @ stk; SW: ① 3.17, ② 3.30, ③ 3.31, ④ 3.29; NE: ① 3.29, ② 3.22, ③ 3.12, ④ 2.95
mean depth			3.22m
Verified by:			JMW 10/18/05
snow stratigraphy notes (ice layers, previous years' summer surface material, etc.)	soft snow	soft snow	3.17 firn, 3.30 ice @ stk; SW: ① 3.12 firn, 3.17 ice; ② 3.30 ice; ③ 3.31; ④ 3.29; NE: ① 3.29 ice, ② 3.22, ③ 3.12, ④ 2.95; stk 2 sections ⊕ 0.42 = 3.42 above
stake height above/below surface (circle one)	(above) below 0.17	(above) below 0.76	(above) below 0.42 to the top of 05 3-5 took off 1 section

Lower glacier region

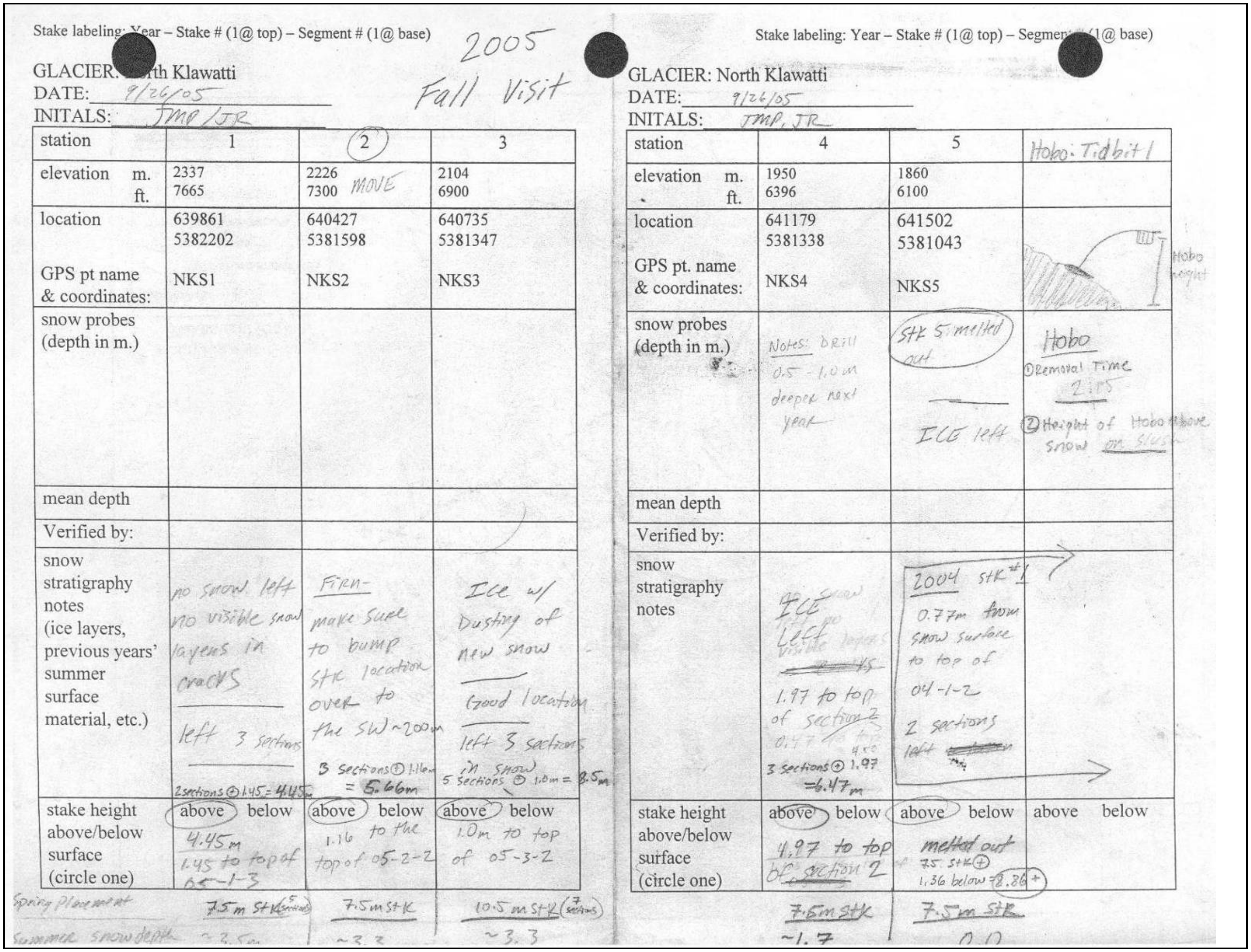
Stake labeling: Year – Stake # (1@ top) – Segment # (1@ base)

20[illegible] 1 of 3
Summer Visit

GLACIER: North Klawatti
DATE: 6/21/2005
INITALS: JMP, Geoff Ruth

station	④	⑤	Hobo
elevation m. / ft.	1950 / 6396	1860 / 6100	
location / GPS pt. name & coordinates:	641179 5381338 NKS4	641502 5381043 NKS5	Time Reached Hobo 2:37 pm
snow probes (depth in m.)	1.87 @ stk; S: ① 1.97, ② 1.72, ③ 1.41, ④ 1.74, ⑤; N: ① 1.97, ② 2.06, ③ 1.83, ④ 1.76, ⑤ 1.77	0.0 @ stk; surface ice	Vertical height above snow (@ 90°) 0.0; Repositioned heig. above snow ~1.90
mean depth	1.81 m	0.0 m	
Verified by:	JMW 10/12/05	JMW 10/18/05	
snow stratigraphy notes	@ stk: ~~1.84 firn~~ 1.87 ice; S: ① 1.97 ice, ② 1.72 ice, ③ 1.41 ice, ④ 1.74 ice; N: ① 1.97 ice, ② [illegible], ③ 1.83 ice, ④ 1.76, ⑤ 1.77 ice	Surface ice	Hobo on snow when arrived; When repositioned hobo/stake leaning
stake height above/below surface (circle one)	(above) below 1.03 only top 05-4-5 Exposed (1 section)	(above) below 1.38 05-5-5 top exposed	above below

Figure 1.2. Sample field data sheets for North Klawatti Glacier, summer 2005.



Stake labeling: Year – Stake # (1@ top) – Segment # (1@ base)

2005 Fall Visit

GLACIER: North Klawatti
DATE: 9/26/05
INITALS: JMP/JR

station	1	2	3
elevation m. / ft.	2337 / 7665	2226 / 7300 MOVE	2104 / 6900
location / GPS pt name & coordinates:	639861 5382202 / NKS1	640427 5381598 / NKS2	640735 5381347 / NKS3
snow probes (depth in m.)			
mean depth			
Verified by:			
snow stratigraphy notes (ice layers, previous years' summer surface material, etc.)	no snow left / no visible snow layers in cracks / left 3 sections / 2 sections ⊕ 1.45 = 4.45m	Firn- make sure to bump stk location over to the SW ~200m / 3 sections ⊕ 1.16m = 5.66m	Ice w/ Dusting of new snow / Good location / left 3 sections in snow / 5 sections ⊕ 1.0m = 8.5m
stake height above/below surface (circle one)	above below: 4.45m 1.45 to top of 05-1-3	above below: 1.16 to the top of 05-2-2	above below: 1.0m to top of 05-3-2
Spring Placement	7.5m stk (5 sections)	7.5m stk	10.5m stk (7 sections)
Summer snow depth	~2.5m	~2.2	~3.3

Stake labeling: Year – Stake # (1@ top) – Segment # (1@ base)

GLACIER: North Klawatti
DATE: 9/26/05
INITALS: JMP, JR

station	4	5	Hobo: Tidbit 1
elevation m. / ft.	1950 / 6396	1860 / 6100	
location / GPS pt. name & coordinates:	641179 5381338 / NKS4	641502 5381043 / NKS5	Hobo height
snow probes (depth in m.)	Notes: Drill 0.5 - 1.0m deeper next year	Stk 5 melted out / ICE left	Hobo ① Removal Time 2:15 ② Height of Hobo above snow on slush
mean depth			
Verified by:			
snow stratigraphy notes	ICE left no visible layers / 1.97 to top of section 2 / 3 sections ⊕ 1.97 = 6.47m	2004 stk #1 0.77m from snow surface to top of 04-1-2 / 2 sections left	
stake height above/below surface (circle one)	above below: 4.97 to top of section 2	above below: melted out 7.5 stk ⊕ 1.36 below = 8.86	above below
	7.5m stk / ~1.7	7.5m stk / 0.0	

Figure 1.3. Sample field data sheets for North Klawatti Glacier, fall 2005.

Long Term Monitoring of Small Glaciers at North Cascades National Park :
A Prototype Park Model for the North Coast and Cascades Network

SOP #3: Snow Density Determination with Snow Core

Version 8/19/2005

Revision History Log

Revision Date	Author	Changes Made	Reason for Change
8/19/05	R. Burrows	error calculated based on measurement error estimates and propagation equations	More realistic error estimates

Overview and Explanation

A second key component of winter balance and meeting goal 1 of this protocol is measurement of snow density. Snow density (ρ_{snow}) on each glacier is measured at the ablation stake location which is closest to the mid-point altitude of the glacier. If time permits, density is measured at the top and bottom stakes on the 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.

Snow density measurement precision and accuracy is primarily due to field measurement error of snow depth and weight. Error estimates for snow depth ($\pm$ 0.03 m) and core push weight ($\pm$ 0.05 kg) are used in error propagation equations (see below) for an estimate of snow density at each snow core location. Total measurement error estimates at the time of this writing range from $\pm$ 0.05 g/ml to $\pm$ 0.15 g/ml, which is 10% to 30% error.

When density is not directly measured, the spring snow density and error is assumed to be 0.50g/ml $\pm$ 0.08g/ml. This quantity is based on average snow density from several years at SCG and NOCA with a range in values from 0.41 g/ml to 0.55 g/ml (altitude and balance year dependent) and a standard deviation of 0.03 g/ml at measurement location P1 on SCG where density has been consistently measured mostly from snow pits (**Appendix C: Snow densities from South Cascade and North Cascades glaciers**). The error estimate of $\pm$ 0.08 g/ml is derived from the average of ten snow core field measurements. Snow density does vary with altitude in the spring, but 0.50 g/ml is a reasonable estimate for the whole glacier.

Procedures

The detailed procedure provided by the manufacturer for proper use of the snow core is below.(Figure 1) 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. See Figure 2 for a standardized data sheet with 2005 North Klawatti Glacier data.

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. This surface may be observed as a distinct dirty layer. If the dirty layer cannot be detected, then snow densities will be measured to find a significant change in density between snow and firn. There is sufficient space on the field data sheet for these notes as well.

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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 1. Instructions for snow corer.

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:

<u>To take core:</u>

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.

<u>Before retrieving</u> 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.)

<u>Remove the top end</u>, 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. Nudge it with the pusher If you 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. <u>Don't bang the tube</u>. 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 <u>warm</u> 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 <u>shortest</u> 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.

<u>As you retrieve the tube, keep scraping to a minimum</u>. 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 1. Instructions for snow corer (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.

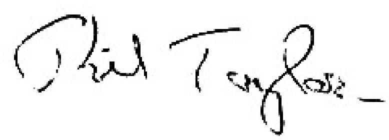
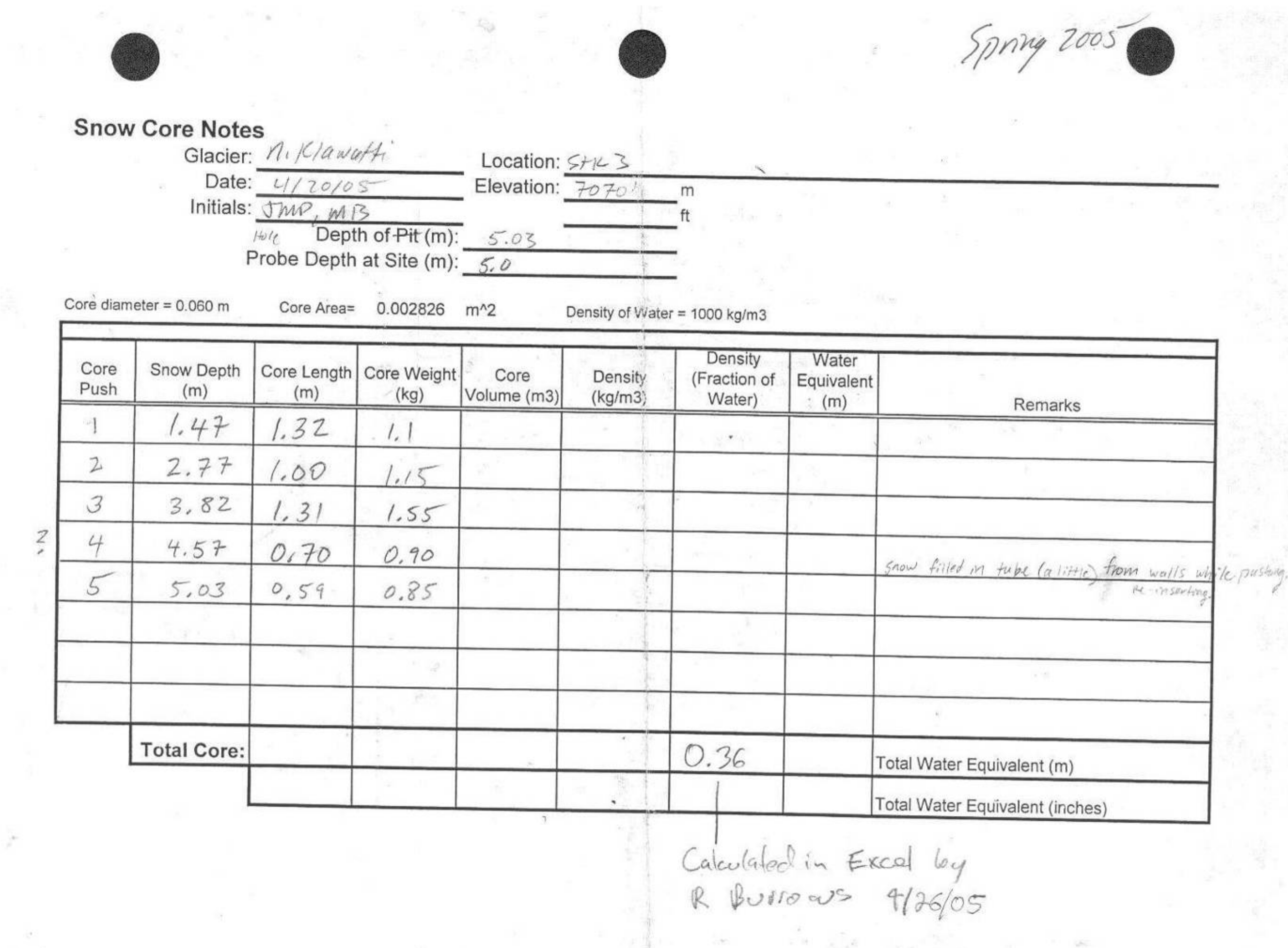


Figure 1. Instructions for snow corer (continued).



Spring 2005

Snow Core Notes

Glacier: N. Klawatti — Location: STK 3
Date: 4/20/05 — Elevation: 7070' m / ft
Initials: JMP, MB
Hole Depth of Pit (m): 5.03
Probe Depth at Site (m): 5.0

Core diameter = 0.060 m — Core Area= 0.002826 m^2 — Density of Water = 1000 kg/m3

Core Push	Snow Depth (m)	Core Length (m)	Core Weight (kg)	Core Volume (m3)	Density (kg/m3)	Density (Fraction of Water)	Water Equivalent (m)	Remarks
1	1.47	1.32	1.1					
2	2.77	1.00	1.15					
3	3.82	1.31	1.55					
4	4.57	0.70	0.90					snow filled in tube (a little) from walls while pushing. Re-inserting.
5	5.03	0.59	0.85					
	Total Core:					0.36		Total Water Equivalent (m)
								Total Water Equivalent (inches)

Calculated in Excel by R Burrows 4/26/05

Figure 2. Example snow core data sheet form North Klawatti glacier, 2005.

Long Term Monitoring of Small Glaciers at North Cascades National Park :
A Prototype Park Model for the North Coast and Cascades Network

SOP #4: Operation of the Steam Drills and Drilling

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview and Explanation

Summer balance at the index glaciers is a measurable objective for goal 1, and is measured between late April and late September annually. Melt is measured against vertical ablation stakes drilled 7-12m into each glacier. We use two models of steam drill for drilling holes in which to place the ablation stakes. Stake locations, lengths and depths for each glacier are summarized in Table 1.1-1.4 in **SOP #1 Field season preparations and task list**. Approximate stake locations are also indicated on Figures 4 -7 in the Narrative. 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 operation manual and mandatory safety measures for the Heucke drill are included below on pages 84-91. Read these to become familiar with both the operating procedures and safety concerns. 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 directly dumped 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.
   Do not let pressure exceed 30 psi!, 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 DO NOT 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.

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!**

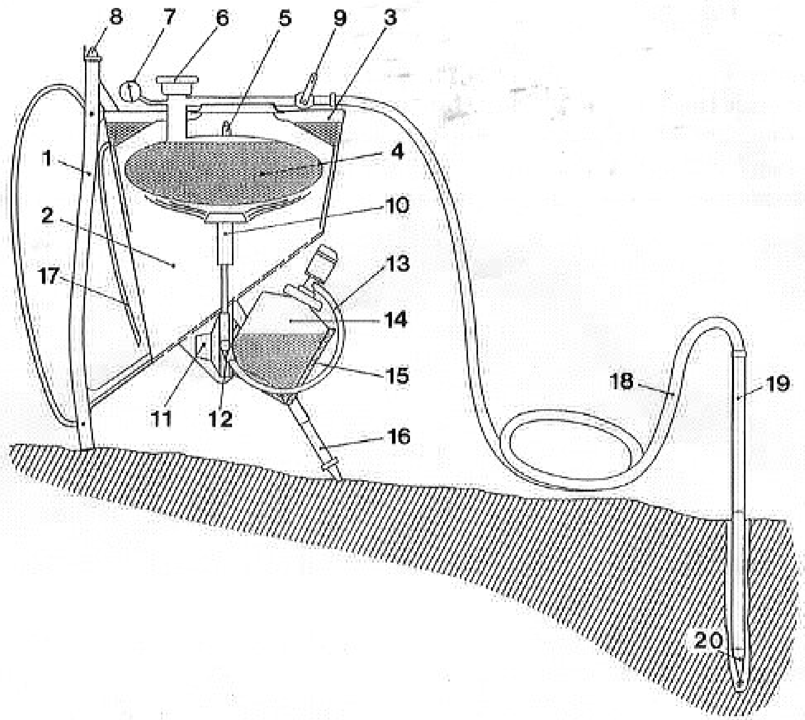
11. **<u>Important</u>:** Never allow the water level in the boiler to drop to zero. Accidental heating of an empty boiler will cause its destruction within a very short time. If pressure quickly falls to zero this is a sure sign of lack of water. Shut off the gas immediately ! Refer to no. 9 of the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

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

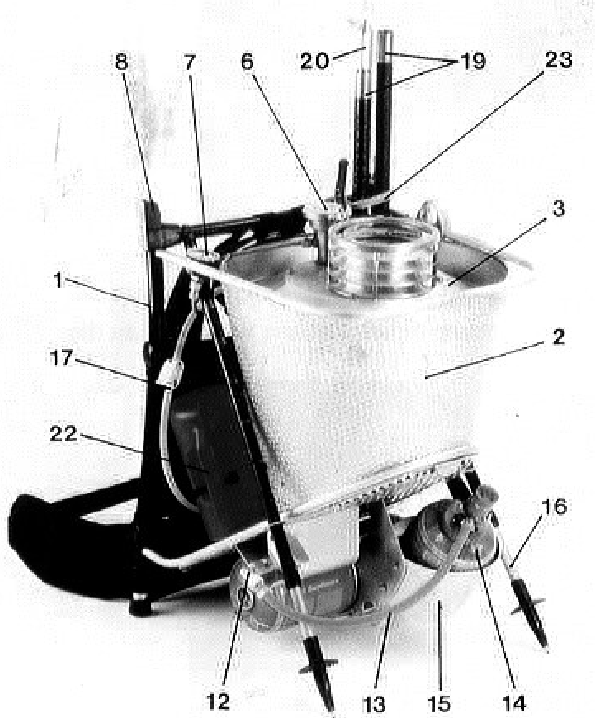
Please keep in mind:
A portable ice drill light enough to be carried
on your back cannot possibly made of cast iron.
It is necessarily somewhat fragile and must be handled with care.

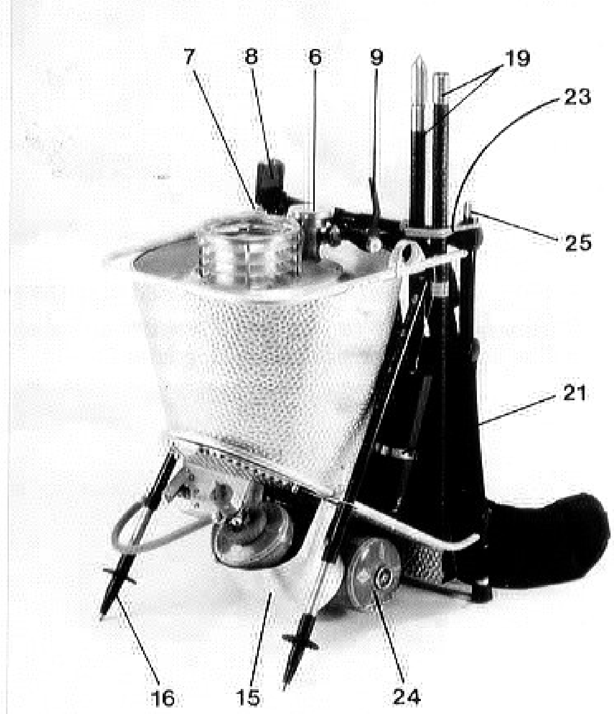
HEUCKE ICE DRILL

OPERATING INSTRUCTIONS



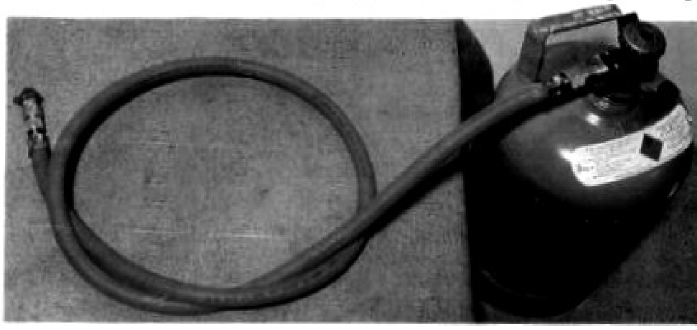
(1) Frame
(2) Aluminum Casing
(3) Circular Bowl
(4) Boiler
(5) Safety Valve
(6) Filler Cap
(7) Manometer
(8) Piezo Igniter
(9) Steam Valve
(10) Gas Burner
(11) Gas Pressure Regulator
(12) Connector Socket for the Gas Hose
(13) Gas Hose
(14) Gas Cartridge
(15) Cartridge Container
(16) Length adjustable Legs
(17) Drainage Hose
(18) Bore Hose
(19) Drilling Pipe
(20) Drill Tip
(21) Service Tube
(22) Scoop
(23) Fastener of the Drilling Pipe
(24) Storage of Cartridges
(25) Holder for another Drill Tip



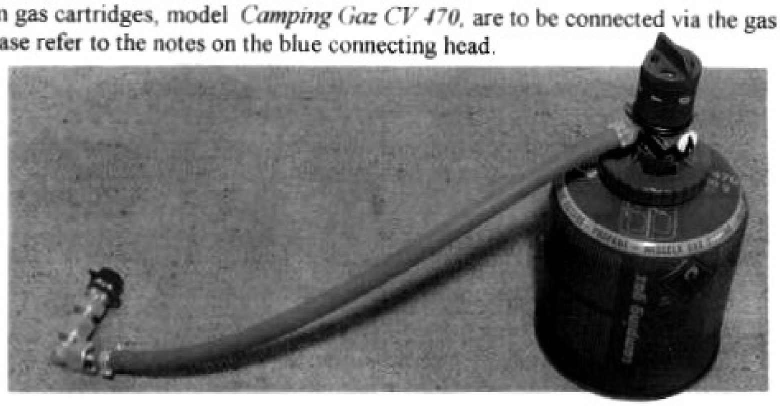


1. Putting up the Drill.
The drilling device must be set up in such a way that the circular bowl (3) is horizontal. You can pull out the two forelegs (16) for adjusting the device to the terrain. For loosening a leg please turn the lower end to the left and for fixing it in the correct position turn 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.

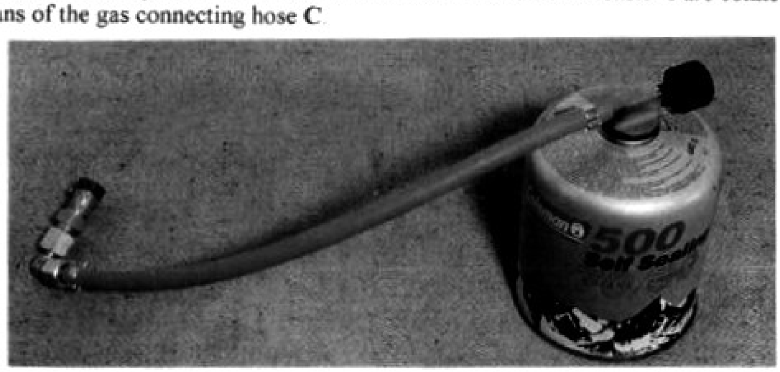
2. Connecting Gas Containers.
a) Propane cylinders of any size (including refillable minimum content bottles with 425 g) as well as butane cylinders containing 2 or 3 kg of gas *(Camping Gaz bottles 904 and 907)* are to be connected by means of the gas connecting hose **A**, if necessary with the appropriate 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**.



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.)**

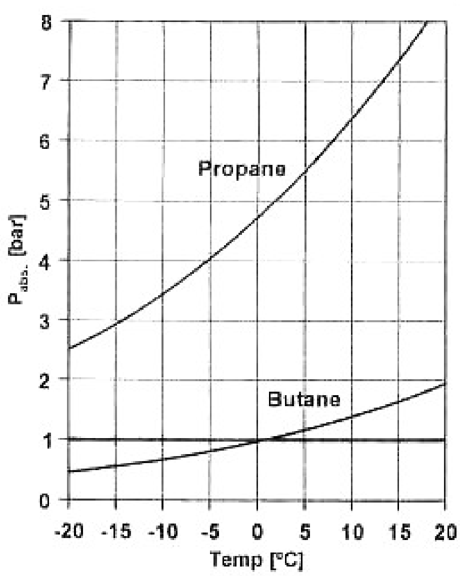
5. Connecting the Bore Hose.
The bore hose (18) can be connected during the water heats up. The upper end of the hose shall be screwed by hand tightly on the steam valve, thereby taking account of the depth marker. Please do not use any tool! The two-part drilling pipe (19) shall be screwed at the other 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 between 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.

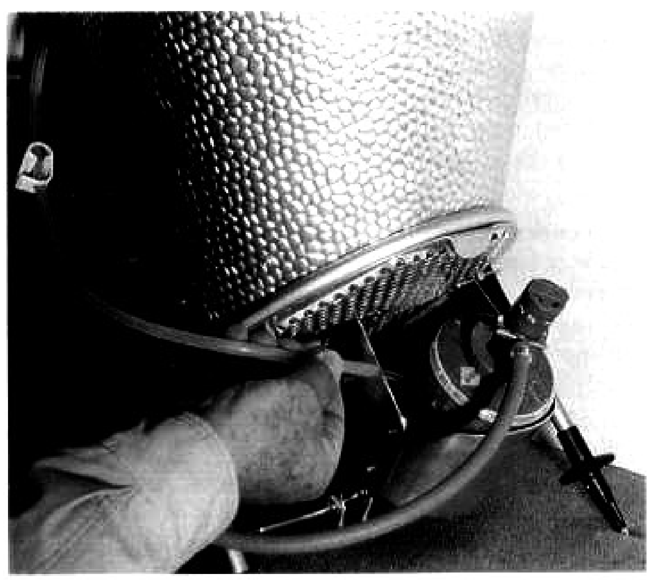
6. Starting the Drilling Process.
Once steam is discharged from the drill tip, please **close** the red steam valve (vertical position) and observe the manometer (7) until the pressure has increased to about 1 bar. Then the steam valve can be re-opened and the drilling be started. **Attention: turn the 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.

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!

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

Long Term Monitoring of Small Glaciers at North Cascades National Park :
A Prototype Park Model for the North Coast and Cascades Network

SOP #5: Vertical Aerial Photography Specifications

Version 8/18/2005

Revision History Log

Revision Date	Author	Changes Made	Reason for Change
8/18/05	R. Burrows	Change from contact prints to diapositives	Better image quality and for photogrammetry
8/18/05	R. Burrows	Add "Report of Calibration of aerial mapping camera"	Needed for photo-grammetric analysis

Explanation and Overview

Vertical aerial photographs are taken annually of each index glacier as a record of annual 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 diapositives 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 from the air photos, 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).

NOCA Glaciers Aerial Photography Specifications

Glaciers

*Scale ~ 1:12,000, for a 6-inch focal length lens use appropriate altitudes above mid altititude of each glacier. Flight Altitude for each glacier:

Noisy Creek:	12,000 feet asl
North Klawatti:	13,000 feet asl
Sliver Creek:	13,500 feet asl
Sandalee	13,000 feet asl

*See Table 1 and Figures 1-5 for target areas. The target areas should have good stereo coverage.

* Use flight lines most appropriate for photogrammetric construction of a DEM with 30-meter grid spacing.

Other specifications

*Center of photos will be georeferenced using Universal Trans Mercator (UTM) grid system, Zone 10, NAD27 and NAD83, presumably by airborne GPS.

*NPS receives a single set of color diapositives.

*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%.

<u>Contract deliverables:</u>

1.) Diapositives of air photo images (this is a change from previous years-better for photogrammetry

2) GPS coordinates of air photo centers. Horizontal Datum: Universal Trans Mercator (UTM) grid system Zone 10, NAD83

3) Report of Calibration of aerial mapping camera. This should include:

    a. calibrated focal length (CFL)
    b. lens distortion
    c. lens resolving power in cycles/mm
    d. filter parallelism
    e. shutter calibration
    f. magazine platen
    g. principal points and fiducial coordinates
    h. distances between fiducial marks
    i. stereomodel flatness
    j. lens/film resolving power in cycles/mm

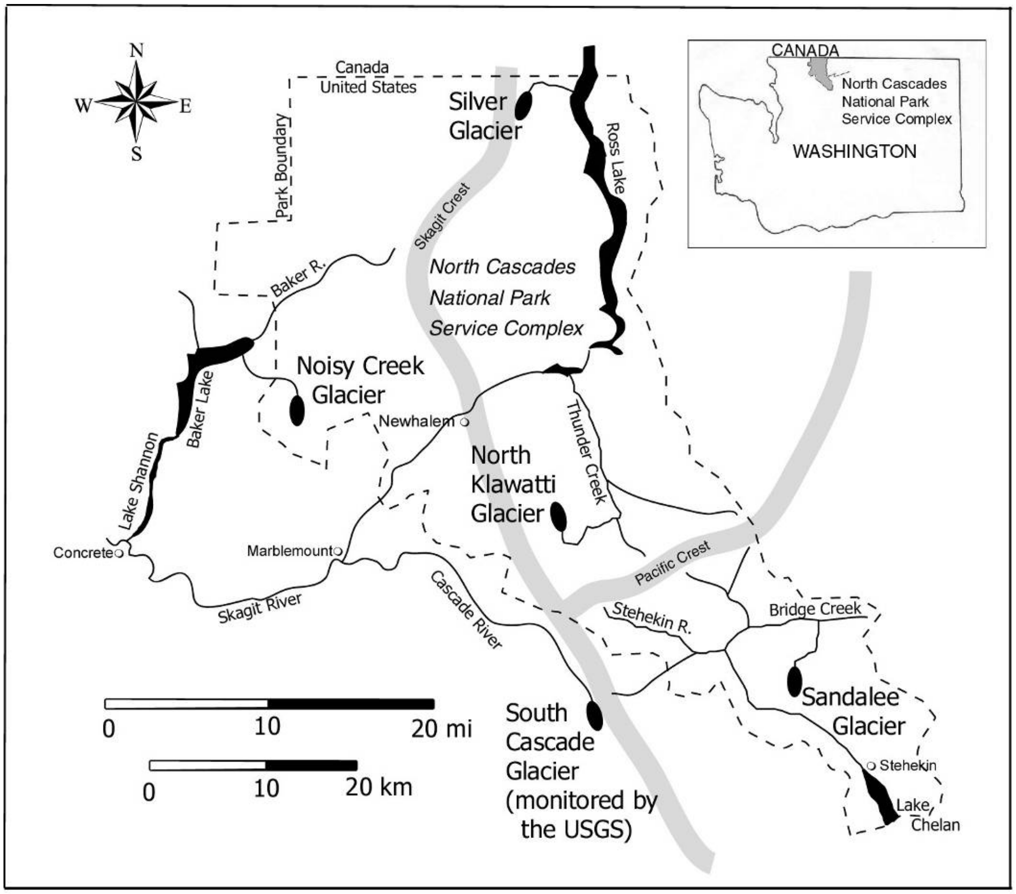

Figure 1. Locations of NOCA glaciers n the North Cascade National Park Service Complex.

Table 1. Aircraft GPS photo center coordinates for NOCA glaciers. 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

Photo Label	Photo Center ID	Northing (m)	Easting (m)	Aircraft meters	Altitude feet
Sandalee 1-1	7001	5363545.95	663628.71	3991.04	13,091
Sandalee 1-2	7002	5364455.45	663578.90	3991.95	13,094
N Klawatti 1-1	8001	5380838.46	641750.43	4044.71	13,267
N Klawatti 1-2	8002	5381429.35	640848.57	4036.65	13,240
N Klawatti 1-3	8003	5381912.72	640091.64	4036.43	13,240
N Klawatti 1-4	8004	5382341.20	639418.97	4034.48	13,233
Silver 1-1	9001	5425217.28	628684.56	4240.04	13,907
Silver 1-2	9002	5426071.15	628667.72	4238.46	13,902
Silver 1-3	9003	5426984.11	628656.83	4228.40	13,869
Noisy 1-1	10001	5392714.87	608661.05	3744.60	12,282
Noisy 1-2	10002	5391721.72	608676.99	3745.47	12,285
Noisy 1-3	10003	5390839.98	608694.41	3740.56	12,269

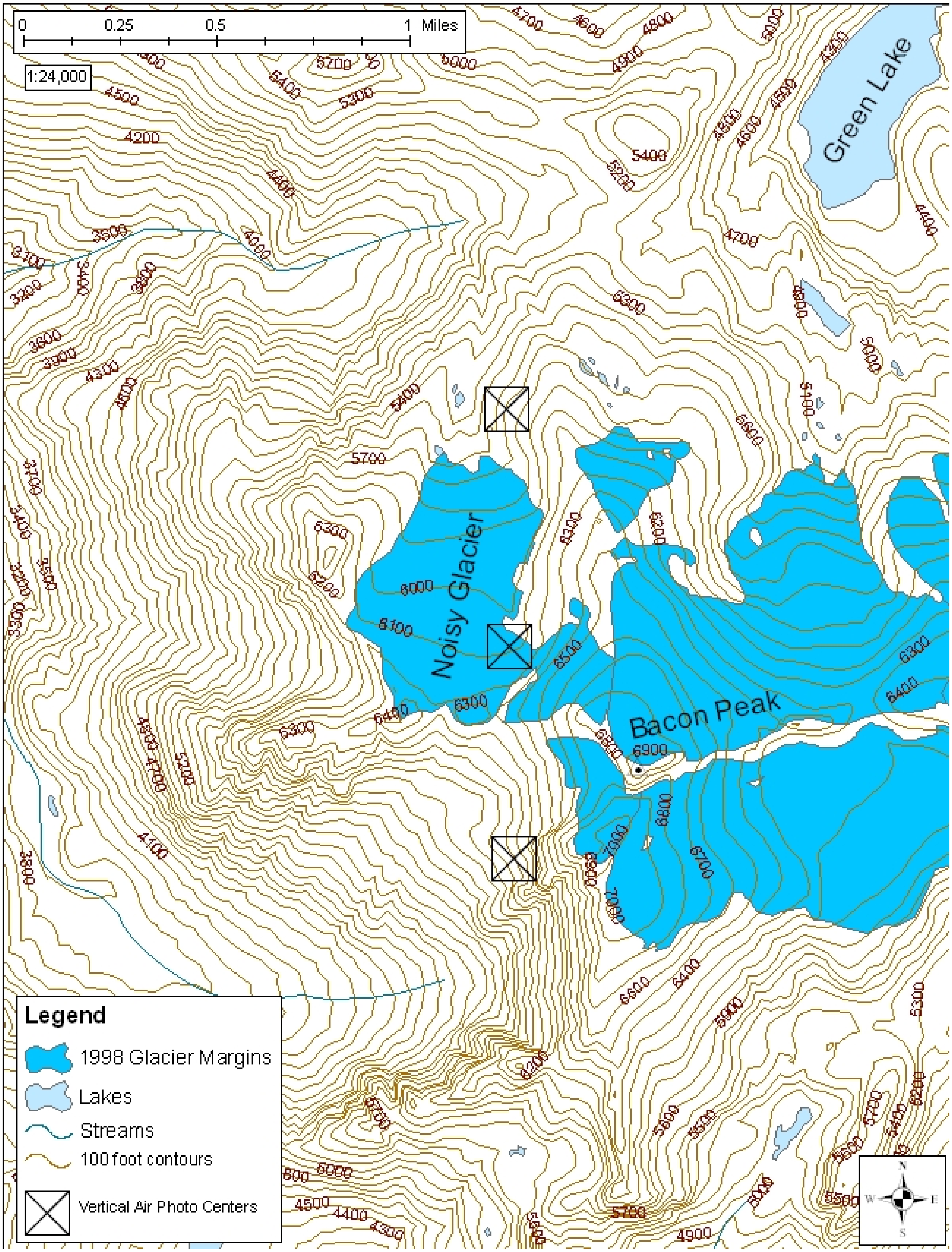

Figure 2. Location of air photo centers and flight lines from 2004 flights for Noisy Glacier.

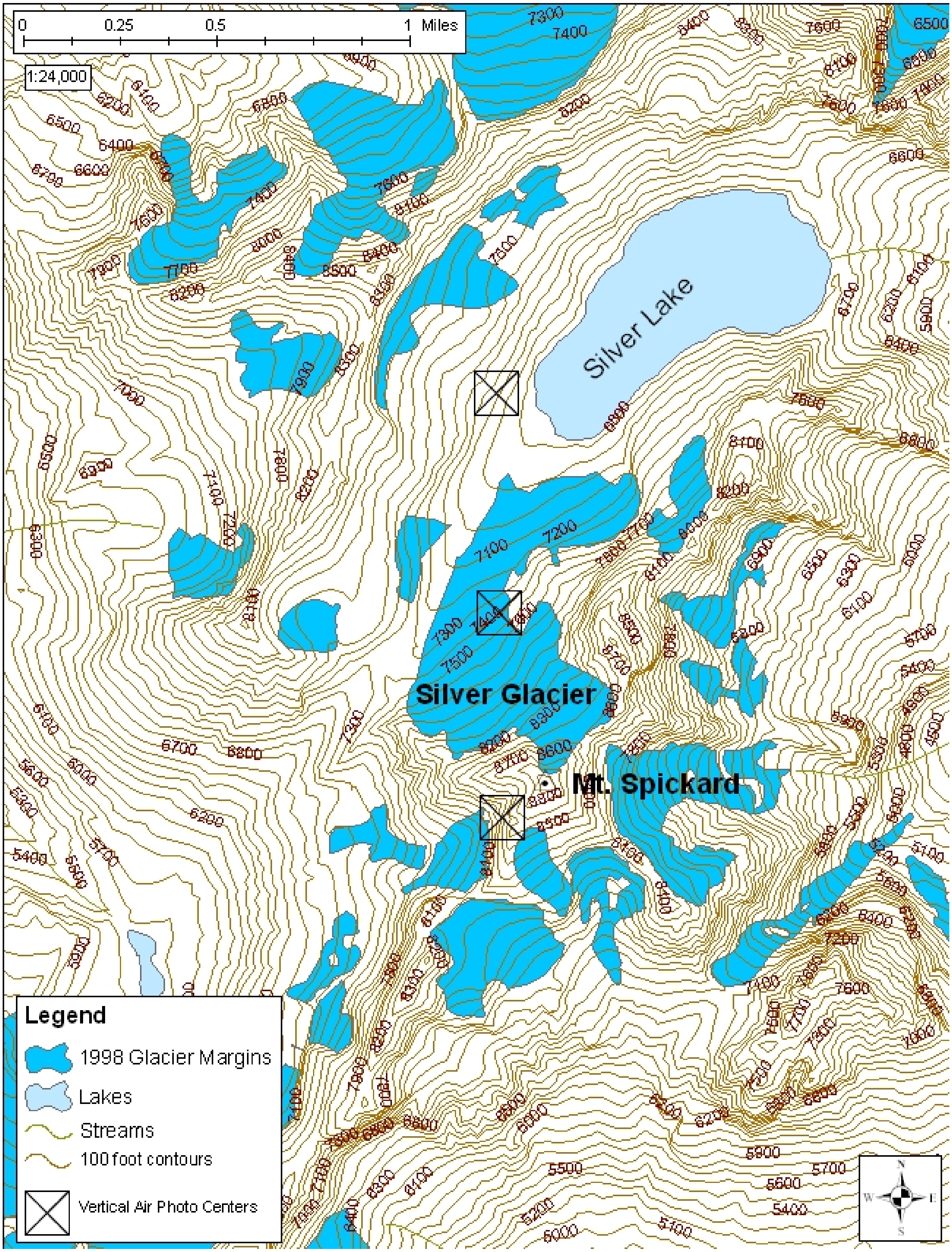

Figure 3. Location of air photo centers and flight lines from 2004 flights for Silver Glacier.

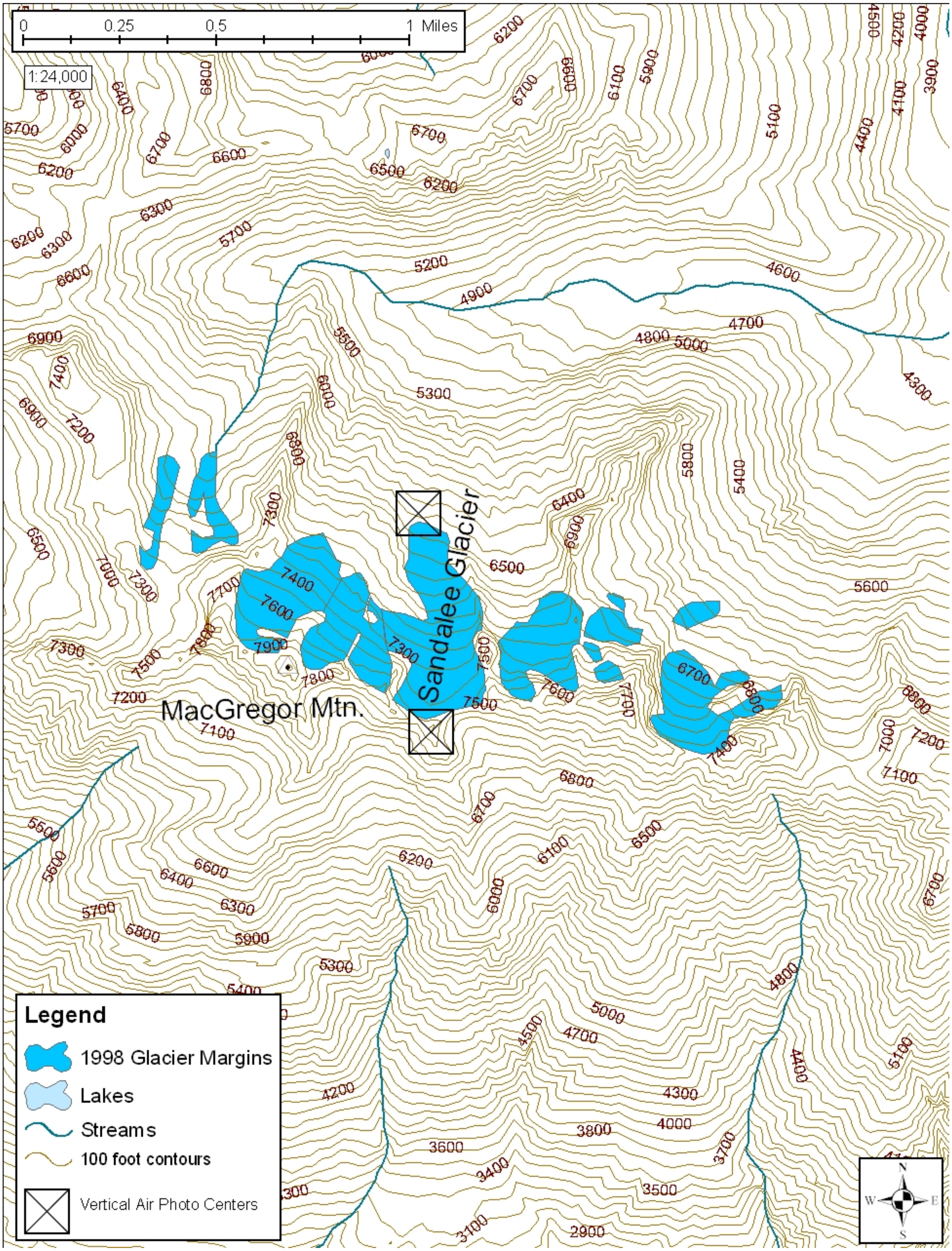

Figure 4. Location of air photo centers and flight lines from 2004 flights for Sandalee Glacier.

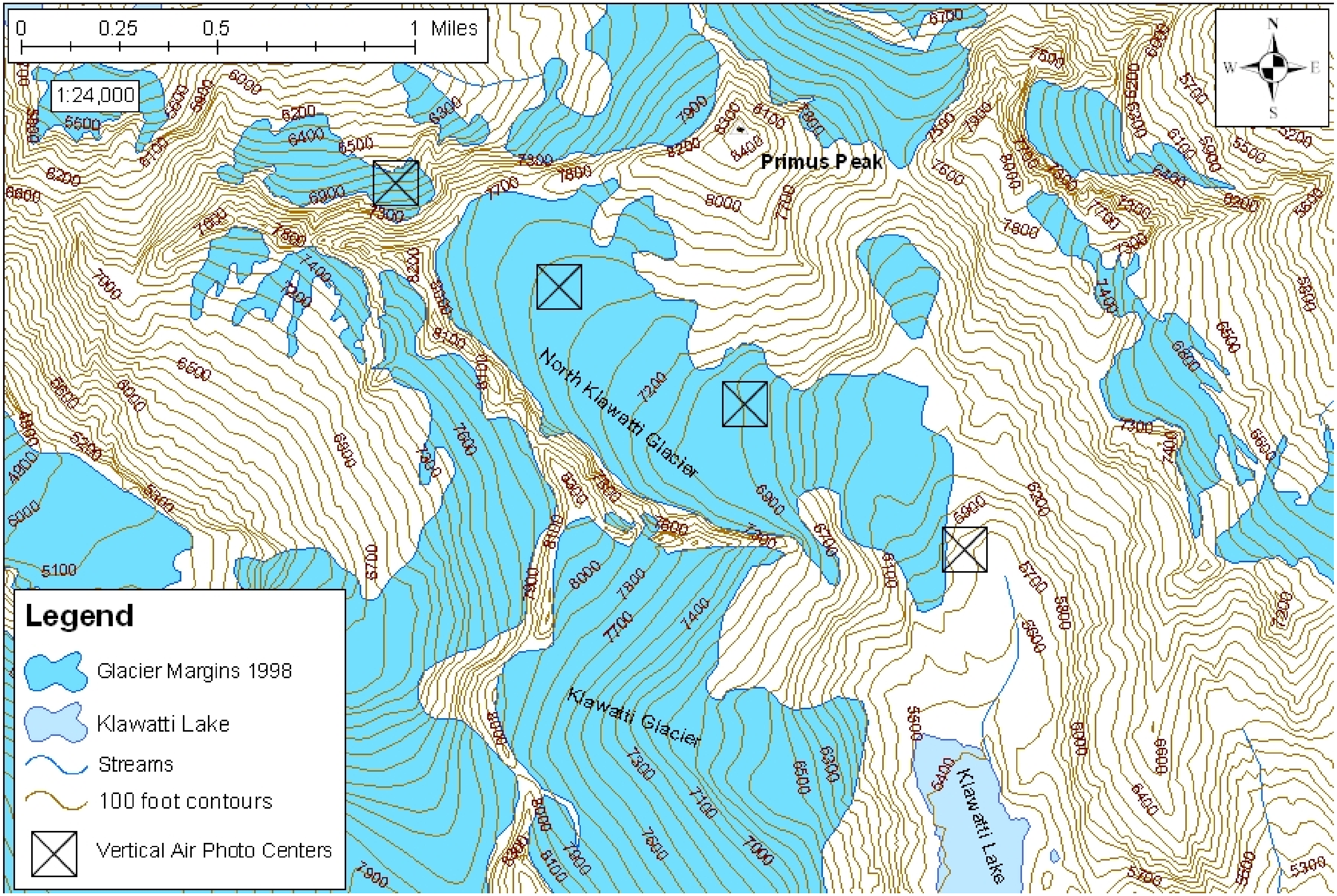

Figure 5. Location of air photo centers and flight lines from 2004 flights for North Klawatti Glacier.

Long Term Monitoring of Small Glaciers at North Cascades National Park :
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SOP #6: Glacier Mapping and Volume Change Determination Specifications

Version 11/2006

Revision History Log

Revision Date	Author	Changes Made	Reason for Change
11/2006	J. Riedel & J. Wenger	Update glacier mapping process	Photogrammetry inaccurate

Overview and Explanation

Current glacier contour maps and digital elevation models (DEMs) have important functions in this monitoring program. 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. DEMs provide a record of glacier surface elevations. Each time these DEMs and glacier maps are generated, the detailed methods should be documented for repeatability and long term institutional memory.

Using vertical aerial photography and high precision GPS point data, 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. In addition, remapping can compare 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; Andreassen, 1999).

To ensure mapping precision, it is important to revisit defined bedrock locations with the GPS unit. In 2005 and 2006, ¼ inch steel screws with labeled two inch diameter washers were installed at several locations around each of the index glaciers for ground control benchmark (see Table 1.1-1.4). All points are maintained in Universal Trans Mercator (UTM) grid system, Zone 10, NAD83.

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 (see **SOP #5: Vertical Aerial Photography Specifications**).

Aerial photographs are scanned and brought into ortho-rectifying software OrthoMapper to determine the glacier boundary. It is imperative that bedrock areas outside of the glacier boundaries also be mapped to provide comparison of ortho rectified photos of different vintages.

New DEMs of the glacier surface are created every ten years using high precision GPS field surveys. In order to attain an accurate DEM of the glacier surface a sufficient quantity and distribution of points must be collected. This is most easily accomplished by surveying a series of transects, profiles, and cluster of points where it is possible to travel by foot on the glacier. A useful rule of thumb is to collect more points where there is more complexity in the glacier surface.

In order to take advantage of minimal snow conditions that make for more useable images for defining boundaries, 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. Ideally, each glacier is also visited in the fall when there is the least amount of snow cover and the most bedrock exposed.

Procedures

The original transect and profile points were collected using a “post-processed kinematic” (PPK) survey. These points are accurately revisited later using a “real-time kinematic” (RTK) survey. This requires a base station, a rover unit and a radio connection between the two. Mapping each glacier and determining volume change has both a field and an office component.

Field Component:

Before entering the field, preprogram coordinates of each point into the high precision GPS unit (a Trimble 5700 is currently being used, see Trimble operation procedures below) for ease of finding point location (see Table 1.1-1.4). Coordinate locations include ground control benchmarks, and minimum of one profile and one transect. You should also familiarize yourself with operating the GPS. Once in the field, set up the GPS base station, retain satellite coverage, and take the roving GPS unit on the glacier. A photo and/or map with an overlay of the point locations will aid in choosing a route to visit each point (e.g. Figures 4-7 in NOCA Protocol Narrative).

Office Component:

In the office GPS data is downloaded into spreadsheets, glacier images are scanned, and then both are brought into GIS software, ArcMap, for remapping and comparing surface height changes.

1) Scan glacier images
2) In ArcMap, Ortho-rectify glacier images
3) In Arc Map, define glacier boundary, surface cover types (firn, snow, debris cover and ice), crevasse zones, and ELA.
4) Download the GPS data into Excel
5) Import X, Y, and Z point data into ArcGis software and create a georeferenced DEM.
6) Compare the new DEM with the old to determine surface elevation changes. Comparisons can be on a point by point basis (predefined control point locations and transects), by elevation band, and/or entire glacier change.
7) Generate contours from elevation points. The DEM and glacier margins will be carried along in the steps above.

8) Use volume change comparison method of Krimmel (1999; 1996) which compares surface change at each grid point.

Table 1.1. Noisy Glacier benchmarks.

September 26-27, 2005			
NAD 83 Zone 10N			
Benchmark	Northing	Easting	Elevation
1	5391608.54	608164.686	1919
2	5391642.69	608719.743	1970
3	5392095.72	608573.591	1788
4	5392598.05	608459.999	1695
5	5392718.36	608345.404	1668

Table 1.2. Silver Glacier benchmarks.

July 14,2005			
NAD 83 Zone 10N			
Benchmark	Northing	Easting	Elevation
1	5426315.16	628022.09	2312
2	5426978.35	628860.684	2046
3	5426902.4	628503.641	2099
4	5425670.03	628309.892	2469
5	5425695.79	628898.468	2579
6	5426067.72	628840.32	2455
7	5426355.22	628752.916	2285
7a	5426357.01	628751.75	2287

Table 1.3. North Klawatti Glacier benchmarks.

August 1, 2006			
NAD 83 Zone 10N			
Benchmark	Northing	Easting	Elevation
2	5382530.032	639740.182	2370
3	5382585.996	640076.665	2387
4	5382216.566	640313.495	2309
5	5381975.012	640457.093	2227

Table 1.4. Sandalee Glacier benchmarks.

July 26-27 2006			
NAD 83 Zone 10N			
Benchmark	Northing	Easting	Elevation
1	5364253.769	663268.416	2228
2	5363854.574	663656.093	2289
3	5364014.299	662951.187	2480
4	5364378.533	663692.542	2088
5	5364561.974	663582.899	1985
6	5364786.112	663376.419	1931

Literature Cited

Andreassen, L.M. 1999. Comparing traditional mass balance measurements with long-term volume change extracted from topographical maps: a case study of Storbreen glacier in Jotunheimen, Norway, in the period 1940 - 1997. Geografiska Annaler, V.81 A, p 467-476.

Etzelmuller, B. and J.L. Sollid. 1997. Glaciar geomorphometry – an approach for analyzing long-term glaciar changes using gris-based digital elevation models. Annals of Glaciology, V.24, pp. 135-141.

Jacobsen, F.M. and W.H. Theakstone. 1997. Monitoring glacier changes using a global positioning system in differential mode. Annals of Glaciology, .V.24, pp. 314-319.

Krimmel, R.M. 1996. Water, Ice and Meteorological Measurements at South Cascade Glacier, Washington, 1995 Balance Year. USGS WRI-96-4139.

Krimmel, R.M. 1999. Water, Ice and Meteorological Measurements at South Cascade Glacier, Washington, 1998 Balance Year. USGS WRI-99-4139.

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SOP #7: Mass Balance Calculations

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview and Explanation

Mass balance is a key measurable objective of goal 1. This SOP describes how mass balance is calculated from field data. We currently use Microsoft Excel workbook templates for mass 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 made 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 find out how worksheets and cells are linked in calculations. A relational Access database will replace current Excel procedures in 2007. 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 data reduction methods outlined here are unique to this program, however, they follow the general principles from Ostrem and Brugman (1991) and Krimmel (1994, 1995, 1996a, 1996b, 1997, 1998, 1999, 2000). Summaries of their methods are described in the protocol narrative as a basis for the description of our methods. In this protocol the mass balance calculation procedures are laid out according to work done after the seasonal field trips. Figures 1-6 and Table 1 are copies of the Excel worksheets for North Klawatti Glacier, for balance year 2005. The data reduced in these worksheets corresponds to the field data sheets which are included in **SOP #2: Snow Depth Probing**.

Depending on the glacier, patterns of accumulation, and quality of the data, winter balance (B_W) is calculated in one of three ways: best-fit functions, best-fit hybrid, and stake-area method. Our data reduction best-fit functions and best-fit hybrid methods use 10-meter elevation bands for each glacier.

1) If the relationship between elevation and b_w has a correlation coefficient $\geq$ 0.70 and not one stake exceeds 0.5m w.e. away from line, then the values generated from this relation are used to calculate the winter mass balance (B_W) by summing the specific winter balance (b_w) for 10-meter elevation bands. Best-fit functions used for $b_w(z)$ can be linear,

exponential, or logarithmic. In the past, linear functions have fit the best. Regardless of type of line used, only one line is used to fit the data and is not broken into two or three parts.

2) If winter balance regression has a R^2 of $\geq$0.7 and one stake exceeds 0.5m w.e. away from line, method 2 is used (best-fit hybrid). This method uses the best fit function for all 10-meter elevation bands except for the one outlying stake, which is represented by using the stake-area method.
3) If the winter balance data does not follow a linear, exponential, or logarithmic relation with elevation (R^2 is $\leq$0.7 and more than one stake exceeds 0.5m w.e. away from line) then the stake-area method is used for the entire glacier. This method lets each stake represent a predetermined area of the glacier. The local winter balance for each stake is multiplied by the area it represents and the mass balances for each area are summed to find B_W.

If the hybrid method is used on Noisy Glacier, the outlying stakes are almost always stake one or stake two. Because Noisy Glacier is unique in that there are two stakes placed near the same altitude on different sides of the glacier, the hybrid method must calculate stake-area for both stakes one and two. The best-fit calculated b_w is then used for each 10-meter elevation band below these two stakes. Stake three on Silver Glacier is a wind deposition area creating usually higher than glacier average snow fall. Stake three is usually the outlying stake and is represented by the stake-area method in the hybrid method. The same is true for stake four on Sandalee Glacier, though higher b_w is a result of snow avalanching instead of wind deposition.

4) Summer balance (b_s) is primarily controlled by elevation, and a b(z) function is determined and applied with 10-meter elevation bands to determine the summer mass balance (B_S) of the glacier. In the past, linear functions have fit the best. If there is not a good fit for $b_s(z)$ then best-fit hybrid or stake-area can be used, see above for method criteria.

Net mass balance (B_N) is the sum of winter and summer balance across the entire glacier. A combination of methods can be used to find B_N (i.e. stake-area can be used for B_W and best-fit for B_S). The methods used are documented in the summary report (Figure 6).

Procedures

Data management activities are listed below by seasons. Each set of procedures are carried out for each glacier.

Post spring visit:

1) Enter the date, stake elevation, and the height of each stake below the surface into the "Data and Stake-Area Balance" worksheet (Figure 1).
2) Enter the probed snow depths for each location into the "Stake and Probe Comparison" worksheet (Figure 2).
3) Consider all the snow probes near each stake and disregard any individual probes that are not within 1.0m of the mean of all probes near the stake.
4) 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 to add mid season melt.
5) The mean depth from the probes at each stake is the provisional b_w at each stake.

6) Determine the snow density at each site at which it is measured in the “Snow Density” worksheet (See **SOP# 3: Snow Density Determination with Snow Core** for worksheet).
7) Find the best-fit for the $b_w(z)$ function using regression, ie. excel or Origin 7 (Origin 7 curve fitting procedure detailed below) for all stake data for each glacier. Display the results in the “Balance Charts” worksheet (Figure 4). If regression has a R^2 of ≥0.7 and not one stake exceeds 0.5m w.e. away from line, then use this equation along with the elevation band data to find the summation of B_W for the glacier in the “Band Balance” worksheet (Figure 5).
8) If regression has a R^2 of ≥0.7 and only one stake exceeds 0.5m w.e. away from the regression line use method 2, “best-fit hybrid”. Multiply outlying stake predetermined area by stake b_w (see “Stake-Area Delineations” (Figure 7)) Enter the calculated stake-area b_w into one cell of the confining 10m elevation bands in the “Band Balance” worksheet that the stake represents. Use the best-fit calculated b_w for each 10-meter elevation band determined in step 4 for the remaining unfilled 10-meter bands. Sum the “band b_w”, in the “Band Balance” worksheet to find B_W for the whole glacier.
9) If regression has a R^2 of ≤0.7 and more than one stake exceeds 0.5m w.e. away from line than use method 3, “stake-area”. Multiply predetermined area that each stake represents by stake specific b_w and sum together for the glacier Bw.
10) Enter method and, if applicable, regression equation used in finding B_W into the “Summary Report” worksheet” and include any other valuable information pertaining to B_W calculations. Also include the glacier average B_W by dividing B_W by glacier area.
11) Write the “Glacier Page” and send to Scott Pattee at the NRCS by the end of May and distribute throughout the park. See **Appendix G: Example Reporting Documents** for an example.

<u>Post summer visit:</u>

1) Enter the probed snow depths for each location into the “Stake and Probe Comparison” worksheet (Figure 2). Enter the date, stake elevation, and the height of each stake above the surface into the “Data and Stake-Area Balance” worksheet (Figure 1).
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 and ablation stake heights are consistent with the spring probe depth. Use the “Stake and Probe Comparison” worksheet (Figure 2) to analyze each stake location data. 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, >0.5m different, then the calculated spring depth (adding the mid-season stake melt to each of the summer probe depths) should be used for spring specific bw 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.

   When calculated spring depths are used instead of initial spring probes, it should be noted in the current year’s “Summary Report” worksheet and in the “Changes Log” spreadsheet.

4) If additional probing was done during this field visit, enter the additional probe values into the "Mid-Season Probes" worksheet (Figure 3) and work the following operations:
    a. Summer probing is based on the assumption that ablation has a consistent mathematical relationship with elevation on the glacier during the period between the spring visit and the summer visit.
    b. Generate an elevation vs. ablation (measurement taken from stake melt) relation for the spring to summer visit interval and use this to add on the lost snow onto the summer probe depths based on their elevation (for points other than stakes).
    c. Plot the reconstructed b_w from the summer probes and find the best-fit for the reconstructed b_w using regression for each glacier, see above steps #4 in post spring visit. Check against spring b_w probe measurements.
5) 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 6).

<u>Post fall visit:</u>

1) Enter the probed snow depths (if any) for each location into the "Stake and Probe Comparison" worksheet (Figure 2). Enter the date and the total height of each stake above the surface into the "Data and Stake-Area Balance" worksheet (Figure1). If a stake is not recoverable, see below for reconstruction directions.
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 (Figure 2). 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).
    a. 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) Generate an elevation vs. b_s (summer balance) curve. Using all summer stake data plot a regression line. Use step# 4-6 in "Post Spring Visit" above to figure out b_S. If there is an unrecovered stake, see below for reconstruction melt.
5) Compare percent difference between band balance and stake-area methods.
6) Enter method and, if applicable, equation used in finding B_S into the "Summary Report" worksheet (Figure 6). Include any other valuable information pertaining to B_S calculations. Also include the average $B_{s.}$
7) In the "Summary Report" worksheet (Figure 6), calculate average b_n and B_N.
8) Other calculations:
    a. Equilibrium Line Altitude (ELA): this altitude occurs where the net balance is zero and is determined graphically from a plot of bn vs. altitude. If a plot is not possible (i.e. stake-area method was used) then aerial photographs and a topographical map can be used. On the photo, determine snow, firn, and ice coverage. Look at past photos to see trends in remaining snow cover. Decide where the most continuous snow line of current year is located. Overlay a contour map and find the elevation of where it meets the bottom of the snow line. In any case, a plot and photo/map should be used together if possible to compare elevations and provide a data quality control measure.

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.

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

<u>Managing Unrecovered stakes</u>
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 melt 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. It is also possible during the spring visit when locating the stake position by GPS, the GPS can have an error of ~10m. This error can position the stake closer to a cravasse field occuring in higher probality of hitting a cravasse 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. 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 plane 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 inserted into the hole. With gravity lean and a low profile of remaining hole, the stake can “pop” out.
4) Stake removed. Stakes are purposely placed in areas where public visitatation is minimal but it is possible that a stake can be removed by a climber.
5) Stake buried by new, earlier than anticipated snow. As in the case of the fall of 2007, approximately 1m of new snow buried several high elevation stakes before final summer melt could be measured.

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 are 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. On the North Klawatti Glacier keep in mind that stake five, the lowest, is south facing where as the upper glacier is east facing. Stake five may have a much higher melt rate later in the year.
2) Best fit curve. Plot available b_s stake data with altitude and find a best-fit function with a R^2 of ≥ 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:	North Klawatti		Area (m2):	1,461,726		
	Balance Year:	2005					
	Station:	1	2	3	4	5	
	Elevation (ft):	7649	7268	6891	6416	6124	
	Elevation (m):	2332	2216	2101	1956	1867	
	Firn 2or 3 years old (m w.e.)	1.46	0.00	0.00	0.00	0.00	
	Firn from previous year (snow depth, meters)	0	0	0	0	0	
	Specific Winter Balance (4/20/05)						
	Snow Depth (m)	5.04	4.94	4.98	4.32	2.49	
	Density (g/ml)	0.35	0.35	0.36	0.36	0.37	2005 Density = -0.00004z + 0.44
bw	Winter Balance (m w.e.)	1.75	1.74	1.77	1.56	0.91	
	bw error	0.05	0.06	0.07	0.07	0.05	
	Mid Season Measurements (6/21/05)						
	Mid-season Stake Ht. (m)	0.17	0.76	3.42	1.03	1.38	
	Original Stake Height (m) (4/20/05)	-1.28	-0.96	1.47	-1.51	-1.36	
	Mid-season Melt (m)	1.45	1.72	1.95	2.54	2.74	
	Mid Season Melt Std Error	0.08	0.08	0.08	0.08	0.08	
	End Season Measurements (9/26/05)						
	End Stake Height (m)	4.45	5.66	8.50	6.47	melt out	
	Original Stake Height (m) (4/20/05)	-1.28	-0.96	1.47	-1.51	-1.36	
	Final Melt (m)	5.73	6.62	7.03	7.98	8.86	Final melt determined by adding stke length (7.5m) and depth of placement below surface (1.36m).
	End Snow Melt (m)	5.04	4.94	4.98	4.32	2.49	
	Water Eq. Melt	1.75	1.74	1.77	1.56	0.91	
	End 2-year Firn Melt (m)	0.69	0.00	0.00		0.00	
	Water Eq. Melt (m x 0.7 g/ml)	0.49	0.00	0.00		0.00	
	End Ice Melt (m)		1.68	2.05	3.66	6.37	Ice melt determined by subtracting final melt (8.86m) from winter balance (2.74m)
	Water Eq. Melt (m x 0.9 g/ml)		1.51	1.84	3.30	5.73	
bs	**Specific Summer Balance (m w.e.)**	-2.23	-3.25	-3.62	-4.86	-6.64	
	bs error	0.08	0.06	0.48	0.25	0.21	Taken from stks 1-4 error average.
	Remaining Snow/Firn (m)	0	0	0	0	0	
	Remaining 2-year old firn (m)	0.77	0.00	0.00	0.00	0.00	
bn	**Net Balance (bw) + (bs)**	-0.49	-1.51	-1.84	-3.30	-5.73	
	bn error	0.09	0.09	0.48	0.26	0.22	Taken from stks 1-4 error average.

Stake-Area Balance Calculations

	Area (m2)	210,248	360,426	510,603	150,177	230,272	
	Fraction Glacier Area	0.14	0.25	0.35	0.10	0.16	
	Area Balance (m3 w.e.)	-102,085	-543,784	-940,809	-495,053	-1,319,458	
BN	*Net Mass Balance (m^3 w.e.)*	-3,401,189					
	Average Net Balance (m w.e.)	**-2.33**					
BW	Winter Mass Balance (m3)	367,137	626,058	905,632	234,549	209,466	2,342,843
	Average Winter Balance (m w.e.)	1.60					sum
BS	Summer Mass Balance (m3)	-469,222	-1,169,842	-1,846,441	-729,602	-1,528,924	-5,744,032
	Average Summer Balance (m w.e.)	-3.93					

11/8/2006 C:\Documents and Settings\All Users\Documents\Glaciers\North Klawatti\N. Klawatti 2005/Data and Stk-Area Balance

Figure 1. “Data and Stake-Area Balance” Worksheet.

North Klawatti Glacier 2005

Stake and Probe Comparisons

	Station:	1	2	3	4	5
	Elevation (m):	2332	2216	2101	1956	1867
4/20/2005	Spring Probe Depth	4.97	5.03	5.17	4.48	2.60
6/21/2005	Summer Probe Depth	3.52	3.29	3.30	1.87	0.00
	Fall Probe Depth	na	na	na	na	na

Summer Comparison

	1	2	3	4	5
Ablation from Probe	1.45	1.74	1.87	2.61	2.60
Ablation from Stakes	1.45	1.72	1.95	2.54	2.74
Difference Stake-Probe	0.00	0.02	-0.08	0.07	-0.14

Spring Visit Probe Depth Report

2005

Stake	Depth		Stake	Depth	
Stake 1	4.97	stk	4	4.48	stk
	4.98	E		4.5	E
	5.02			4.37	
	5.05			4.2	
	5.06			4.03	
	5.03			4.33	
	5.03	W		4.46	W
	5.08			4.47	
	5.06			4.38	
	5.01			4.07	
	5.11			4.2	
2	5.03	stk	5	2.6	stk
	5.06	E		2.62	E
	4.89			2.29	
	4.98			2.47	
	5.01			2.34	
	5.11			2.32	
	4.98	W		2.47	W
	4.81			2.53	
	4.85			2.59	
	4.82			2.61	
	4.84			2.58	
3	5.17	stk			
	5.04	E			
	5.01				
	5.06				
	5.11				
	5.12				
	4.92	W			
	4.89				
	4.78				
	4.91				
	4.80				

Summary 4/20/2005

Stake	N	ave	Min	Max	Difference	Variance	S.D.
1	11	5.04	4.97	5.11	**0.14**	0.0017	0.04
2	11	4.94	4.81	5.11	**0.30**	0.011	0.11
3	11	4.98	4.78	5.17	**0.39**	0.017	0.12
4	11	4.32	4.03	4.50	**0.47**	0.028	0.17
5	11	2.49	2.29	2.62	**0.33**	0.02	0.12
				Ave.	**0.33**		

stake values not used

Summer Visit Probe Depth Report

6/21/2005

Stake	Depth		Stake	Depth	
Stake 1	3.52	stk	4	1.87	stk
	3.55	S		1.97	N
	3.6			2.06	
	3.6			1.83	
	3.66			1.76	
	3.69			1.77	
	3.5	N		1.97	S
	3.52			1.72	
	3.52			1.41	
	3.53			1.74	
2	3.29	stk	5	0	stk
	3.29	S			N
	3.22				S
	3.3				
	3.35				
	3.60				
	3.25	N			
	3.18				
	3.2				
	3.19				
	3.18				
3	3.30	stk			
	3.29	N			
	3.22				
	3.12				
	2.95				
	3.17	S			
	3.30				
	3.31				
	3.29				

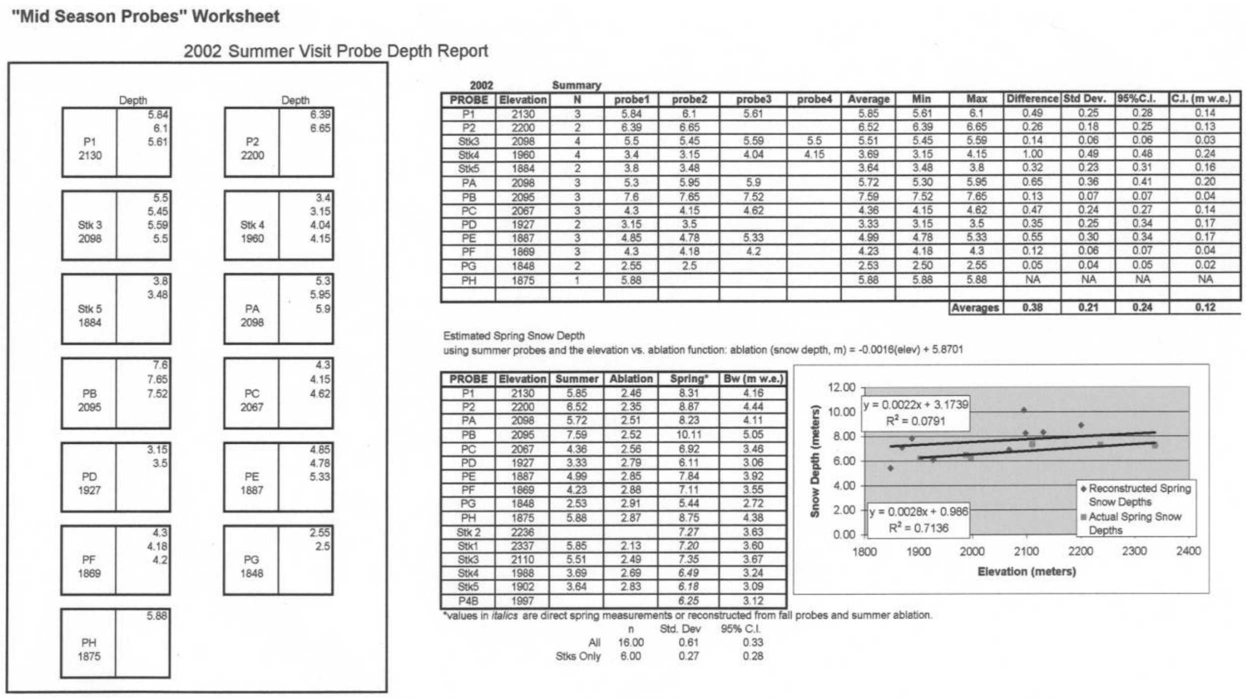
Summary 6/21/2005

Stake	N	ave	Min	Max	Difference	Variance	Std Dev
1	10	3.57	3.50	3.69	**0.19**	0.0043	0.065566
2	11	3.28	3.18	3.60	**0.42**	0.0147	0.121169
3	9	3.22	2.95	3.31	**0.36**	0.0145	0.120416
4	10	1.81	1.41	2.06	**0.65**	0.0328	0.180985
5	1	0.00	0.00	0	**0.00**	#DIV/0!	#DIV/0!
				Ave.	**0.32**		

stake values not used

Figure 2. “Stake and Probe Comparison” Worksheet.

"Mid Season Probes" Worksheet



2002 Summer Visit Probe Depth Report

2002 Summary

PROBE	Elevation	N	probe1	probe2	probe3	probe4	Average	Min	Max	Difference	Std Dev.	95%C.I.	C.I. (m w.e.)
P1	2130	3	5.84	6.1	5.61		5.85	5.61	6.1	0.49	0.25	0.28	0.14
P2	2200	2	6.39	6.65			6.52	6.39	6.65	0.26	0.18	0.25	0.13
Stk3	2098	4	5.5	5.45	5.59	5.5	5.51	5.45	5.59	0.14	0.06	0.06	0.03
Stk4	1960	4	3.4	3.15	4.04	4.15	3.69	3.15	4.15	1.00	0.49	0.48	0.24
Stk5	1884	2	3.8	3.48			3.64	3.48	3.8	0.32	0.23	0.31	0.16
PA	2098	3	5.3	5.95	5.9		5.72	5.30	5.95	0.65	0.36	0.41	0.20
PB	2095	3	7.6	7.65	7.52		7.59	7.52	7.65	0.13	0.07	0.07	0.04
PC	2067	3	4.3	4.15	4.62		4.36	4.15	4.62	0.47	0.24	0.27	0.14
PD	1927	2	3.15	3.5			3.33	3.15	3.5	0.35	0.25	0.34	0.17
PE	1887	3	4.85	4.78	5.33		4.99	4.78	5.33	0.55	0.30	0.34	0.17
PF	1869	3	4.3	4.18	4.2		4.23	4.18	4.3	0.12	0.06	0.07	0.04
PG	1848	2	2.55	2.5			2.53	2.50	2.55	0.05	0.04	0.05	0.02
PH	1875	1	5.88				5.88	5.88	5.88	NA	NA	NA	NA
									Averages	0.38	0.21	0.24	0.12

Estimated Spring Snow Depth
using summer probes and the elevation vs. ablation function: ablation (snow depth, m) = -0.0016(elev) + 5.8701

PROBE	Elevation	Summer	Ablation	Spring*	Bw (m w.e.)
P1	2130	5.85	2.46	8.31	4.16
P2	2200	6.52	2.35	8.87	4.44
PA	2098	5.72	2.51	8.23	4.11
PB	2095	7.59	2.52	10.11	5.05
PC	2067	4.36	2.56	6.92	3.46
PD	1927	3.33	2.79	6.11	3.06
PE	1887	4.99	2.85	7.84	3.92
PF	1869	4.23	2.88	7.11	3.55
PG	1848	2.53	2.91	5.44	2.72
PH	1875	5.88	2.87	8.75	4.38
Stk 2	2236			*7.27*	3.63
Stk1	2337	5.85	2.13	*7.20*	3.60
Stk3	2110	5.51	2.49	*7.35*	3.67
Stk4	1988	3.69	2.69	*6.49*	3.24
Stk5	1902	3.64	2.83	*6.18*	3.09
P4B	1997			*6.25*	3.12

*values in *italics* are direct spring measurements or reconstructed from fall probes and summer ablation.

	n	Std. Dev	95% C.I.
All	16.00	0.61	0.33
Stks Only	6.00	0.27	0.28

Figure 3. “Mid Season Probes” Worksheet.

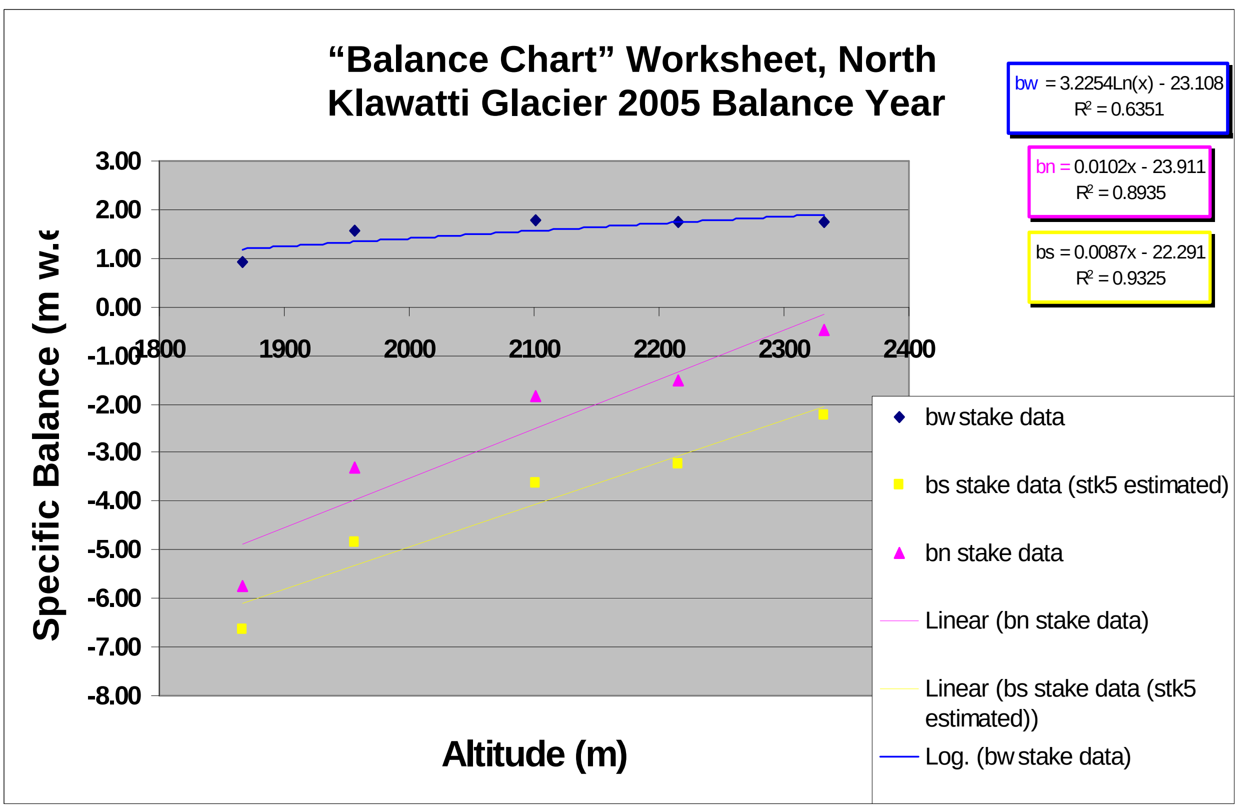


Figure 4. “Balance Chart” Worksheet, North Klawatti Glacier 2005 Balance Year.

North Klawatti Glacier (2005)

Band Balance within 10-meter altitude bands.

Stake data only Total Area = 1,461,726 square meters 70 elevation bands

Upper Limit Elevation Band (m)	Elevation Band Midpoint (m)	sq m	Band specific bw	Band BW	Band specific bs	Band BS	Band specific bn	Band BN	
1730	1728	90	0.94	84	-7.26	-654	-6.32	-569	bw = 3.2254Ln(x) - 23.108
1740	1735	686	0.95	652	-7.20	-4938	-6.25	-4287	R2 = 0.6351
1750	1745	1664	0.97	1611	-7.11	-11828	-6.14	-10218	
1760	1755	2238	0.99	2208	-7.02	-15719	-6.04	-13511	
1770	1765	2189	1.00	2199	-6.94	-15179	-5.93	-12980	
1780	1775	2331	1.02	2385	-6.85	-15966	-5.83	-13581	
1790	1785	1982	1.04	2064	-6.76	-13404	-5.72	-11340	
1800	1795	2390	1.06	2531	-6.67	-15950	-5.62	-13419	
1810	1805	3367	1.08	3627	-6.59	-22182	-5.51	-18555	
1820	1815	4390	1.09	4807	-6.50	-28537	-5.41	-23730	bs=0.0087x- 22.291
1830	1825	5901	1.11	6565	-6.41	-37846	-5.30	-31280	R2=0.9325
1840	1835	7739	1.13	8747	-6.33	-48963	-5.20	-40216	
1850	1845	9754	1.15	11195	-6.24	-60861	-5.09	-49665	
1860	1855	18436	1.17	21482	-6.15	-113429	-4.99	-91947	
1870	1865	35146	1.18	41561	-6.07	-213177	-4.88	-171616	
1880	1875	44427	1.20	53303	-5.98	-265608	-4.78	-212305	
1890	1885	50605	1.22	61583	-5.89	-298137	-4.67	-236554	
1900	1895	27921	1.23	34454	-5.80	-162065	-4.57	-127611	
1910	1905	17905	1.25	22399	-5.72	-102371	-4.47	-79972	
1920	1915	15185	1.27	19253	-5.63	-85499	-4.36	-66246	
1930	1925	15252	1.28	19593	-5.54	-84548	-4.26	-64954	
1940	1935	13563	1.30	17650	-5.46	-74006	-4.16	-56355	
1950	1945	11102	1.32	14632	-5.37	-59612	-4.05	-44979	
1960	1955	8492	1.33	11332	-5.28	-44857	-3.95	-33524	
1970	1965	7263	1.35	9812	-5.20	-37734	-3.84	-27922	
1980	1975	5691	1.37	7782	-5.11	-29072	-3.74	-21290	
1990	1985	4880	1.38	6753	-5.02	-24507	-3.64	-17754	
2000	1995	5407	1.40	7569	-4.93	-26682	-3.53	-19113	
2010	2005	5634	1.42	7978	-4.85	-27311	-3.43	-19333	
2020	2015	5326	1.43	7627	-4.76	-25355	-3.33	-17728	
2030	2025	4576	1.45	6626	-4.67	-21386	-3.23	-14760	
2040	2035	9927	1.46	14532	-4.59	-45528	-3.12	-30997	
2050	2045	7552	1.48	11174	-4.50	-33978	-3.02	-22804	
2060	2055	7810	1.50	11679	-4.41	-34461	-2.92	-22782	
2070	2065	12716	1.51	19215	-4.33	-55001	-2.81	-35787	
2080	2075	17064	1.53	26051	-4.24	-72325	-2.71	-46274	
2090	2085	16640	1.54	25662	-4.15	-69080	-2.61	-43418	
2100	2095	44159	1.56	68783	-4.06	-179484	-2.51	-110700	
2110	2105	60328	1.57	94895	-3.98	-239953	-2.40	-145058	
2120	2115	30177	1.59	47930	-3.89	-117405	-2.30	-69475	
2130	2125	29231	1.60	46872	-3.80	-111182	-2.20	-64309	
2140	2135	30957	1.62	50108	-3.72	-115051	-2.10	-64943	
2150	2145	25109	1.63	41021	-3.63	-91135	-2.00	-50113	
2160	2155	22264	1.65	36706	-3.54	-78869	-1.89	-42163	
2170	2165	20667	1.66	34383	-3.46	-71416	-1.79	-37033	
2180	2175	19086	1.68	32037	-3.37	-64293	-1.69	-32256	
2190	2185	20086	1.69	34012	-3.28	-65913	-1.59	-31901	
2200	2195	25186	1.71	43019	-3.19	-80458	-1.49	-37439	
2210	2205	30041	1.72	51751	-3.11	-93352	-1.38	-41601	
2220	2215	34882	1.74	60600	-3.02	-105362	-1.28	-44762	
2230	2225	38398	1.75	67265	-2.93	-112640	-1.18	-45374	
2240	2235	42912	1.77	75795	-2.85	-122150	-1.08	-46355	
2250	2245	42160	1.78	75073	-2.76	-116341	-0.98	-41267	
2260	2255	42921	1.80	77044	-2.67	-114707	-0.88	-37663	
2270	2265	45471	1.81	82271	-2.59	-117566	-0.78	-35296	
2280	2275	61049	1.82	111323	-2.50	-152532	-0.68	-41209	
2290	2285	61730	1.84	113436	-2.41	-148861	-0.57	-35424	
2300	2295	50823	1.85	94110	-2.32	-118138	-0.47	-24028	
2310	2305	43911	1.87	81926	-2.24	-98250	-0.37	-16324	
2320	2315	46189	1.88	86822	-2.15	-99330	-0.27	-12508	
2330	2325	47380	1.89	89719	-2.06	-97768	-0.17	-8049	
2340	2335	43065	1.91	82145	-1.98	-85119	-0.07	-2974	Curve ELA
2350	2345	30026	1.92	57687	-1.89	-56734	0.03	953	
2360	2355	22669	1.93	43863	-1.80	-40860	0.13	3003	
2370	2365	18406	1.95	35865	-1.72	-31575	0.23	4291	Photo ELA
2380	2375	10273	1.96	20159	-1.63	-16730	0.33	3429	
2390	2385	5855	1.98	11567	-1.54	-9025	0.43	2543	
2400	2395	2231	1.99	4438	-1.45	-3245	0.53	1193	
2410	2405	707	2.00	1416	-1.37	-967	0.64	449	
2417	2413	137	2.01	275	-1.30	-177	0.72	98	

Total-Band Balance	BW= 2,382,696	BS= -5,254,341	BN= -2,871,645
Total-Stake Area Method	BW= 2,342,843	BS= -5,744,032	BN= -3,401,189

Percent Difference of Total Band Balance and Stake Area Method -17

Average balances from Altitude Band Calcs		
bw= 1.63	bs= -3.59	bn= -1.96
Average balances from Stake-Area Calcs		
bw= 1.60	bs= -3.93	bn= -2.33
Percent Difference between average balances of results from above		
bw= 2	bs= -9	bn= -17

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Figure 5. “North Klawatti Glacier Band Balance” Worksheet.

North Klawatti Glacier **2005**

Summary Report

Calculations:

JMW 4-18-2006, updated 11-7-2006

Winter	bw = 3.2254Ln(x) - 23.108 R2 = 0.6351
Winter Balance was determined by stake area method due to poor fit regression. Snow Density was measured at Stake 3 only (0.36), so the gradient was estimated from the 2004 gradient. Slope of the line generated from the snow densities at Stakes 1 and 5 in 2004 was used but the y-intercept was changed to 0.44	

Summer	bs=0.0087x- 22.291 R2=0.9325
Band Balance is used for calculating Bs. Stake #5 melted out. Determining final melt for stake 5= Method 1- After plotting stake 1-4 to a linear fit (R2=0.97), the line was projected to stake #5. Total estimated melt for stake #5 is -5.36 m w.e. This seems too low due to stake five position south facing. When retrieving stake 5 during fall visit, no melt hole was visible indicating the stake "popped out" of hole (from gravity lean and melt down) so tried method 2. Method 2- Final melt determined by adding stake length (7.5m) and depth of placement below surface (1.36m). Ice melt determined by subtracting final melt (8.86m) from winter balance (2.74m). Summer balance is 6.64m w.e. Method 2 was used. Hard to determine error for melt out stake. Error estimated from averaging stakes errors 1-4.	

	North Klawatti Data Summary	**2005**		
BW	Winter Mass Balance (m3 w.e.)	2,342,843	Uncertainty	
ave bw	Average Winter Balance (m w.e.)	1.60	0.06	stake-area
BS	Summer Mass Balance (m3 w.e.)	-5,254,341		
ave bs	Average Summer Balance (m w.e.)	-3.59	0.29	band balance
BN	Net Mass Balance (m3 w.e.)	-2,911,498		
ave bn	**Average Net Balance (m w.e.)**	**-1.99**	**0.21**	
	Equilibrium Line Altitude(curve)	**2340m**	Where bn =0	
	Equilibrium Line Altitude (map)	**2370m**	Final ELA	
	Accumulation Area (km2)	0.02		
	Ablation Area (km2)	1.44		
	Total Area (km2)	1.46		
	Accumulation/Area Ratio	0.01		

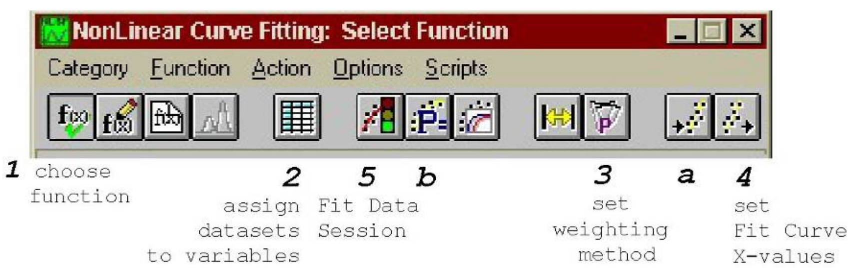
Figure 6. “North Klawatti Glacier Summary” Worksheet.

Table 1. Stake Area Delineations for Silver, Noisy Creek, Sandalee, and N Klawatti glaciers.

Glacier name	Total area (sq m)	% of glacier	Top altitude	Bottom altitude
Silver Glacier				
Stake 1	85653	0.185	2697	2490
Stake 2	162566	0.332	2490	2340
Stake 3	78480	0.160	2340	2260
Stake 4	162693	0.332	2260	2080
Noisy Creek Glacier				
Stake 1	181038	0.169	1929	1810
Stake 2	"	0.169	1929	1810
Stake 3	172484	0.322	1810	1780
Stake 4	105471	0.197	1780	1750
Stake 5	76583	0.143	1750	1666
Sandalee Glacier				
Stake 1	88055	0.451	2285	2200
Stake 2	37978	0.195	2200	2140
Stake 3	29570	0.152	2140	2050
Stake 4	39510	0.202	2050	1960
N Klawatti Glacier				
Stake 1	239161	0.16	1910	1726
Stake 2	112297	0.08	2040	1910
Stake 3	324673	0.22	2170	2040
Stake 4	402195	0.28	2280	2170
Stake 5	383400	0.26	2417	2280

Curve Fitting Procedure on Origin 7

- Compile all the data that you want to fit the curve to in a table in the Excel worksheet including elevation, balance, and balance error.
- 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 “Advanced Fitting Tool”.
- 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.

Curve Fitting Procedure on Origin 7 (continued)

(5) Fitting Session

- 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.
- Once everything above is set, click on the "100 Iter." box until the chi-sqr is not reduced.
- At this point you are done, click the "Done" button.
- The graph and results will automatically pop up in new window

Literature Cited:

Krimmel, R.M. 1994. Water, Ice and Meteorological Measurements at South Cascade Glacier, Washington, 1993 Balance Year. USGS WRI-94-4139.

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Krimmel, R.M. 1997. Water, Ice and Meteorological Measurements at South Cascade Glacier, Washington, 1996 Balance Year. USGS WRI-97-4139.

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Krimmel, R.M. 1999. Water, Ice and Meteorological Measurements at South Cascade Glacier, Washington, 1998 Balance Year. USGS WRI-99-4139.

Krimmel, R.M. 2000. Water, Ice and Meteorological Measurements at South Cascade Glacier, Washington, 1999 Balance Year. USGS WRI-00-4139.

Ostrem, G. and M. Brugman. 1991. "Glacier Mass Balance Measurements: A manual for field and office work." NHRI Science Report No. 4, Environment Canada, 224 p.

Long Term Monitoring of Small Glaciers at North Cascades National Park:
A Prototype Park Model for the North Coast and Cascades Network

SOP #8: Watershed-wide Glacier Runoff Calculations

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview and Explanation

The watershed-wide glacial contribution to summer stream flow is a measurable objective of this protocol. Glacial contributions to summer stream flow are estimated using summer balance data from the index glaciers and the area-altitude distributions of all glaciers in each of four watersheds (Figure 3 in Narrative). Estimates are made annually for the Baker River, Thunder Creek, Stehekin River, and Ross Lake watersheds. Summer balance data for three index glaciers and South Cascade Glacier are plotted against elevation to create a park-wide relationship between elevation and ablation (See graph in example worksheet below). This regression typically has correlation coefficient values (r^2) with a range from 0.72 to 0.95. Data from Noisy Creek Glacier are not included because the ablation for this glacier has a weak relationship to elevation.

Procedures

Area-elevation distributions of glacierized areas for each of the three selected watersheds are determined using GIS analysis in 50m elevation bands for each watershed. See the GIS procedure in the next section to calculate glacier areas for the 50 m elevation bands. Glacier extents from the most recent 20-year inventory are used, currently Granshaw (2001).

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 gauges as reported in the Water Resources Data Report Washington, Water Years 1993-2003. Detailed calculation worksheets for each watershed in Water Year 2000 are included below. The results of this are reported annually in the “Glacier Page” (see **SOP #12:Products and Reporting**)

<u>Required data:</u>

1. Summer balance data (b_s) versus elevation for North Klawatti, Silver, Sandalee, and South Cascade Glaciers. Typically, there is a lag of a year or two in the availability of South

Cascade balance data from the USGS. In this case use the data from three NOCA glaciers and update the analysis when the USGS data becomes available.

2. Total Summer Mass Balance (B_S) for each glacier listed above.
3. Watershed-wide glacier area by 50-meter elevation band for Baker, Stehekin, Thunder, and Ross Lake watersheds. Generated from GIS analysis using the latest glacier inventory data, which is currently Granshaw (2001).
4. USGS stream runoff data from Thunder Creek near Newhalem (site #12175500); Baker River at Concrete, (site #12193500); and Stehekin River at Stehekin, (site #12451000), as reported in the Water Resources Data Report, Washington. Websites for each:
   Thunder Creek:
   http://nwis.waterdata.usgs.gov/wa/nwis/dv?format=html&period=550&site_no=12175500
   Baker River:
   http://waterdata.usgs.gov/wa/nwis/dv?format=html&period=550&site_no=12193500
   Stehekin River:
   http://waterdata.usgs.gov/wa/nwis/dv?format=html&period=550&site_no=12451000
   -Download "Surface Water: Daily Streamflow Statistics" from these sites for the Water Year 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. Natural flow data at Ross Dam from Seattle City Light.
   Ross:
   Contact Seattle City Light, Ole Kjosnes, power management: Ole.Kjosnes@Seattle.gov, (206)386-4544)
6. Obtain NRCS summer runoff forecast data for each watershed for the water year of interest. This is the May – September "Most Probable" forecast (50% chance of exceedance) from the May 1 Washington Basin Outlook Report.
7. The existing Excel Workbooks you will be working with in the "Glaciers/Runoff/" folder:
   "glacierunoffnew.xls"
   "YYYYRunoff.xls" from the previous year
   The Excel Workbook you'll be creating:
   "YYYYRunoff.xls" for the current year

Procedure:

Example tables and graphs are below. These do not exactly match the format of the Excel worksheets but show what is needed to understand the 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 stream gauging station you downloaded of the daily mean streamflow (in cubic feet per second, cfs). Name this file "YYYYRunoff.xls" (for example "2000Runoff.xls"). Determine the monthly sum of the daily values in ft^3/sec. Tto convert daily mean to daily total multiply daily mean by 86,400. Then determine the annual (water year) and May through September sums. These are the values that you will link into the "glacierunoffnew.xls" workbook to compare with the glacial contribution to watershed runoff.

Steps 2-8 below take place in the “glacierunoffnew.xls” workbook.

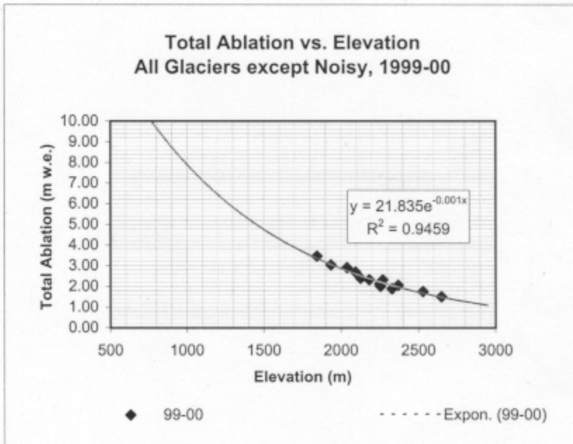
2. Plot summer balance (b_s) vs. altitude (z) for the 4 glaciers above by entering data in “B vs. Z Regressions” worksheet (Figure 1).
3. Find the best fit linear and exponential curves/functions in Excel (“B vs. Z Regressions” worksheet (Exhibit 1)). Typically a linear function is used at the lower altitudes because it is likely that the exponential overestimates ablation at these altitudes. Likewise, the linear function likely underestimates ablation at higher altitudes, thus exponential function is used in this range. For the altitude range of the data use whichever function fits the data best.
4. Apply the functions determined for the altitude ranges in Step 3. These are summarized in the “B vs. Z calculation data” worksheet (Exhibit 1) for each 50-meter elevation band. Using function from step 3, insert on elevation band value for x. To estimate total ablation per elevation band, solve for Y. Repeat for all 50m elevation bands of four glaciers.
5. Each watershed has a summary worksheet in the workbook: “Baker Estimated Runoff” (Exhibit 2), “Thunder Estimated Runoff”, “Stehekin Estimated Runoff”, and “Ross Estimated Runoff”. Each watershed has a unique range of altitude that glaciers occupy. Link the appropriate values from the “B vs. Z calculation data” worksheet into each watershed worksheet (“ablation from glaciers” column). These values 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”). Sum the “glacier runoff” values for all elevation bands to determine the total watershed-wide glacier contribution to runoff. This quantity is reported to the right of the cell labeled “SUM”.
6. In the cell below the “SUM” labeled “*glacier name* TOTAL”, link to the Summer Mass Balance for the resident glacier for each watershed worksheet.
7. Summarize and compare the values from step 4 and the predicted and actual watershed runoff values (from USGS and NRCS reports) in the watershed worksheets named in step 3.
8. Plot results in existing charts in the watershed worksheets.
9. Copy the previous year’s, “Glacier Page Table YYYY” worksheet and link the appropriate values in this table to convert cubic meters to acre-feet.

Ablation by Elevation for Glacial Contribution to Runoff Calculations

2000 Water Year

Using Growth function to estimate total ablation per band of elevation (m w.e.)

Elev. (m)	Exp. growth 99-00
700	10.72
750	10.19
800	9.68
850	9.20
900	8.75
950	8.31
1000	7.90
1050	7.51
1100	7.14
1150	6.78
1200	6.45
1250	6.13
1300	5.82
1350	5.54
1400	5.26
1450	5.00
1500	4.75
1550	4.52
1600	4.29
1650	4.08
1700	3.88
1750	3.69
1800	3.50
1850	3.33
1900	3.16
1950	3.01
2000	2.86
2050	2.72
2100	2.58
2150	2.45
2200	2.33
2250	2.22
2300	2.11
2350	2.00
2400	1.90
2450	1.81
2500	1.72
2550	1.63
2600	1.55
2650	1.48
2700	1.40
2750	1.33



Total ablation at each stake, North Klawatti, South Cascade, Silver, and Sandalee Glaciers (without Noisy data)

sta. elev.	99-00
2650	1.51
2530	1.76
2370	2.06
2330	1.89
2270	2.31
2256	2.01
2250	2.11
2183	2.32
2127	2.39
2095	2.69
2040	2.91
1936	3.04
1845	3.46

These numbers derived from data sets (see above) which do not include Noisy Glacier

Exhibit 1. Summer Balance vs. Altitude Regressions.

Glacial Contribution to Runoff Calculations, Baker River Watershed, Water Year 2000

Using Growth function to estimate total ablation per band of elevation (exponential estimate)

Estimated ablation per elevation band (m w.e.)

Elev.	99-00
700	10.72
750	10.19
800	9.68
850	9.20
900	8.75
950	8.31
1000	7.90
1050	7.51
1100	7.14
1150	6.78
1200	6.45
1250	6.13
1300	5.82
1350	5.54
1400	5.26
1450	5.00
1500	4.75
1550	4.52
1600	4.29
1650	4.08
1700	3.88
1750	3.69
1800	3.50
1850	3.33
1900	3.16
1950	3.01
2000	2.86
2050	2.72
2100	2.58
2150	2.45
2200	2.33
2250	2.22
2300	2.11
2350	2.00
2400	1.90
2450	1.81
2500	1.72
2550	1.63
2600	1.55
2650	1.48
2700	1.40
2750	1.33

These numbers derived from data sets (see D:\glaciers) which do not include Noisy Glacier

Using GROWTH estimates above to calculate glacier runoff for Baker River watershed

Elevation	Ablation from Glaciers (m w.e.)	2000 Glacier Area (m2)	Glacier Runoff (m3)
700	10.72	4,460	47,803
750	10.19	20,610	209,952
800	9.68	59,220	573,373
850	9.20	39,470	363,213
900	8.75	15,484	135,426
950	8.31	9,107	75,704
1000	7.90	1,229	9,710
1050	7.51	13,852	104,018
1100	7.14	75,847	541,330
1150	6.78	141,304	958,525
1200	6.45	120,501	776,901
1250	6.13	128,850	789,560
1300	5.82	235,539	1,371,796
1350	5.54	213,120	1,179,713
1400	5.26	251,421	1,322,756
1450	5.00	373,523	1,867,761
1500	4.75	504,633	2,398,310
1550	4.52	612,270	2,765,658
1600	4.29	832,969	3,576,104
1650	4.08	977,550	3,988,834
1700	3.88	1,128,367	4,376,059
1750	3.69	1,370,004	5,049,873
1800	3.50	1,442,690	5,054,258
1850	3.33	1,522,460	5,069,394
1900	3.16	1,391,486	4,403,670
1950	3.01	1,076,187	3,237,050
2000	2.86	887,290	2,536,606
2050	2.72	728,760	1,980,149
2100	2.58	595,184	1,537,058
2150	2.45	600,612	1,474,208
2200	2.33	726,648	1,695,176
2250	2.22	646,560	1,433,591
2300	2.11	508,660	1,071,938
2350	2.00	419,714	840,662
2400	1.90	248,910	473,845
2450	1.81	218,715	395,729
2500	1.72	94,444	162,413
2550	1.63	42,840	70,020
2600	1.55	22,982	35,701
2650	1.48	18,645	27,529
2700	1.40	1,918	2,692
		SUM:	63,984,069
		Noisy Total:	1,647,750

NRCS ESTIMATED RUNOFF: MAY 1 BASIN OUTLOOK REPORTS
(MAY-SEPT FORECAST PERIOD; 50% PROBABILITY ESTIMATE)

WATER YR.	ACRE FT.	(m3)
2000	946,000	1,166,880,140

BAKER RIVER ANNUAL RUNOFF (USGS gage)

	Total water year		MAY - SEPT PERIOD	
WATER YR.	ACRE FT.	(m3)	ACRE FT.	(m3)
2000	2,146,000	2,647,066,364	893,600	1,102,245,341

Acre feet to m3 : 1233.48852

COMPARING NRCS ESTIMATED RUNOFF TO GLACIER AND ACTUAL RUNOFF

WATER YEAR 2000	
BAKER RIVER	
Noisy Glacier Runoff (m3)	1,647,750
Total Glacier Runoff	63,984,069
NRCS Estimated Runoff	1,166,880,140
USGS Actual Watershed Runoff	1,102,245,341
% Glacier Contribution to Total	6
% Estimated to Actual Runoff	106

GLACIER CONTRIBUTION TO TOTAL ANNUAL STREAMFLOW OF BAKER RIVER

WATER YEAR 2000

Noisy Glacier Runoff (m3)	**1,647,750**
Total Glacier Runoff	**63,984,069**
Total Watershed Runoff	**2,647,066,364**
% Glacier Contribution to Total	**2**

Exhibit 2. Example worksheet of calculations for Baker River Watershed.

Literature Cited

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

Long Term Monitoring of Small Glaciers at North Cascades National Park:
A Prototype Park Model for the North Coast and Cascades Network

SOP #9: Mass Balance Error Calculations and Determination

Version 8/17/2005

Revision History Log

Revision Date	Author	Changes Made	Reason for Change
8/17/05	R. Burrows	calculate density error estimates instead of using set values	more realistic error estimates

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 is checked for errors and consistency in a final procedure outlined at the end of this SOP.

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 1, below. Errors must be calculated on an annual, stake-by-stake, glacier-by-glacier basis. See Figures 1 and 2 for an example of calculations for North Klawatti Glacier in 2002 using the values and equations outlined below. 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). Errors in stake/probe position and altitude contribute to error but the complexity of including these quantities in error propagation equations prohibits including them at this time.

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 (Figure 1) are where these general equations are applied. To understand how they are applied study the “Uncertainty Calculations Formulas” worksheet (Figure 2). The references in this worksheet refer to the left most row labels, 3 to 29, and the topmost column labels, A to J, on the “Uncertainty Calculations” worksheet (Figure 1). The formulas for Stakes 1 and 4 only are included in this worksheet as examples.

Table 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 ± 0.05	No direct measurement
Snow density	calculated	determined on case by case basis using error propagation equations. See SOP #3.
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 variable.

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:

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

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 each stake is the combination of Equations 7 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. All quantities are meters water equivalent

Remember, it is the variances (σ^2) for each variable that are used and carried through the error propagation equations.

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.

When the data is published in a ten-year report the data is checked for errors and consistency After all data is collected and calculations are made staff make a final annual data review using the procedures outlined below.

- -Assemble and organize ALL information (hard copy and electronic) for each glacier.
- -Go through data for each glacier year by year- follow history.
  - -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.
- -Check snow depth data 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.
- -Check Spring Probe Confidence Spreadsheets
- -Snow density (some years 0.51 is used whereas others 0.50 is used)
  - Why difference? Which to use?
  - -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.

	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 1. Uncertainty Calculations, North Klawatti Glacier, 2002.

Uncertainty Calculation Formulas, North Klawatti Glacier, 2002									
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 2. Uncertainty Calculation Formulas, North Klawatti Glacier, 2002.

Literature Cited:

Bevington and Robinson. 1992. Data reduction and error analysis for the physical sciences, Second Edition. McGraw-Hill, Inc, NY, 350 p.

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 IHD. Journal of Glaciology V. 11, n. 61, pp. 3-14.

Rasmussen, L.A. 2002-2003. Personal communication. Department of Earth and Space Sciences, University of Washington, Seattle, WA, USA.

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SOP #10: Revising the Protocol

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview

This document explains how to make and track changes to the North Cascades 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 (master [MS Word]) version of the appropriate protocol document (i.e., not the most recent versioned copy – see below). Note that the protocol is split into separate sections for narrative, SOPs and appendixes. Also note that a change in one section 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 other sections. 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 the Revision History Log embedded in the protocol narrative and each SOP. Log changes only in the section being edited (i.e., if there is a change to an SOP, log those changes only in that SOP). 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 (master) 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 # 11: 20-Year Glacier Inventory

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview and Explanation

This document explains the basic procedures for conducting a 20-year inventory of all glaciers at North Cascades National Park. It is designed to meet goal numbers 1 and 2 of this monitoring program: (1) monitor change in mass and area of all glaciers, and (2) monitor impact of glacier changes on aquatic and terrestrial ecosystems. To meet these goals, specific procedures will include:

1. obtain large scale stereo aerial photographs or satellite images of the glaciers over the entire park
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

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. Due to the importance of these requirements, images should be obtained at opportune times and not at exact 20 year intervals.

   The previous two inventories of glaciers at NOCA relied on aerial photographs (Post and others, 1971; Granshaw, 2001). Due to the large expense of obtaining these images, resources must be pooled with other monitoring or resource management programs. In 1998 it cost the NPS ~$70,000 to obtain 1:12,000 scale color, stereo air photos of the 684,000 acre park. Cost for this effort was low since the NPS worked with a cooperator in the Washington State Department of Natural Resources, who provided contracting and project oversight.

Recently obtained images from the IKONOS satellite at Mt. Rainier offer a potentially cheaper and more accurate means of obtaining glacier inventories. A consultant is currently investigating the feasibility of using satellite images to monitor glaciers, vegetation and other landscape changes.

2. Procedures for using aerial photographs to inventory glaciers are described in detail in Granshaw (2001). In summary, the most recent inventory process involved manipulation of existing digital geographic glacier data using the new photographs. Glacier boundaries were first outlined on overlays on the aerial photos, then transferred to a GIS by a 'heads-up' process on a computer screen. Ideally, aerial photos are geo-rectified or orthophotoquads are available, however, othhophotoquads must be of sufficient resolution to identify glacier margins. Oblique aerial photographs and field visits can be used to resolve a small number of glacier margin issues.

3. 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.

Literature Cited:

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

Post, A., D. Richardson, W.V. Tangborn, and F.L. Rosselot. 1971. Inventory of glaciers in The North Cascades, Washington. US Geological Survey Prof. Paper, 705-A.

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SOP #12: Products and Reporting

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview and Explanation

This document explains how this protocol will meet goal number 4: sharing 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:

1. annual training of NPS interpreters in Stehekin and Newhalem
2. annual training of mountain school staff in Newhalem
3. annual public programs at Stehekin and Newhalem visitor centers and Skagit Bald Eagle Festival in Marblemount
4. annual posting of data on the park and NCCN internet sites
5. annual summary of program in park newspaper Challenger
6. annual entry of data into Network relational databases and international glacier monitoring services
7. spring publishing of winter balance and glacier runoff data in the Washington State Snow Survey Report, Glacier Page (see Appendix H).
8. decadal publishing of a summary report of mass balance and glacial runoff data
9. occasional publishing of research papers in peer-reviewed journals
10. presentations at professional society meetings, including annually at the Northwest Glaciologists Meeting
11. publication of glacier inventories in a technical report.

Staff are also encouraged to present glacier monitoring data to local schools as time and resources permit during the winter.

Procedures

1. 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. Seasonal staff training typically consists of a half day presentation to staff in Stehekin and Skagit Districts in early June.

2. Mountain School is a North Cascades Institute program that brings all 5th Graders in Skagit County to an NPS campground for a week of instruction on mountain ecosystems. A half day of training is provided to NCI staff in early April.
3. Glacier monitoring data is also presented directly to the public at three times annually, including at Stehekin and Newhalem NPS Visitor centers and at the Skagit River Bald Eagle Festival in February.
4. The North Coast and Cascades Network and North Cascades National Park have websites where glacier monitoring data is posted. These sites should be updated with new glacier aerial photos, cumulative mass balance data and glacier runoff data (at a minimum) each winter.
5. North Cascades N.P. has several local newsletter type publications for park staff and visitors (i.e. Challenger, Complex Issues). Data from the glacier program is included with a brief synopsis of results for preparation of Challenger each spring, which is coordinated by park interpretive staff.
6. 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. Glacier monitoring at NOCA has regional and global significance as part of larger efforts to monitor glaciers. Data is sent annually to the National Snow and Ice Data Center and the World Glacier Monitoring Service.
7. 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' is attached at the end of this SOP, pages 136-137.
8. Following decadal remapping of glaciers, which provides an independent check on cumulative mass balance, a technical report will be prepared. The first of these reports will be prepared in 2004-2005. The reports will include discussion of data on variation and trends in winter, summer, and net mass balance, and glacial runoff for four watersheds.
9. When staff expertise and time allow, analysis of glacier monitoring data with respect to pertinent research questions will be published in peer-reviewed journals. 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.
10. Results from the inventory of glaciered area including all NOCA 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 (Granshaw, 2001).

Literature Cited:

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

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SOP # 13: Field Form Handling Procedures

Version 7/27/2007

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 #18: Project Delivery Specifications). The PDF files may then serve as a convenient digital reference of the original if needed.

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SOP # 14: Managing Photographic Images

Version 7/27/2007

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 oblique photo taken by helicopter to capture 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, crevass 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:

A. File Structure Setup – Set up the file organization for images prior to acquisition
B. Image Acquisition
C. 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

D. Establish Database Links
E. Deliver Image Files for Final Storage

A. 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 – Snd (Sandalee), Nsy (Noisy), Nkl (North Klawatti), Slv (Silver)
[Year]	The appropriate year – 2007, 2008, etc.
[Season]	The season of visit – Spring, Summer, Fall
_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 (1,1E, 2, 2W, 3, 4, 5)
Other_misc_data	Data images not taken at or near stake locations
[Feature name]	Arrange by abbreviated name of captured feature
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 #19: Workspace Setup and Project Records Management.

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
- Use full name of glacier
- Use full year as 2007
- Use full season name as Spring, Summer, Fall

B. 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).

C. Download and Processing Procedures

1. Download the raw, unedited images from the camera into the appropriate "_Processing" folder.
2. 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 #13: Field Form Handling Procedures.
3. 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.
4. 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.
5. 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:

1. Abbreviated glacier name (nsy (Noisy), snd (Sandalee), nkl (North Klawatti), slv (Silver)
2. Year (2006, 2007, etc.)
3. Season (spring, summer, fall)
4. Optional: a sequential letter if multiple images were captured (a, b, c, etc.)
5. Optional: the number of the ablation stake that the photo was taken at or near (1, 1e, 2, 2w, 3, 4, 5)

6. Optional: abbreviated name that image is featuring

Examples:

- nsy_2006_spring_b.jpg — The second of two photos (b) of Noisy glacier in Spring of 2006
- nkl_2004_summer_stk1.jpg — Stake 1 of North Klawatti glacier in the Summer of 2004
- snd_2005_fall_terminus.jpg — The terminus of Sandalee Glacier in Fall of 2004

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.

<u>D. Establish Database Links</u>

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 #16: 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.

<u>E. Deliver Image Files for Final Storage</u>

Note: Please refer to SOP #18: 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.

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SOP # 15: Metadata Development

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

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.

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.

Specific procedures for creating, parsing and posting the metadata record are found in NCCN Metadata Development Guidelines (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 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 #18: 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.

Literature Cited:

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. 88 pp. Available at: http://science.nature.nps.gov/im/units/nccn/dm_docs/NCCN_DMP_Sep2005.pdf

North Coast and Cascades Network – National Park Service. 2006. Metadata Development Guidelines. USDI National Park Service. Available at: http://science.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm

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SOP #16: Data Entry and Verification

Version 7/27/2007

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 #17: 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

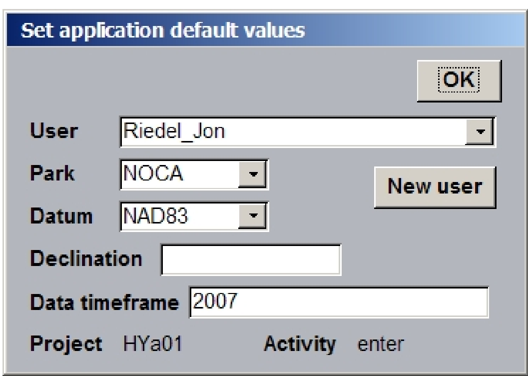
The working front-end application has the following functional components, which are accessed from the main application switchboard form that opens automatically when the application starts:

- 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 #17: 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.

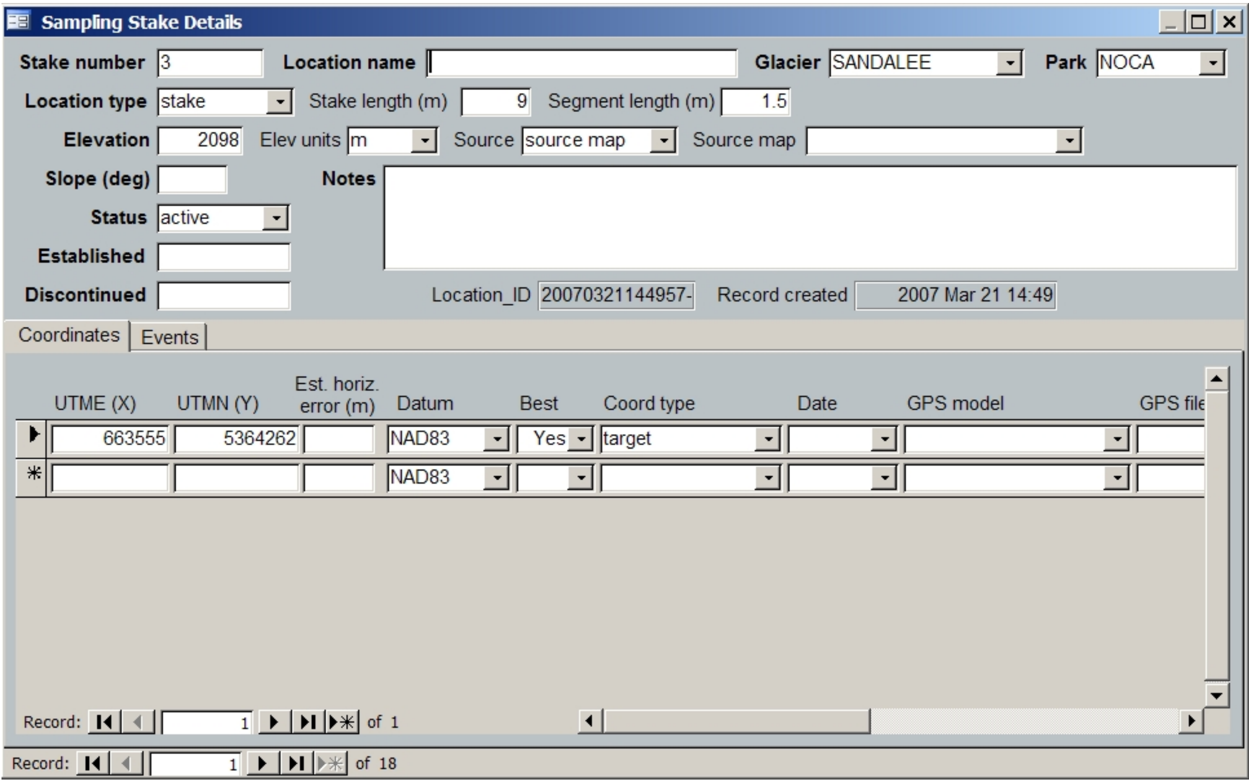
The second tab shows the current application default settings.

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.



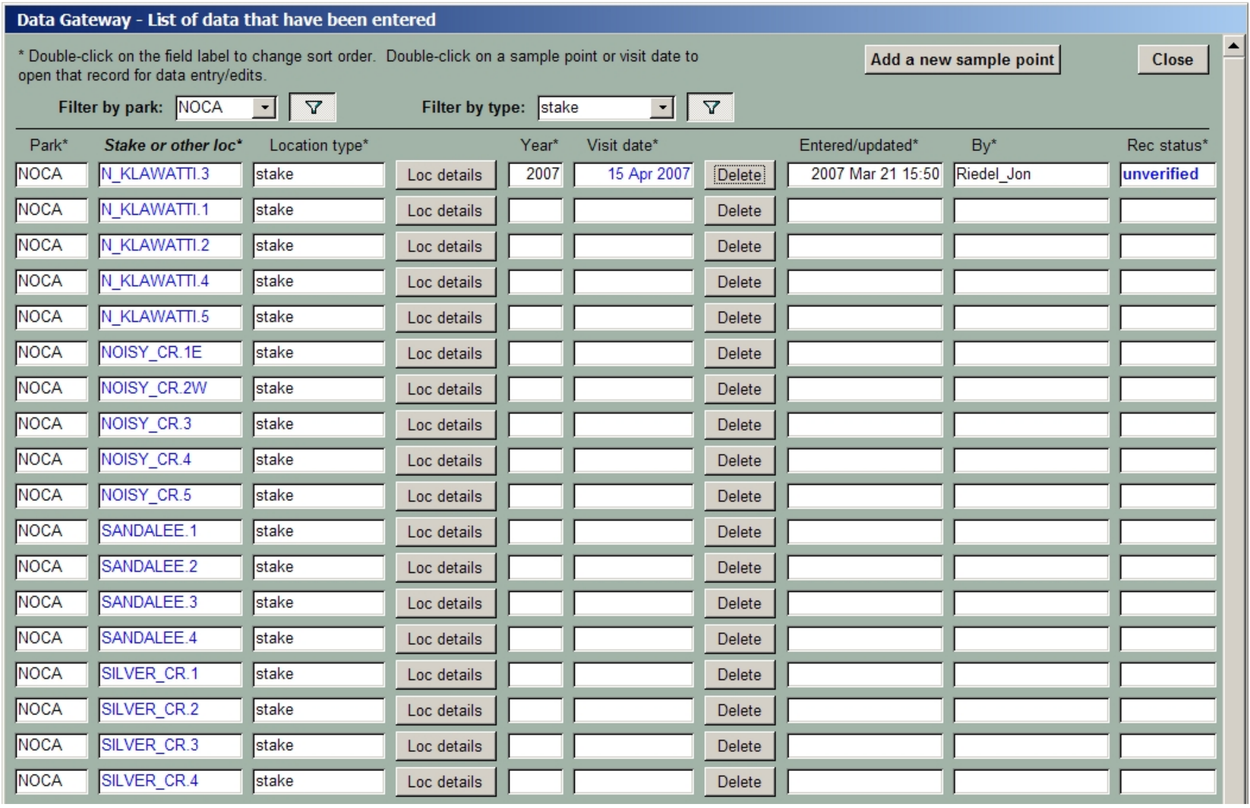
Entering Data

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

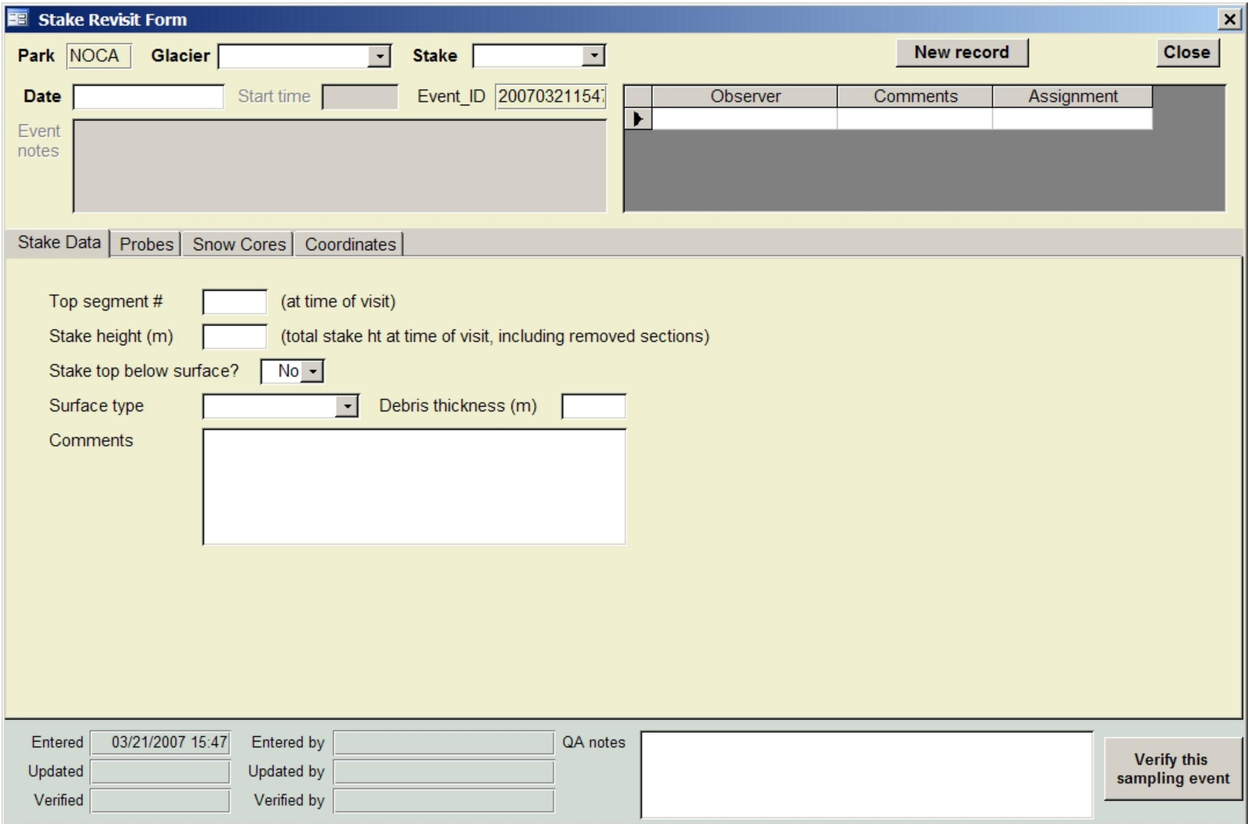
* Double-click on the field label to change sort order. Double-click on a sample point or visit date to open that record for data entry/edits.

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			

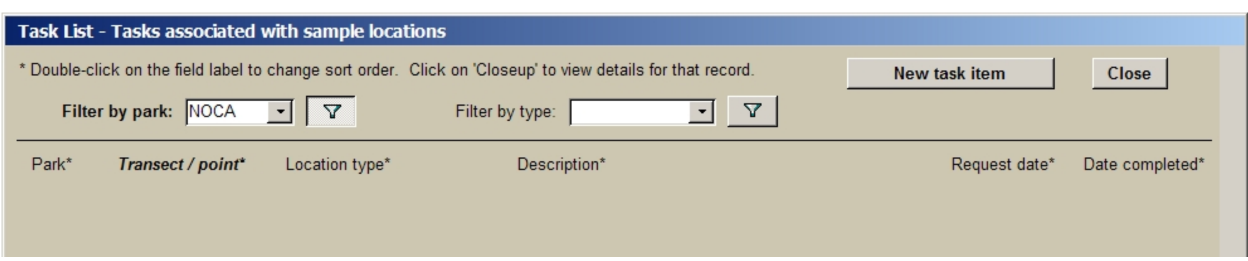
Clicking the “Add a new sampling point” button (upper right corner) will open the Sampling Stake Details form to a blank record. To open an existing record for edits or to complete data entry, click on the “Loc details” button associated with the desired record.



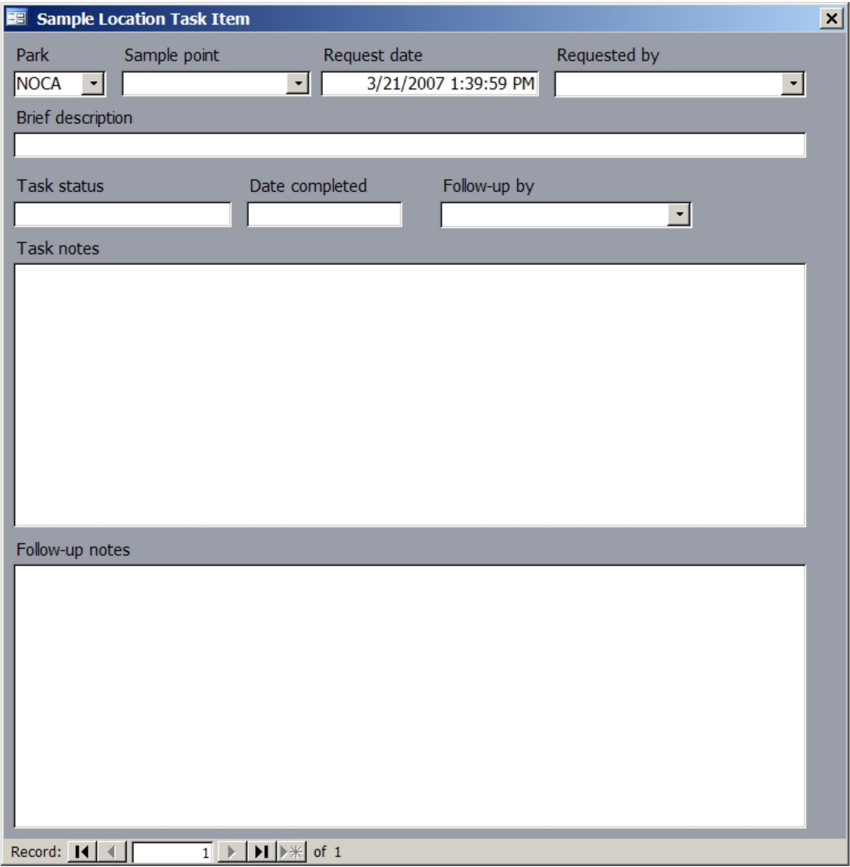
Upon finishing data entry for each stake, the database entries should be compared against the original field forms. When all of the data for the sampling event have been entered, hit the button that says "Verify this sampling event" to indicate that the event record is complete and accurately reflects 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:



Sample Location Task Item

Park	Sample point	Request date	Requested by
NOCA		3/21/2007 1:39:59 PM	

Brief description

Task status	Date completed	Follow-up by

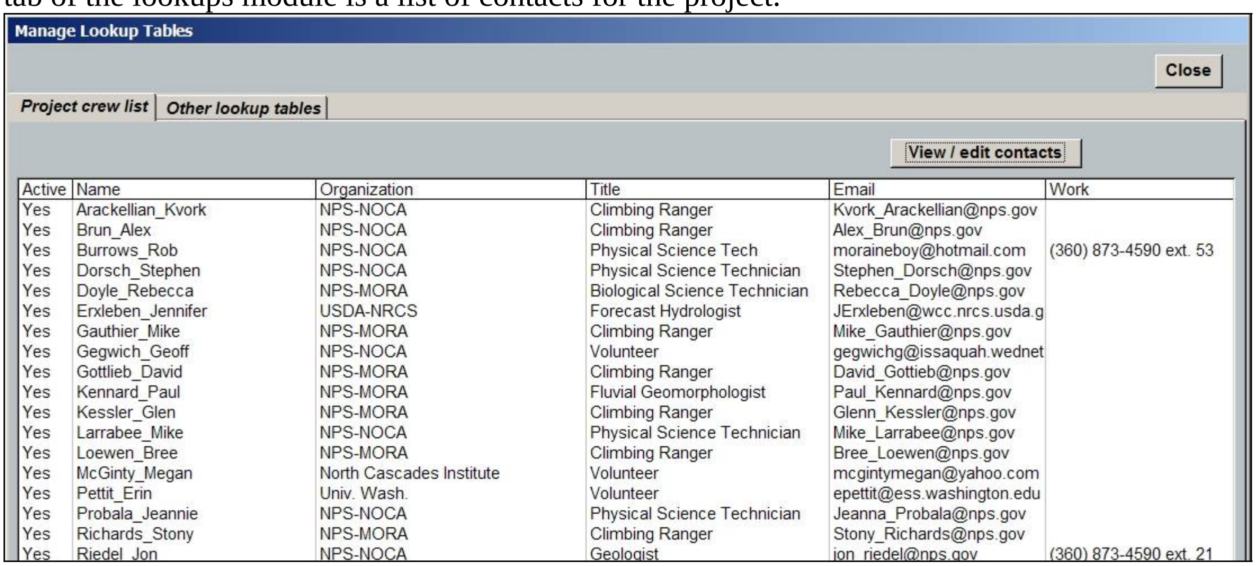
Task notes

Follow-up notes

Record: 1 of 1

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.



Manage Lookup Tables

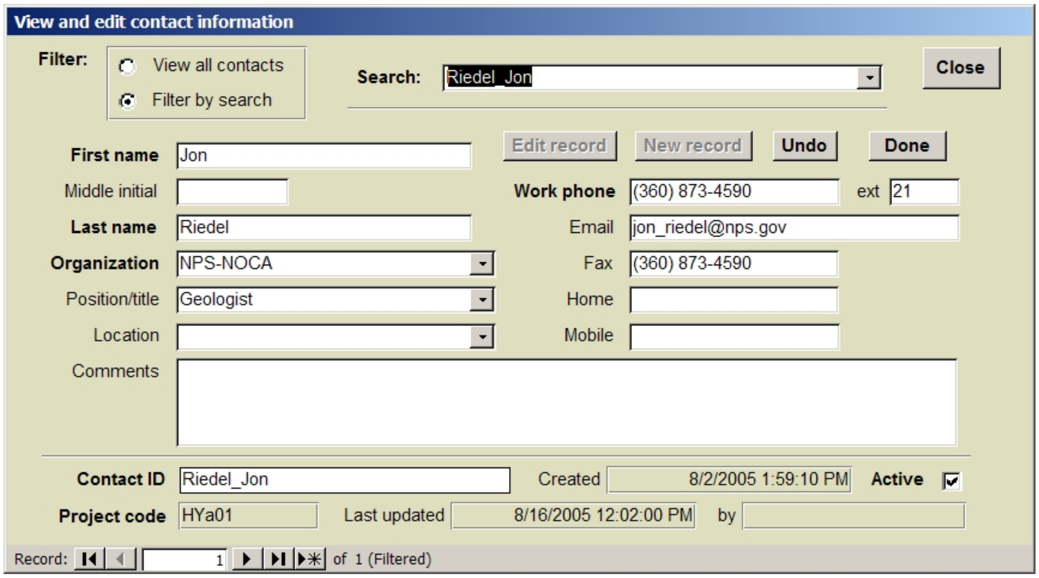
Close

Project crew list | Other lookup tables

View / edit contacts

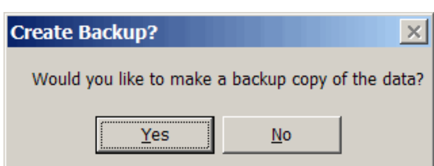
Active	Name	Organization	Title	Email	Work
Yes	Arackellian_Kvork	NPS-NOCA	Climbing Ranger	Kvork_Arackellian@nps.gov	
Yes	Brun_Alex	NPS-NOCA	Climbing Ranger	Alex_Brun@nps.gov	
Yes	Burrows_Rob	NPS-NOCA	Physical Science Tech	moraineboy@hotmail.com	(360) 873-4590 ext. 53
Yes	Dorsch_Stephen	NPS-NOCA	Physical Science Technician	Stephen_Dorsch@nps.gov	
Yes	Doyle_Rebecca	NPS-MORA	Biological Science Technician	Rebecca_Doyle@nps.gov	
Yes	Erxleben_Jennifer	USDA-NRCS	Forecast Hydrologist	JErxleben@wcc.nrcs.usda.g	
Yes	Gauthier_Mike	NPS-MORA	Climbing Ranger	Mike_Gauthier@nps.gov	
Yes	Gegwich_Geoff	NPS-NOCA	Volunteer	gegwichg@issaquah.wednet	
Yes	Gottlieb_David	NPS-MORA	Climbing Ranger	David_Gottieb@nps.gov	
Yes	Kennard_Paul	NPS-MORA	Fluvial Geomorphologist	Paul_Kennard@nps.gov	
Yes	Kessler_Glen	NPS-MORA	Climbing Ranger	Glenn_Kessler@nps.gov	
Yes	Larrabee_Mike	NPS-NOCA	Physical Science Technician	Mike_Larrabee@nps.gov	
Yes	Loewen_Bree	NPS-MORA	Climbing Ranger	Bree_Loewen@nps.gov	
Yes	McGinty_Megan	North Cascades Institute	Volunteer	mcgintymegan@yahoo.com	
Yes	Pettit_Erin	Univ. Wash.	Volunteer	epettit@ess.washington.edu	
Yes	Probala_Jeannie	NPS-NOCA	Physical Science Technician	Jeanna_Probala@nps.gov	
Yes	Richards_Stony	NPS-MORA	Climbing Ranger	Stony_Richards@nps.gov	
Yes	Riedel_Jon	NPS-NOCA	Geologist	jon_riedel@nps.gov	(360) 873-4590 ext. 21

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.

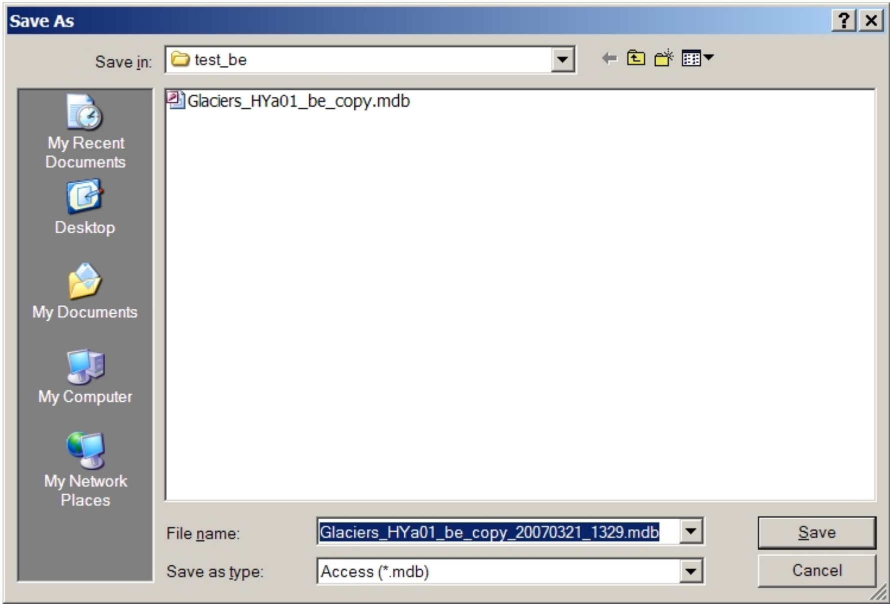


Database Backups

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.

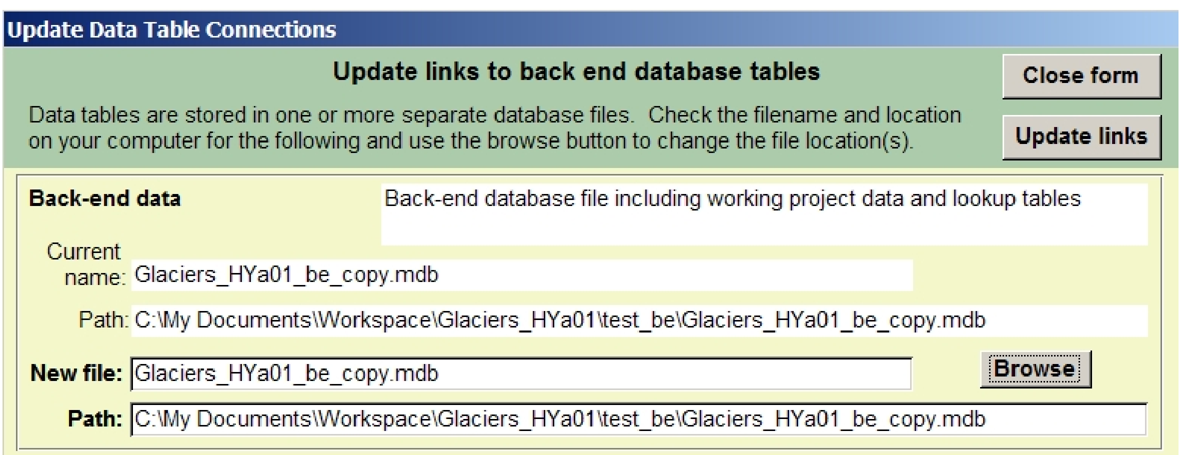


If you respond 'Yes' to the backup prompt, a window will open to allow you to indicate where to save the file. The default path is the same as the back-end database file, and the default name is that for the back-end file with a date stamp appended to the end. It is recommended that backups be made in 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.



Long Term Monitoring of Small Glaciers at North Cascades National Park :
A Prototype Park Model for the North Coast and Cascades Network

SOP #17: Data Quality Review and Certification

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

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. 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

Table 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.

Table 1. Automated validation checks performed on the 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
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'

Table 1. Automated validation checks performed on the data prior to certification (continued).

Query_name	Returns records meeting the following criteria
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
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

Table 1. Automated validation checks performed on the data prior to certification (continued).

Query_name	Returns records meeting the following criteria
qa_4h_Coordinates_illogical_dates	Coordinates with updated dates before creation dates
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
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

Table 1. Automated validation checks performed on the data prior to certification (continued).

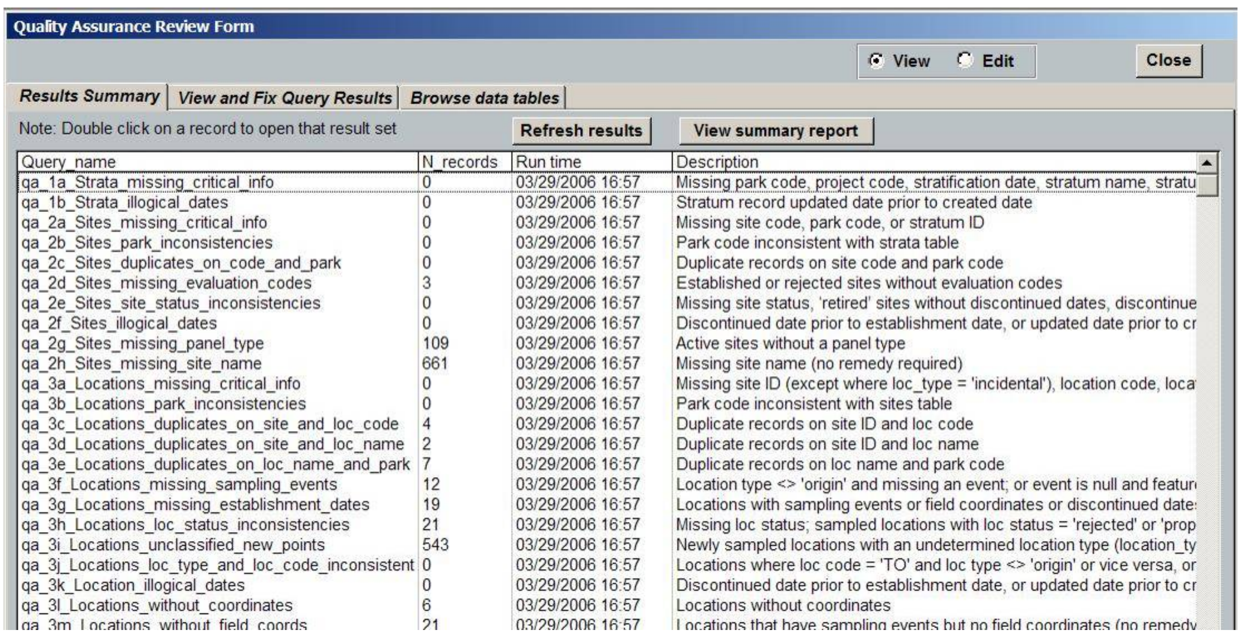
Query_name	Returns records meeting the following criteria
qa_6l_Events_missing_conditions	Point count events with missing environmental conditions - noise level, wind_cond, precip_cond, cloud_cover, temperature
qa_6m_Events_illogical_dates	Events with start date/times occurring after end date/times; 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
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

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.

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

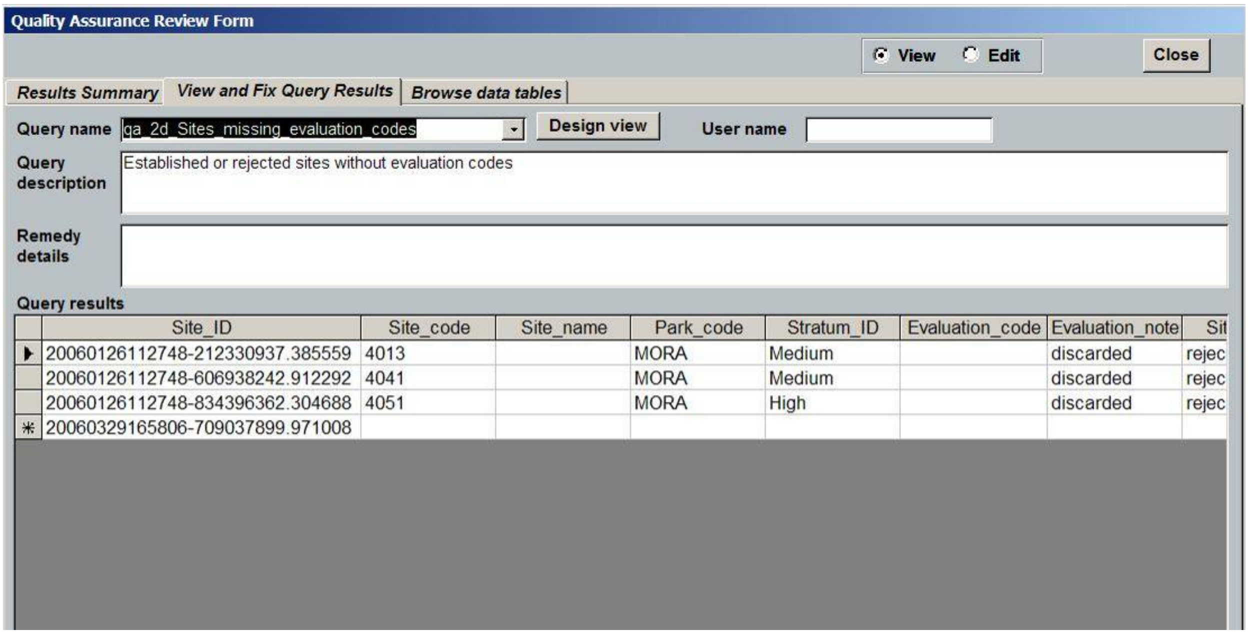
Results Summary | View and Fix Query Results | Browse data tables

Note: Double click on a record to open that result set

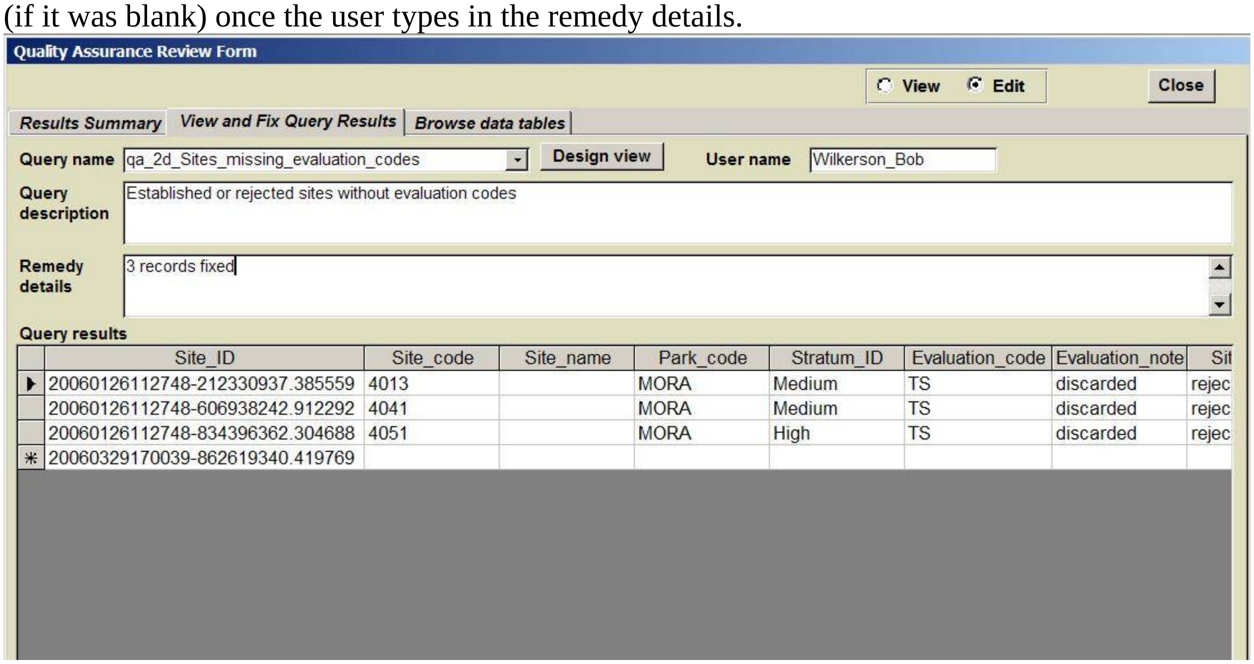
Refresh results | View summary report

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

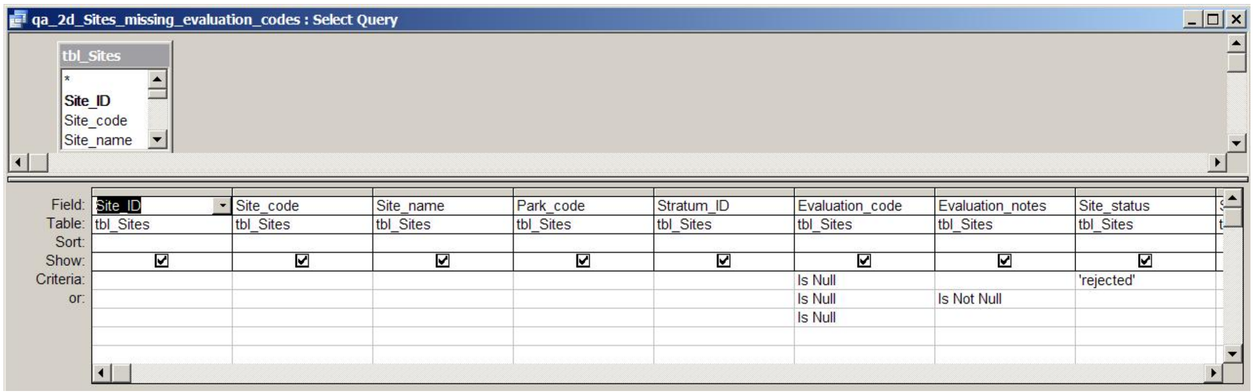
Upon double-clicking a particular query name, the second page will open up to show the results from that query.



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.

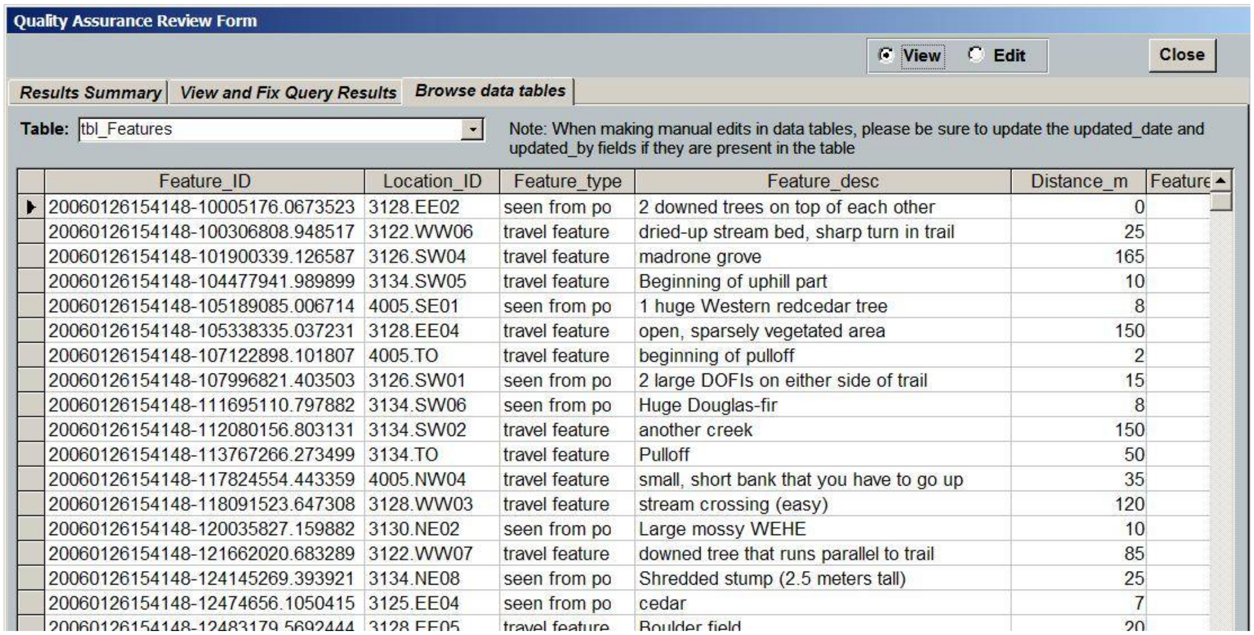


On this page is also a button labeled “Design view”, which will open the currently selected query in the design interface in Access. In this manner, the user can verify that the query is in fact filtering records appropriately. Note: Any desired changes to query structure or names should be discussed 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.



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	

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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 #18: Product Delivery Specifications for delivery instructions.

Long Term Monitoring of Small Glaciers at North Cascades National Park :
A Prototype Park Model for the North Coast and Cascades Network

SOP #18: Product Delivery Specifications

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

Overview

This document provides details on the process of submitting completed data sets, reports and other project deliverables. Prior to submitting digital products, files should be named according to the naming conventions appropriate to each product type (see below for 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 1. Product delivery schedule and specifications.

Deliverable Product	Primary Responsibility	Target Date	Instructions
Field season report	Field Lead	October 15 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 #14: Managing Photographic Images.

Table 1. Product delivery schedule and specifications (continued).

Deliverable Product	Primary Responsibility	Target Date	Instructions
Certified working database	Project Lead	November 30 of the same year	Refer to the following section on delivering certified data and related materials.
Certified geospatial data	Project Lead with GIS Specialist		
Data certification report	Project Lead		
Metadata interview form	Project Lead and NPS Lead		
Full metadata (parsed XML)	Data Manager and GIS Specialist	March 15 of the following year	Upload the parsed XML record to the NPS Data Store [2], and store in the NCCN Digital Library [1].
Washington Water Supply Outlook 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	January 31 of the following year	
Seatle City of Light Report	Project Lead	April 30 of the following year	
Annual I&M report	Project Lead	April 30 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 #19 [4].

[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://science.nature.nps.gov/im/apps/nrbib/index.cfm). 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 #17: 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 #17: Data Quality Review and Certification.
- 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://science.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://science.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm. For more details, refer to SOP #15: 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 #20: Product Posting and Distribution.

Specific Instructions for Reports and Publications

Annual reports and trend analysis reports and other peer-reviewed technical reports will use the NPS Natural Resource Publications template, a pre-formatted Microsoft Word template document based on current NPS formatting standards. 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 Pacific West 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.

Examples:

- NCCN_HYa01_2007_Annual_report.pdf
- NCCN_HYa01_2007_Field_season_report.doc
- NCCN_HYa01_2007_Certification_report.doc

Literature Cited:

North Coast and Cascades Network – National Park Service. 2006. GIS Development Guidelines. USDI National Park Service. Available at: http://science.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm

North Coast and Cascades Network – National Park Service. 2005a. GIS Product Specifications. USDI National Park Service. Available at: http://science.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm

North Coast and Cascades Network – National Park Service. 2005b. GIS Naming Conventions. USDI National Park Service. Available at: http://science.nature.nps.gov/im/units/nccn/datamgmt_guide.cfm

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SOP #19: Workspace Setup and Project Records Management

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

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 1. Certain folders – especially those for GPS data and images – should be retained in separate folders for each calendar year as shown in Figure 1. This will make it easier to identify and move these files to the project archives at the end of each season.

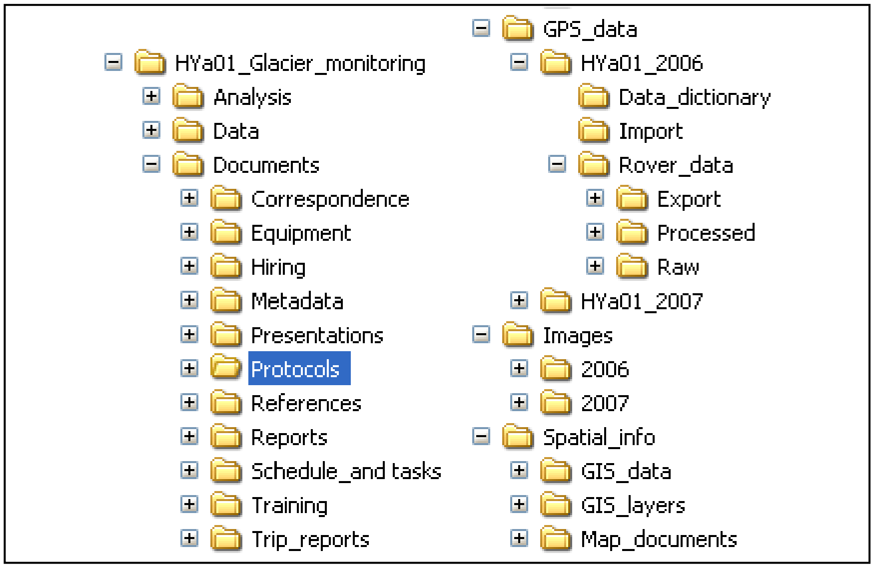

Figure 1. Recommended file structure for project workspace. Note that the workspace folder name includes 'HYa01', the NCCN project code.

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 #14: 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, 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 #18: 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.

Literature Cited:

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. 88 pp. Available at: http://science.nature.nps.gov/im/units/nccn/datamgmt.cfm

SOP #20: Product Posting and Distribution

Version 7/27/2007

Revision History Log

Revision Date	Author	Changes Made	Reason for Change

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 #18: 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://science.nature.nps.gov/im/apps/nrbib/index.cfm). 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.
3. Species observations will be extracted from the database and entered into NPSpecies, which is the NPS database and application for maintaining park-specific species lists and observation data (http://science.nature.nps.gov/im/apps/npspp/index.htm).

These three 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 distrubuting 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 Biologists, 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 Biologists 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 can not 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 fulfulling 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.

Appendixes

Appendix A. Roles and responsibilities for glacier monitoring in NOCA.

Role	Responsibilities	Name / Position
NPS Lead	• Project oversight and administration • Track project objectives, budget, requirements, and progress toward project objectives • Facilitate communications between NPS and cooperator(s) • Coordinate and ratify changes to protocol • Assist in training field crews • Assist in performing data summaries and analysis, assist interpretation and report preparation • Review annual reports and other project deliverables for completeness and compliance with Inventory and Monitoring Program specifications • Ensure project compliance with park requirements • Maintain and archive project records	Jon Riedel, Geologist, NOCA
Project Lead	• Project operations and implementation • Certify each season's data for quality and completeness • Complete reports, metadata, and other products according to schedule	Jon Riedel, Geologist, NOCA or Jeanna Wenger, Physical Science Tech., NOCA
Data Analyst	• Perform data summaries and analysis, assist interpretation and report preparation	
Field Lead	• Train and ensure safety of field crew • Plan and execute field visits • Acquire and maintain field equipment • Oversee data collection and entry, verify accurate data transcription into database • Complete a field season report	Jeanna Wenger, Physical Science Tech., NOCA
Technicians	• Collect, record, enter and verify data	NOCA Technicians
Data Manager	• Consultant on data management activities • Facilitate check-in, review and posting of data, metadata, reports, and other products to national databases and clearinghouses according to schedule • Maintain and update database application • Provide database training as needed	Ron Holmes, Data Manager, NOCA*
Network Coordinator	• Review annual reports for completeness and compliance with I&M standards and expectations	Mark Huff, NCCN Network Coordinator
Park Curator	• Receive and archive copies of annual reports, analysis reports, and other publications • Facilitate archival of other project records (e.g., original field forms, etc.)	Park Curator and Collections Manager at NOCA

* These individuals act as coordinators and primary points of contact for this project. Their responsibility is to facilitate communication among network and park staff and to coordinate the work which may be shared among various staff to balance work load and to enhance the efficiency of operations.

Appendix B. Yearly NOCA glacier monitoring task list.

This table identifies each task by project stage, indicates who is responsible, and establishes the timing for its execution. Protocol sections and SOPs are referred to as appropriate.

Project stage	Task description	Responsibility	Timing
Preparation (*Section 3A, 3B, 3C, and 4B*)	Initiate announcements for seasonal technician positions, begin hiring	Project Lead	Nov-Jan
	Notify Data Manager of planned activities for the coming year	Project Lead	by Dec 1
	Ensure all project compliance needs are completed for the coming season	Project Lead	Jan-Feb
	Plan schedule and logistics, including ordering any needed equipment and supplies	Project Lead and Field Lead	Feb
	Inform Data Manager of specific support needs for upcoming season	Project Lead	by Mar 1
	Initiate computer access and key requests	Project Lead	by Apr 1
	Provide field crew email addresses and user logins to Data Manager	Project Lead	by Apr 1
	Ensure that project workspace is ready for use (SOP #19)	Project Lead and Data Manager	by Apr 1
	Implement working database copy, provide training as needed	Data Manager	by Apr 1
	Update and load GPS data dictionary and target coordinates	Field Lead	by Apr 1
	In office and on-glacier training as needed for data collection and safety	Project Lead and Field Lead	Apr
Data Acquisition Visit 1 (*Section 3A*)	Spring field trip to install stakes and collect data	Technicians	Apr
	Review data forms in field and in office for completeness and accuracy	Field Lead	Apr
Data Entry & Processing Visit 1 (*Section 4C, 4D*)	Process GPS data for new stakes, record probes, show density and stake heights	Field Lead	May
	Download and process digital images (SOP #14)	Technicians	May
	Enter data into working copy of the database (SOP #16)	Technicians	May
	Verification of accurate transcription as data are entered	Technicians	May
	Periodic review of database entries for completeness and accuracy	Field Lead	May
Data Acquisition Visit 2 (*Section 3B*)	Summer field data collection	Technicians	late Jun
	Review data forms in field and in office for completeness and quality	Field Lead	late Jun

Appendix B. Yearly NOCA glacier monitoring task list (continued).

Project Stage	Task Description	Responsibility	Timing
Data Entry & Processing	Download and process digital images (SOP #14)	Technicians	Jul
Visit 2 (*Section 4C, 4D*)	Enter data into working copy of the database (SOP #16)	Technicians	Jul
	Verification of accurate transcription as data are entered	Technicians	Jul
	Periodic review of database entries for completeness and accuracy	Field Lead	Jul
Data Acquisition	Fall field data collection	Technicians	Sep
Visit 3 (*Section 3C*)	Review data forms in field and in office for completeness and quality	Field Lead	Oct
Data Entry & Processing	Download and process digital images (SOP #14)	Technicians	Oct
Visit 3 (*Section 4C, 4D*)	Enter data into working copy of the database (SOP #16)	Technicians	Oct
	Verification of accurate transcription as data are entered	Technicians	Oct
	Periodic review of database entries for completeness and accuracy	Field Lead	Oct
Product Development (*Section 4I*)	Complete field season report	Field Lead	Sep-Oct
Product Delivery (*Section 4J*)	Send field season report to NPS Lead and Data Manager (SOP #18)	Project Lead	by Oct 15
Quality Review (*Section 4E*)	Quality review and data validation using database tools (SOP #17)	Field Lead and Project Lead	Oct-Nov
Metadata (*Section 4F*)	Update project metadata (SOP #15)	Field Lead and Project Lead	Oct-Nov
Data Certification & Delivery	Certify the season's data and complete certification report (SOP #17)	Project Lead	Oct-Nov
(*Section 4G*)	Deliver certification report, certified data, and updated metadata to Data Manager (SOP #18)	Project Lead	by Nov 30
	Upload certified data into master project database, store data files in NCCN Digital Library [1] (SOP #20)	Data Manager	Nov-Dec
	Notify Project Lead of uploaded data ready for analysis and reporting	Data Manager	by Dec 15
	Finalize and parse metadata records, store in NCCN Digital Library [1] (SOP #15)	Data Manager	Dec-Jan
Data Analysis (*Section 4H*)	Export probe depth and stake melt data for curve fitting, enter curve equations into database	Data Analyst	Dec-Jan
	Calculate mass balance, equilibrium line altitude (ELA), and runoff estimates	Data Analyst	Dec-Jan

Appendix B. Yearly NOCA glacier monitoring task list (continued).

Project Stage	Task Description	Responsibility	Timing
Reporting & Product Development (*Section 4I*)	Washington Water Supply Outlook Report (includes preliminary winter balance data for current year, due in June)	Project Lead	by May 31
	Generate World Glacier Monitoring Service Report	Project Lead	Dec-Jan
	Acquire the proper report template from the NPS website, create annual report	Project Lead	Jan
	Annual I&M Report	Project Lead	Jan-Mar
	Seattle City of Light Report (runoff data)	Project Lead	by Apr 30
Product Delivery (*Section 4J*)	Submit draft I&M report to Network Coordinator for review	Project Lead	Mar
	Review report for formatting and completeness, notify Project Lead of acceptance or need for changes	Network Coordinator	Mar
	Upload completed report to NCCN Digital Library [1] submissions folder, notify Data Manager (SOP #18)	Field Lead and Project Lead	upon approval
	Deliver other products according to the delivery schedule and instructions (SOP #18)	Field Lead and Project Lead	upon completion
	Product check-in	Data Manager	upon receipt
Posting & Distribution (*Section 4J*)	Submit metadata to NPS Data Store [2]	Data Manager	by Mar 15
	Create NatureBib [3] record, post reports to NPS clearinghouse	Data Manager	upon receipt
	Submit certified data and GIS data sets to NPS Data Store [2]	Data Manager	Jun (after 2-year hold)
Archival & Records Management (*Section 4K*)	Store finished products in NCCN Digital Library [1]	Data Manager	upon receipt
	Review, clean up and store and/or dispose of project files according to NPS Director's Order #19 [5]	Project Lead and Field Lead	every Jul
Season Close-out (*Section 4L*)	Inventory equipment and supplies	Field Lead	Oct-Nov
	Meeting or conference call to discuss recent field season, and document any needed changes to field sampling protocols or the working database	Project Lead, Field Lead and Data Manager	by Oct 15
	Discuss and document needed changes to analysis and reporting procedures	Project Lead and Data Manager	Mar

[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.

Appendix B. Yearly NOCA glacier monitoring task list (continued).

[3] NatureBib is the NPS bibliographic database (http://science.nature.nps.gov/im/apps/nrbib/index.cfm). This application has the capability of storing and providing public access to image data (e.g., PDF files) associated with each record.
[4] NPSpecies is the NPS database and application for maintaining park-specific species lists and observation data (http://science.nature.nps.gov/im/apps/npspp/).
[5] 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

Appendix C. Snow densities from South Cascade and North Cascades glaciers.

Table A-1. Spring Snow Densities by Altitude, South Cascade Glacier, 1986-2003

	Dates																		
Altitude	5/15/86	5/6/87	5/19/88	5/3/89	5/1/90	5/1/91	4/15/92	5/5/93	5/4/94	5/16/95	5/24/96	5/9/97	5/598	5/27/99	5/7/00	5/10/01	5/19/03	**Average**	**Std Dev**
1618-1660	0.5	0.52	0.49	0.55	0.49	0.51	0.54	0.49	0.52	0.49	0.55	0.53	0.5	0.53	0.5	0.53		**0.52**	**0.022**
1834-1863	0.46	0.47	0.45	0.51	0.45	0.5	0.49	0.45	0.5	0.52	0.5	0.49	0.54	0.53	0.5	0.45	0.49	**0.49**	**0.029**
2034-2060	0.46	0.42	0.41	0.47	0.41	0.49	0.44	0.41	0.48	0.52	0.45	0.45	0.54	0.53	0.5	0.45		**0.46**	**0.043**

Average density rate ~ -0.015 per 100 m altitude

Year	Equation used
1986	$\rho = -0.0002 * z + 0.83$
1987	$\rho = -0.000255 * z + 0.942$
1988	$\rho = -0.000277 * z + 0.964$
1989	$\rho = -0.0002 * z + 0.884$
1990	$\rho = -0.0002 * z + 0.818$
1991	$\rho = -0.000468 * z + 0.584$
1997	$\rho = -0.02$ per 100 meters altitude gain

Table A-2. Summer Snow Densities by Altitude, South Cascade Glacier

Balance Year	Date	Altitude(m)	Snow Density
1993	18-Aug	2045	0.53
1993	7-Sep	2045	0.55
1994	2-Jun	1834	0.55
1994	21-Jul	1834	0.57
1995	22-Aug	1844	0.58
1996	15-Jul	2068	0.57
1998	29-Jul	1842	0.58
1998	24-Aug	2034	0.60
1999	20-Jul	1651	0.56

Table A-3. Fall Snow Densities by Altitude, South Cascade Glacier

Balance Year	Date	Altitude(m)	Snow Density
1993	12-Oct	2045	0.58
1995	12-Sep	2037	0.59
1996	9-Oct	2068	0.60
1997	20-Sep	1836	0.58
1999	15-Oct	1834	0.60

Table A-4. Spring Snow Densities, North Cascade Glaciers

Balance Year	Date	Altitude (m)	Snow Density	Glacier
1993	17-May	1770	0.51	Noisy
1993	17-May	2190	0.50	N. Klawatti
1993	19-May	2200	0.53	Silver
2003	19-May	1854	0.51	N. Klawatti
2003	19-May	2348	0.47	N. Klawatti
2003	13-May	1800	0.50	Noisy
2003	15-May	2165	0.45	Sandalee
2003	13-May	2329	0.41	Silver

Appendix D. NOCA glacier monitoring blank field data forms.

Stake labeling: **Year** (07)-**Stake #** (1 @ top of glacier)-**Segment #** (1 @ base of hole)

GLACIER: North Klawatti
DATE: ____________
INITIALS: ____________

Recorded by:
Verified in the field by:

Entered date:
Verified date:
Updated date

Entered by:
Verified by:
Updated by:

Station		1	2	3	4	5
Elevation	m.	2337	2226	2104	1950	1858
	ft.	7665	7300	6900	6397	6096
Location	N:	639769	640333	640645	641086	641409
(UTM NAD27)	E:	5382399	5381795	5381512	5381535	5381240
GPS pt name		NKS1	NKS2	NKS3	NKS4	NKS5
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.)						
	@stk					
SW from stk)	1					
	2					
	3					
	4					
	5					
(NE from stk)	6					
	7					
	8					
	9					
	10					
Notes:		Fall: Record sections left in glacier	Fall: Record sections left in glacier		Fall: Record sections left in glacier	Fall: Leave stake in & mark gl surface
Surface type @ stk Debris thickness						
Stake Height Total stk height above @ time of visit including removed sections *		above/below	above/below	above/below	above/below	above/below
# 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 #	m from top of glacier surface to top of seg #
Spring data		7.5m stk 5 segments 8.5m hole 1m below surface __m ave.probe depth	7.5m stk 5 segments 8.5m hole 1m below surface __m ave.probe depth	7.5m stk 5segments 9m hole 1.5m below surface __m ave.probe depth	9m stk 6 segments 10.5m hole 1.5m below surface __m ave.probe depth	10.5m stk 7 segments 12m hole 1.5m 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")

Appendix D. NOCA glacier monitoring blank field data forms (continued).

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

GLACIER: Silver Creek
DATE: ______________
INITIALS: ______________

Recorded by:
Verified in the field by:

Entered date:
Verified date:
Updated date

Entered by:
Verified by:
Updated by:

Station	**1**	**2**	**3**	**4**
Elevation m.	2565	2476	2306	2155
ft.	8451	8123	7565	7070
Location N:	628948	628780	628562	628467
(UTM NAD27) E:	5425853	5425970	5426074	5426397
GPS pt name	SLS1	SLS2	SLS3	SLS4
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type
@stk				
SW from stk) 1				
2				
3				
4				
5				
(NE from stk) 6				
7				
8				
9				
10				
Notes:				Fall: Leave stake in & mark gl surface
Surface type @ stk Debris thickness				
Stake Height Total stk height above @ time of visit including removed sections *	above/below	above/below	above/below	above/below
# 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	6m stk 4 segments 6.5m hole 0.5m below surface ___m ave.probe depth	7.5m stk 5 segments 8m hole 0.5m below surface ___m ave.probe depth	7.5m stk 5 segments 8m hole 0.5m below surface ___m ave.probe depth	9.0m 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")

Appendix D. NOCA glacier monitoring blank field data forms (continued).

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

GLACIER: Sandalee
DATE: ____________
INITIALS: ____________

Recorded by:
Verified in the field by:

Entered date:
Verified date:
Updated date

Entered by:
Verified by:
Updated by:

Station	1	2	3	4
Elevation m.	2244	2196	2047	1995
ft.	7362	7204	6716	6545
Location N:	663533	663626	663555	663503
(UTM NAD27) E:	5363892	5364137	5364262	5364522
GPS pt name	SNDS1	SNDS2	SNDS3	SNDS4
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type
@stk				
(E from stk) 1				
2				
3				
4				
5				
(W from stk) 6				
7				
8				
9				
10				
Notes:				Fall: Leave stake in & mark gl surface
Surface type @ stk Debris thickness				
Stake Height Total stk height above @ time of visit including removed sections *	above/below	above/below	above/below	above/below
# 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 # ___
Standard Spring data	7.5m stk 5 segments 8m hole 0.5m below surface ___m ave.probe depth	6m stk 4 segments 7m hole 1m below surface ___m ave.probe depth	9.0m stk 6 segments 10.5m hole 1.5m below surface ___m ave.probe depth	9.0m stk 6 segments 10.5m hole 1.5m 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")

Appendix D. NOCA glacier monitoring blank field data forms (continued).

Extra probes data sheet

GLACIER:
DATE: ______________
INITIALS: ______________

Recorded by:
Verified in the field by:

Entered date:
Verified date:
Updated date

Entered by:
Verified by:
Updated by:

Station									
Elevation m.									
ft.									
Location N:									
(UTM NAD27) E:									
GPS pt name									
Snow Probes	Record snow layers & type		Record snow layers & type		Record snow layers & type		Record snow layers & type		
(depth in m.)									
@stk									
S from stk) 1									
2									
3									
4									
5									
(N from stk) 6									
7									
8									
9									
10									
Surface type @ stk									
Debris thickness									
Notes:									

Appendix D. NOCA glacier monitoring blank field data forms (continued).

Snow Core Notes

Glacier: ______________ Location: ______________

Date: ______________ Elevation: __________ m

Initials: ______________ __________ ft

Depth of Pit (m): ______________

Probe Depth at Site (m): ______________

Core diameter = 0.060 m   Core Area= 0.002826 m^2   Density of Water = 1000 kg/m3

Core Push	Snow Depth (m)	Core Length (m)	Core Weight (kg)	Core Volume (m3)	Density (kg/m3)	Density (Fraction of Water)	Water Equivalent (m)	Remarks
	Total Core:							Total Water Equivalent (m)
								Total Water Equivalent (inches)

Appendix E. NOCA glacier monitoring protocol revision history.

Glacier	Date	Change/Error	Explanation	Other Comments
All	ongoing since 1996	Later season probes to compare with spring probes	Snow depth is probed at the summer and fall visits and added to the amount of ablation to check the spring probe depths	
All	1998	Vertical vs. perpendicular probe depth change	Prior to 1997, snow depth was probed perpendicular to the surface slope. However, the standard method used by most glacier researchers is to probe vertically. As a result all probe measurements were corrected using trigonometry after the surface slope of the glaciers was determined.	
All	summer 1999, 2000	Reevaluation of probe data	Individual probe depths were compared to each other at each stake and outliers (not within ~ 0.5 m were thrown out. See original field data sheets for changes.	This is now done after every glacier visit where probe depths are measured.
All	Various	Lost Stakes	Where, why, and what was done to replace lost data. Stake by stake, glacier by glacier basis see individual glacier logs.	
All	2001	Change in balance calculations	Change from stake area method to elevation band and balance map methods	See current Data Reduction Protocol
All	2001	Change in timing of summer visits	from mid to late summer (mid July to mid August) to early to mid summer (mid June to mid July).	Justification: we hope that the snow probes will more accurately record last year's summer surface earlier in the summer. This is particularly important for years following positive mass balance years where there was a significant amount of snow leftover in the fall.
All		GPS locations recorded for all stakes	Will be done every year. ~20 to 50 foot accuracy	
Silver	6/2001	Reevaluation of and adjustments to winter balance data. Need to put details in this log…	In looking at the cumulative balance graph for Silver gl. in relation to the other glaciers it makes a large increase in 1998.	
	1999	Stake 2 lost in crevasse	Stake disappeared	summer balance calculated from best fit curve
Sandalee	Summer 2000 only	Monthly summer visits	Summer hikes made in June, July, and August to assess possible stake sinking.	

Appendix E. NOCA glacier monitoring protocol revision history (continued).

Glacier	Date	Change/Error	Explanation	Other Comments
All	August 2005	Development of Relational Database	Data entered in to new MS Access Database, see Protocol Narrative, Section IV.	Protocol changed to Version 1.01
All	8/2005	Snow core measurement calculations included	Measurement error is calculated from estimated field data error.	SOP #3 changed to Version 1.01
All	2006	Change in fall stake removal	During fall visit to glaciers, bottom sections of stakes remain embedded in ice/snow unless ≥0.5m of stake remains under. Mark glacier surface and record stake numbers.	Stake heights recorded in future years.
All	2006	Change in stake length and depth placed	Due to increased melt and because stake are being left in the ice/snow in the fall, stake lengths are increased and stakes are placed deeper in the ice/snow.	See SOP #1
All	2006	New data sheets	Glacier data sheets have been revised and therefore added to all glaciers	
All	2006	Change in UTM coordinates	Update NAD27 to NAD83	See SOP #1

Appendix F. Probe error.

Spring probe depth measurements and statistics for the four NOCA glaciers, 1995, 1998, and 2000 balance years. These data were compiled to compare variation in spring probe measurement for a spring snow pack (1995) following a strong negative balance year and spring snow packs (1998 and 2000) following a strong positive balance year. A summary of the average variation (average of standard deviations) for each glacier for each year is shown below in Tables F-1 and F-2.

Table F-1. Average variation (average of standard deviations) for each glacier for each year.

		Balance Year		
	Glacier	1995	1998	2000
Average uncertainty (m w.e.)	North Klawatti	0.08	0.08	0.11
	Sandalee	0.06	0.11	0.13
	Silver	0.12	0.23	0.20
	Noisy	0.06	0.07	0.06
	Average	0.08	0.12	0.12

Table F-2. Average variation (average of standard deviations) for each glacier for each year.

		Balance Year		
	Glacier	1995	1998	2000
Average Difference (m w.e.)	North Klawatti	0.21	0.22	0.31
	Sandalee	0.14	0.29	0.38
	Silver	0.30	0.29	0.41
	Noisy	0.16	0.20	0.18
	Average	0.20	0.25	0.32

Appendix F. Probe error (continued).

Sandalee
Spring Probe Depth Statistics
All Depths and statistics are in meters, snow depth.

1995 Summary

Stake	N	ave	Min	Max	Difference	Std Dev
1	5	6.20	6.11	6.28	0.17	0.07
2	5	6.86	6.81	6.93	0.12	0.05
3	7	5.97	5.72	6.29	0.57	0.22
				Ave.	0.29	0.12

Probe values not used

stake	Values not used
1	6.86 too high

1995 Data

Stake	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6	Depth 7
1	6.25	6.28	6.19	6.15	6.11		
2	6.91	6.85	6.82	6.81	6.93		
3	5.97	6.02	6.22	6.29	5.72	5.76	5.8

1998 Summary

Stake	N	ave	Min	Max	Difference	Std Dev
1	5	5.79	5.42	6.19	0.77	0.36
2	8	5.88	5.43	6.13	0.70	0.22
3	11	5.44	5.13	5.68	0.55	0.18
4	11	5.66	5.52	5.83	0.31	0.11
				Ave.	0.58	0.22

Probe values not used

stake	Values not used			
1	5.08	5.26	5.07	5.34

1998 Data

Stake	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6	Depth 7	Depth 8	Depth 9	Depth 10	Depth 11
1	6.15	5.42	6.19	5.63	5.56						
2	5.84	6.03	6.13	5.87	5.9	5.75	6.07	5.43			
3	5.62	5.61	5.49	5.68	5.52	5.54	5.34	5.33	5.25	5.29	5.13
4	5.83	5.81	5.7	5.75	5.63	5.72	5.63	5.53	5.6	5.52	5.58

2000 Summary

Stake	N	ave	Min	Max	Difference	Std Dev
1	9	5.74	5.65	5.86	0.21	0.07
2	7	6.91	6.45	7.41	0.96	0.32
3	10	6.53	6.10	7.04	0.94	0.34
4	9	7.56	7.17	8.06	0.89	0.32
				Ave.	0.75	0.26

Probe values not used

stake	Values not used		
1	5.01	5.07	5.24 too low; proba
2	6.01	6.08	6.24 too low
4	8.33 too high		

2000 Data

Stake	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6	Depth 7	Depth 8	Depth 9	Depth 10
1	5.66	5.78	5.76	5.65	5.69	5.82	5.74	5.67	5.86	
2	7	6.45	7.21	6.78	7.41	6.69	6.84			
3	6.61	6.37	6.89	6.12	6.23	6.1	6.9	6.64	6.44	7.04
4	7.17	7.2	7.23	7.48	7.6	7.77	7.62	8.06	7.93	

Appendix F. Probe error (continued).

Silver Glacier

Spring Probe Depth Statistics

All Depths and statistics are in meters, snow depth.

1995 Summary

Stake	N	ave	Min	Max	Difference	Std Dev (m w.e.)
1	4	6.62	6.16	6.85	0.69	0.31
2	5	5.43	5.34	5.51	0.17	0.06
3	5	4.72	4.22	5.3	1.08	0.42
4	7	3.17	2.93	3.37	0.44	0.16
				Ave.	0.60	0.24

Probe values not used

stake	Values not used
2	6.14 too high
3	6.16 too high

1995 Data

Stake	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6	Depth 7
1	6.16	6.75	6.72	6.85			
2	5.34	5.46	5.51	5.42	5.41		
3	5.3	4.44	4.22	4.88	4.76		
4	3.01	2.93	3.11	3.27	3.37	3.31	3.22

1998 Summary

Stake	N	ave	Min	Max	Difference	Std Dev m w.e.
1	9	4.03	3.19	5.23	2.04	0.78
2	10	6.62	5.56	7.3	1.74	0.65
3	7	7.16	6.82	7.54	0.72	0.24
4	11	2.40	2.09	2.65	0.56	0.18
				Ave.	1.27	0.46

Probe values not used

stake	Values not used
1	ice layer @ 3.2-3.6 (is this SS or ice layer?)

1998 Data

Stake	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6	Depth 7	Depth 8	Depth 9	Depth 10	Depth 11
1	4.80	4.09	3.54	3.43	3.64	3.19	3.34	5.23	4.98		
2	7.03	7.13	7.00	7.23	6.98	7.3	5.91	5.92	6.18	5.56	
3	6.97	7.54	7.08	7.12	7.3	7.31	6.82				
4	2.31	2.33	2.47	2.65	2.58	2.62	2.3	2.25	2.09	2.25	2.5

2000 Summary

Stake	N	ave	Min	Max	Difference	Std Dev m w.e.
1	4	6.70	6.00	7.5	1.50	0.74
2	5	4.98	4.43	5.37	0.94	0.43
3	4	8.57	8.33	8.87	0.54	0.28
4	5	3.16	3.00	3.28	0.28	0.12
				Ave.	0.82	0.39

Probe values not used

stake	Values not used	
1	5.47	8.76 too low and too high
3	6.94 too low	

2000 Data

Stake	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5
1	7.15	7.50	6.15	6.00	
2	5.37	5.37	5.10	4.62	4.43
3	8.33	8.33	8.75	8.87	
4	3	3.09	3.25	3.18	3.28

Appendix F. Probe error (continued).

Noisy Glacier
Spring Probe Depth Statistics

All Depths and statistics are in meters, snow depth.

1995 Summary

Stake	N	ave	Min	Max	Difference	Std Dev (m w.e.)
1	7	7.52	7.45	7.72	0.27	0.10
1E	5	7.69	7.49	8.01	0.52	0.19
1W	5	7.16	7.07	7.25	0.18	0.07
2E	6	7.39	7.10	7.58	0.48	0.18
2	6	6.68	6.56	6.85	0.29	0.12
3	4	6.47	6.37	6.53	0.16	0.07
4	6	6.36	6.17	6.57	0.40	0.15
				Ave.	0.33	0.12

Probe values not used

stake	Values not used	
1	6.76	too low

1995 Data

Stake	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6	Depth 7
1	7.53	7.72	7.47	7.47	7.45	7.45	7.53
1E	7.7	7.6	7.49	8.01	7.67		
1W	7.25	7.07	7.21	7.13	7.16		
2E	7.53	7.47	7.58	7.4	7.1	7.25	
2	6.85	6.68	6.63	6.79	6.58	6.56	
3	6.37	6.5	6.53	6.48			
4	6.5	6.57	6.31	6.17	6.33	6.3	

1998 Summary

Stake	N	ave	Min	Max	Difference	Std Dev m w.e.
1	9	6.11	5.78	6.57	0.79	0.26
2	11	6.41	6.24	6.58	0.34	0.11
3	10	5.72	5.62	5.95	0.33	0.12
4	11	5.68	5.57	5.78	0.21	0.07
5	11	5.67	5.50	5.83	0.33	0.10
				Ave.	0.40	0.13

Probe values not used

stake	Values not used
1	5.06

1998 Data

Stake	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6	Depth 7	Depth 8	Depth 9	Depth 10	Depth 11
1	5.89	6.39	6.12	6.18	6.57	5.97	5.78	6.23	5.87		
2	6.4	6.35	6.41	6.24	6.5	6.45	6.46	6.25	6.54	6.38	6.58
3	5.64	5.63	5.64	5.71	5.62	5.62	5.8	5.95	5.86	5.75	
4	5.76	5.76	5.65	5.64	5.61	5.57	5.78	5.74	5.66	5.65	5.71
5	5.58	5.59	5.70	5.75	5.83	5.78	5.50	5.57	5.62	5.73	5.67

2000 Summary

Stake	N	ave	Min	Max	Difference	Std Dev m w.e.
1	10	6.47	6.28	6.72	0.44	0.15
2	10	7.60	7.44	8	0.56	0.18
3	10	6.16	6.00	6.44	0.44	0.15
4	10	5.97	5.91	6.05	0.14	0.05
5	10	5.99	5.85	6.11	0.26	0.09
				Ave.	0.37	0.12

Probe values not used

stake	Values not used
	NONE

2000 Data

Stake	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6	Depth 7	Depth 8	Depth 9	Depth 10
1	6.72	6.34	6.35	6.49	6.51	6.39	6.52	6.68	6.28	6.39
2	7.44	7.44	7.45	7.83	8	7.51	7.59	7.56	7.55	7.64
3	6.06	6	6.2	6.34	6.25	6.44	6.09	6	6.18	6.03
4	5.97	6.02	6	5.91	6.05	5.98	5.93	5.91	5.93	5.95
5	5.85	6.04	6.05	5.98	6.11	5.98	5.87	6	5.94	6.1

Appendix G. Stake sinking assessment Sandalee Glacier, balance year 1999-2000.

Introduction

Stake sinking results in underestimation of summer balance (overestimation of net balance). It is likely that this error is greater when the base of a stake is placed in firn than if it were placed in ice because the stake may make more progress in “self drilling” in the less dense firn.

Error in stake measurement is primarily due to stake sinking (Ostrem and Brugman 1991). Ostrem and Brugman (p. 29, 1991) documented sinking through a summer season for stakes with similar diameters but of different materials (wood, plastic, aluminum, and steel). The stakes were ~ 1.25 inches in diameter after 200 days (comparable to a North Cascades summer season) a plastic stake sank ~0.25 m w.e.

Methods

We assessed stake sinking by monthly probing during the summer of 2000 on Sandalee Glacier. Probe depths were measured directly adjacent to each stake at five different times during the summer season, April 26, June 29, July 28, August 29, and September 25. Ablation between these dates were calculated from the stake and probe measurements respectively. The differences between stake ablation (a_s) and probe ablation (a_p) were compared between successive measurements. If the stake was sinking between any two measurements then $a_s < a_p$ (and the difference would be negative) (Figure G-1). If the stake was sinking between successive measurements then the expected pattern is a gradually increasing negative difference of a_s - a_p.

Results and Discussion

Figure G-2 shows that from visit to visit the difference between stake ablation and probe ablation ($a_s – a_p$) was not consistently negative except at stake 1. However, stake 1 does not have an increasing negative difference (Table G-1). If a probe consistently penetrated to the same depth past the previous summer surface from visit to visit then the difference between stake and probe ablation would be positive. However, if the stake were sinking in this case then a decreasing positive difference would be seen. This may be the case for stake 4, which has the largest cumulative difference of 0.44 m. The base of stake 4 was placed in firn so stake sinking is expected. Unfortunately, this value falls in the range of uncertainty for probe data so it is impossible to draw firm conclusions from this data.

Appendix G. Stake sinking assessment Sandalee Glacier, balance year 1999-2000 (continued).

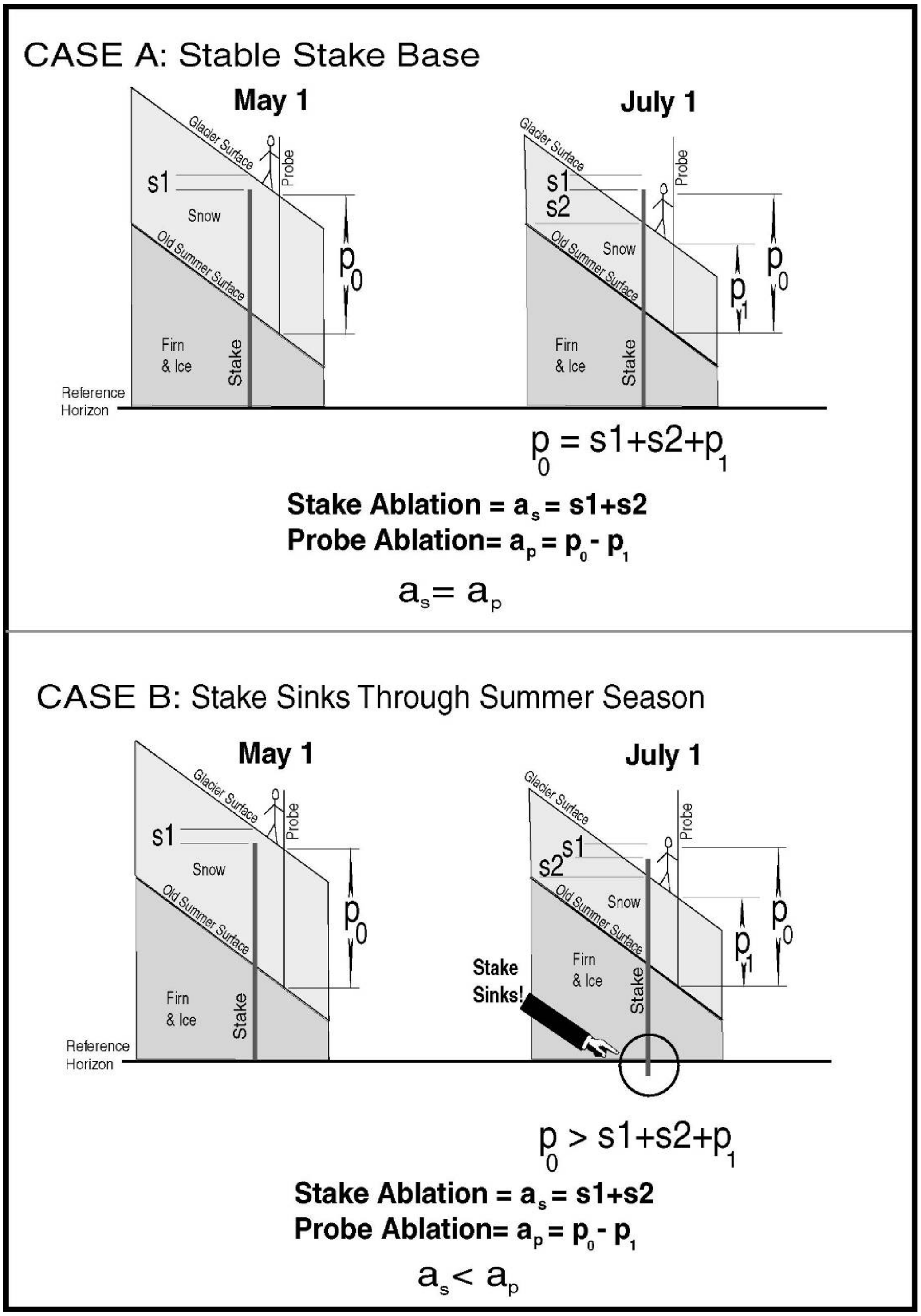

Figure G-1. This diagram outlines relationships between probe and stake measurements and how they relate in the case of stake sinking.

Appendix G. Stake sinking assessment Sandalee Glacier, balance year 1999-2000 (continued).

6/29/00

	Station:	1	2	3	4
	Elevation (m):	2250	2183	2095	2040
	Spring Probe Depth	5.66	7.00	6.61	7.17
	Summer Probe Depth	4.47	5.45	4.52	5.87
	Original Stake Height*	-0.46	-0.58	-0.50	-1.54
	Stake Height @ Visit	0.71	1.16	1.40	0.56
a_p	Ablation from Probe	1.19	1.55	2.09	1.30
a_s	Ablation from Stakes	1.17	1.74	1.9	2.1
a_s-a_p	Difference Stake-Probe	-0.02	0.19	-0.19	0.80

At Stakes 2 and 4 the probe may have penetrated into the firn, yielding a value which under estimates ablation

7/28/00

	Station:	1	2	3	4
	Elevation (m):	2250	2183	2095	2040
	Spring Probe Depth	5.66	7.00	6.61	7.17
	Summer Probe Depth	2.98	4.22	2.95	4.22
	Original Stake Height*	-0.46	-0.58	-0.50	-1.54
	Stake Height @ Visit	1.97	2.40	2.85	2.05
a_p	Ablation from Probe	2.68	2.78	3.66	2.95
a_s	Ablation from Stakes	2.43	2.98	3.35	3.59
a_s-a_p	Difference Stake-Probe	-0.25	0.20	-0.31	0.64

8/29/00

	Station:	1	2	3	4
	Elevation (m):	2250	2183	2095	2040
	Spring Probe Depth	5.66	7.00	6.61	7.17
	Summer Probe Depth	1.67	2.16	3.04	2.18
	Original Stake Height*	-0.46	-0.58	-0.50	-1.54
	Stake Height @ Visit	3.22	3.69	4.40	3.81
a_p	Ablation from Probe	4.00	4.84	3.57	4.99
a_s	Ablation from Stakes	3.68	4.27	4.90	5.35
a_s-a_p	Difference Stake-Probe	-0.32	-0.57	1.33	0.36

Probe at Stake 3 may be in crevasse

9/25/00

	Station:	1	2	3	4
	Elevation (m):	2250	2183	2095	2040
	Spring Probe Depth	5.66	7.00	6.61	7.17
	Fall Probe Depth	1.20	2.41	0.32	0.13
	Original Stake Height*	-0.46	-0.58	-0.50	-1.54
	Stake Height @ Visit	3.76	4.06	4.88	4.27
a_p	Ablation from Probe	4.46	4.59	6.30	7.04
a_s	Ablation from Stakes	4.22	4.64	5.38	5.81
a_s-a_p	Difference Stake-Probe	-0.24	0.05	-0.92	-1.23

* Original stake height on 4/26/00 (depth below surface, hence negative value)

Figure G-2. Raw data and ablation calculations of stake and probe data from Sandalee Glacier, balance year 2000.

Appendix G. Stake sinking assessment Sandalee Glacier, balance year 1999-2000 (continued).

Table G-1. Summary of stake ablation minus probe ablation (a_s – a_p) throughout the summer season of 2000 on Sandalee Glacier. All values are in meters of snow depth.

Station:	1	2	3	4	
Elevation (m):	2250	2183	2095	2040	
May-June	-0.02	0.19	-0.19	0.80	
July	-0.25	0.20	-0.31	0.64	
August	-0.32	NA*	NA*	0.36	
September	-0.24	0.05	NA*	NA*	
May-September, Cumulative	-0.22	-0.14	-0.12	-0.44	(May-August)

*Not Available as a result of bad probe data

Appendix H. Example reporting documents.

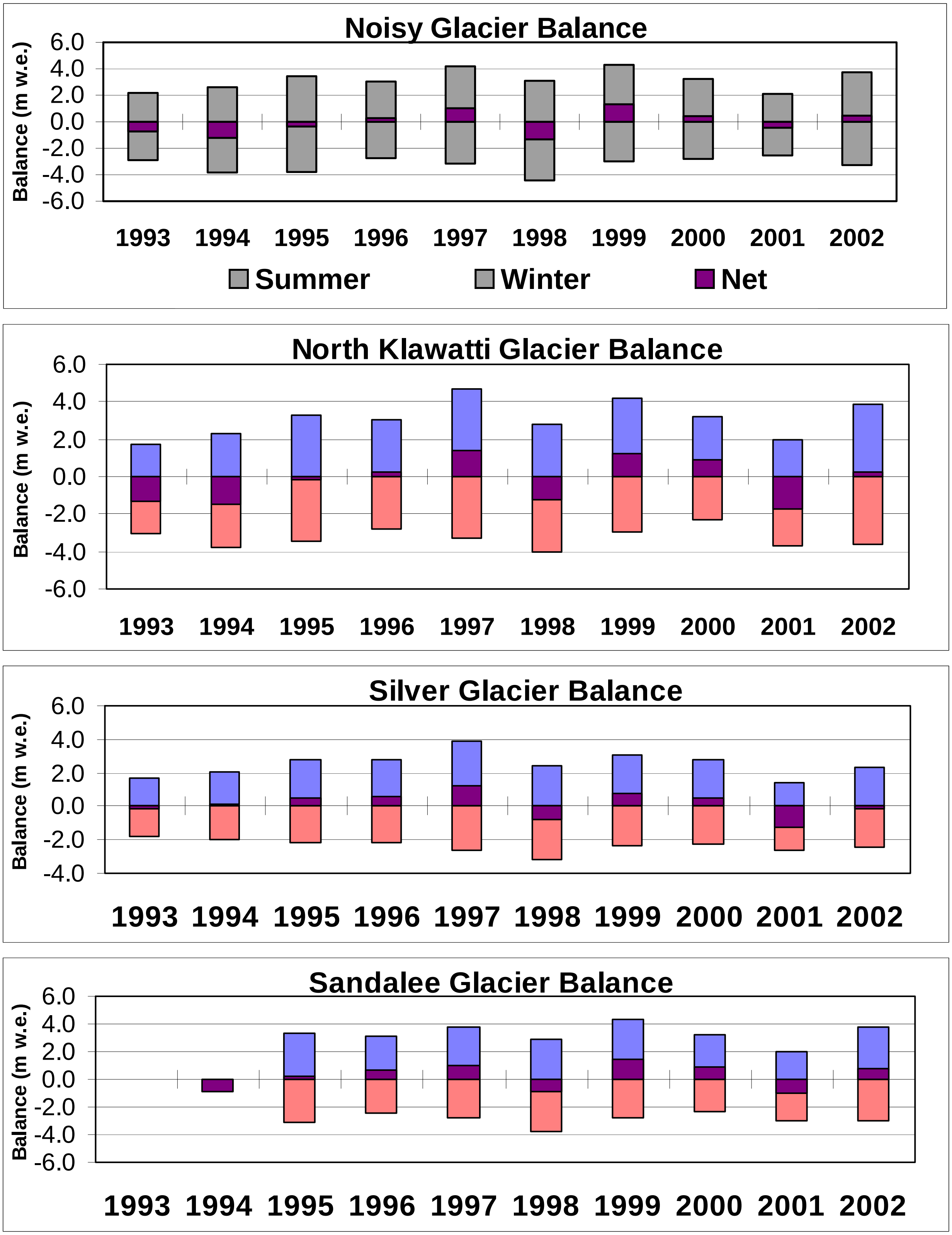

Figure 1. Graphic data summary for North Cascades glaciers.

Appendix H. Example reporting documents (continued).

Table 1. North Cascades glaciers net winter and summer balances.

NOISY CR. GLACIER (.58 km2)												
BALANCE YEAR	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Averages	Cumulatives
Net balance (m w.e.)	-0.74	-1.23	-0.37	0.27	1.02	-1.34	1.32	0.43	-0.45	0.46	-0.06	
Cumulative balance (m w.e.)	-0.74	-1.97	-2.33	-2.06	-1.05	-2.39	-1.07	-0.64	-1.09	-0.63		-0.63
Winter balance (m w.e.)	2.17	2.60	3.44	3.03	4.19	3.09	4.31	3.24	2.10	3.74	3.19	31.89
Summer balance (m w.e.)	-2.90	-3.83	-3.80	-2.76	-3.17	-4.43	-3.00	-2.81	-2.56	-3.27	-3.25	-32.53
Equilibrium line altitude (m)	1834	2000	1785	1758	1690	2000	1550	1900	1860	1750	1810	
Station 1E:												
Elevation (m)	1784	1830	1842	1827	1804	1820	1869	1844	1848	1841	1831	
Winter balance (m w.e.)	2.30	2.86	3.97	3.19	4.61	3.06	4.18	3.24	2.16	3.78	3.33	
Summer balance (m w.e.)	-2.95	-3.65	-3.82	-2.79	-2.97	-4.66	-3.18	-2.85	-2.62	0.00	-2.95	
Net balance (m w.e.)	-0.66	-0.79	0.15	0.41	1.64	-1.61	1.00	0.39	-0.47	0.17	0.02	
Area (km2)	0.12	0.15	0.36	0.83	0.83	0.83	0.83	0.83	0.83	0.83		
Station 1:												
Elevation (m)			1831									
Winter balance (m w.e.)			3.86									
Summer balance (m w.e.)			-3.57									
Net balance (m w.e.)			0.29									
Area (km2)			0.00									
Station 1W:				*(2W)*	*(2W)*	*(2W)*	*(2W)*	*(2W)*	*(2W)*	*(2W)*		
Elevation (m)	1781	1795	1834	1845	1815	1815	1854	1834	1850	1869	1829	
Winter balance (m w.e.)	2.08	2.78	3.70	3.47	4.33	3.21	4.41	3.80	2.49	4.31	3.46	
Summer balance (m w.e.)	-2.94	-3.85	-3.64	-2.67	-2.85	-4.15	-2.93	-2.86	-3.05	0.00	-2.89	
Net balance (m w.e.)	-0.86	-1.07	0.06	0.80	1.48	-0.94	1.48	0.95	-0.57	0.20	0.15	
Area (km2)	0.17	0.18	0.00	0.83	0.83	0.83	0.83	0.83	0.83	0.83		
Station 2E:												
Elevation (m)			1820									
Winter balance (m w.e.)			3.82									
Summer balance (m w.e.)			-3.48									
Net balance (m w.e.)			0.34									
Area (km2)			0.01									
Station 2:				*(3)*	*(3)*	*(3)*	*(3)*	*(3)*	*(3)*	*(3)*		
Elevation (m)			1814	1800	1789	1749	1832	1806	1800	1799	1799	
Winter balance (m w.e.)			3.45	2.99	3.76	2.86	4.13	3.08	1.91	3.56	3.22	
Summer balance (m w.e.)			-3.48	-2.56	-2.96	-3.77	-2.72	-2.61	-2.48	0.00	-2.57	
Net balance (m w.e.)			0.34	0.43	0.80	-0.91	1.41	0.48	-0.57	0.15	0.26	
Area (km2)			0.00	1.66	1.66	1.66	1.66	1.66	1.66	1.66		
Station 3:				*(4)*	*(4)*	*(4)*	*(4)*	*(4)*	*(4)*	*(4)*		
Elevation (m)	1769	1777	1780	1787	1770	1735	1808	1768	1776	1756	1773	
Winter balance (m w.e.)	2.08	2.48	3.24	2.84	3.84	2.84	4.27	2.99	1.87	3.36	2.98	
Summer balance (m w.e.)	-3.11	-3.87	-4.11	-2.71	-3.83	-4.59	-2.90	-2.62	-2.31	0.00	-3.00	
Net balance (m w.e.)	-1.03	-1.39	-0.87	0.13	0.01	-1.75	1.37	0.37	-0.44	0.16	-0.34	
Area (km2)	0.08	0.08	0.46	0.28	0.28	0.28	0.28	0.28	0.28	0.28		
Station 4:				*(5)*	*(5)*	*(5)*	*(5)*	*(5)*	*(5)*	*(5)*		
Elevation (m)	1754	1761	1744	1708	1737	1707	1769	1723	1768	1716	1739	
Winter balance (m w.e.)	2.11	2.38	3.26	2.66	3.77	2.84	4.26	3.00	1.93	3.47	2.97	
Summer balance (m w.e.)	-3.39	-3.67	-4.04	-2.99	-4.16	-5.05	-3.22	-2.99	-2.27	0.08	-3.17	
Net balance (m w.e.)	-1.27	-1.30	-0.78	-0.33	-0.39	-2.21	1.04	0.01	-0.34	0.18	-0.54	
Area (km2)	0.08	0.06	0.12	0.18	1.75	1.75	1.75	1.75	1.75	1.75		
Station 5:												
Elevation (m)	1739	1728										
Winter balance (m w.e.)	1.98	2.47										
Summer balance (m w.e.)	-3.35	-4.04										
Net balance (m w.e.)	-1.37	-1.57										
Area (km2)	0.08	0.06										

Appendix H. Example reporting documents (continued).

Table 1. North Cascades glaciers net winter and summer balances (continued).

SILVER GLACIER (.49 km2)												
BALANCE YEAR:	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Averages	Cumulatives
Net balance (m w.e.)	-0.11	0.09	0.54	0.57	1.22	-0.81	0.74	0.52	-1.23	-0.15	0.17	
Cumulative balance (m w.e.)	-0.11	-0.02	0.52	1.09	2.31	1.50	2.24	2.76	1.54	1.39		1.39
Winter balance (m w.e.)	1.68	2.08	2.75	2.77	3.88	2.41	3.10	2.80	1.44	2.33	2.52	25.24
Summer balance (m w.e.)	-1.79	-1.99	-2.21	-2.20	-2.66	-3.22	-2.36	-2.28	-2.67	-2.47	-2.37	-23.84
Equilibrium line altitude (m)	2300	2430	2380	2290	2325	2470	2280	2265	2450	2340	2354	
Station 1:												
Elevation (m)	2506	2497	2504	2550	2523	2530	2535	2650	2576	2570	2544	
Winter balance (m w.e.)	2.36	2.63	3.50	2.67	3.84	2.39	4.79	3.35	2.09	3.61	3.12	31.23
Summer balance (m w.e.)	-1.64	-1.81	-1.54	-1.66	-1.68	-2.47	-1.76	-1.51	-1.56	0.00	-1.74	-15.63
Net balance (m w.e.)	0.72	0.82	1.96	1.02	2.17	-0.08	3.04	1.85	0.53	3.61	1.34	15.64
Area (km2)	0.16	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16		
Station 2:												
Elevation (m)	2360	2356	2349	2420	2436	2389	2419	2530	2439	2470	2417	
Winter balance (m w.e.)	1.56	2.42	3.14	2.71	4.05	2.50	3.60	2.49	2.00	2.46	2.69	26.93
Summer balance (m w.e.)	-1.45	-1.99	-2.24	-2.09	-2.22	-3.04	-2.40	-1.76	-2.31	0.00	-2.17	-19.50
Net balance (m w.e.)	0.12	0.43	0.90	0.62	1.83	-0.54	1.20	0.74	-0.31	2.46	0.55	7.45
Area (km2)	0.14	0.10	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20		
Station 2b:												
Elevation (m)					2378							
Winter balance (m w.e.)					4.33							
Summer balance (m w.e.)					-2.26							
Net balance (m w.e.)					2.07							
Area (km2)												
Station 3:												
Elevation (m)	2270	2270	2245	2298	2263	2279	2318	2370	2302	2305	2292	
Winter balance (m w.e.)	2.64	1.43	2.40	3.47	5.10	4.22	4.17	3.91	1.81	3.52	3.27	32.67
Summer balance (m w.e.)	-1.53	-1.94	-2.55	-2.13	-3.40	-3.15	-2.23	-2.06	-2.37	0.00	-2.37	-21.36
Net balance (m w.e.)	1.11	-0.51	-0.15	1.34	1.70	0.44	1.94	1.86	-0.55	3.52	0.80	10.70
Area (km2)	0.05	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06		
Station 4:												
Elevation (m)	2198	2209	2148	2198	2211	2202	2236	2270	2180	2146	2200	
Winter balance (m w.e.)	0.74	1.87	1.72	2.57	2.51	3.70	1.59	1.58	0.3	2.63	1.92	19.21
Summer balance (m w.e.)	-2.38	-1.59	-3.24	-2.32	-3.49	-5.40	-2.98	-2.68	-3.9	0.37	-3.11	-27.61
Net balance (m w.e.)	-1.64	0.29	-1.52	0.25	-0.98	-4.20	-1.39	-1.1	-3.6	3.00	-1.54	-10.89
Area (km2)	0.14	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07		
Station 5:												
Elevation (m)	2166	2141										
Winter balance (m w.e.)	0.15	0.74										
Summer balance (m w.e.)		-3.76										
Net balance (m w.e.)		-3.02										
Area (km2)		0.07										

Appendix H. Example reporting documents (continued).

Table 1. North Cascades glaciers net winter and summer balances (continued).

N. KLAWATTI GLACIER (1.46 km2)												
BALANCE YEAR:	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Averages	Cumulatives
Net balance (m w.e.)	-1.35	-1.47	-0.17	0.23	1.42	-1.23	1.26	0.87	-1.72	0.22	-0.19	
Cumulative balance (m w.e.)	-1.35	-2.82	-2.99	-2.76	-1.34	-2.57	-1.31	-0.44	-2.16	-1.94		-1.94
Winter balance (m w.e.)	1.7	2.3	3.28	3.03	4.69	2.83	4.21	3.19	2.00	3.84	3.11	31.07
Summer balance (m w.e.)	-3.05	-3.77	-3.45	-2.8	-3.26	-4.06	-2.95	-2.32	-3.72	-3.62	-3.30	-33.00
Equilibrium line altitude (m)	2240	2310	2102	2025	2070	2310	1975	1915	2440	2070	2146	
Station 1: Elevation (m)	2308	2317	2317	2323	2327	2300	2368	2330	2337	2337	2093	
Winter balance (m w.e.)	2.11	2.31	3.50	3.28	5.04	2.95	4.64	2.99	1.9	7.20	3.59	
Summer balance (m w.e.)	-1.86	-2.64	-2.68	-2.08	-2.56	-3.2	-1.47	-1.89	-2.82	0.00	-2.12	
Net balance (m w.e.)	0.25	-0.33	0.82	1.2	2.48	-0.25	3.17	1.11	-0.92	-2.80	0.47	
Area (km2)	0.35	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21		
Station 2: Elevation (m)	2250	2294	2286	2286	2297	2269	2336	2256	2226	2	2050	
Winter balance (m w.e.)	1.98	2.23	3.53	2.85	5.37	3.04	4.84	3.2	2.19	7.27	3.65	
Summer balance (m w.e.)	-1.72	-2.56	-2.63	-2.09	-2.77	-3.17	-2.23	-2.01	-3.22	0.00	-2.24	
Net balance (m w.e.)	0.27	-0.33	0.90	0.76	2.60	-0.13	2.62	1.19	-1.03	-3.27	0.36	
Area (km2)	0.30	0.16	0.16	0.36	0.36	0.36	0.36	0.36	0.36	0.36		
Station 2N: Elevation (m)		2300										
Winter balance (m w.e.)		2.07										
Summer balance (m w.e.)		-2.40										
Net balance (m w.e.)		-0.33										
Area (km2)		---										
Station 2S: Elevation (m)		2294										
Winter balance (m w.e.)		2.86										
Summer balance (m w.e.)		-2.39										
Net balance (m w.e.)		0.47										
Area (km2)		---										
Station 3: Elevation (m)	2189	2263	2271									
Winter balance (m w.e.)	1.23	2.25	3.22									
Summer balance (m w.e.)	-2.93	-3.54	-2.75									
Net balance (m w.e.)	-1.70	-1.29	0.47									
Area (km2)	0.12	0.40	0.40									
Station 4:					*(3)*	*3*	*3*	*3*	*3*	*3*		
Elevation (m)	2065	2106	2109	2099	2104	2090	2163	2127	2104	3	1897	
Winter balance (m w.e.)	2.47	2.37	3.46	3.49	5.10	2.83	4.26	3.32	1.98	7.35	3.66	
Summer balance (m w.e.)	-2.93	-3.90	-3.41	-2.54	-3.08	-4.15	-2.78	-2.39	-3.67	0.00	-2.89	
Net balance (m w.e.)	-1.70	-1.52	0.05	0.96	2.02	-1.32	1.48	0.93	-1.69	-3.14	-0.39	
Area (km2)	0.27	0.27	0.19	0.51	0.51	0.51	0.51	0.51	0.51	0.51		
Station 5:					*(4)*	*4*	*4*	*4*	*4*	*4*		
Elevation (m)	1912	1955	1926	1922	1946	1938	2000	1936	1919	4	1746	
Winter balance (m w.e.)	1.63	2.01	2.91	2.85	3.66	2.24	4.26	3.19	2.04	6.49	3.13	
Summer balance (m w.e.)	-5.22	-6.00	-5.22	-4.76	-4.02	-6.47	-3.87	-3.04	-4.77	0.00	-4.34	
Net balance (m w.e.)	-3.59	-3.99	-2.30	-1.91	-0.36	-4.23	0.39	0.15	-2.73	-4.84	-2.34	
Area (km2)	0.42		0.27	0.15	0.15	0.15	0.15	0.15	0.15	0.15		
Station 6N: Elevation (m)		1891									1891	
Winter balance (m w.e.)		1.87									1.87	
Summer balance (m w.e.)		-5.58									-5.58	
Net balance (m w.e.)		-3.71									-3.71	
Area (km2)		---										
Station 6:					*(5)*	*5*	*5*	*5*	*5*	*5*		
Elevation (m)		1891	1884	1876	1915	1856	1931	1845	1867	5	1674	
Winter balance (m w.e.)		1.73	2.48	2.45	3.12	2.38	3.31	2.86	1.52	6.18	2.89	
Summer balance (m w.e.)		-5.41	-5.24	-4.00	-4.37	-5.82	-3.88	-3.47	-5.6	0.00	-4.20	
Net balance (m w.e.)		-3.68	-2.76	-1.54	-1.25	-3.44	-0.57	-0.6	-4.09	-4.29	-2.47	
Area (km2)		0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23		
Station 6S: Elevation (m)		1876										
Winter balance (m w.e.)		2.09										
Summer balance (m w.e.)		-5.55										
Net balance (m w.e.)		-3.46										
Area (km2)		---										

Appendix H. Example reporting documents (continued).

Table 1. North Cascades glaciers net winter and summer balances (continued).

SANDALEE GLACIER (.195 km2)												
BALANCE YEAR	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Averages	Cumulatives
Net Balance (m w.e)	n/a	-0.90	0.27	0.68	1.03	-0.9	1.48	0.86	-1.00	0.75	0.19	
Cumulative Balance (m w.e.)		-0.90	-0.63	0.05	1.08	0.18	1.66	2.52	1.52	2.27		2.27
Winter Balance (m w.e.)	n/a	n/a	3.35	3.08	3.77	2.85	4.28	3.23	1.96	3.75	3.28	26.27
Summer Balance (m w.e.)	n/a	n/a	-3.07	-2.40	-2.74	-3.75	-2.80	-2.37	-2.97	-3.00	-2.87	-23.10
Equilibrium Line Altitude (m)	n/a	2305	2150	2100	2050	2270	1960	1965	2294	2200	2137	
Station 1:												
Elevation (m)	n/a	n/a	2227	2249	2224	2223	2255	2238	2250	2267	2238	
Winter balance(m w.e.)	n/a	n/a	3.14	3.14	3.80	2.85	3.88	2.87	1.70	3.22	3.05	
Summer balance (m w.e.)	n/a	n/a	-2.91	-2.24	-2.56	-3.35	-2.52	-2.11	-2.61	0.0	-2.61	
Net balance (m w.e.)	n/a	n/a	0.23	0.91	1.25	-0.50	1.36	0.76	-0.91	1.0	0.44	
Area (km2)	n/a	n/a	0.103	0.103	0.087	0.087	0.087	0.087	0.087	0.087		
Station 2:												
Elevation (m)	n/a	n/a	2142	2170	2140	2153	2184	2146	2182	2195	2160	
Winter balance(m w.e.)	n/a	n/a	3.70	3.31	3.85	2.97	4.71	3.34	2.03	3.8	3.42	
Summer balance (m w.e.)	n/a	n/a	-2.72	-2.25	-2.87	-3.35	-2.78	-2.32	-2.86	0.0	-2.74	
Net balance (m w.e.)	n/a	n/a	0.98	1.06	0.98	-0.38	1.93	1.02	-0.83	1.9	0.68	
Area (km2)	n/a	n/a	0.061	0.061	0.039	0.039	0.039	0.039	0.039	0.039		
Station 3:												
Elevation (m)	n/a	n/a	2044	2064	2066	2081	2089	2058	2090	2111	2070	
Winter balance(m w.e.)	n/a	n/a	3.45	2.82	3.06	2.72	3.85	3.27	1.92	3.7	3.01	
Summer balance (m w.e.)	n/a	n/a	-3.67	-2.96	-3.09	-5.16	-3.18	-2.69	-3.40	0.0	-3.45	
Net balance (m w.e.)	n/a	n/a	-0.23	-0.14	-0.04	-2.44	0.68	0.58	-1.48	0.8	-0.44	
Area (km2)	n/a	n/a	0.031	0.031	0.039	0.039	0.039	0.039	0.039	0.039		
Station 4:												
Elevation (m)	n/a	n/a	n/a	n/a	1994	2018	2036	2000	2010	2029	2012	
Winter balance(m w.e.)	n/a	n/a	n/a	n/a	4.46	2.83	5.44	3.82	1.80	3.9	3.67	
Summer balance (m w.e.)	n/a	n/a	n/a	n/a	-3.61	-4.42	-3.35	-2.91	-2.90	0.0	-3.44	
Net balance (m w.e.)	n/a	n/a	n/a	n/a	0.86	-1.59	2.09	0.92	-1.10	0.9	0.24	
Area (km2)	n/a	n/a	n/a	n/a	0.031	0.031	0.031	0.031	0.031	0.031		

Appendix H. Example reporting documents (continued).

GLACIER PAGE 2002

North Cascades National Park - Glacier Monitoring Program

The National Park Service began monitoring glaciers in North Cascades National Park in 1993. Goals for this program and additional data can be found at North Cascades National Park home page at http:/www.nps.gov/noca/massbalance.htm.

The four glaciers monitored are located at the headwaters of four park watersheds, each with large hydroelectric operations (Figure 1). The glaciers represent a range in elevation from 8500 to 5700 feet, and a range in climatic conditions from maritime to continental. Methods include at least two visits annually to each glacier to measure winter accumulation and summer melt. Measurements are taken at a series of points down the centerline of each glacier (Table 1), then integrated across the entire glacier surface to determine mass balance for the entire glacier. Glaciers east of the hydrologic crest of the park (Silver and Sandalee) have recently had more positive mass balances than the west-side glaciers (Noisy, North Klawatti, South Cascade) due to their higher elevations, and north aspects (Figure 2). We are entering our tenth year of this program. In addition to the accumulation and ablation measurements each glacier will be remapped to quantify terminus and surface elevation changes. A 10-year summary will be published next year.

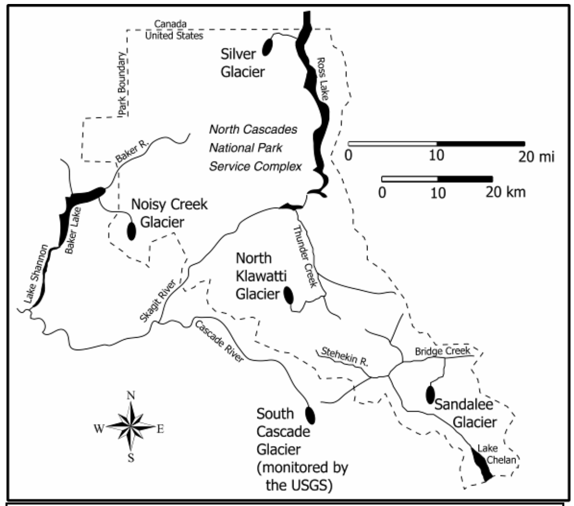

Figure 1. Glaciers monitored in North Cascades N.P.S. Complex.

Table 1.

Glacier:	Elevation (feet)	Average Accumulation (inches W.E.)	2002 Accumulation (inches W.E.)	2002 Percent of Average
Noisy Creek	**Entire Glacier**	**125**	**141**	**113**
	6130	134	146	109
	6040	131	149	113
	5900	127	140	111
	5760	117	132	113
	5630	117	137	117
Silver	**Entire Glacier**	**103**	**125**	**122**
	8430	125	167	133
	7940	112	154	138
	7560	128	135	105
	7040	76	104	137
North Klawatti	**Entire Glacier**	**121**	**137**	**113**
	7665	128	151	118
	7400	129	138	107
	7000	129	134	104
	6520	110	128	116
	6240	100	122	121
Sandalee	**Entire Glacier**	**128**	**137**	**107**
	7380	120	127	105
	7085	134	150	111
	6757	119	146	123
	6560	144	137	95

Table 1 presents this spring's winter accumulation data, along with average values and percent of the 10-year average. The 2002 snow depths were measured between April 29 and May 1 on the four glaciers. Ice layers and cold temperatures within the snowpack made probing difficult for the stations in gray text. These data are suspect and may be revised after a July visit. Snow water equivalent is determined using an assumed density of 0.5. Accumulation generally increases with elevation, but this winter, wind and avalanching were responsible for significantly redistributing snow. This year's accumulation values are above the ten-year average, and are the third highest in the last 10 years (behind the winters of 96/97 and 98/99).

Appendix H. Example reporting documents (continued).

GLACIER PAGE 2002 (continued)

Estimates of glacial contribution to runoff for three watersheds are based on the mass balance measurements and GIS analysis to determine glacier area within 165 ft elevation bands (Table 2). Glaciers reduce the variation of flow in these watersheds by providing melt water from ice in dry/warm years, and by storing water in wet/cool years. Glacial contribution to streamflow in these watersheds varies by as much as 100% annually. Magnitude of glacial contribution to streamflow is large, but varies by the amount of glacial cover in each watershed. Thunder Creek is 13% glaciated, while Baker River and Stehekin River are 6% and 3%, respectively (Post and others, 1971).

Relative importance of glacial contribution to streamflow increases from west to east. For example, glaciers annually contribute a higher percentage of melt water to streamflow in the Stehekin watershed than in the Baker, despite the fact that the Baker is more glaciated. This is due to lower snowfall east of the hydrologic crest of the North Cascades. In this high accumulation year we anticipate that glacial contribution to summer runoff will be below average in these watersheds.

	Mean Glacial Runoff	Range of Glacial Runoff		Percent Glacial Runoff to Total Summer Runoff	
		Minimum	Maximum	Minimum	Maximum
Noisy Creek Glacier	1.6	1.1	2.1	---	---
Baker River Watershed	74.0	51.0	93.0	6	14
North Klawatti Glacier	3.9	2.8	4.8	---	---
Thunder Creek Watershed	102.0	80.0	135.0	23	45
Sandalee Glacier	0.4	0.4	0.5	---	---
Stehekin River Watershed	68.0	54.0	91.0	6	16

Table 2. Glacial contribution to summer stream flow (May 1 to Sept. 30) for three watersheds. Runoff units are thousands of acre-feet. Data from 1993-2001 except the Sandalee Glacier and Stehekin River Watershed (1995-2001).

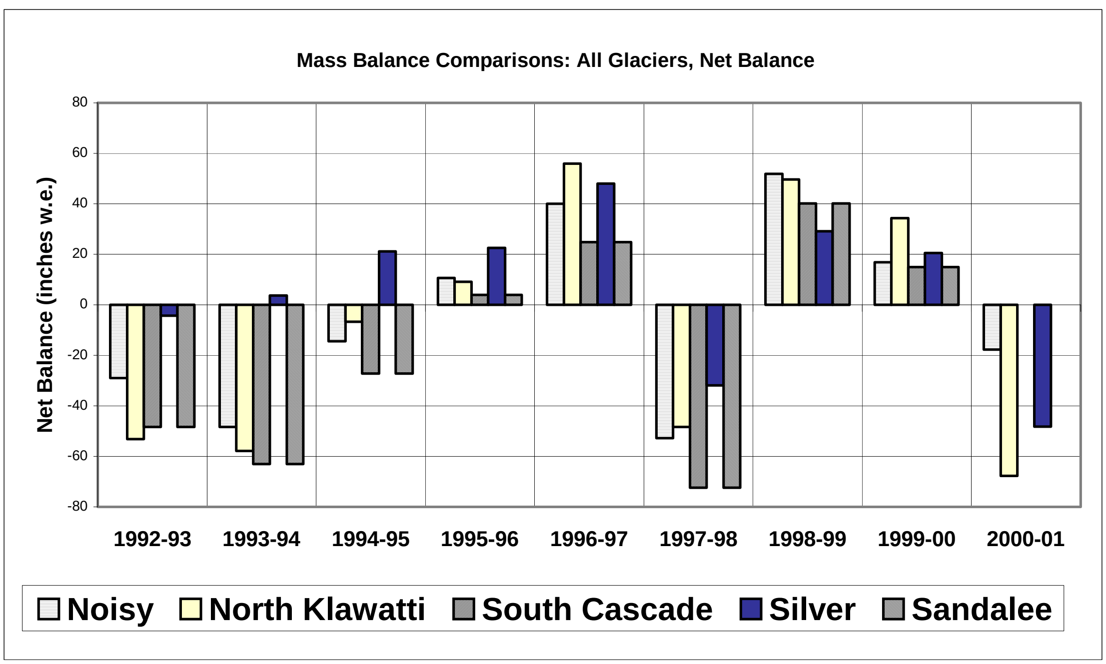

Figure 2. Net annual mass balance for the five glaciers monitored in the North Cascades.

Appendix I. Job hazard analysis.

Project Analyzed: Glacier Monitoring
Date: July 2002
Analyst: Jon Riedel, Park Geologist

Analysis Approved:
Title:
Date:

Task	Hazard	Action to mitigate hazard
access to glacier	helo. travel	-helicopter briefings before each trip -flight request and load calculations completed before each trip -all employees conducting this program have received helo training. Mike Larrabee took S317 class for helo managers in ’06. Jeannie Wenger took helo spot S217/S271 class in ’01 (M L in ‘02). JW, and ML have all taken I-272, helo spot manager class, and A-330, transportation of hazardous materials.
access to glacier	cross country travel including but not limited to; stream crossings, boulder hopping, crossing steep snow/ice resulting in twisted ankles, broken bones, etc..	-employees briefed in job KSA’s and are familiar, competent traveling on this terrain. -all wear appropriate footwear -1-2 first aid/trauma kits are carried on each trip
drilling holes in ice	burns from steam	-Employees are properly trained in steam drill use. -A safer drill was purchased in 1995. A new lighter drill was purchased in ’02.
	back injury	-employees always assist each other in placing backpack mounted steam drill on an individual

Appendix I. Job hazard analysis (continued).

Task	Hazard	Action to mitigate hazard
glacier travel	falling into crevasse	-all employees and volunteers are briefed on associated with each glacier before every trip -employees are always roped up when on a glacier, and never travel alone -at least one member of each rope team has experience and/or training in glacier travel - principle investigators have received training in glacier travel and crevasse rescue. P.I.s assisted a member of the park staff who is a professional mountain climbing and glacier travel guide in instructing a refresher course in '02
glacier travel	snow avalanches	-during spring visits when avalanche danger is high, all employees will carry an avalanche beacon and have snow shovels available
glacier travel	altitude (Rainier)	-employees have had wilderness 1st aid/First Responder, courses which includes training in identifying and treating altitude sickness.
objective hazards	injuries associated with falling rock and ice	-helmets are worn in high risk areas -try to travel during appropriate times. ie. early morning when snow bridges over crevasses have frozen and rock and ice are frozen to cliffs.

Appendix J. Glacier monitoring protocol database documentation.

The database for this project consists of three types of tables: core tables describing the “who, where and when” of data collection, project-specific tables, and lookup tables that contain domain constraints for other tables. Although core tables are based on NCCN standards, they may contain fields, domains or descriptions that have been added or altered to meet project objectives.

The database includes the following standard tables:

tbl_Sites	Sample sites - glaciers that are monitored
tbl_Locations	Sample locations - specific data collection points (e.g., stakes, probes)
tbl_Coordinates	Coordinate data for sample locations
tbl_GPS_Info	GPS information associated with sample location coordinates
tbl_Sample_Periods	The span of dates during which data collection occurs
tbl_Events	Data collection event for a given location
tbl_Observers	Observers for each sampling event
tbl_QA_Results	Quality assurance query results for the working data set
tbl_Edit_Log	Edit log for changes made to data after certification
tbl_Task_List	Checklist of tasks to be completed at sampling locations
tbl_Images	Images associated with sample locations

The following are project-specific data tables:

tbl_Air_Photos	Air photos related to this project
tbl_Core_Pushes	Snow core density measurements from individual core pushes
tbl_Depth_Probes	Measurements for snow depth and/or debris thickness depths
tbl_Elevation_Bands	Elevation band areas for source maps associated with this project
tbl_Glacier_Areas	Glacier area estimates
tbl_Maps	Source maps for this project
tbl_Snow_Cores	Snow core density sampling information
tbl_Stake_Heights	Relative stake height measurements
tbl_Surface_Profile	Surface profile data

The following is one of the more prominent, standard lookup tables:

tlu_Project_Crew	List of personnel associated with a project

Appendix J. Glacier monitoring protocol database documentation (continued).

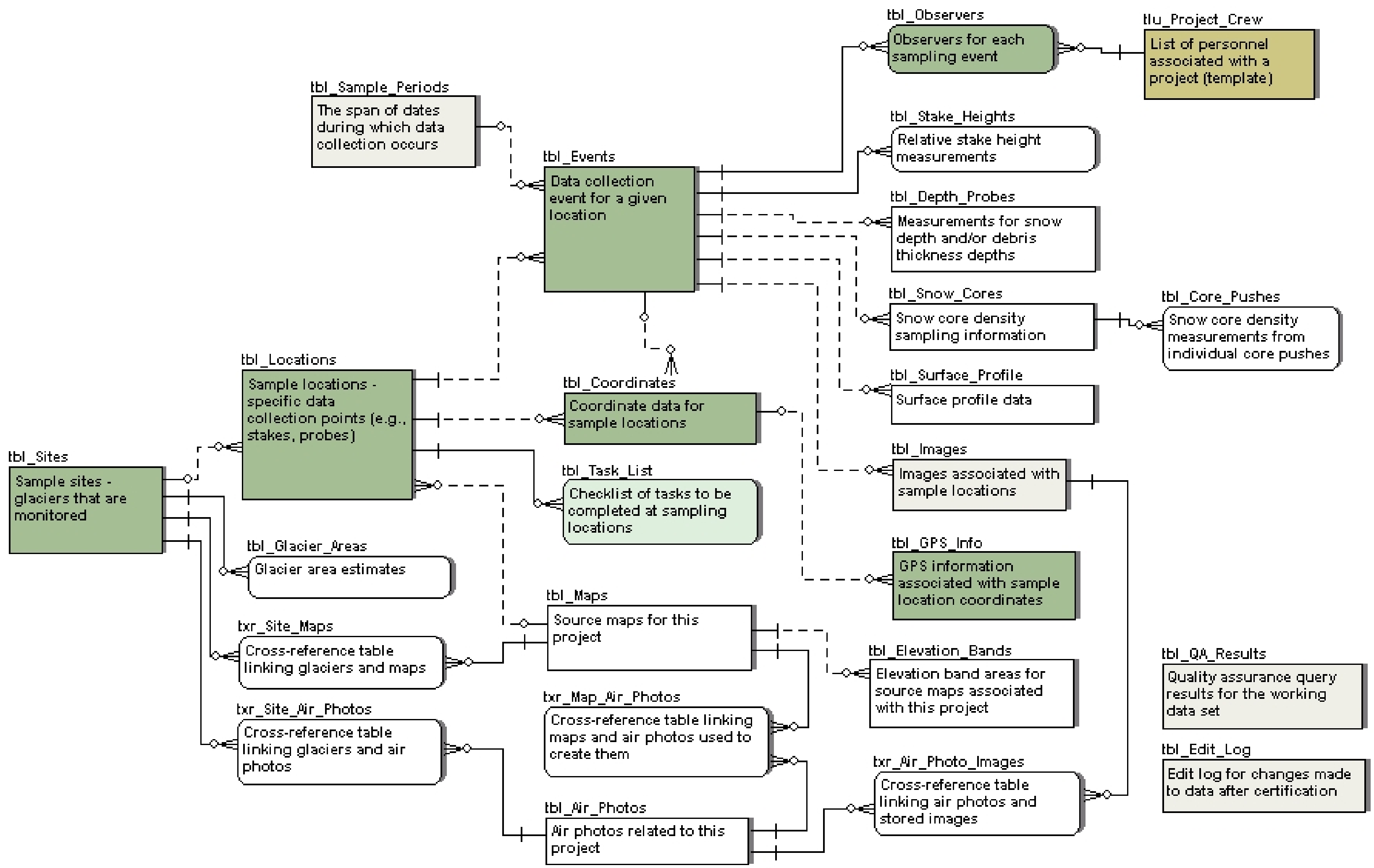

Figure 1. Entity Relationship Diagram of the project database. Relationships between tables are represented by lines. Dark green tables represent core standard tables; light green represents extended standard tables; light brown are standard lookup tables. Project-specific tables are unshaded.

Appendix J. Glacier monitoring protocol database documentation (continued).

Data Dictionary

Required fields are denoted with an asterisk (*).

tbl_Air_Photos - Air photos related to this project

Index	*Index columns*
Image_quality	Photo_quality, <lastindexcol>
Photo_date	Photo_date, <lastindexcol>
Photo_num	Photo_num, <lastindexcol>
pk_tbl_Air_Photos (primary)	Air_photo_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Air_photo_ID	primary *	text (50)	Unique identifier for each air photo
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Photo_num	indexed	text (25)	Number of the air photo, if any
Photo_date	indexed	datetime	Date on which the air photo was taken
Photo_scale		text (16)	Scale of the photograph (e.g., 1:24,000)
Color_scheme		text (16)	Color scheme of the photograph
Photo_format		text (12)	Format of the photograph
Photo_source		text (50)	Name of the person or organization that produced the photograph
Photo_altitude_ft		int	Altitude of the aircraft, in feet
	Constraint: Is Null Or >0		
Flight_direction		text (5)	Orientation of the flight line
UTM_east		double	Air photo center coordinates - UTM Easting (zone 10N), in meters
UTM_north		double	Air photo center coordinates - UTM Northing (zone 10N), in meters
Datum_horiz		text (5)	Center coordinate horizontal datum
Datum_vert		text (25)	Center coordinate vertical datum
Photo_time		datetime	UTC time of air photograph
Photo_quality	indexed	tinyint	Suitability of the photograph for photogrammetry
Snow_cover_percent		tinyint	Percent of the image covered by snow
	Constraint: Is Null Or (>=0 And <=100)		
Photo_interp_notes		text (255)	Notes on photo interpretation suitability
Text_on_photo		text (255)	Text that is present on the photo
Photo_location		text (255)	Storage location of the photograph
N_copies		tinyint	Number of copies of the photograph
Photo_is_active		bit	Indicates whether the photo is still being used for interpretation
	Default: Yes		
Air_photo_notes		memo	Additional comments about the air photo

Appendix J. Glacier monitoring protocol database documentation (continued).

tbl_Coordinates - Coordinate data for sample locations

Index	*Index columns*
Coord_label	Coord_label, <lastindexcol>
Coord_type	Coord_type, <lastindexcol>
Coord_updated	Coord_updated, <lastindexcol>
Datum	Datum, <lastindexcol>
Event_ID	Event_ID, <lastindexcol>
Field_coord_source	Field_coord_source, <lastindexcol>
GIS_loc_ID	GIS_loc_ID, <lastindexcol>
Location_ID	Location_ID, <lastindexcol>
pk_tbl_Coordinates (primary)	Coord_ID, <lastindexcol>
Process_type	Public_type, <lastindexcol>
Public_scale	Public_scale, <lastindexcol>
udx_Coord_index (unique)	Location_ID, Event_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Coord_ID	primary *	text (50)	Unique identifier for each coordinate record
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
GIS_loc_ID	indexed	text (50)	GIS feature ID for each set of coordinates, to link with geospatial layers
Location_ID	unique (FK)*	text (50)	Sample location
Event_ID	unique (FK)	text (50)	Sampling event of coordinate data collection
Coord_label	indexed	text (25)	Name of the coordinate feature (e.g., plot center, NW corner)
Is_best		bit	Indicates whether this set of coordinates is the best available for this location
UTM_east		double	Final UTM easting (zone 10N, meters), including any offsets and corrections
UTM_north		double	Final UTM northing (zone 10N, meters), including any offsets and corrections
Coord_type	indexed	text (20)	Coordinate type stored in UTM_east and UTM_north: target, field, post-processed
Datum	indexed	text (5)	Datum of UTM_east and UTM_north
	Default: "NAD83"		
Est_horiz_error		double	Estimated horizontal error (meters) of UTM_east and UTM_north
UTME_public		double	UTM easting (zone 10N, meters) after any dithering or resolution reduction
UTMN_public		double	UTM northing (zone 10N, meters) after any dithering or resolution reduction
Public_type	indexed	text (50)	Type of processing performed to make coordinates publishable
Public_scale	indexed	text (50)	Estimated accuracy of public coordinates
Field_UTME		double	UTM easting (zone 10N) as recorded in the field
Field_UTMN		double	UTM northing (zone 10N) as recorded in the field
Field_datum		text (5)	Datum of field coordinates
Field_horiz_error		double	Field coordinate horizontal error (m)
Field_offset_m		double	Distance (meters) from the field coordinates to the target
	Constraint: Is Null Or >=0		
Field_offset_azimuth		int	Azimuth (degrees, declination corrected) from the coordinates to the target
	Constraint: Is Null Or (>=0 And <=360)		
Field_coord_source	indexed	text (12)	Field coordinate data source
GPS_file_name		text (50)	GPS rover file used for data downloads
GPS_model		text (25)	Make and model of GPS unit used to collect field coordinates

Appendix J. Glacier monitoring protocol database documentation (continued).

Source_map_scale		text (16)	Approximate scale of the source map
Source_citation		text (250)	Name and date of the source map
Target_UTME		double	Target UTM easting (zone 10N)
Target_UTMN		double	Target UTM northing (zone 10N)
Target_datum		text (5)	Target coordinate datum
	Default: "NAD83"		
Coordinate_notes		memo	Notes about this set of coordinates
Coord_created_date		datetime	Time stamp for record creation
	Default: Now()		
Coord_updated	indexed	datetime	Date of the last update to this record
Coord_updated_by		text (50)	Person who made the most recent edits

tbl_Core_Pushes - Snow core density measurements from individual core pushes

Field name	*Index/key*	*Data type*	*Description*
Snow_core_ID	primary (FK)*	text (50)	Unique identifier for each core sample
Core_push_num	primary *	tinyint	Sequential number used to differentiate between core pushes
Push_depth_m		double	Depth of snow core hole after the core push, in meters
	Constraint: Is Null Or (>=0 And <=30)		
Core_length_m		double	Measured length of the core, in meters
	Constraint: Is Null Or (>=0 And <=3)		
Core_weight_kg		double	Weight of the core section, in kilograms
	Constraint: Is Null Or (>=0 And <=5)		
Core_push_notes		memo	Notes about this core push measurement

tbl_Depth_Probes - Measurements for snow depth and/or debris thickness depths

Index	*Index columns*
Event_ID	Event_ID, <lastindexcol>
pk_tbl_Depth_Probes (primary)	Depth_ID, <lastindexcol>
Raw_or_adjusted	Raw_or_adjusted, <lastindexcol>
Snow_depth_type	Snow_depth_type, <lastindexcol>
Surface_type	Surface_type, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Depth_ID	primary *	text (50)	Unique identifier for each depth measurement
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Event_ID	indexed (FK)*	text (50)	Sampling event
Probe_location_desc		text (50)	Description of the measurement location relative to the reference coordinates (e.g., "2 m N of stake")
Snow_depth_m		double	Snow depth, in meters
	Constraint: Is Null Or (>=0 And <=15)		
Raw_or_adjusted	indexed	text (50)	Indicates whether or not the depth value is raw or adjusted to include initial snow melt
Snow_depth_type	indexed	text (10)	Classification of probe depths, made after fall field work
Debris_thickness_m		double	Debris thickness, in meters
	Constraint: Is Null Or (>=0 And <=15)		
Surface_type	indexed	text (20)	Glacier surface type assessment
Depth_notes		memo	Notes about the depth measurement

Appendix J. Glacier monitoring protocol database documentation (continued).

tbl_Edit_Log - Edit log for changes made to data after certification

Index	*Index columns*
Edit_date	Edit_date, <lastindexcol>
Edit_type	Edit_type, <lastindexcol>
pk_tbl_Edit_Log (primary)	Data_edit_ID, <lastindexcol>
Project_code	Project_code, <lastindexcol>
Table_affected	Table_affected, <lastindexcol>
User_name	User_name, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Data_edit_ID	primary *	text (50)	Unique identifier for each data edit record
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Project_code	indexed *	text (10)	Project code, for linking information with other data sets and applications
	Default: "HYa01"		
Edit_date	indexed *	datetime	Date on which the edits took place
	Default: Date()		
Edit_type	indexed *	text (12)	Type of edits made: deletion, update, append, reformat, tbl design
Edit_reason		text (100)	Brief description of the reason for edits
User_name	indexed	text (50)	Name of the person making data edits
Table_affected	indexed	text (50)	Table affected by edits
Fields_affected		text (200)	Description of the fields affected
Records_affected		text (200)	Description of the records affected
Data_edit_notes		memo	Comments about the data edits

tbl_Elevation_Bands - Elevation band areas for source maps associated with this project

Index	*Index columns*
Map_ID	Map_ID, <lastindexcol>
pk_tbl_Elevations_Bands (primary)	Elev_band_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Elev_band_ID	primary *	text (50)	Unique identifier for each elevation band
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Map_ID	indexed (FK)*	text (50)	Elevation source map
Elevation_midpt_m		double	Elevation midpoint (meters) between the contours that define the elevation band
	Constraint: Is Null Or (>=0 And <=5000)		
Band_area_sqm		double	Area of the elevation band, in square meters
	Constraint: Is Null Or >=0		
Elev_band_notes		memo	Comments about the elevation band

Appendix J. Glacier monitoring protocol database documentation (continued).

tbl_Events - Data collection event for a given location

Index	*Index columns*
Certified_by	Certified_by, <lastindexcol>
Certified_date	Certified_date, <lastindexcol>
Entered_date	Entered_date, <lastindexcol>
Location_ID	Location_ID, <lastindexcol>
Period_ID	Period_ID, <lastindexcol>
pk_tbl_Events (primary)	Event_ID, <lastindexcol>
Project_code	Project_code, <lastindexcol>
Start_date	Start_date, <lastindexcol>
Updated_date	Updated_date, <lastindexcol>
Verified_date	Verified_date, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Event_ID	primary *	text (50)	Unique identifier for each sampling event
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Location_ID	indexed (FK)*	text (50)	Sampling location for this event
Project_code	indexed *	text (10)	Project code, for linking information with other data sets and applications
	Default: "HYa01"		
Period_ID	indexed (FK)	text (50)	Sample period during which this event occurred
Start_date	indexed *	datetime	Start date of the sampling event
Start_time		datetime	Start time of the sampling event
End_date		datetime	End date of the sampling event (optional)
End_time		datetime	End time of the sampling event (optional)
Declination		text (25)	Declination correction factor for measurement of compass bearings
Logistics_notes		memo	Comments about logistics difficulties
Event_notes		memo	Comments about the sampling event
Entered_by		text (50)	Person who entered the data for this event
Entered_date	indexed	datetime	Date on which data entry occurred
	Default: Now()		
Updated_by		text (50)	Person who made the most recent updates
Updated_date	indexed	datetime	Date of the most recent edits
Verified_by		text (50)	Person who verified accurate data transcription
Verified_date	indexed	datetime	Date on which data were verified
Certified_by	indexed	text (50)	Person who certified data for accuracy and completeness
Certified_date	indexed	datetime	Date on which data were certified
QA_notes		memo	Quality assurance comments for the selected sampling event

tbl_Glacier_Areas - Glacier area estimates

Index	*Index columns*
Area_est_is_active	Area_est_is_active, <lastindexcol>
pk_tbl_Glacier_Areas (primary)	Site_ID, Area_date, <lastindexcol>
Site_ID	Site_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Site_ID	primary (FK)*	text (50)	Glacier associated with the area estimate
Area_date	primary *	datetime	Date on which the area estimate was created
Glacier_area_ha		double	Area of the glacier, in hectares
	Constraint: Is Null Or >0		
Area_est_is_active	indexed	bit	Indicates that the area estimate is currently in use for this glacier
	Default: Yes		

Area_est_notes		memo	Notes about the glacier area estimate

tbl_GPS_Info - GPS information associated with sample location coordinates

Index	*Index columns*
Coord_ID	Coord_ID, <lastindexcol>
Corr_type	Corr_type, <lastindexcol>
Datum	GPS_datum, <lastindexcol>
Feat_name	Feat_name, <lastindexcol>
Feat_type	Feat_type, <lastindexcol>
GIS_loc_ID	GIS_loc_ID, <lastindexcol>
GPS_date	GPS_date, <lastindexcol>
GPS_file	GPS_file, <lastindexcol>
Location_ID	Location_ID, <lastindexcol>
pk_tbl_GPS_Info (primary)	GPS_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
GPS_ID	primary *	text (50)	Unique identifier for the GPS record
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Coord_ID	indexed (FK)	text (50)	Coordinate identifier
Location_ID	indexed	text (50)	Sample location, used for temporary links
GIS_loc_ID	indexed	text (50)	GIS feature ID, used to link with geospatial layers
Feat_type	indexed	text (20)	Feature type (point, line, or polygon) collected with GPS
Data_dict_name		text (50)	Data dictionary name used to collect feature
Feat_name	indexed	text (50)	Feature name in data dictionary
GPS_file	indexed	text (50)	GPS file name
GPS_date	indexed	datetime	Date GPS file was collected
GPS_time		datetime	Time GPS file was collected
AM_or_PM		text (2)	Ante-meridian or post-meridian (AM or PM) if a 12 hour clock was used
Corr_type	indexed	text (50)	GPS file correction type
GPS_UTME		double	UTM easting in GPS unit
GPS_UTMN		double	UTM northing in GPS unit
UTM_zone		text (5)	UTM projection system zone
	Default: "10N"		
GPS_datum	indexed	text (5)	Datum of GPS coordinates
Elev_m		double	Elevation (meters) in GPS unit
Num_sat		int	Number of satellites tracked by GPS unit during data collection
GPS_duration		text (25)	Length of time GPS file was open
Filt_pos		int	Number of GPS positions exported from GPS file
PDOP		double	Position dilution of precision scale
HDOP		double	Horizontal dilution of precision scale
H_err_m		double	Horizontal error (meters)
V_err_m		double	Vertical error (meters)
Std_dev_m		double	Standard deviation (meters)
GPS_process_notes		text (255)	GPS file processing notes

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tbl_Images - Images associated with sample locations

Index	*Index columns*
Event_ID	Event_ID, <lastindexcol>
Image_label	Image_label, <lastindexcol>
Image_quality	Image_quality, <lastindexcol>
Image_type	Image_type, <lastindexcol>
pk_tbl_Images (primary)	Image_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Image_ID	primary *	text (50)	Unique identifier for each image record
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Event_ID	indexed (FK)*	text (50)	Sampling event
Image_type	indexed	text (20)	Type of image
	Default: "oblique"		
Image_label	indexed	text (25)	Image caption or label
Image_desc		text (255)	Brief description of the image bearing, perspective, etc.
Frame_number		text (10)	Frame number for photographic images
Image_date		datetime	Date on which the image was created, if different from the sampling event date
Image_source		text (50)	Name of the person or organization that created the image
Image_quality	indexed	tinyint	Quality of the image
Is_edited_version		bit	Indicates whether this version of the image is the edited (originals = False)
Object_format		text (20)	Format of the image
Orig_format		text (20)	Format of the original image
Image_edit_notes		text (200)	Comments about the editing or processing performed on the image
Image_is_active		bit	Indicates whether the image is still being used for navigation or interpretation
	Default: True		
Image_root_path		text (100)	Drive space location of the main project folder or image library
Image_project_path		text (100)	Location of the image from the main project folder or image library
	Default: "images\"		
Image_filename		text (100)	Name of the image including extention (.jpg) but without the image path
Image_notes		memo	Comments about the image

tbl_Locations - Sample locations - specific data collection points (e.g., stakes, probes)

Index	*Index columns*
Glacier_source_map	Glacier_source_map, <lastindexcol>
Loc_updated	Loc_updated, <lastindexcol>
Location_code	Location_code, <lastindexcol>
Location_status	Location_status, <lastindexcol>
Location_type	Location_type, <lastindexcol>
Park_code	Park_code, <lastindexcol>
pk_tbl_Locations (primary)	Location_ID, <lastindexcol>
Site_ID	Site_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Location_ID	primary *	text (50)	Unique identifier for each sample location
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Park_code	indexed *	text (4)	Park code

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Site_ID	indexed (FK)	text (50)	Site membership of the sample location
Location_code	indexed *	text (10)	Alphanumeric code for the sample location
Location_type	indexed *	text (20)	Indicates the type of sample location
Location_name		text (50)	Brief colloquial name of the sample location (optional)
Stake_length_m		double	Total length of the stake, in meters
	Constraint: Is Null Or (>=0 And <=15)		
Segment_length_m		double	Length of each segment
	Default: 1.5		
	Constraint: Is Null Or (>=0 And <=3)		
Glacier_source_map	indexed (FK)	text (50)	Source map used to estimate elevations
Elevation		double	Elevation of the location
	Constraint: Is Null Or (>=0 And <5000)		
Elev_units		text (2)	Units for elevation data
	Default: "m"		
Elev_source		text (20)	Source of elevation data
	Default: "source map"		
Slope_deg		int	Slope steepness, in degrees
	Constraint: Is Null Or >=0		
Aspect_deg		int	Dominant slope aspect, in degrees, corrected for declination
	Constraint: Is Null Or (>=0 And <=360) Or -1		
Travel_notes		memo	Comments about navigation to the point - kept up to date as conditions change
Location_desc		memo	Environmental description of the sampling location
Location_status	indexed	text (10)	Status of the sample location
Location_notes		memo	Other notes about the sample location
Loc_established		datetime	Date the sample location was established
Loc_discontinued		datetime	Date the sample location was discontinued
Loc_created_date		datetime	Time stamp for record creation
	Default: Now()		
Loc_updated	indexed	datetime	Date of the last update to this record
Loc_updated_by		text (50)	Person who made the most recent edits

tbl_Maps - Source maps for this project

Index	*Index columns*
Map_date	Map_date, <lastindexcol>
Map_desc	Map_desc, <lastindexcol>
Map_is_active	Map_is_active, <lastindexcol>
pk_tbl_Maps (primary)	Map_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Map_ID	primary *	text (50)	Unique identifier for each map
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Map_desc	indexed	text (50)	Brief description or title of the map
Map_date	indexed	datetime	Date on which the map was produced
Map_scale		text (16)	Scale of the map (e.g., 1:24,000)
Map_datum		text (5)	Datum of the mapping ellipsoid
Map_format		text (12)	Format of the map
Map_source		text (50)	Name of the person or organization that created the map
Contour_interval_m		int	Elevation contour interval, in meters
	Constraint: Is Null Or >0		
Map_is_active	indexed	bit	Indicates whether the map is in active use for data interpretation
	Default: Yes		
Map_notes		memo	Other comments about the map

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tbl_Observers - Observers for each sampling event

Index	*Index columns*
Observer_role	Observer_role, <lastindexcol>
pk_tbl_Observers (primary)	Event_ID, Contact_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Event_ID	primary (FK)*	text (50)	Sampling event identifier
Contact_ID	primary (FK)*	text (50)	Observer identifier
Observer_role	indexed	text (25)	Role of the observer during data collection (optional)
Observer_notes		text (200)	Comments about the observer specific to this sampling event

tbl_QA_Results - Quality assurance query results for the working data set

Index	*Index columns*
pk_tbl_QA_Results (primary)	Query_name, Time_frame, <lastindexcol>
Query_name	Query_name, <lastindexcol>
Query_result	Query_result, <lastindexcol>
Query_type	Query_type, <lastindexcol>
Time_frame	Time_frame, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Query_name	primary *	text (100)	Name of the quality assurance query
Time_frame	primary *	text (30)	Field season year or range of dates for the data being passed through quality assurance checks
Query_type	indexed	text (20)	Severity of data errors being trapped: 1=critical, 2=warning, 3=information
Query_result	indexed	text (50)	Query result as the number of records returned the last time the query was run
Query_run_time		datetime	Run time of the query results
Query_description		memo	Description of the query
Query_expression		memo	Evaluation expression built into the query
Remedy_desc		memo	Details about actions taken and/or not taken to resolve errors
Remedy_date		datetime	When the remedy description was last edited
QA_user		text (50)	Name of the person doing quality assurance

tbl_Sample_Periods - The span of dates during which data collection occurs

Index	*Index columns*
Period_updated	Period_updated, <lastindexcol>
pk_tbl_Sample_Periods (primary)	Period_ID, <lastindexcol>
Protocol_version	Protocol_version, <lastindexcol>
Start_date	Start_date, <lastindexcol>
Trip_season	Trip_season, <lastindexcol>
Trip_sequence	Trip_sequence, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Period_ID	primary *	text (50)	Unique identifier for each sample period
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Start_date	indexed *	datetime	Start date of the sample period
End_date	*	datetime	End date of the sample period
Trip_sequence	indexed	tinyint	Sequence of the trip within the context of the hydrologic year (e.g., 1, 2, 3, etc.)
Trip_season	indexed	text (10)	Season of the trip
Trip_purpose		text (200)	Brief description of the purpose of the trip
Protocol_version	indexed	text (100)	Version of the protocol used for sampling
Trip_notes		memo	Details about the trip

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Period_created		datetime	Time stamp for record creation
	Default: Now()		
Period_updated	indexed	datetime	Date of the last update to this record
Period_updated_by		text (50)	Person who made the most recent edits

tbl_Sites - Sample sites - glaciers that are monitored

Index	*Index columns*
Panel_type	Panel_type, <lastindexcol>
Park_code	Park_code, <lastindexcol>
pk_tbl_Sites (primary)	Site_ID, <lastindexcol>
Site_code (unique)	Site_code, <lastindexcol>
Site_status	Site_status, <lastindexcol>
Site_updated	Site_updated, <lastindexcol>
Watershed	Watershed, <lastindexcol>
Glacier_inv_code	Glacier_inv_code, <lastindexcol>
Glacier_local_num	Glacier_local_num, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Site_ID	primary *	text (50)	Unique site identifier
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Park_code	indexed *	text (4)	Park in which the site is located
Site_code	unique *	text (10)	Unique alphanumeric code for each site
Site_name		text (25)	Brief colloquial name of the site
Glacier_inv_code	indexed	text (25)	World Glacier Inventory number
Glacier_local_num	indexed	text (25)	Local PSFG number from the World Glacier Monitoring Service
Watershed	indexed	text (25)	Watershed in which the site is located
Panel_type	indexed	text (20)	Sampling panel for the site
Site_status	indexed	text (10)	Status of the site (i.e., proposed, active, rejected, retired)
Site_notes		memo	Comments about the site
Site_established		datetime	Date the sample site was established
Site_discontinued		datetime	Date the sample site was discontinued
Site_created_date		datetime	Time stamp for record creation
	Default: Now()		
Site_updated	indexed	datetime	Date of the last update to this record
Site_updated_by		text (50)	Person who made the most recent edits

tbl_Snow_Cores - Snow core density sampling information

Index	*Index columns*
Event_ID	Event_ID, <lastindexcol>
pk_tbl_Snow_Cores (primary)	Snow_core_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Snow_core_ID	primary *	text (50)	Unique identifier for each core sample
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Event_ID	indexed (FK)*	text (50)	Sampling event
Core_location_desc		text (50)	Description of the sample location relative to the reference coordinates (e.g., “2 m N of stake”)
Core_diameter_m		double	Diameter of the core, in meters
	Default: 0.06		
	Constraint: Is Null Or (>=0.01 And <=0.25)		
Snow_core_notes		memo	Notes about the core sample event

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tbl_Stake_Heights - Relative stake height measurements

Constraints: : ([Rel_stake_height_m] Is Null) Or ([Is_below_snow]=False And [Rel_stake_height_m]>=0) Or ([Is_below_snow]=True And [Rel_stake_height_m]<=0)

Index	*Index columns*
Is_below_snow	Is_below_snow, <lastindexcol>
pk_tbl_Stake_Heights (primary)	Event_ID, <lastindexcol>
Segment_num	Segment_num, <lastindexcol>
Surface_type	Surface_type, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Event_ID	primary (FK)*	text (50)	Sampling event
Segment_num	indexed	tinyint	Segment number of the stake, as numbered sequentially from base to top
Rel_stake_height_m		double	Relative stake height (meters); positive values indicate heights above snow level, negative values indicate that the stake is below snow level
	Constraint: Is Null Or (>=-10 And <=15)		
Is_below_snow	indexed	bit	Indicates that the stake was below the level of the snow, and so the stake height value should be negative (used for QA)
	Default: No		
Debris_thickness_m		double	Debris thickness, in meters
	Constraint: Is Null Or (>=0 And <=15)		
Surface_type	indexed	text (20)	Glacier surface type assessment
Stake_height_notes		memo	Notes about the stake height measurement

tbl_Surface_Profile - Surface profile data

Index	*Index columns*
Event_ID	Event_ID, <lastindexcol>
pk_tbl_Surface_Profile (primary)	Profile_meas_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Profile_meas_ID	primary *	text (50)	Unique identifier for the surface profile measurement
	Default: =Format(Now(),"yyyymmddhhnnss") & '-' & 1000000000*Rnd(Now())		
Event_ID	indexed (FK)*	text (50)	Sampling event
Distance_m		double	Distance from the benchmark, in meters
Azimuth_deg		double	Azimuth from the benchmark, in degrees
	Constraint: Is Null Or (>=0 And <=360)		
Profile_meas_notes		memo	Comments about the profile measurement

tbl_Task_List - Checklist of tasks to be completed at sampling locations

Index	*Index columns*
Date_completed	Date_completed, <lastindexcol>
pk_tbl_Task_List (primary)	Location_ID, Request_date, Task_desc, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Location_ID	primary (FK)*	text (50)	Sampling location
Request_date	primary *	datetime	Date of the task request
	Default: Now()		
Task_desc	primary *	text (100)	Brief description of the task
Requested_by		text (50)	Name of the person making the initial request
Task_status		text (50)	Status of the task
Date_completed	indexed	datetime	Date the task was completed
Followup_by		text (50)	Name of the person following up on or completing the task

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Task_notes		memo	Notes about the task
Followup_notes		memo	Comments regarding what was done to follow-up on or complete this task

tlu_Color_Scheme - List of image color schemes

Field name	*Index/key*	*Data type*	*Description*
Color_scheme	primary *	text (16)	
Color_scheme_desc		text (50)	
Sort_order		tinyint	

tlu_Coord_Label - List of project-specific coordinate labels (template)

Field name	*Index/key*	*Data type*	*Description*
Coord_label	primary *	text (25)	
Coord_label_desc		text (100)	
Sort_order		tinyint	

tlu_Coord_Source - List of coordinate data sources (standard)

Field name	*Index/key*	*Data type*	*Description*
Coord_source	primary *	text (12)	
Coord_source_desc		text (100)	
Sort_order		tinyint	

tlu_Coord_Type - List of coordinate types (standard)

Field name	*Index/key*	*Data type*	*Description*
Coord_type	primary *	text (20)	
Coord_type_desc		text (100)	
Sort_order		tinyint	

tlu_Datum - List of coordinate datum codes (standard)

Field name	*Index/key*	*Data type*	*Description*
Datumprimary *	text (5)		
Datum_desc		text (50)	
Sort_order		tinyint	

tlu_Direction_Code - List of codes for cardinal directions

Field name	*Index/key*	*Data type*	*Description*
Direction_code	primary *	text (5)	
Direction_code_desc		text (25)	
Sort_order		tinyint	

tlu_Edit_Type - List of the types of post-certification edits made to data (standard)

Field name	*Index/key*	*Data type*	*Description*
Edit_type	primary *	text (12)	
Edit_type_desc		text (100)	
Sort_order		tinyint	

tlu_Elevation_Source - List of elevation data source codes (template)

Field name	*Index/key*	*Data type*	*Description*
Elev_source	primary *	text (20)	
Elev_source_desc		text (100)	
Sort_order		tinyint	

Appendix J. Glacier monitoring protocol database documentation (continued).

tlu_GPS_Model - List of GPS devices used to collect coordinate data (template)

Field name	*Index/key*	*Data type*	*Description*
GPS_model	primary *	text (25)	
Sort_order		tinyint	

tlu_Image_Format - List of image, map, and photographic formats (template)

Field name	*Index/key*	*Data type*	*Description*
Image_format	primary *	text (12)	
Image_format_desc		text (100)	
Sort_order		tinyint	

tlu_Image_Quality - List of quality ranks for images (template)

Field name	*Index/key*	*Data type*	*Description*
Quality_code	primary *	tinyint	
Image_quality	*	text (20)	
Image_quality_desc		text (100)	

tlu_Image_Type - List of image types (template)

Field name	*Index/key*	*Data type*	*Description*
Image_type	primary *	text (12)	
Image_type_desc		text (100)	
Sort_order		tinyint	

tlu_Linear_Unit - List of measurement units for linear distances (template)

Field name	*Index/key*	*Data type*	*Description*
Units	primary *	text (2)	
Units_desc		text (25)	
Sort_order		tinyint	

tlu_Location_Type - List of location type codes (template)

Field name	*Index/key*	*Data type*	*Description*
Location_type	primary *	text (20)	
Loc_type_desc		text (200)	
Sort_order		tinyint	

tlu_Observer_Role - List of observer role assignments (template)

Field name	*Index/key*	*Data type*	*Description*
Observer_role	primary *	text (25)	
Role_desc		text (100)	
Sort_order		tinyint	

tlu_Panel_Type - List of sampling panel types (template)

Field name	*Index/key*	*Data type*	*Description*
Panel_type	primary *	text (20)	
Panel_type_desc		text (200)	
Sort_order		tinyint	

tlu_Parks - List of NCCN parks and park codes (standard)

Field name	*Index/key*	*Data type*	*Description*
Park_code	primary *	text (4)	
Park_name		text (50)	

Appendix J. Glacier monitoring protocol database documentation (continued).

tlu_Project_Crew - List of personnel associated with a project (template)

Index	*Index columns*
Contact_location	Contact_location, <lastindexcol>
Contact_updated	Contact_updated, <lastindexcol>
First_name	First_name, <lastindexcol>
Last_name	Last_name, <lastindexcol>
Organization	Organization, <lastindexcol>
pk_tlu_Project_Crew (primary)	Contact_ID, <lastindexcol>
Project_code	Project_code, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Contact_ID	primary *	text (50)	Unique identifier for the individual (Lastname_Firstname_MI)
Project_code	indexed *	text (10)	Project code, for linking information with other data sets and applications
Last_name	indexed *	text (24)	Last name
First_name	indexed	text (20)	First name
Middle_init		text (4)	Middle initials
Organization	indexed	text (50)	Employer (e.g., NPS-MORA)
Position_title		text (50)	Position title held by the individual
Email		text (50)	Email address
Work_voice		text (25)	Work phone number
Work_ext		text (5)	Work extension number
Mobile_voice		text (25)	Mobile phone number
Home_voice		text (25)	Home phone number
Fax		text (25)	Fax number
Contact_location	indexed	text (255)	Where the individual is located
Contact_notes		memo	Notes about the contact
Contact_created		datetime	Time stamp for record creation
	Default: Now()		
Contact_updated	indexed	datetime	Date of the last update to this record
Contact_updated_by		text (50)	Person who made the most recent edits
Contact_is_active		bit	Indicates that the contact record is currently available for data entry pick lists
	Default: True		

tlu_Season - List of seasons associated with project field work

Field name	*Index/key*	*Data type*	*Description*
Season_name	primary *	text (10)	
Season_desc		text (100)	
Sort_order		tinyint	

tlu_Site_Status - List of status codes for sampling stations (standard)

Field name	*Index/key*	*Data type*	*Description*
Site_status	primary *	text (10)	
Site_status_desc		text (200)	
Sort_order		tinyint	

tlu_Snow_Depth_Type - List of snow depth types

Field name	*Index/key*	*Data type*	*Description*
Snow_depth_type	primary *	text (10)	
Snow_depth_type_desc		text (100)	
Sort_order		tinyint	

Appendix J. Glacier monitoring protocol database documentation (continued).

tlu_Source_Scale - List of common map scales associated with maps and imagery (standard)

Field name	*Index/key*	*Data type*	*Description*
Source_scale	primary *	text (16)	
Source_scale_desc		text (100)	
Sort_order		tinyint	

tlu_Surface_Type - List of glacier surface types

Field name	*Index/key*	*Data type*	*Description*
Surface_type	primary *	text (20)	
Surface_type_desc		text (100)	
Sort_order		tinyint	

tlu_Watersheds - List of major watersheds used for grouping and summarization (standard)

Index	*Index columns*
Park_code	Park_code, <lastindexcol>
pk_tlu_Watersheds (primary)	Watershed_name, Park_code, <lastindexcol>
Watershed_GIS	Watershed_GIS, <lastindexcol>
Watershed_name	Watershed_name, <lastindexcol>
WRIAID	WRIA_ID, <lastindexcol>

Field name	*Index/key*	*Data type*	*Description*
Watershed_name	primary *	text (25)	Name of the watershed
Park_code	primary *	text (4)	Park in which the watershed is found
Larger_basin		text (25)	The larger watershed basin in which this watershed is found
Huc4_basin		text (25)	Crosslink field for the Hydrologic Universal Code 4th field names
WRIA_ID	indexed	int	Crosslink field for the Water Resource Inventory Area number of the watershed
On_park_list		bit	Indicates that the watershed is normally part of the park pick list
Is_grouped		bit	Indicates that the watershed represents a grouping of natural watersheds, typically of small coastal streams that drain to salt water
Watershed_notes		text (255)	Comments regarding this watershed record
Watershed_GIS	indexed	int	GIS ID code for the watershed

txr_Air_Photo_Images - Cross-reference table linking air photos and stored images

Field name	*Index/key*	*Data type*	*Description*
Air_photo_ID	primary (FK)*	text (50)	Air photo identifier
Image_ID	primary (FK)*	text (50)	Image identifier

txr_Map_Air_Photos - Cross-reference table linking maps and air photos used to create them

Field name	*Index/key*	*Data type*	*Description*
Air_photo_ID	primary (FK)*	text (50)	Air photo identifier
Map_ID	primary (FK)*	text (50)	Map identifier

txr_Site_Air_Photos - Cross-reference table linking glaciers and air photos

Field name	*Index/key*	*Data type*	*Description*
Site_ID	primary (FK)*	text (50)	Site identifier
Air_photo_ID	primary (FK)*	text (50)	Air photo identifier

Appendix J. Glacier monitoring protocol database documentation (continued).

txr_Site_Maps - Cross-reference table linking glaciers and maps

Field name	*Index/key*	*Data type*	*Description*
Site_ID	primary (FK)*	text (50)	
Map_ID	primary (FK)*	text (50)	

Appendix K. Administrative history.

<u>Contents:</u>

Appendix K. Administrative history (continued).

Email from Al Rasmussen to Rob Burrows, 6/9/03. Reply to Burrow's glacier uncertainty questions, 1p

Email from Rob Burrows to Al Rasmussen, 7/23/03. Draft of glacier errors, 5p

Email from Al Rasmussen to Rob Burrows, 7/24/03. Comments on Burrow's Draft of Glacier Errors, 1p

Email from Rob Burrows to Al Rasmussen, 7/28/03. Addressing Rasmussen's error comments, 1p

Email from Al Rasmussen to Rob Burrows, 8/4/03. Comments on Burrow's glacier errors, 1p

Document of North Cascades Glacier Project proposal to Earthwatch Institute, 10/25/01. 26p

Email from Lotus Vermeer to Jon Riedel and Robert Burrows, 12/21/01. Review comments on the Earthwatch Glacier Project Proposal, 2p

Evaluation document from Earthwatch Institute to Jon Riedel and Rob Burrows, Material not dated. Glacier monitoring project proposal comments, 7p

Letter from Jon Riedel to Lotus Vermeer, 1/12/02, Response to review comments on the Earthwatch Glacier Project Proposal, 2p

Letter from Jack Oelfke to Penny Latham, 12/3/2003. Approval for Glacier Protocol report, 1p

Letter from Penny Latham to Jon Riedel, 7/21/2007, Approval for NCCN Glacier monitoring protocol for North Cascades, with final review comments.

Email from Ron Holmes to Penny Latham, 6/19/2008 submitting updated protocol, manuscript submittal form with notes addressing previous comments.

Email from Penny Latham to Ron Holmes, 8/02/2008, returning manuscript submittal form and providing additional formatting comments.

Email from Penny Latham to Ron Holmes, 10/05/2008, approving manuscript for publication in NRR Series.

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