National Park Service
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Natural Resource Program Center

Long Term Monitoring of Glaciers at Mount Rainier National Park

Appendices Version 1.0

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

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

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

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U.S. Department of the Interior
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This report is available from The North Coast and Cascades Network (http://science.nature.nps.gov/im/units/nccn/reportpubs.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/NRPM).

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Change History

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

Version No.	Date	Revised by	Changes (with page numbers)	Justification

Contents

Figures and Tables

Abstract

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

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

Acknowledgements

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

Appendix A. Roles and responsibilities

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 MORA project 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.

Yearly MORA Project Task List

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
	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 #22)	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 March 15
	In office and on-glacier training as needed for data collection and safety	Project Lead and Field Lead	March 15
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	June
	Download and process digital images (SOP #17)	Technicians	May

Yearly MORA Project Task List

Project Stage	Task Description	Responsibility	Timing
	Enter data into working copy of the database (SOP #16 & 19)	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	Jul
	Review data forms in field and in office for completeness and quality	Field Lead	Jul
Data Entry & Processing Visit 2 (Section 4C, 4D)	Download and process digital images (SOP #17)	Technicians	Jul
	Enter data into working copy of the database (SOP #19)	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 Visit 3 (*Section 3C*)	Fall field data collection	Technicians	Sep
	Review data forms in field and in office for completeness and quality	Field Lead	Oct
Data Entry & Processing Visit 3 (*Section 4C, 4D*)	Download and process digital images (SOP #17)	Technicians	Oct
	Enter data into working copy of the database (SOP #19)	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	Nov
Product Delivery (*Section 4J*)	Send field season report to NPS Lead and Data Manager (SOP #21)	Project Lead	by Nov 15
Quality Review (*Section 4E*)	Quality review and data validation using database tools (SOP #20)	Field Lead and Project Lead	Oct-Nov

Yearly MORA Project Task List

Project Stage	Task Description	Responsibility	Timing
Metadata (*Section 4F*)	Update project metadata (SOP #18 & 13)	Field Lead and Project Lead	Oct-Nov
Data Certification & Delivery (*Section 4G*)	Certify the season's data and complete certification report (SOP #13)	Project Lead	Oct-Nov
	Deliver certification report, certified data, and updated metadata to Data Manager (SOP #21)	Project Lead	by Nov 30
	Upload certified data into master project database, store data files in NCCN Digital Library [1] (SOP #23)	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 #13 &20)	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
Reporting & Product Development (*Section 4I*)	Washington State Snow Survey Report (includes preliminary winter balance data for current year, due in June)	Project Lead	by May 31
	Generate World Glacier Monitoring Service table	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
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

Yearly MORA Project Task List

Project Stage	Task Description	Responsibility	Timing
	Upload completed report to NCCN Digital Library [1] submissions folder, notify Data Manager (SOP #13)	Field Lead and Project Lead	Nov 30
	Deliver other products according to the delivery schedule and instructions (SOP #13)	Field Lead and Project Lead	Nov 30
	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 Nov .1
	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.
[3]NatureBib is the NPS bibliographic database (http://www.nature.nps.gov/nrbib/index.htm). This application has the capability of storing and providing public access to image data (e.g., PDF files) associated with each record.
[4]NPSpecies 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).
[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. Analysis for the Best Timing of Glacier Visits

Introduction

Temperature and Snowpack data from weather stations and SNOTEL sites in the vicinity of Mount Rainier are used as proxies for the timing of minimum and maximum balances on Nisqually and Emmons Glaciers. The sites used are those closest to these study glaciers. The data recorded at the nearest SNOTEL site is assumed to track the maximum balance of a stake location with the same altitude on the nearby glacier. The dates derived from this analysis will guide us for the best time to visit the glaciers to measure balance minimums and maximums.

The main factors that influence the timing of maximum and minimum balances at a site on a glacier are mean daily temperature and snowfall. The maximum balance occurs at a time in the spring when the snow level rises to a height that rain falls instead of snow and daily mean temperatures rise enough that the snow pack begins to significantly settle and melt. However, because the snow level is often lower than the freezing level, snow will continue to accumulate for a time when the mean daily temperature is above freezing.

Minimum balance can occur under two different temperature and snowfall scenarios: 1) When the average daily temperature drops below freezing in the fall with or without new snow. 2) When enough snow mass accumulates on the glacier to offset the mass lost in melting. For simplicity in this analysis we assume that the minimum balance occurs when snow begins to accumulate.

Methods

Temperature Records and Freezing Level Analysis

Four daily mean temperature lapse rates are determined from four pairs of four weather data sites. The two sites on the southwest side of Mount Rainier are Longmire (830 m) and Paradise (1560 m) (Figure C.1). The two sites on the northeast side are Huckleberry Creek (610 m) and Corral Pass (1829 m). These lapse rates are extrapolated to higher altitudes and assumed to represent conditions 3,000 to 4,000 meters above the highest stations.

The basic method determines the linear relationship with altitude (dependent variable) and temperature (independent variable) between two sites of a significant altitude difference. Freezing level is interpolated/extrapolated from the linear relationship (FORECAST function in Excel) (Figure C.2).

Paradise and Longmire have the two longest running records in the vicinity of Mt. Rainier and are located on the south/southwest flank (Figure C.1). The daily mean temperature were used of the 30 year average from these stations summarized by the Western Regional Climate Center (WRCC) (1971-2000) (http://www.wrcc.dri.edu/summary/climsmwa.html) (Figure C.2). This data is smoothed by the WRCC using a 29 day running average.

Huckleberry Creek and Corral Pass are Natural Resource Conservation Service (NRCS) SNOTEL sites and have a common period of record from 1998 to 2004 (http://www.wcc.nrcs.usda.gov/snotel/Washington/washington.html) (Figure C.1 for locations). Though more distant from the Emmons Glacier, Huckleberry Creek and Corral Pass offered the best set of sites to use because of their proximity to each other. To make this data comparable to the WRCC data, the daily freezing level data is smoothed using a 29 day running average (Figure C.2). Two pertinent sites exist on the east side of the mountain, Morse Lake and Corral Pass. Corral Pass data is used to construct the lapse rate with the Huckleberry Creek site because, though it is higher, Corral Pass tends to be warmer than Morse Lake most of the year. Probably, a better representative of temperature on the East and NE flanks of Rainier where there is quite a bit of terrain at 1829m and lots of thermal mass. Also Corral Pass is much closer to Huckleberry Creek.

The "freezing season" at each stake is determined by finding the first and last date in which the freezing is below the stake altitude (Table C.1).

Snow Dates Analysis

Data used are from SNOTELs: Paradise and Morse Lake between 1984 and 2004. Morse Lake was chosen here because it is closer to the Emmons Glacier. The snow dates analysis is simply a comparison between sites of the date on which snow began to accumulate at each site ("accumulation start" column in Tables C.2–3). Also recorded in Tables C.2–3 are: 1) the first date snow is recorded on the ground; 2) if the first snow melted away then the second date snow is recorded on the ground. In all cases this marks the beginning of winter accumulation) the date at which the maximum snowpack occurred and the snow water equivalent (SWE) at that date; the last date that snow was recorded on the ground.

Results, Discussion, and Conclusions

Nisqually Glacier

The average date of the beginning of snow accumulation at the Paradise SNOTEL occurs on October 27 (Table C.2). The earliest this has occurred was October 9, 1985, and the latest November 18, 1998. Note: 38% of the time in this 21-year record, this first snow melts away and then a second event marks the beginning of snow accumulation. The stake on the Nisqually Glacier closest in altitude to the Paradise SNOTEL is stake 5 and these dates are interpreted to be concurrent just below this site on the glacier.

The average date of minimum balance defined by the beginning of the "freezing season" is November 4 (Table C.1). This is nearly 10 days later than the average of the beginning of snow accumulation. To estimate the minimum balance dates summarized in Table C.4, the 10 day difference is subtracted from the "first freezing level" dates (Table C.1) for the other stakes to estimate their dates of minimum balance.

The average date of maximum balance just below stake 5 is May 3, defined by the maximum snowpack at the Paradise SNOTEL. The earliest maximum snowpak occurs on April 1, 1999 and the latest on May 23, 2003 (Table C.2). This is 26 days later than when the 30-year average daily mean temperature climbs consistently above freezing on April 8. This implies that snow will continue to accumulate with a daily mean temperature above freezing until the temperature rises to such a point the precipitation consistently turns to rain. This is important in interpreting the spring freezing level dates higher on the mountain and suggests that these should be regarded as early dates for the average cessation of snow accumulation. The 26 day difference is added to the "second freezing level" dates at the other stakes to find the estimated maximum balance dates

(Table C.4). At stakes 1 and 2 these dates seem much too late based on field observations and are not heeded. Instead the maximum balance is probably closer to the early June time frame as predicted from the Longmire to Corral Pass lapse rate.

Emmons Glacier

The average date of the beginning of snow accumulation at the Morse Lake SNOTEL occurs on October 27 (Table C.3). The earliest this has occurred was October 9, 1998, and the latest November 14, 1994. Note: 14% of the time in this 21-year record this first snow melts away and then a second event marks the beginning of snow accumulation. The stake on the Emmons Glacier closest in altitude to the Morse Lake SNOTEL is stake 4 (1,700 m) and these dates are interpreted to be concurrent for this site on the glacier.

The average date of minimum balance defined by the beginning of the “freezing season” is November 9 (Table C.1). This is nearly 14 days later than the average of the beginning of snow accumulation. To estimate the minimum balance dates summarized in Table C.4 the 14 day difference is subtracted from the “first freezing level” dates (Table C.1) for the other stakes to estimate their dates of minimum balance.

The average date of maximum balance for stake 4 is April 20, defined by the maximum snowpack at the Morse Lake SNOTEL. The earliest maximum snowpack occurs on March 11, 1992 and the latest on May 21, 1999 (Table C.3). This is nearly10 days later than when the 30-year average daily mean temperature climbs consistently above freezing on April 12 (Table C.1). This implies that snow will continue to accumulate with a daily mean temperature above freezing until the temperature rises to such a point the precipitation consistently turns to rain. This is important in interpreting the spring freezing level dates higher on the mountain and suggests that these should be regarded as early dates for the average cessation of snow accumulation. The 26 day difference is added to the “second freezing level” dates at the other stakes to find the estimated maximum balance dates (Table C.4). At stakes 1 and 2 these dates seem much too late based on field observations and are not heeded. Instead the maximum balance is probably closer to the early June time frame as predicted from the Longmire to Corral Pass lapse rate.

Summit

The best freezing date estimates from the summit are probably from using sites that are “across the mountain” from each other. Both “Longmire to Corral Pass” and “Huckleberry to Paradise” lapse rates predict a very short summer season from mid to late July to early to mid August (Tables C.1 and Figure C.2).

Sources of Error and Uncertainty

Errors from the results from applying the temperature lapse rates become greater at higher altitudes above the highest station used. Particularly because the highest stakes and the summit of Mount Rainier are ~1,500 to 3,000 meters above Paradise and Corral Pass. The problems with using these lapse rates are due to two factors 1) stratification of air layers and lack of mixing of these layers in the atmosphere may make the lapse rate invalid at a certain boundary layer, and 2) localized climate effects (such as cold air drainage), particularly in the lower sites that sit in valley bottoms may skew the lapse rate.

When the average daily temperature drops below freezing in the fall with or without new snow, there is probably a lag time for the ice to cool and free water to runoff and freeze, but this is ignored because it is difficult to measure and quantify. When enough snow mass accumulates on the glacier to offset the mass lost in melting, it may occur at the freezing point and thus melting and runoff processes may not readily stop on the glacier. In addition a blanket of new snow may insulate the glacier below and further delay stoppage of these processes. When the temperature hovers around freezing this situation may go on for a while or most of the winter season, particularly on the lower glacier.

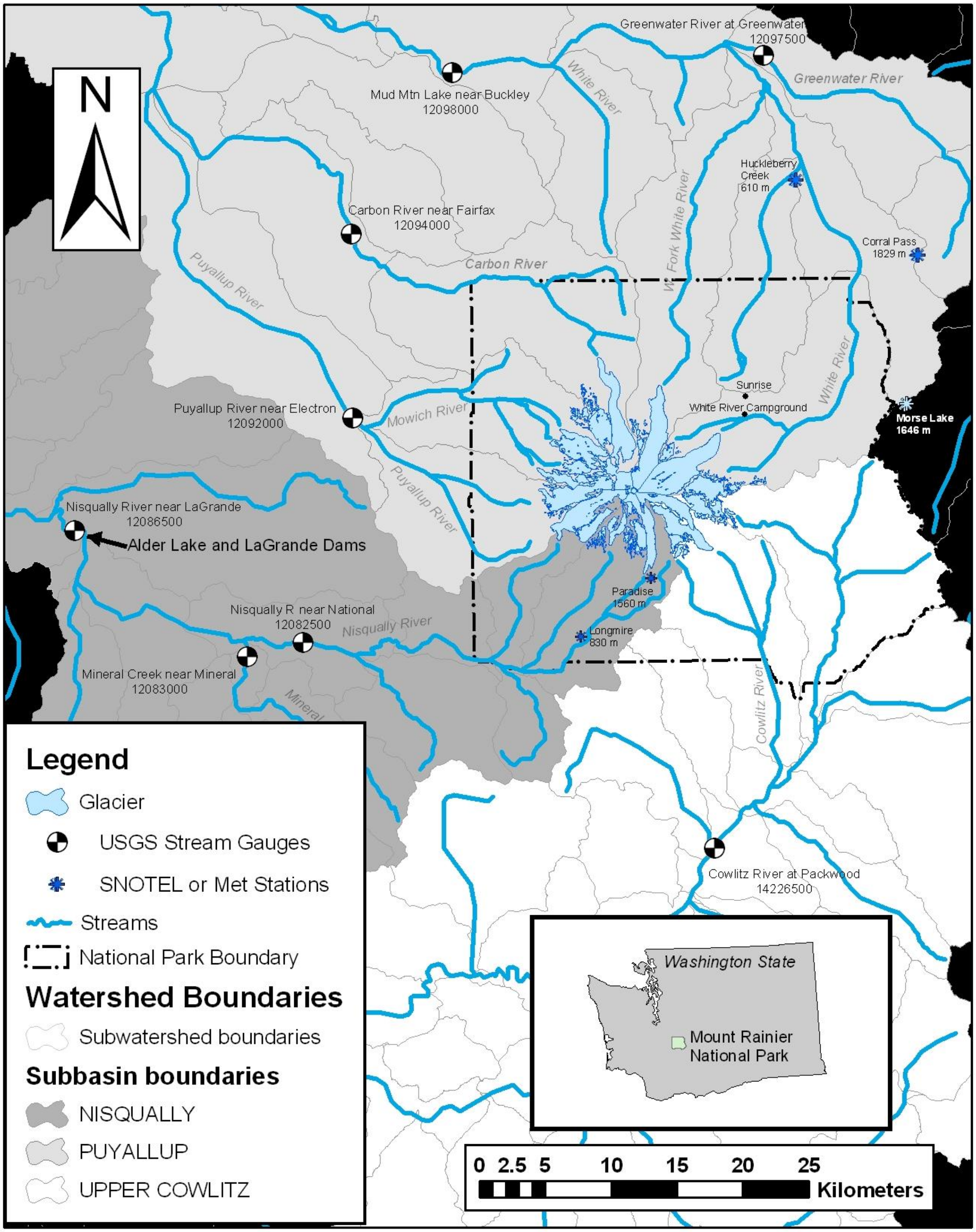

Figure C.1. Location map for Mount Rainier and nearby sampling site locations referred to in the text.

Table C.1. "Freezing Season" dates for Nisqually and Emmons Glacier stakes and the Summit Crater, generated from Longmire and Paradise weather station data. Highlighted dates are those that will be used as a guide for the best date to visit each location. These dated refer to freezing level vs. date curves shown in figure 2.

		Longmire to Paradise		Huckleberry to Corral Pass		Longmire to Corral Pass		Huckleberry To Paradise	
Nisqually Stake	Altitude meters	1st Freezing Level Date	2nd Freezing Level Date	1st Freezing Level Date	2nd Freezing Level Date	1st Freezing Level Date	2nd Freezing Level Date	1st Freezing Level Date	2nd Freezing Level Date
1	3382	16-Sep	13-Jul	10-Oct	25-Jun	28-Sep	26-Jun	9-Oct	11-Jul
2	2960	8-Oct	30-Jun	16-Oct	11-Jun	3-Oct	15-Jun	15-Oct	20-Jun
3	2175	25-Oct	9-May	na	na	23-Oct	12-May	27-Oct	2-May
4	1890	1-Nov	23-Apr	na	na	4-Nov	18-Apr	2-Nov	21-Apr
4A	1870	2-Nov	22-Apr	na	na	5-Nov	17-Apr	3-Nov	20-Apr
5	1778	4-Nov	16-Apr	na	na	6-Nov	14-Apr	4-Nov	16-Apr
Terminus	1450	11-Nov	20-Mar	na	na	17-Nov	21-Mar	11-Nov	25-Mar
Emmons Stake	Altitude meters	1st Freezing Level Date	2nd Freezing Level Date	1st Freezing Level Date	2nd Freezing Level Date	1st Freezing Level Date	2nd Freezing Level Date	1st Freezing Level Date	2nd Freezing Level Date
1	3118	8-Jul	1-Oct	14-Oct	15-Jun	30-Sep	23-Jun	15-Oct	2-Jul
2	2810	24-Jun	13-Oct	26-Oct	3-Jun	10-Oct	12-Jun	18-Oct	10-Jun
3	1970	na	na	29-Oct	22-Apr	3-Nov	28-Apr	1-Nov	24-Apr
4	1700	na	na	13-Nov	11-Apr	8-Nov	12-Apr	6-Nov	12-Apr
4A	1705	na	na	13-Nov	11-Apr	8-Nov	12-Apr	6-Nov	12-Apr
5	1580	na	na	18-Nov	5-Apr	11-Nov	29-Mar	8-Nov	6-Apr
Terminus	1480	na	na	19-Nov	21-Mar	16-Nov	25-Mar	10-Nov	29-Mar
Summit Crtr	4315	below	below	29-Sep	12-Jul	8-Aug	16-Jul	16-Aug	25-Jul

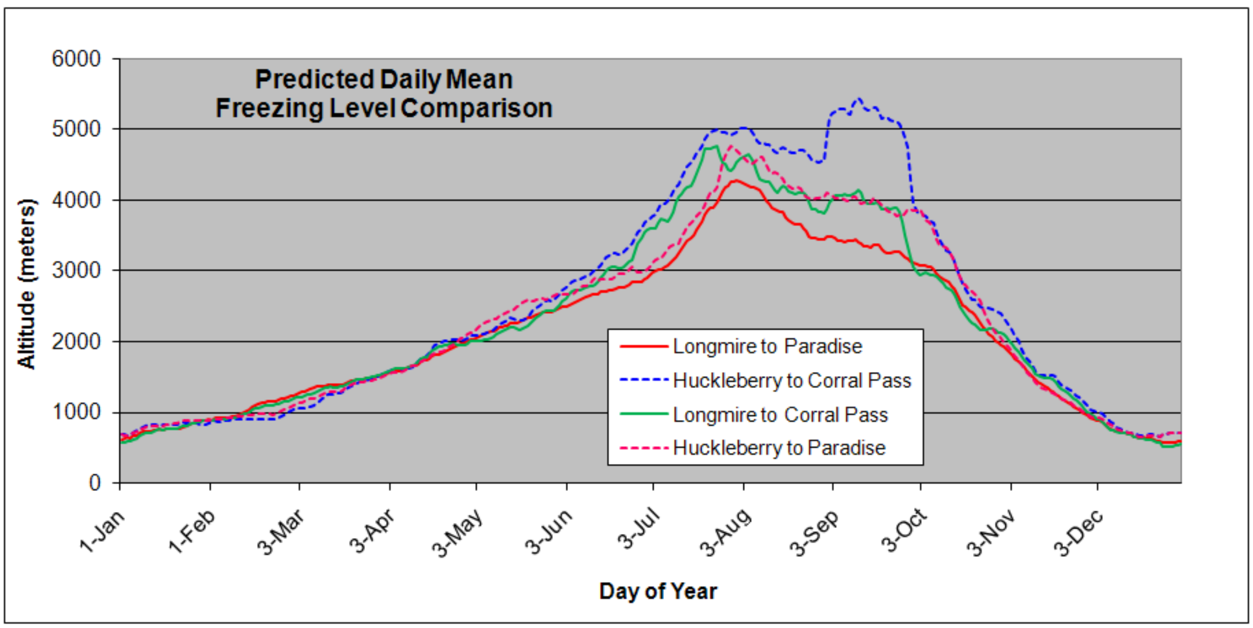

Figure C.2. Predicted daily mean freezing level from four calculated temperature lapse rates. See figure C-1 for locations and elevations of each of the sites used here. Stake altitudes are compared to the data this graph represents to find the "freezing season" for each of these measurement points, see Table C.1. Longmire and Paradise are derived from the 30 year average daily mean temperatures, 1971 to 2000. Huckleberry (creek) and corral Pass data are from average daily mean temperatures from 1998 to 2004. Both Curves are smoothed by applying a 29-day moving average.

Table C.2. Snow dates from the Paradise SNOTEL.

Paradise SNOTEL Snow Date Summary 1560 m (5120 ft)						
	snow date				max depth	
Year	first	second	**accumulation start**	last	**date**	inches SWE
1984	5-Nov		**5-Nov**	29-Jul	**17-May**	70.5
1985	9-Oct		**9-Oct**	7-Jul	**30-Apr**	75
1986	7-Oct	22-Oct	**22-Oct**	5-Jul	**15-May**	64.5
1987	6-Nov		**6-Nov**	13-Jun	**24-Apr**	62.1
1988	14-Nov		**14-Nov**	11-Jul	**8-May**	69.4
1989	13-Oct	3-Nov	**3-Nov**	18-Jul	**6-Apr**	86.2
1990	24-Oct		**24-Oct**	21-Jul	**16-May**	74.3
1991	5-Oct	12-Oct	**12-Oct**	31-Jul	**11-May**	84.0
1992	19-Oct		**19-Oct**	17-Jun	**24-Apr**	55.4
1993	30-Oct		**30-Oct**	7-Jul	**6-May**	68.0
1994	2-Nov		**2-Nov**	12-Jul	**18-Apr**	63.6
1995	14-Oct		**14-Oct**	10-Jul	**2-May**	81.8
1996	11-Oct	22-Oct	**22-Oct**	13-Jul	**14-May**	66.9
1997	14-Oct		**14-Oct**	7-Aug	**9-May**	123.1
1998	9-Oct	18-Nov	**18-Nov**	15-Jul	**25-Apr**	71.4
1999	3-Oct	4-Nov	**4-Nov**	21-Aug	**1-Apr**	107.3
2000	28-Oct		**28-Oct**	25-Jul	**15-May**	87.0
2001	28-Oct		**28-Oct**	9-Jul	**8-May**	54.9
2002	13-Oct	22-Oct	**22-Oct**	24-Jul	**14-May**	97.8
2003	7-Nov		**7-Nov**	6-Jul	**23-May**	61.4
2004	9-Oct	2-Nov	**2-Nov**	2-Jul	**27-Apr**	73.9
Average	**20-Oct**	**28-Oct**	**27-Oct**	**14-Jul**	**3-May**	**76.1**
Medians	**14-Oct**	**27-Oct**	**28-Oct**	**12-Jul**	**8-May**	
Earliest	**3-Oct**	**12-Oct**	**9-Oct**	**13-Jun**	**1-Apr**	
Latest	**14-Nov**	**18-Nov**	**18-Nov**	**21-Aug**	**23-May**	

Table C.3. Snow dates from the Morse Lake SNOTEL.

Morse Lake SNOTEL Snow Date Summary, 1646 m (5400 ft)						
	snow date				max depth	
Year	first	second	accumulation start	last	date	inches SWE
1984	19-Oct		**19-Oct**	13-Jun	**12-May**	58.6
1985	29-Oct		**29-Oct**	18-Jun	**4-Apr**	47.3
1986	22-Oct		**22-Oct**	12-Jun	**13-May**	44
1987	6-Nov		**6-Nov**	13-Jun	**28-Apr**	58.9
1988	13-Nov		**13-Nov**	22-Jun	**12-Apr**	59.5
1989	3-Nov		**3-Nov**	6-Jun	**9-Apr**	61.7
1990	24-Oct		**24-Oct**	26-Jun	**27-Mar**	50.3
1991	14-Oct		**14-Oct**	5-Jul	**22-Apr**	64.5
1992	23-Oct		**23-Oct**	30-May	**11-Mar**	45.2
1993	29-Oct		**29-Oct**	31-May	**3-May**	44.3
1994	14-Nov		**14-Nov**	9-Jun	**15-Apr**	44.1
1995	14-Oct		**14-Oct**	28-Jun	**8-May**	78.0
1996	3-Oct	3-Nov	**3-Nov**	2-Jul	**29-Apr**	52.7
1997	15-Oct		**15-Oct**	3-Jul	**6-May**	90.4
1998	9-Oct		**9-Oct**	1-Jun	**21-Apr**	73.4
1999	5-Nov		**5-Nov**	8-Aug	**21-May**	91.7
2000	28-Oct		**28-Oct**	27-Jun	**2-Apr**	61.6
2001	11-Oct	27-Oct	**27-Oct**	11-Jun	**20-Apr**	28.6
2002	11-Oct	23-Oct	**23-Oct**	1-Jul	**5-Apr**	57.0
2003	5-Nov		**5-Nov**	5-Jul	**12-May**	55.6
2004	8-Nov		**8-Nov**	16-Jun	**2-Apr**	48.6
Average	**24-Oct**	**28-Oct**	**27-Oct**	**20-Jun**	**20-Apr**	**57.9**
Medians	**24-Oct**	**27-Oct**	**28-Oct**	**18-Jun**	**21-Apr**	
Earliest	**3-Oct**	**23-Oct**	**9-Oct**	**30-May**	**11-Mar**	
Latest	**14-Nov**	**3-Nov**	**14-Nov**	**8-Aug**	**21-May**	

Table C.4. Summary of the average dates for maximum and minimum balances.

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

Appendix D. Field Data Forms

Field forms included below are used to collect data at different times in the field season. The "upper" and "lower" field sheets are generally taken into the field for the spring and fall visits. The lower most stakes, 3–5, are placed the earliest and the uppermost stakes, 1–2, are placed a month later. Separating these data sheets out assists in managing the data. There are also datasheets which include all stakes. These sheets are used generally for the summer visits when all stakes are visited in the same "trip", within a few days. There is no designated space on the forms for past year's stakes, which may be found on the glacier. There is no space for collecting snow depths at the Paradise snotel. This type of data can be recorded on the back or in the margins. Also included below is the standard snow core data sheet. All datasheets are printed out on write in the rain paper.

APP D.2

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

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

GLACIER: Emmons

DATE: ______________ **Recorded by:**

INITIALS: ______________ **Verified in the field by:**

Station	1	2	2x	3	4	4A	5
Elevation m.	3118	2810		1970	1700	1705	1580
ft.	10,230	9,219		6,461	5,576	5,592	5,184
Location N:	596323	596876		599353	600587	600537	600956
(UTM NAD83) E:	5191005	5191446		5191728	5192733	5192750	5193487
GPS pt name	EMS1A	EMS2	EMS2x	EMS3	EMS4	EMS4A	EMS5
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	
@stk							
S from stk) 1							
2							
3							
4							
5							
(N from stk) 6							
7							
8							
9							
10							
Notes:							
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	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 # ____	____m from glacier to seg # ____	____m from glacier to seg # ____
Spring data	9m stk 6 segments 8.5m hole 0.5m above surface ____m ave.probe depth	9m stk 6 segments 9m hole stk @ surface ____m ave.probe depth	9m stk 6 segments 9m hole stk @ surface ____m ave.probe depth	12m stk 8 segments 13.5m hole 1.5m below surface ____m ave.probe depth	12m stk 8 segments 13.5m hole 1.5m below surface ____m ave.probe depth	9m stk 6 seg 8.5m hole 0.5m above surface ____m ave.probe depth	9m stk 6 seg 8.5m hole 0.5m above surface ____m ave.probe

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

updated 3/05/07

APP D.3

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

GLACIER: Emmons (Lower)
DATE: ______________
INITIALS: ______________

Recorded by:
Verified in the field by:

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

Station	3	4	4A	5	Extra Probe??
Elevation m.	1970	1700	1705	1580	
ft.	6,461	5,576	5,592	5,184	
Location N:	599353	600587	600537	600956	
(UTM NAD83) E:	5191728	5192733	5192750	5193487	
GPS pt name	EMS3	EMS4	EMS4A	EMS5	
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type
@stk					
SW from stk) 1					
2					
3					
4					
5					
(SE from stk) 6					
7					
8					
9					
10					
Notes:					
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	12m stk 8 segments 13.5m hole 1.5m below surface ___m ave.probe depth	12m stk 8 segments 13.5m hole 1.5m below surface ___m ave.probe depth	9m stk 6 segments 8.5m hole 0.5m above surface ___m ave.probe depth	9m stk 6 segments 8.5m hole 0.5m above 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")

updated 3/05/2007

APP D.4

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

Entered date:
Verified date:
Updated date

Entered by:
Verified by:
Updated by:

GLACIER: Emmons (Upper)

DATE: ______________

INITIALS: ______________

Recorded by:

Verified in the field by:

Station	1	2	2x	extra probe??	extra probe??
Elevation m.	3118	2810			
ft.	10,230	9,219			
Location N:	596323	596876			
(UTM NAD83) E:	5191005	5191446			
GPS pt name	EMS1	EMS2	EMS2x		
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type
@stk					
(W from stk) 1					
2					
3					
4					
5					
(E from stk) 6					
7					
8					
9					
10					
Notes:					
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	9m stk _6 segments 8.5m hole 0.5m above surface ___m ave.probe depth	9m stk _6 segments 9m hole stk @ surface ___m ave.probe depth	9m stk _6 segments 9m hole stk @ surface ___m ave.probe depth	9m stk _6 segments 9m hole stk @ surface ___m ave.probe depth	9m stk _6 segments 9m hole stk @ 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")

updated 3/05/2007

APP D.5

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

GLACIER: Nisqually

DATE: ______________

INITIALS: ______________

Recorded by:

Verified in the field by:

Entered date:
Verified date:
Updated date

Entered by:
Verified by:
Updated by:

Station	1	2	2x	3	4	4a	5
Elevation m.	3382	2960		2175	1890	1870	1778
ft.	11,096	9,711		7,136	6,201	6,135	5,833
Location N:	596439	596550		596042	595996	596234	595977
(UTM NAD83) E:	5188702	5187304		5185677	5184588	5184418	5183966
GPS pt name	**NIS1**	**NIS2**	**NIS2x**	**NIS3**	**NIS4**	**NIS4A**	**NIS5**
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type	snow layers & type
@stk							
S from stk) 1							
2							
3							
4							
5							
(N from stk) 6							
7							
8							
9							
10							
Notes:							
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	above/below	above/below
# of whole segments above snow + remaining meters *							
*	______m to top of seg # _____	______m to top of seg # _____	______m to top of seg # _____	______m to top of seg # _____	______m to top of seg # _____	______m to top of seg # _____	____m to top seg # _____
Spring data	9m stk 6 segments 8.5m hole 0.5m above surface __m ave.probe depth	9m stk 6 segments 8.5m hole 0.5m above surface __m ave.probe depth	9m stk 6 segments 8.5m hole 0.5m above surface __m ave.probe depth	10.5m stk 7 segments 11.5m hole 1m below surface __m ave.probe depth	12m stk 8 segments 13.5m hole 1.5m below surface __m ave.probe depth	9m stk 6 segments 10m hole 1m below surface __m ave.probe	9m stk 6 seg 10m hole 1m below surface __m ave.probe

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

updated 3/5/2007

APP D.6

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

GLACIER: Nisqually (Upper)

DATE: _______________ **Recorded by:**

INITIALS: _______________ **Verified in the field by:**

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

Station	1	2	Probe extra?	Probe extra?
Elevation m.	3382	2960		
ft.	11,096	9,711		
Location N:	596439	596550		
(UTM NAD83) E:	5188702	5187304		
GPS pt name	NIS1A	NIS1		
Snow Probes (depth in m.)	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type
@stk				
W from stk) 1				
2				
3				
4				
5				
(E from stk) 6				
7				
8				
9				
10				
Notes:				
Surface type @ stk Debris thickness				
Stake Height Total stk height above @ time of visit including removed sections *	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 # ______		
Spring data	9m stk 6 segments 8.5m hole 0.5m above surface ___m ave.probe depth	9m stk 6 segments 8.5m hole 0.5m above 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")

updated 3/05/2007

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

GLACIER: Nisqually (Lower)

DATE: ________________

INITIALS: ________________

Recorded by:

Verified in the field by:

Entered date:
Verified date:
Updated date

Entered by:
Verified by:
Updated by:

Station	3	4	4A	5
Elevation m.	2175	1890	1870	1778
ft.	7,136	6,201	6,135	5,833
Location N:	596042	595996	596234	595977
(UTM NAD83) E:	5185677	5184588	5184418	5183966
GPS pt name	NIS3	NIS4	NIS4A	NIS5
Snow Probes	Record snow layers & type	Record snow layers & type	Record snow layers & type	Record snow layers & type
(depth in m.)				
@stk				
W from stk) 1				
2				
3				
4				
5				
(E from stk) 6				
7				
8				
9				
10				
Notes:				
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	10.5m stk 7 segments 11.5m hole 1m below surface ___m ave.probe depth	12m stk 8 segments 13.5m hole 1.5m below surface ___m ave.probe depth	9m stk 6segments 10m hole 1m below surface ___m ave.probe	9m stk 6segments 10m hole 1m below surface ___m ave.probe

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

updated 2/21/2007

Extra probe 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 NAD83) E:						
GPS pt name						
Snow Probes	Record snow layers & type	Record snow layers & type	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 E. Probe Error

The methods and equipment for monitoring the glaciers at MORA are equivalent to those used for glacier monitoring in North Cascades National Park (NOCA). Therefore, by assessing spring probe depth measurements and statistics for the four glaciers monitored at NOCA (during 1995, 1998, and 2000 balance years) we can presumably approximate probe error at either park. Figures F.1–4 display the snow depth measurements in meters (m) measured at each stake location on each glacier. Probe data is summarized to assess snow depth differences and standard deviations at each glacier. These data were then compiled to compare variation in spring probe measurement for a spring snow pack following a strong negative balance year (1995) and spring snow packs following a strong positive balance year (1998 and 2000). A summary of the average variation (average of standard deviations) for each glacier for each year is shown in Tables E.1 and E.2 (unit of measurement is meters water equivalent [m w.e.]).

Table E.1. Average uncertainty variation for glaciers between strong negative year (1995) and strong positive years (1998, 2000)

		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 E.2. Average difference variation for glaciers between strong negative year (1995) and strong positive years (1998, 2000)

		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

North Klawatti
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	6.93	6.61	7.31	0.70	0.27
2	5	7.04	7.00	7.09	0.09	0.04
3	5	6.41	6.28	6.51	0.23	0.10
4	7	6.56	6.28	6.69	0.41	0.14
5	6	5.72	5.42	5.95	0.53	0.18
6	4	4.95	4.59	5.14	0.55	0.25
				Ave.	0.42	0.16

Probe values not used

stake	Values not used
	NONE

1995 Data

Stake	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5	Depth 6	Depth 7
1	7.02	7.10	7.09	6.61	7.31	6.64	6.76
2	7.09	7.01	7.00	7.04	7.04		
3	6.47	6.28	6.47	6.32	6.51		
4	6.57	6.28	6.47	6.61	6.6	6.69	6.69
5	5.42	5.95	5.84	5.71	5.72	5.65	
6	4.59	5.14	5.01	5.07			

1998 Summary

Stake	N	ave	Min	Max	Difference	Std Dev m w.e.
1	12	5.91	5.39	6.26	0.87	0.31
2	11	6.08	5.82	6.34	0.52	0.19
3	9	5.65	5.61	5.7	0.09	0.04
4	4	4.49	4.35	4.66	0.31	0.14
5	10	4.76	4.53	4.92	0.39	0.12
				Ave.	0.44	0.16

Probe values not used

stake	Values not used				
3	4.96 too low				
4	5.3	5.34	5.55	5.12	5.29
5	5.73 too high				

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	Depth 12
1	5.96	5.97	6.00	5.80	5.42	5.39	5.50	6.04	6.26	6.21	6.26	6.05
2	6.08	5.91	5.86	5.94	5.96	5.82	6.19	6.25	6.2	6.32	6.34	
3	5.64	5.62	5.67	5.69	5.7	5.69	5.63	5.61	5.62			
4	4.66	4.54	4.35	4.39								
5	4.92	4.90	4.70	4.80	4.76	4.53	4.79	4.77	4.58	4.80		

2000 Summary

Stake	N	ave	Min	Max	Difference	Std Dev m w.e.
1	7	5.98	5.83	6.11	0.28	0.12
2	8	6.42	6.27	6.71	0.44	0.15
3	7	6.65	6.43	6.88	0.45	0.15
4	10	6.38	5.87	7.05	1.18	0.45
5	11	5.72	5.40	6.1	0.70	0.21
				Ave.	0.61	0.21

Probe values not used

stake	Values not used	
1	5.52	5.54 ice layer
2	5.62 ice layer	

2000 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	6.06	6.00	6.09	6.11	5.94	5.84	5.83				
2	6.3	6.47	6.34	6.38	6.27	6.71	6.53	6.33			
3	6.77	6.88	6.52	6.43	6.7	6.64	6.64				
4	6.62	6.87	6.57	7.05	6.77	6.01	5.87	5.87	5.92	6.23	
5	5.52	5.62	5.76	6.1	5.88	5.64	5.54	5.8	5.96	5.75	5.4

Figure E.1. Spring Probe Statistics for North Klawatti Glacier 1995, 1998, 2000.

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	

Figure E.2. Spring Probe Statistics for Sandalee Glacier 1995, 1998, 2000.

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

Figure E.3. Spring Probe Statistics for Silver Glacier 1995, 1998, 2000.

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

Figure E.4. Spring Probe Statistics for Noisy Glacier 1995, 1998, 2000.

Appendix F. Stake Sinking Assessment

Example from Sandalee Glacier (NOCA), 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. (meters water equivalent).

Methods

Since we use the same methods and equipment to monitor the glaciers in North Cascades National Park (NOCA) as we do in MORA, we assessed stake sinking by monthly probing during the summer of 2000 on Sandalee Glacier. Sandalee Glacier is located on the north face of McGregor Mountain in the Stehekin River watershed of NOCA. The 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 F.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

Table F.1 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 F.2). 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.

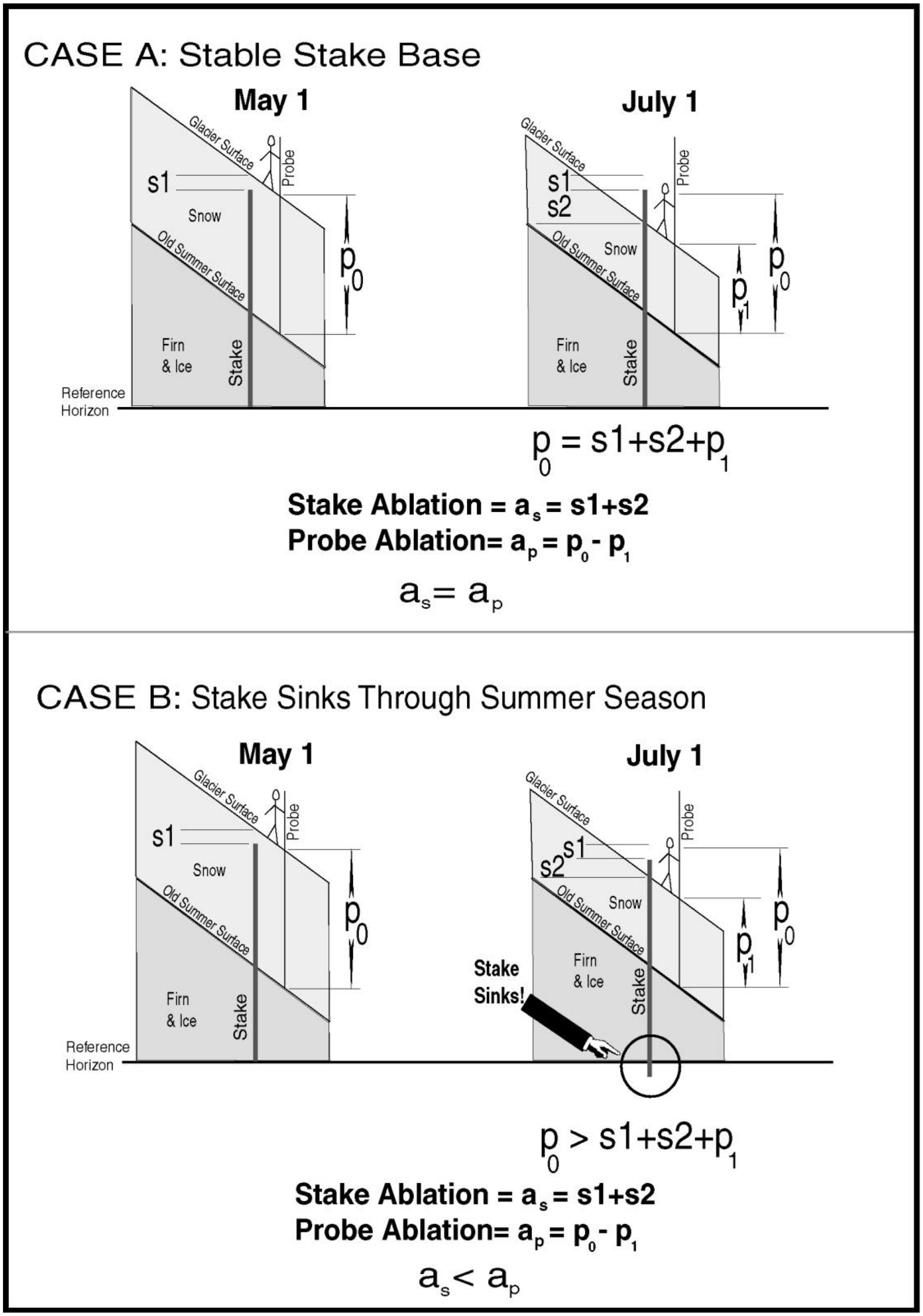

Figure F.1. Relationships between probe and stake measurements and how they relate in the case of stake sinking.

Table F.1. Raw data and ablation calculations of stake and probe data from Sandalee Glacier, balance year 2000.

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)

Table F.2. Summary of stake ablation minus probe ablation (as – ap) 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-Sept., Cumulative	-0.22	-0.14	-0.12	-0.44	(May-August)

*Not Available as a result of bad probe data

Appendix G. Example Reporting Documents

Figures G.1–4 are regularly included with annual, 10 year, and 20 year reports. Figures G.1–2 compare winter, summer, and net balances in m w.e. (meters water equivalent) for each glacier for every year of monitoring. Note that all years have had negative net balances since monitoring began. Identifying trends in glacier health can be achieved by comparing the cumulative net balance of each glacier as shown in Figure G.3. Fluctuations of the Equilibrium Line Altitude (ELA) on each glacier are shown in Figure G.4. Note in all years of monitoring, the Nisqually Glacier (south facing) has a higher ELA than the Emmons Glacier (east facing).

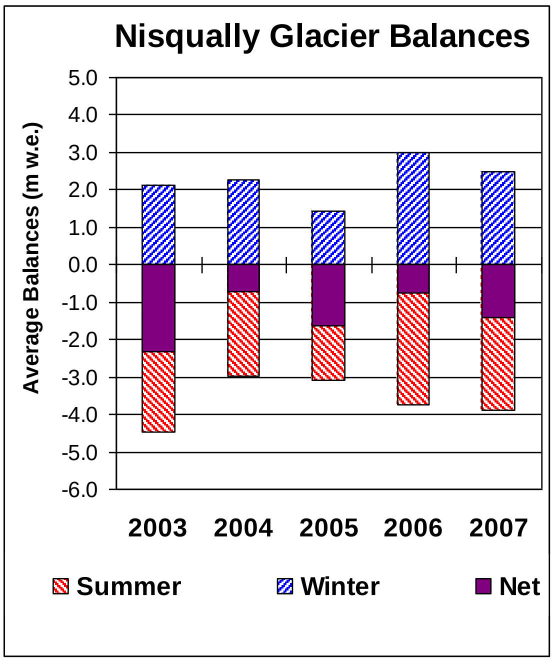

Figure G.1. Summer, winter, and net balance by year for the Nisqually Glacier.

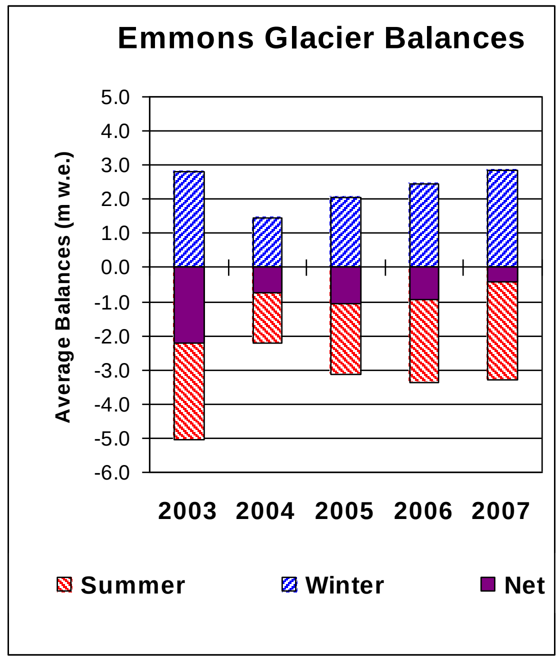

Figure G.2. Summer, winter, and net balance by year for the Emmons Glacier.

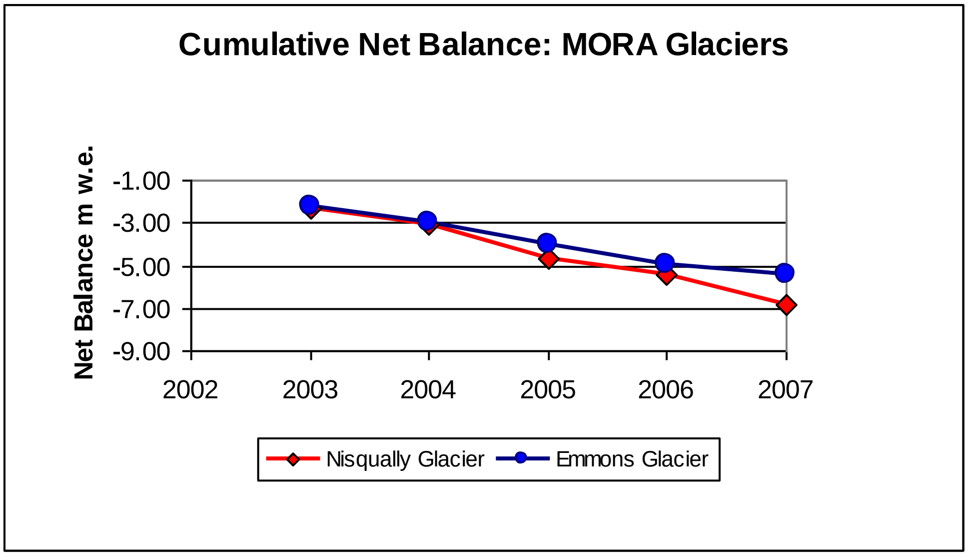

Figure G.3. Cumulative net balance for the Nisqually and the Emmons glaciers by year.

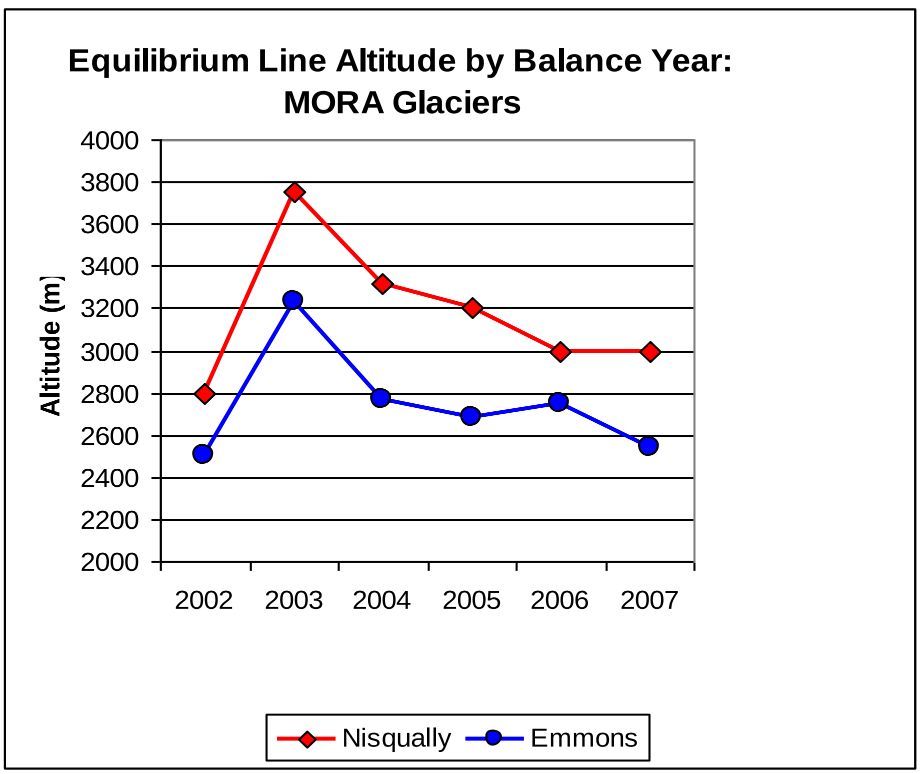

Figure G.4. Equilibrium Line Altitude (ELA) for the Nisqually and Emmons glaciers by year.

Appendix H. Job Hazard Analysis:

Operational Risk Management Analyses for Long-Term Monitoring Of Glaciers in Mount Rainier National Park

Overview

This document, Appendix H. Job Hazard Analysis, is provided to address the seven steps listed below in order to ensure crew safety while conducting field work for the Glacier Monitoring Protocol for Mount Rainier National Park.

1. Define the Mission/Task
2. Identify the Hazards
3. Assess the Risk
4. Identify the Options
5. Evaluate Risk vs. Gain
6. Execute the Decision
7. Monitor the Situation

1. Define the Mission/Task

The general goal of the glacier monitoring program is to provide information on glacier change (glacial advance/recession and range of variation and trends in mass balance) and ecosystem dynamics (glacial runoff/stream buffering). The glacier monitoring program outlined below is designed to meet four more specific goals.

a. Monitor change in area and mass of MORA index glaciers;
b. Relate glacier changes to status of aquatic and terrestrial ecosystems;
c. Link glacier monitoring observations to research on climate and ecosystem change;
d. Share information on glaciers with the public and professionals.

Field work involves multiple trips to the Emmons and Nisqually Glacier from the terminus up to 11,100 feet during the spring, summer, and fall.

2. Identify the Hazards

Task: Access to glacier:

Hazard: Cross country travel including but not limited to; stream crossings, boulder hopping, crossing steep snow/ice resulting in twisted ankles, broken bones etc..

Action to mitigate hazard:

- Employees briefed in job KSA’s and are familiar and competent traveling on this terrain.
- All employees wear appropriate footwear
- 1–2 first aid/trauma kits are carried on each backcountry trip

Hazard: Snowmobile travel resulting in machine crash or rollover sustaining high impact injuries.

Action to mitigate hazard:

- Only employees knowing how to operate machines are allowed to drive. Employees must be briefed on use and safety of individual snowmobiles by qualified personnel. At Mount Rainier, qualified personnel include the East Side District Ranger and the Electric Shop Lead.
- Path is scouted for and cleared of downed trees and hanging braches to allow passage
- Driver always use conservative speeds
- If sled is used, it is loaded properly and luggage is securely strapped
    - If sled is used, sled is disconnected and pulled/pushed over excessive dips and difficult terrain.

Hazard: Use of chainsaw to clear obstacles (trees, branches)

Action to mitigate hazard:

- Only employees who are certified through NPS training are allowed to operate chainsaws. If no team members are certified, the crew must rely on an outside party to accompany the team to the White River Ranger station, or obtain information prior to departure that no obstacles are blocking access. East side are certified and have access to a chainsaw.
- Proper personal protective equipment must be worn when operation a chainsaw. This includes, eye protection, hard hat, gloves, and ear protection.
- Chainsaw must be equipped with a chain brake
- An active spotter must be present when chainsaw is in use.

Task: Drilling holes in ice

Hazard: Burns from steam drill, and back injury from carrying drill.

Action to mitigate hazard:

- Employees are properly trained in steam drill use.
- A new lighter drill was purchased in ’02.
- Employees always assist each other in placing backpack mounted steam drill on an individual

Hazard: Propane leak leading flames:

Action to mitigate hazard:

- Drill, connectors, and propane tank are checked in office for any leaks prior to each trip.
- Propane tanks are stored in designated propane storage areas and steam drill is stored in a dry location.

Task: Glacier travel

Hazard: Fall into crevasse

- Action to mitigate hazard:
- Before every trip all employees and volunteers are briefed on glacier hazards.

- 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. -Field personnel have received training in glacier travel and crevasse rescue.
- NPS staff attends a preseason glacier travel refresher class conducted by the lead field technician at North Cascades National Park.

Hazard: Caught in snow avalanches

Action to mitigate hazard:

- Trip is canceled if group feels danger is too high to safely travel in avalanche terrain.
- During spring visits when avalanche danger is high, all employees carry an avalanche beacon and have snow shovels and know how to use beacons

Hazard: High altitude sickness on Mount Rainier

Action to mitigate hazard:

- Field leads or all field personnel have had wilderness 1st aid/First Responder, courses which includes training in identifying and treating altitude sickness.
- Employees are continually reminded to stay hydrated and are encouraged to voice any health concerns

Hazard: Objective hazards with injuries associated with falling rock and ice.

Action to mitigate hazard:

- Helmets are worn in high risk areas
- Staff try to travel during appropriate times. ie. early morning when crevasses snow bridges are frozen and rock/ice are frozen to cliffs.

Other areas of Concern

Personnel

Volunteers are essential for the glacier monitoring project.

Hazard: Inexperienced volunteers and/or volunteers that are not physically fit for the demanding physical field work.

Each field excursion varies with technical and physical challenges. Some trips may require one to have extensive background experience in glacier travel while others require only excellent physical fitness. Before each trip, the field lead with the supervisor's oversight and assistance must define these challenges and choose field partners who can meet the needs of the trip. The following questions are asked by the field lead to assess the physical fitness and experience of the volunteer:

- What backpacking experience do you have?
- What glacier travel experience do you have?
- What type of experience do you have: skiing, climbing and mountaineering?
- Have you climbed Mount Rainier before and under what circumstances did you climb it (i.e. guided, personal)?

- How do you currently stay in shape?
- Have you been out skiing, climbing, or mountaineering recently?
- When is the last time you carried a heavy pack (60lbs)?
- Can you and are you willing to carry a heavy (60lb+) awkward pack for an extended day (10+hrs) over rough and hazardous (snow, ice, crevassed, rock) terrain?

In order to participate on a trip which requires high elevation (<10,000') and crevasse travel, all field members (volunteer or paid employee) must have formal training in glacier travel and rescue.

- Potential field crew without formal training can participate in the lower glacier trips if 1) the person can demonstrate glacier travel proficiency (including good mountain judgment, and off trail experience) during an interview with the field lead or supervisor and 2) all other field participants are glacier travel qualified.

Questions to Always Address Prior to Departing on a Trip:
Equipment: Is the equipment functioning properly and can it be expected to function properly throughout the planned field trip? Does every member of team have required gear? Does everyone on team know how to use gear?

All team members are required to bring and know how to use glacier gear listed below:
Helmet

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

Environment: How will the weather and snow conditions affect travel to and on the glacier? Does the trip need to be postponed due to visibility conditions, avalanche concerns, and/or snow conditions (visibility of crevasses, deep snow leading to long travel time and increased fatigue)?

Personnel: Is the team properly trained and capable of handling the demands of the mission? Is anyone on the trip fatigued, complacent, or suffering from the affects of physical or mental stress? Is anyone unsure about the conditions on the mountain?

3. Assess the Risk

GAR MODEL

Element	Risk Rating
Supervision	7
Planning	3
Contingency Resources	9
Communication	3
Team Selection	5
Team Fitness	5
Environment	9
Incident Complexity	9
Total	50 (Amber Zone)

Table H.1. GAR Model. Summary of 8 elements of risk concern and management for glacier monitoring field activities.

1. Supervision
Decisions and work are typically carried out by field crew with little contact with supervisor during field work. Field Lead makes decision with group discussion. There is limited to no contact with supervisor during field trips.

2. Planning
Planning is essential to the glacier program. Trips are planned around good weather and low avalanche conditions. Trips will be cancelled and re-scheduled to fit the best weather and snow conditions. Once team is in the field, field work will be cancelled if conditions are not suitable for field work. It is critical that the team is willing to cancel the trip if conditions deteriorate.

3. Contingency Resources
We consider two aspects to contingency resources:
(1) If one of initial team members cannot make the trip, due to trip rescheduling or other conflict, a back-up is selected in their spot. It is often difficult to fill that spot with an equally experienced and fit team member. There is still considerable control in the decision to go or not to go and risk versus benefit must be applied.
(2) If an accident does occur on the mountain, how available is extra help? With proper communication, contact with help is readily available. Depending on the location and weather conditions on the mountain, there may be quite a delay in help actually arriving on scene.

4. Communication
At minimum, 2 radios with a back-up battery are carried on all trips. The communications center is available 24 hours a day, either through Mount Rainier or Enumclaw Dispatch. Communication on the upper mountain is generally good. An employee patrol log is completed for all overnight trips prior to departure. Field crews checks-in with the communication center on overnight trips in the morning prior to departure and at the end of each day.

5. Team Selection
Good team selection is top consideration for the field trips. All team members must be experienced and trained and teams must be selected appropriately depending on the demands of the trip. Due to funding and availability, volunteers are often used on trips. It is critical that volunteers are experienced and physically and mentally fit for the demanding field trips and meet the requirement defined in number 2: Identify the Hazards, Volunteers. It is challenging, but doable, to put together a qualified team with the ever changing weather, snow conditions, and schedules. The team must be willing to cancel if there are too few team members or if a volunteer is not determined to be experienced enough for the particular trip. Each field excursion varies with technical and physical challenges. Therefore, each trip and team must be assessed thoroughly before each trip.

5. Team Fitness
Following the rational for proper team selection, team members must be rested and physically fit for the arduous trips, particularly the high elevation trips. Packs are heavy and access to high camps can vary from 5-9 hours depending on snow

6. Conditions
Fatigue will occur even with a physically fit team. If one member is feeling the fatigue or affect of the high elevation, a discussion must ensue whether to abandon the trip or continue. That team member must be constantly monitored by all other team members.

7. Environment
The environment dictates the timing of the trip. However, when in the field, team members often encounter harsh weather conditions. Navigation can be challenging, the cold and heat can greatly affect performance, and snow, crevasse, and rock-fall create hazards on all trips.

8. Incident Complexity
Glacier field work often results in long field days. Exposure to hazards is controlled by avoiding crevasses, roping up in teams, passing quickly through rock-fall areas and avoiding high avalanche days. On the upper mountain, exposure to hazard is constant during all seasons. Mitigations measures are listed in Step 2.

4. Identify the Options
Mitigation measures are defined in Step 2. In additions to those measures defined in step 2, the following measures are included in the *Long term Monitoring of Glaciers at MORA NP*. See highlighted sections in attached SOP 1.

For new employees, primary training for their roles and responsibilities is accomplished on the job by reading the protocols, briefings, and by experience. Additional glacier travel training is required for compliant and safe execution of duties for each of the primary personnel. NPS staff attends an annual preseason glacier travel refresher class conducted by the lead field technician at North Cascades National Park. New employees must demonstrate knowledge of glacier travel and proper to the field lead.

All staff need to review the Job Hazard Analysis in this appendix once a year while going through the annual safety checklist with a supervisor.

Access to each glacier is dictated by seasonal visit and avalanche and weather conditions. SOP 1 (Field Season Timeline, Preparations, and Procedures) describes access options and factors to consider with each field trip.

5. Evaluate Risk vs. Gain

Team members primarily determine risk based on:

1. Weather Conditions
2. Avalanche Conditions
3. Team availability and fitness weighed against demands of particular trip

A glacier field trip will proceed if all three criteria are suitable for the demands of the trip. If any one of the elements is not suitable for any one member, the gain of completing the trip does not out weigh the risk and the trip is rescheduled. If conditions change during the field trip and are no longer suitable, the team is turned around. Constant monitoring in the field of the conditions and the team is critical.

6. Execute the Decision

Trips are rescheduled and personnel replaced based on risks listed in #5. Any one team member and supervisor is responsible for assessing the risk of a particular trip.

7. Monitor the Situation

Team members are constantly monitoring the situation (environmental conditions and team availability and fitness) prior to departure and during the trip.

Appendix I: 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

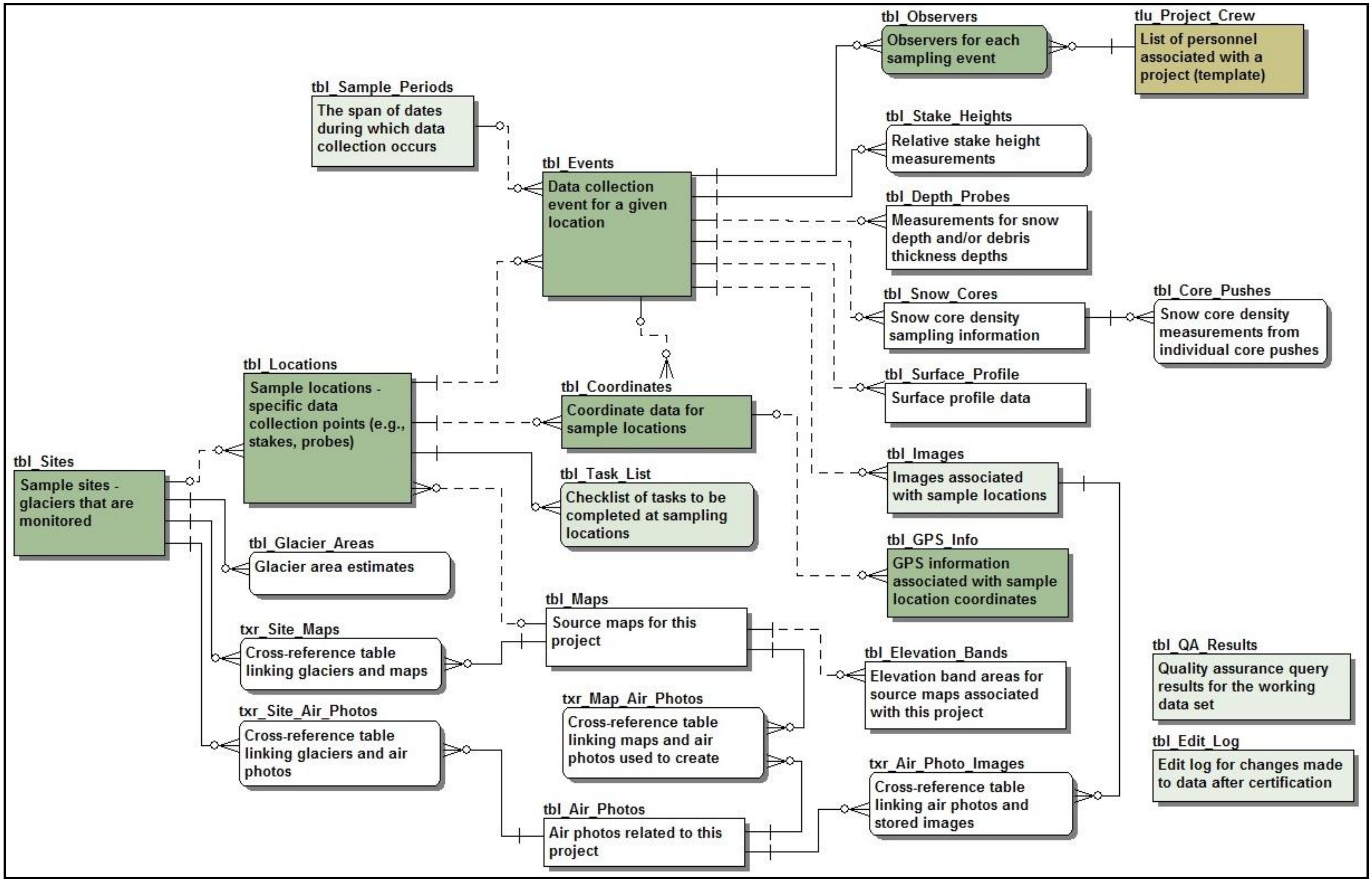

Figure I.1. Entity Relationship Diagram of the project database. Relationships between tables are represented by lines. Dark green tables represent core standard tables; light green represents extended standard tables; light brown are standard lookup tables. Project-specific tables are unshaded.

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

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

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

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

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

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
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

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

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

tbl_Stake_Heights - Relative stake height measurements
<u>*Constraints*</u>: : ([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
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
Datum	primary *	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	

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)	

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	

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

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 J. Administrative History of MORA Glacier Protocol Development

Sept, 18 2001

C:\network\moraglaciers.doc

Options for Monitoring Glaciers at Mount Rainier National Park

Key questions:
Goal identification-
1) Are we monitoring glacier-climate-hydrologic-ecological relationships? AND/OR
2) Are we monitoring glacial hazards? (link with volcanic processes)
3) Importance of continuing historical observations and methods?

Methodological
1) How significant is the time-transgressive nature of the balance year on the large glaciers on Mt. Rainier?
    1a) Do we need more than one system/approach to monitor the large, hazardous glaciers and the two climates at Mount Rainier?
    1b) Are any of the methods better/worse at accommodating this?
2) What glaciers, or parts of the mountain, should we monitor?
    2a)Why S. Tahoma selected at Vital Signs?
    2b)Will smaller isolated ice masses give better glacier-climate signal?
3) What are the appropriate time intervals for different methods?
    3a) Annual, 5-year, and 10-year intervals.
    3b) Do any of the methods work better with different intervals?
4) Are there elements of approaches defined below that we can combine? (e.g. stakes at low elevations, satellite/mapping and/or modeling of accumulation zones).
5) How important are subglacial/geothermal ablation processes?

Partnerships
1) Can we identify any partners to share cost? (USGS, State, UW, PSU, Counties, Utilities, etc).
2) Need to link cost-sharing, data collection and measurement and reporting systems within Park and Network and beyond.

Figure J.1. Options for Monitoring Glaciers at Mount Rainier National Park, 8/18/01, pp. 1–6.

Option 1: Conduct Traditional Surface Mass Balance Monitoring

A. Background: This is the basic approach used at USGS-South Cascade, NOCA, likely OLYM, and elsewhere. Only extensive stake networks previously on Mt. Rainier was Steve Hodge, who used 13 stakes to monitor the movement (and balance?) of the lower Nisqually Glacier in the 1970s.

B. Glacier Selection-Need to limit monitoring to a sub-population….Monitor a glacier on each side of the mountain: Nisqually, Carbon, Emmons, Puyallup?

C. General Protocols-

1. Initial-Detailed base maps with 10m contour intervals would be constructed of the four glaciers monitored using LIDAR or photogrammetry. These maps would be used to get an accurate estimate of the area-altitude distribution of each glacier for integrating point data.

2. Annual-Three visits would be made annually to each glacier, and to each point measurement site (ablation stake?). Spring (April) and fall (late September) trips would be supported by a helicopter. An early summer trip to each site would be on foot, and could be supported by the rangers. Due to the high elevation of the accumulation area, it would probably not be necessary to place stakes above (~8000 ft?). Probes would probably suffice to monitor accumulation and ablation at high elevations. At lower elevations, 4-5 ablation stakes would be placed on each glacier. Aerial photographs of the four glaciers would be taken at the end of the ablation season. **Could modify to Mayo/DENA approach, with only 2-3 stakes/glacier.**

3. **Ten-year–** Base maps of the four monitoring glaciers would be redone, and all of the glaciers on Mount Rainier are inventoried (area). Ideally, we would obtain Orthophotoquads that would allow direct measurements of area. This effort could be expanded/altered to measure ice volume. This effort could be coordinated with obtaining aerial photographs of the entire park.

D. Estimated Cost- Assuming that four glaciers are chosen and ~20 ablation stakes would be placed, and a helicopter could be used to support this effort, an initial cost estimate is:

1. Base maps the first year, then every ten years- $15,000 (once every 10 years)
2. Field Measurements annual - $25,000 (annually)
3. Inventory Every 10 years- $40,000 (this effort could be coordinated with obtaining aerial photographs of the entire park).

E. Advantages

1. Data collected similar to NOCA, SOCA, OLYM and other programs regionally and world wide.
2. Annual measure of glacier change.
3. Protocols well-established.
4. Some measurements can be taken even if the weather isn't perfect.

Figure J.1. Options for Monitoring Glaciers at Mount Rainier National Park, 8/18/01, pp. 1–6 (continued).

5. Detailed site measures would provide data for calibrating other approaches.
6. Could use rangers to take simple surface measurements on stakes and with probes.

F. Disadvantages

1. Would require helicopter support in Spring and Fall
2. Safety and Access concerns on heavily crevassed areas.
3. Traditional mass balance techniques would underestimate balance on the heavily crevassed glaciers of MORA
4. All of the glaciers identified above have common accumulation zones and flow divergence at their lower ends. These factors make it difficult to identify the area of individual glaciers.
5. Identification of the previous summer surface high on the mountain.
6. Labor intensive. It would likely take four days of good weather with one – three person team to conduct the spring measurements and place ablation stakes.
7. Only ~¼ of the glaciers are monitored, and we don't know how representative they are.

Option 2. Monitor mass balance using remote sensing/photogrammetry.

A. Background-There has been some work done by the USGS using classified satellite imagery to monitor South Cascade Glacier, and glaciers in North Cascades National Park. Driedger and Kennard (1984) used aerial photographs, maps and empirical methods to estimate total ice volume on Mount Rainier. Nylen and others monitored area changes 1913-1962-1994, and estimated volume changes 1913-1994.

B. Glacier selection Either two (Carbon- Nisqually) or four (add Puyallup and Emmons) glaciers.

C. General protocol. Using spy satellites images (or LIDAR) measurements would be taken of the selected areas twice a year. The first image would be obtained near the end of the accumulation season in late April-early May. Detailed base maps would be constructed of the four glaciers monitored using LIDAR or photogrammetry. These maps would be used to get an accurate estimate of the area-altitude distribution of each glacier for integrating point data.

D. Estimated costs. Based on previous work at NOCA by USGS $40,000 annually.

E. Advantages

1. Not labor intensive?
2. No need for helicopter support in Wilderness.
3. Much safer than on site measurements.

Figure J.1. Options for Monitoring Glaciers at Mount Rainier National Park, 8/18/01, pp. 1–6 (continued).

4. Could be linked to aerial photograhpy of entire park/shared costs.
5. Could select other than annual time intervals (monitor changes at 5-years?).
6) Could easily be combine with other methods.
7) Limited # of observations (may not accommodate time-transgressive or multi-environment/climate conditions

F. Disadvantages

1. Need for calibration data?
2. Weather can limit time of observation.
3. Satellite availability?
4. Relatively high cost-effort to conduct measurements annually.

Option 3. Monitor glaciers using an energy-balance model, meteorologic data, and limited observations.

A. Background. Thomas Nylen did work in this area at Mt. Rainier. Others have also used this approach, including Tangborn, who has related mass balance to stream gage records, precipitation and temperature in the North Cascades (PT model). I believe he is still refining this approach. Also see Orlemans (1992) application of this approach in Norway, and Willis use of this approach in the Alps.

B. Glacier selection. Likely would include all glaciers on mountain.

C. General protocol. This option could involve use of MM5 or other climate models to predict ppt.

D. Estimated costs. Unknown at this time.

E. Advantages

1. Safety- nobody physically on mountain.
2. Easy to link with other approaches.
3. Some protocols established.
4. Should account for time-transgressive nature of long glaciers.
5. No wilderness-helicopter conflicts.

F. Disadvantages.

1. Need calibration data for model.
2. Are there enough met stations in park to characterize climate?
3. Accuracy and need to combine with other measures.

Option 4. Monitor glaciers with longitudinal profiles.

Figure J.1. Options for Monitoring Glaciers at Mount Rainier National Park, 8/18/01, pp. 1–6 (continued).

A. Background. Nisqually Glacier has been monitored almost continually since the early 1920s by longitudinal profiles.

B. Glacier selection. Nisqually and others?

C. General protocol. Well established. Could use LIDAR or photogrammetry to replace surface measurements.

D. Estimated costs.

E. Advantages

1. Continues long-term effort.
2. No helicopter use.
3. Annual measure of glacier change.
4. Protocols well-established.
5. Some measurements can be taken even if the weather isn't perfect.

F. Disadvantages

1. Provides limited, and uncertain information on glacier-climate relationships over short time periods.
2. Relationship of measurements to other glaciers uncertain.

Option 5. Use hydrologic (stream gages) methods to monitor glaciers.

A. Background. Tangborn, Krimmel and Meier (1975) compared this method to mapping and glaciological methods. The hydrologic approach was believed to be the least accurate and consistent of the three methods examined because of the release of liquid water stored in the glacier.

B. Glacier selection

C. General protocol. Establish stream gages below glaciers and monitor discharge through year.

D. Estimated costs. Adding stream gages to four glaciers would cost ~$15,000 for installation, and ~$10,000/ year for operation and maintenance.

E. Advantages

1. Could account for internal ablation.
2. Relatively simple technology.
3. Not labor intensive.
4. Cost share with USGS/others?
5. Annual measure of glacier change.
6. Protocols well-established.
7. Measurements can be taken in all weather conditions.

Figure J.1. Options for Monitoring Glaciers at Mount Rainier National Park, 8/18/01, pp. 1–6 (continued).

F. Disadvantages

1. Accuracy (non glacial sources)
2. Debris flows
3. Gage stability
4. Identifying non-glacial contribution to flow.

Figure J.1. Options for Monitoring Glaciers at Mount Rainier National Park, 8/18/01, pp. 1–6 (continued).

Sept, 18 2001

Mt Rainier Meeting

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Figure J.2. List of attendees of the Mount Rainier Scoping meeting, 8/18/01, 1p.

2001 Glacier Contracts with Portland State University
Cooperative Agreement No. 1443-CA9000-99-003
Modification 0003

Article 2 – Assist with development of glacier monitoring protocols for Mount Rainier National Park.

Glaciers on Mount Rainier can not be monitored with standard protocols used elsewhere by the USGS and NPS because of their large size, a common accumulation area, and difficulty of access. Therefore, the NPS is currently developing new protocols. The goal of this contract is have PSU assist North Cascades National Park with protocol development. PSU faculty and students have studied the glaciers at MORA previously. Specific objectives include:

1) Assess 2-3 basic protocols developed by the NPS, including their feasibility (safety, access, cost, personnel, etc).

2) Recommend a single methodology to be employed for future long term monitoring of MORA glaciers. Protocols should address annual monitoring at selected sites as well as periodic monitoring of the entire volume of ice at MORA.

The NPS will develop two to three general approaches for PSU to assess, including longitudinal profiles, mass balance measurement with probing and ablation stakes, photogrammetry, or some combination of these approaches. NPS will also provide necessary GIS data, and other information including aerial photographs and reports.

The primary product produced by PSU would be a report that assesses the range of protocols and recommends which single protocol the NPS should follow.

Cost of this work shall not exceed $7000. NPS account classification for article 2 is 9453-M106-nii.

Completion date March 31, 2002.

Figure J.3. Document of 2001Glacier Contract with Portland State University Cooperative Agreement No. 1443-CA9000-99-003 Modification 0003, 2001, 1p

Glacier Monitoring Protocol Development
Mount Rainier National Park
J. Riedel, Fall 2001

Draft 3 1/31/01 (2002?)

Cooperative Agreement between the National Park Service and Portland State University

– Ikonos data – glacier area / inventory ?

– Nisqually Glacier Surveys (Carolyn D.).

Figure J.4. Document of Glacier Monitoring Protocol Development, 1/31/02, pp. 1–6

Introduction

Glaciers are a critical resource and feature of Mount Rainier National Park (MORA) that have undergone substantial change in the past century. There is currently 4.34 km^3 of ice on Mt. Rainier, and since 1913 the total area of the mountain covered by glaciers has decreased 18.5 % (Nylen, 2001).

The importance of glaciers to the park ecosystem and park management is stressed in the park's General Management Plan, and more recently at a Vital Signs Workshop in Spring 2001. At this meeting of resource management professionals, glaciers were identified as a vital sign of ecological condition at Mt. Rainier National Park that should be monitored. Participants in this workshop indicated that monitoring should focus on "…present and future spatial extents of glaciation and snowpack, and its interconnection with ecological and hydrological systems…." This group also suggested that all glaciers in the park be inventoried periodically.

The overall goal of the proposed glacier monitoring program is to provide information on geological hazards (outbursts, ice avalanches), ecosystem dynamics (glacial runoff/stream buffering), and global change (glacial advance/recession). The glacier monitoring program outlined below is designed to meet four objectives. These objectives were developed at the Vital Signs workshop, the Tacoma meeting, and by NOCA staff.

Objective 1 – Measure annual changes in the volume (elevation and extent) of lower portions of selected glaciers.

Objective 2 – Monitor changes in surface features of glaciers, including ponds and ice falls.

Objective 3 – Establish annual relationships between elevation and accumulation and elevation and ablation.

Objective 4 – Use data from objective 3 to estimate winter, summer and net balance for Emmons and Nisqually glaciers.

The purpose of this document is to further develop glacier monitoring protocols for Mount Rainier. North Cascades NPS Complex (NOCA) staff have developed a general protocol that is described below. Originally, Portland State University (PSU) was to finalize protocol development by selecting a methodology from a range of potential approaches developed by the NPS. This effort was to be coordinated through a Cooperative Agreement between NPS staff at NOCA and PSU. A meeting among regional glaciologists held in Tacoma has made it possible for us to identify a single preferred approach. Thus, the NPS requests that PSU slightly change the focus of our agreement to conduct final development of the preferred protocol. Specific objectives and questions for PSU are listed below.

Tacoma Meeting

An interagency meeting at the USGS-WRD Tacoma Office in September 2001 assessed five alternative approaches to monitoring glaciers at MORA. These included:

2

Figure J.4. Document of Glacier Monitoring Protocol Development, 1/31/02, pp 1–6 (continued).

1. Surface mass balance monitoring with probes and stakes,
2. Mass changes using repeated mapping,
3. Mass changes using an energy balance model,
4. Surface elevation changes at margin with surveys, and
5. Mass changes using gauging station data.

Discussion focused on the advantages and limitations of approaches number one and two. Most participants in the Tacoma meeting favored monitoring annual mass changes of index glaciers using approach number two. The repeat mapping glacier monitoring approach would allow for quantitative measure of volume changes at the margin by annually mapping glacier surface elevations. It would also provide monitoring of glacial advance/retreat, and development of surface features such as crevasses and ponds. Monitoring annual changes in the size of glacier margins by repeated mapping would provide a once-annual estimation of change in glacier volume. This information will be critical for understanding glacial hazards such as outburst floods and ice avalanches

There are several limitations to the repeated mapping approach. First, it will not provide a direct annual measure of glacier response to climate because changes in ice margins are also controlled by several factors not directly related to climate. Further, repeated mapping will not provide a measurement that can be linked to sub-decadal change in aquatic ecosystems or data that can be compared to glacier monitoring networks at the regional and global scale. Another limitation of the repeated mapping approach is that it does not provide data for a large part of the park above elevation 8,000 ft. Images taken at the end of the melt season will provide only a hind-cast of glacier change for the previous year.

There was considerable discussion about the appropriate technology for monitoring glaciers with repeated mapping. Participants at the meeting agreed that kinematic GPS assisted photogrammetry was currently the method of choice for annual mapping. However, satellite data or LIDAR could also be used in place of or in combination with photogrammetry using aerial photographs.

Preferred Protocol Design

After reviewing the discussion from the Tacoma meeting and other recommendations provided by people who could not attend the meeting, we propose a combined approach to monitoring the glaciers at MORA. This approach would involve use of both repeat mapping and surface measurements.

The proposed approach to glacier monitoring is similar to an approach recently suggested by Fountain and Nylen. In contrast to their approach, however, we do not propose at this time to use satellite imagery to monitor volume changes in glaciers on Mt. Rainier. The participants of the Tacoma meeting suggested that for the near future aerial photography should be used. It offers the advantage of providing other ecosystem data relevant to park management (i.e. vegetation, soils, and hydrology), and can be obtained at a relatively low cost when the entire park is covered. However, satellite imagery may be

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Figure J.4. Document of Glacier Monitoring Protocol Development, 1/31/02, pp 1–6 (continued).

the preferred method for mapping all of the glaciers on Mt. Rainier due to limited distortion and the ability to analyze digital data more rapidly.

Because all of the lower Nisqually Glacier will be mapped, surface profile measurements will be discontinued. However, mapping will allow for continued monitoring of surface profiles.

This protocol does not address the identified need for more weather data at the park, particularly at higher elevations and on the northeast side of Mt. Rainier.

Glacier Selection
Four glaciers are proposed for this monitoring program and include Nisqually, Carbon, Emmons and Tahoma glaciers. Stake placement and probing would be focused on Nisqually and Emmons glaciers. Mapping of glacier margins would include all of the glaciers.

Annual Mapping
Mapping would focus on those parts of the four glaciers below 8,000 ft. Annual images of the glacier margins would be taken late in the melt season (late August-early September). The combined area of the four glaciers below 8,000 ft elevation is 13.3km^2 (Table 1). Annual DEMs would be compared to the previous year's DEMs to determine volume changes. Mapping would be accomplished through a private contractor.

Table 1. Areas of glaciers proposed for monitoring. Data from NPS GIS.

Glacier	Area <8000 ft (km2)	Total Glacier Area (km2)
Carbon	5.4	10.1
Emmons	4.9	11.2
Nisqually	1.8	4.3
Tahoma	2.5	6.9
Totals	**14.6**	**32.5**

Annual Surface Measurements
To address shortcomings in the repeat mapping approach, we propose to conduct limited probing and ablation stake measurement. Data on accumulation and ablation will allow the NPS to develop important information about the hydrology and climate of the park. Probes will be used to construct annual relationships between elevation and snow water accumulation. Probe and stake data will be used to construct annual relationships between snow and ice ablation and elevation. This information will compliment the mapping effort and provide a link with regional and global glacier-climate monitoring programs. Probing and ablation stake data will also provide critical information on climate at higher elevations on Mount Rainier, where the highest permanent weather station is at Paradise 6,000 ft.

Probing and stake placement would focus on Nisqually and Emmons glaciers for several reasons. First, the lower portions of these glaciers are the most accessible in the park,

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Figure J.4. Document of Glacier Monitoring Protocol Development, 1/31/02, pp 1–6 (continued).

which is important because the steam drill and other stake placing equipment can be transported overland (no helicopter support necessary). Second, major climbing routes along both glaciers will allow us safe access to high country areas where we can conduct probing through the melt season. Third, accumulation areas of both glaciers extend to the summit. Finally, selection of these glaciers will allow us to monitor aspect-related extremes in climate and glacier change, with Emmons on the northeast side of the mountain and Nisqually the southwest side.

Probing would generally occur in late April to early May on the glacier surface. If that surface is heavily crevassed or otherwise inaccessible, probes will be conducted along climbing routes on the east side of Nisqually Glacier and on the north side of Emmons Glacier. A minimum of five probe measurements would be made on each glacier, and would be located every 1,000 ft (300m) in elevation above Paradise (5557 ft) and White River Camp (4120 ft). Probing would be focused on areas below Camp Muir on the south side of Mt. Rainier, and below Camp Schurman on the north side. Probing would occur at a minimum of twice annually, with a spring trip in early May and a fall trip in late September. At least one trip annually will be made to probe between the summit and Camps Schurman and Muir.

Stakes would be placed at three locations on lower Emmons and Nisqually glaciers. Approximate centerline stake elevations on Emmons would be 5200 ft, 6600 ft and 8000 ft (1150, 1700 and 1950m). On Nisqually the stake elevations would be approximately 4800 ft, 5600 ft and 6400 ft (1460, 1700 and 1950m). Stakes could be placed in either early May or early summer, so long as they were placed before the last snow from the previous winter disappears from the glacier surface at the measurement point, and probes are conducted in May at the same locations.

Annual surface measurements will be conducted initially by a combination of NOCA staff familiar with probing and placing ablation stakes and MORA climbing rangers and resource management staff familiar with the mountain.

Data reduction

Point measurements from probes and stakes would be used along with weather data at Longmire to construct winter and summer balance curves. Data from these curves will be combined with areal measures of the glaciers from mapping to determine winter, summer, and net mass balance.

Summer and winter balance for the glaciers with surface measurements will be calculated by use of the balance curves. Balance values will be generated for each 30m elevation band, then summed for the entire glacier to estimate net balance.

Material density values used will be 0.5 for spring snow, 0.6 for snow that has lasted through the summer, 0.7 for two year-old firn, and 0.9 for glacier ice. Use of these values will be checked with snow density measurements where and when possible, recognizing that density values are likely to be time transgressive on the large glaciers.

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Figure J.4. Document of Glacier Monitoring Protocol Development, 1/31/02, pp 1–6 (continued).

Five Year Inventory Mapping
Every 5th year the surface elevation and extent of all the glaciers on Mt. Rainier would be mapped. The inventory would include several characteristics of each glacier, including area, aspect, ELA, etc. This effort could be accomplished using photogrammetry, satellite data, or LIDAR.

Reporting
Results of the glacier monitoring program will be made available to the public and scientists on Mt. Rainier National Park's web site, and in in-park publications.

Results will also be made available in a variety of publications, including:
-Annual update on winter accumulation/balance in the NRCS Washington Snow Survey Report for June 1.
-Annual reporting of data to World Data Center.
-Annual fall hindsight report on mass balance of Emmons and Nisqually glaciers based on surface measurements.
-Annual winter hindsight report on glacier change from repeated mapping and map analysis.

Five year reports on glacier mass balance and change will be made in professional journals such as Northwest Science, Journal of Glaciology, etc.

Focus of PSU Contract
The NPS requests assistance from PSU in three areas related to final protocol development:

1) Compare cost, accuracy, repeatability of satellite vs. LIDAR vs. airphoto mapping of selected glacier margins and for all glacierized areas on Mount Rainier. Make these comparisons for annual measurements on selected glaciers, as well as five-year mapping of all glaciers in the park. Provide recommendation on best approach among these three options for mapping.

2) Assess the preferred protocol and develop a final protocol. Consideration should be given to developing a program that can operate annually at approximately $30,000/year. Key questions include:
- -What are appropriate locations of ablation stakes?
- -What is an appropriate number of stakes on the two glaciers?
- -Can we extrapolate from observations on Carbon and Nisqually glaciers to all glaciers on the mountain?
- -How will large amounts of mapping data be stored and used?
- -Are the glaciers selected the most appropriate ones to monitor?
- -Can point measurements on the lower glaciers represent conditions on the upper glaciers ?
- -Are data reduction procedures (including material density assumptions) appropriate?

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Figure J.4. Document of Glacier Monitoring Protocol Development, 1/31/02, pp 1–6 (continued).

Department of Geology
Portland State University
Portland, OR 97212

June 15, 2002

Mr. Jon Riedel
North Cascades National Park
7280 Ranger Station Road
Marblemount, WA. 98267

Dear Jon,

Per your request I have examined the Glacier Monitoring Protocol Development for Mount Rainier National Park. The purpose of this protocol is to best track glacier change in the park given the limited resources available for such a study. Mount Rainier is a particularly important area for glacier observations because glacier changes have been monitored, off an on, since the 1800's. From a glacier-climate perspective, it is important to continue these important observations. Given the recent rapid advances in computers and imagery acquisition, both satellite and aircraft, we are at the cusp of monitoring all glaciers in a cost-effective manner. Therefore, this is an important time to evaluate the variety of procedures that can be applied to this task. I appreciate your invitation to be involved.

The following is an evaluation of your two basic questions posed in the contract with Portland State University. Within the response

1. Comparison of Remote Sensing Approaches for assessing topography and extent of Mt. Rainier Glaciers.

LIDAR (Light Detection and Ranging) also known as laser altimetry. The basic idea is that one monitors the travel time of an emitted light pulse and because its velocity is constant the distance can be calculated. If the LIDAR is on an aircraft, and its position is precisely known, then the changing distance to ground yields the surface topography. Repeated surveys yields a topographic map. The accuracy of airborne LIDAR is about 15 cm. Commerical cost is about $500 per square mile and with about 100 square miles of ice cover on Mount Rainier, the cost is roughly $50,000. However, the cost varies depending on the set up time and the number of set ups required, which is partly based on topography. Also, the light detector has to be adjusted for the brightness of the reflected light against the backround of the surrounding terrain. Snow and ice next to dark rock can present a challenge to LIDAR systems. For a non-glacier application in the Puget Sound region refer to, http://duff.geology.washington.edu/data/raster/lidar/About_LIDAR.htm

Another source of LIDAR coverage is from research aircraft. This alternative would cost little, but one can not be certain of repeated coverage, depending on the arrangements made with the research scientist. NASA has flown Mt. Rainier in the past using their LIDAR instrument (Dr. Jim Garvin). This is a comparatively sophisticated instrument, which, like commercial aircraft, scans the ground resulting in a depiction of a surface. Alternatively, the University of Alaska, Fairbanks (Dr. Keith Echelmeyer) has a nadir pointing unit in a small private aircraft. This would be suitable for measuring single line profiles for glacier elevation and length. He has taken his aircraft into Washington previously. (Dr. Jim Garvin: garvin@denali.gsfc.nasa.gov); (Dr. Keith Echelmeyer: kechel@gi.alaska.edu)

Figure J.5. Letter from Andrew Fountain to Jon Riedel, 5/15/02, Evaluation to Portland State University Contract, pp. 1–5.

Satellite Remote Sensing. The ever-increasing number of satellite systems orbiting the earth makes this strategy more and more attractive. The images provided by the satellites can be used to map glacier extent and snowline. In one case, SPOT, the dual on-board cameras can be used to make stereo images suitable for mapping. Several satellite systems are currently available. Not included below are any of the synthetic aperture radar satellites because of their severe ground distortions resulting from this type of satellite system and the extreme topographic relief on Mount Rainier. The software used to correct the data for ground distortion is currently research-grade quality and not suitable for the open market.

Table 1. A comparison between satellites, accuracy and cost. Panchromatic is a color image, and optical bands refer to images collected within a small range of wavelengths in the optical spectrum. Costs are based on the entire area of glacier cover at Mount Rainier which is about 100 mi^2 (256 km^2).

SATELLITE	ACCURACY	COST
Landsat - 7	15 m panchromatic 30 m optical bands http://edcdaac.usgs.gov/dataproducts.html	$600 Level 1 processing
Aster	15 m optical bands http://edcdaac.usgs.gov/dataproducts.html	Free
SPOT	10 m panchromatic 20 m optical bands http://www.spot.com/	$1500 (archived since 2000) $2500 custom order
Ikonos	1 m, 4 m panchromatic http://www.spaceimaging.com/level1/index38.htm	~$20-$60 /km^2, 25 km^2 min ~$5100 – $15,360/total

The imaged area of both Landsat, Aster, and Spot include all of the park and much area surrounding the park so there is no cost reduction for partial areas. Clearly, the Ikonos satellite is the most accurate system but equally clear is the high cost of acquisition. It has a minimum of 25 km^2 of acquisition. Aster is currently free, although how long this situation will continue is unclear. The most cost-effective satellites are Aster and Landsat-7. The imagery is suitable for snow-line detection and glacier area. A 15 meter difference in equilibrium line altitude is well within the normal error. However, a 15-meter accuracy of terminus position is quite large. Therefore, it can not be used for annual terminus fluctuations, but perhaps for positions at 5-years intervals.

As you know, the imagery would be acquired in late autumn to catch the highest snow line and equilibrium line. Keep in mind that satellite imagery acquisition depends on when the satellite is over the mountain and that depends on the image area and repeat interval of the satellite. For Aster and Landsat, the effective repeat interval is every couple of weeks. So given the poor weather in the autumn and the possibility of early snow, it is quite feasible to completely miss a period of perfect weather and ground conditions to image the glacier.

Figure J.5. Letter from Andrew Fountain to Jon Riedel, 5/15/02, Evaluation to Portland State University Contract, pp. 1–5 (continued).

Aerial Photography: Aerial photography has been the traditional method of tracking glacier activity since Austin Post pioneered the effort in the 1960's. This method offers several advantages. First, the resolution of the images is comparable to that of satellites. Second, if the aircraft is local to the region, it provides flexibility to take advantage of short periods of clear weather to accomplish the photographic mission. Also, some flexibility exists in selecting the time of day, and specific targets. The images can be provided in hard copy or digital, thus making it accessible to digital analysis. Also, the aircraft can acquire stereo imagery for terrain modelling. The nice feature of aerial imagery is that one has more control and interaction over the image acquisition.

For the purposes of the Mount Rainier, only the Washington State Department of Transportation aerial photography office (Jim Walker, walkerj@wsdot..wa.gov) was assessed for costs. They have much experience working for the US Geological Survey and taking aerial photographs of glaciers.

True color, block coverage aerial photography of all Mt Rainier glaciers at 1:20,000 negative scale (1 mm on photo = 20 m ground), estimated 65 negatives, is about $8,060. This photography can be accomplished with the WADOT jet prop photo aircraft using a 6" or an 8 1/4" focal length lens. Although more expensive than either Aster or Landsat, and more comparable to Ikonos, the aerial photography can provide the basis for developing digital terrain models.

RECOMMENDATION: For annual monitoring purposes, I recommend using satellite images from either Landsat or Aster platforms. This provides a cost-effective approach for tracking all glaciers on Mount Rainier. It has the additional benefit that the images could be used by other NPS efforts to monitor landscape change within the park. For select glaciers either aerial photography or Ikonos images could be acquired. The price would be similar for both and more affordable because the area of interest is smaller. Which one to acquire depends on the specific purpose. If only glacier position is required, then Ikonos might be the preferred choice. If topography were also of interest, then aerial photography would be the choice. The resolution of the aerial images is flexible depending on the lens and flight altitude. Thus it is possible to achieve Ikonos resolution if the local regulations governing minimum flight altitudes and the pilot's safety assessment of flying in such terrain.

The emphasis in the mapping part of the protocol for the four selected glaciers is on the glacier areas below the 8000 foot level. While it is true that much of the mass change over time takes place in the lower part of a glacier, the upper regions should not be ignored entirely. For the purposes of annual mapping on the select glaciers, acquiring imagery for the areas below 8000 feet is acceptable, but mapping grade imagery should be acquired, at less frequent intervals, of the upper regions of each glacier. I propose that the full glacier be entirely imaged every 5-10 years.

Finally, I would investigate the feasibility of either NASA and/or University of Alaska in joining a near-operational effort to monitor glacier change on Mount Rainier.

2. Assess Preferred Protocols for Mount Rainier Glacier Mass Balance Program.

The approach to assessing glacier change should follow the approach developed for the North Cascades. A few glaciers are studied in detail to gain understanding of the

Figure J.5. Letter from Andrew Fountain to Jon Riedel, 5/15/02, Evaluation to Portland State University Contract, pp. 1–5 (continued).

physical processes controlling the change (snow accumulation and melt), and many glaciers should be monitored for size change to quantify the magnitude and variation of change on all the glaciers. The interplay between the two approaches provides a cost-effective means of tracking glacier change (Fountain et al., 1997). The method has to be adapted for the special conditions present at Mount Rainier.

Glacier selection. Results from Nylen (anticiapted 2002) show that the glaciers on the north side of Mount Rainier have more or less remained constant in size over the past 30 years, whereas the ones on the south side have retreated dramatically. The causes for this remain unclear. Therefore, two glaciers on Mount Rainier should be chosen for monitoring, one representing each side of the mountain (north, south). Given considerations of access and previous history of observations, the two glaciers should be Nisqually and Emmons. The other two glaciers selected for mapping but no field work, Tahoma and Carbon are suitable choices.

Mass Balance. Under ideal circumstances, ablation stakes should be installed over the entire glacier surface to capture the variation in mass balance over the altitude range of the glacier. However, at Mount Rainier, this approach is not feasible due to the steepness of the terrain, crevasses, and the danger of avalanches. Therefore, an alternative method is proposed. The mass balance is measured at several points in the ablation zone. Year to year changes in the mass balance at this one locality are indicative of the year to year changes over the entire glacier, as first pointed out by Meier and Tangborn, (1965). However, the a priori relation between changes at a point to that on the rest of the glacier, particularly at higher altitudes is unknown.

To infer the year to year mass change of the entire glacier, it must be done after the fact. Topographic mapping at 5-10 year intervals, as recommended in the remote sensing section, above, will provide an estimate of volume (mass) change over the time interval (Krimmel, 1980). The year to year changes in the point values of mass change in the ablation zone, based on the stakes, can be scaled to estimate the yearly changes in total mass of the entire glacier. ((The accuracy of this method should be tested with the data from South Cascade Glacier))

Field Effort Ablation stakes should be placed in a reasonably accessible location in the ablation zone of each glacier. The proposed strategy of a center-line profile of stakes at three locations, up to the 8,000 ft altitude on each glacier (Nisqually and Emmons) is sound. That would provide an estimate of mass balance on the ablation zone of each glacier Of course, some care should be taken to avoid areas subject to avalanches, human disturbance, and thin ice subject to melting away. When the ablation stakes are installed snow depth and density should be measured as part of the normal course of mass balance measurements. My only suggestion different than the Glacier Monitoring Protocol is that two to three stakes should be installed at each location to provide redundancy for error estimate, provide back-up in case a stake is lost.

To amplify a comment in the Protocol, if at all possible it would be of great help if climbing rangers or others in the park could make measurements, when feasible, of snow pack thickness with altitude on Mount Rainier. This is a critical need in understanding the glaciers of the mountain and for calculating the glacier mass balance with altitude that is otherwise precluded without this data.

Figure J.5. Letter from Andrew Fountain to Jon Riedel, 5/15/02, Evaluation to Portland State University Contract, pp. 1–5 (continued).

Extrapolation. Results from the method described above can be extrapolated to other glaciers around the mountain. I anticipate that the year to year variations for the two measured glaciers will be similar, but offset from each other. This is the finding of Granshaw (2002) for glaciers much further apart in the North Cascade Range. Therefore, if glacier topography can be acquired for the other glaciers in the park, and volume change estimated between mappings (Nylen, anticipated 2002), annual changes in mass can be estimated from the results from the two measured glaciers.

Storage The storage of glacier mapping data can be readily accomplished on CD ROMs now that the price of CD burners have dropped dramatically and the cost of each CD is small.

If you have any questions or comments on my summary or recommendations, please let me know. I look forward to working with you on this in the future.

Regards,

Andrew G. Fountain

Figure J.5. Letter from Andrew Fountain to Jon Riedel, 5/15/02, Evaluation to Portland State University Contract, pp. 1–5 (continued).

Andrew Fountain
<bjaf@pdx.edu>
06/13/2002 05:10 AM MST

To: Jon_Riedel@nps.gov
cc:
Subject: MORA protocol

Hi Jon,

Hows the weather up by you? Here in the UK its cool and rainy. 50's - 60's cloudy, day after day. I can well understand why they wanted an empire...they wanted the warmth and sun.

Attached is a preliminary draft of my evaluation of the MORA glacier protocol. Its doesn't recommend much different from what you guys already decided. A few nuances here and there. The main difference is the proposed use of the Ikonos satellite, which compares favorably in cost to aerial photography.

Please give it a quick read through and see what you think. I'll make the requested changes and send in a more formal document.

Take care,

Andrew

===============
Andrew G. Fountain
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International Country Code - 1

On Mon, 22 Apr 2002, Andrew Fountain wrote:

> Hi Jon,
>
> I left you a phone message and I'll repeat it here. I hope you received
> my email of last week via Frank Granshaw. I was hoping to get your
> comments on my letter before I sent the official version in. I know you
> are busy, so if I don't hear from you by the end of the week, I'll assume
> that you are ok with it and I'll send it in.
>
> I will also get the Rainier protocol development plan to you as well.
>
> We leave for England on May 1 and I wanted you to have all this stuff
> before I leave.
>
> Cheers, Andrew
>

Figure J.6. Email from Andrew Fountain to Jon Riedel, 6/13/02, Preliminary draft of evaluation of MORA protocol, 1p.

UNIVERSITY OF WASHINGTON

College of Forest Resources Box 352100
University of Washington, Seattle, Washington 98195

James K. Agee, Emeritus Professor of Forest Ecology Phone: none Fax: 206-543-3254
112 Winkenwerder Hall email: jagee@u.washington.edu

April 20, 2009
The review for the revised "Long Term Monitoring of Glaciers at Mount Rainier National Park" for the North Coast and Cascades Network is complete. This protocol receives the following decision:
Acceptable With Minor Revision
This version was reviewed by Dr. Penny Latham and me. The science part is quite good, but what we refer to as "administrative review" still needs attention.

Review by Agee

There are a few minor editorial issues that you will want to address before submitting this in the Natural Resources Report series:

p.22 has two references (Anonymous 1969, [IHD] 1970 not in lit cited.
Blank p. 48 has a page number of 281.
Two pictures of photo ground control points are not visible: Figure 6, p. 161, and Figure 11 (top photo), p. 165

The literature cited is pretty consistent for journal citation, but does not use the preferred NRR style (Ecology). A journal would be cited as: Journal of Glaciology 25:334-336 rather than v.25, pp. 334-336.

References section:

Bevington and Robinson need initials
Drieger and Kennard, cap on Sisters
Fountain 2002 goes before the Fountain and ___ refs.
Hayes et al. out of order, goes after Harrison
Mayo 1992 goes before Mayo et al. 1972
Ostrem and Haakensen 1999, Porter 1977, Rasmussen and Conway 2003 could not be found in text. Also the latter ref needs initials for authors.
Riedel 2003 on p 41 is Riedel and Burrows 2003?

Figure J.7. Document of Revised Mount Rainier Glacier Monitoring Protocol review "acceptable with minor revisions", 4/20/09, pp. 1–5.

Scott et al. comes before Sigafoos refs.

Review by Latham

As far as I can tell, the authors did not specifically respond to any of the Administrative Reviewer's comments. This required re-reading and review of the protocol in its entirety and will require some additional response from the protocol authors. Several small editorial errors were found which I do not list here but most are related to formatting for the NRRS. In general this is a very well done protocol with good attention to detail. Where questions are referenced in the comments below, they refer to the PWR protocol review checklist.

Overall Organization and Presentation of Protocol Narrative (including SOPs)

There are still a number of formatting inconsistencies with the NRR Series such as font size for section headers, section numbering is not carried over into the SOPs, landscape pages are not numbered in the same place as the rest of the document, subordinate section headers in the TOC are not indented, use of a numbering scheme for figures and tables that is not unique and could lead to confusion, and others.

None of the figures and tables appear in a table of contents so they are not easily discoverable by the reader. This is probably due to being unclear regarding how to format SOPs in the protocols, i.e. where to put the TOC, whether SOPs should be modular, etc. A lot of the important information in the protocol is in these tables and figures and should be easily found by the reader, so this will need to be fixed before the protocol is published to the series. I'd suggest consulting with your data management staff and/or Kris Freeman, our technical editor (kfreeman@u.washington.edu), regarding how to approach this. However, these issues can be addressed later and there is no need to hold up approval of the protocol because of them. Overall, the protocol is fairly well organized and the relationships of various sections of it to other parts of the document are clear.

Some things that do need attention before approval include the following:

- TOC. The Abstract is missing in the TOC. Acknowledgements appear on pg. xiii. The Abstract is on pg. xi. There is an error at the top of the TOC on pg. iii.
- Pg. 77, h. Do you mean "recording" instead of "recoding"?

Tables and Figures

- Fig. 8, pg. 39. I couldn't find any mention of Figure 8 in the text. I may have missed it but I looked a couple of times. Perhaps it is misnumbered in the text?
- Pg. 66. The text refers to Tables 1 and 2 for GPS coordinates. The Tables that appear directly below this text and contain the coordinates are Tables 2 and 3.

C. Field Methods

Q1. The field methods section in the narrative gives an overview of the timing of field visits, tasks to be accomplished during seasonal visits, and some cautionary information. The

Figure J.7. Document of Revised Mount Rainier Glacier Monitoring Protocol review "acceptable with minor revisions", 4/20/09, pp. 1–5 (continued).

reader is referred to SOPs 1-3 for more in-depth information, methods, data sheets and equipments lists. This seems adequate. However, please check field methods that are included in SOP 7 to see if they should be referenced in the narrative under spring, summer, or fall procedures.

Q6. I still was unable to find much in the way of end of season procedures except for the data handling and analysis tasks and the short paragraph on pg. 41. Where would I find this information? Is there no need to clean and store field equipment, or other things that need to be done?

D. Data Handling, etc.
The data handling, documentation, analysis and reporting sections are very well done. But see comment below.

- Pg. 245-247, SOP 23, Appendix B. There appear to be some minor inconsistencies between due dates in Appendix B and the product delivery schedule on pg. 232. Please check dates for generating the World Glacier Monitoring Service table, the Annual I&M Report, uploading completed report to NCCN Digital Library, and storing finished products in NCCN Digital Library.

F. Operational Requirements
Q5. The budget still needs improvement. Some of the information related to the budget table on pg. 47 is found on pg. 45 beneath Table 2, e.g. the numbers and types of employees needed to implement the protocol. All of this information should appear in the budget table with associated costs. While you may consider this "your work" at the park, the cost of the work should still be clear for others to see. Also, other agencies or parks may consider similar glacier monitoring and will want to know the full cost of implementing this type of protocol. Budget figures should be updated. They are 5 years out of date.

G. Literature

- References sections should be titled Literature Cited as they only include literature actually cited in this document.

Section 2. SOPs
Q1. A list of figures and tables associated with SOPs needs to be included. However, as the protocol is fairly clear in its organization, I think it can be approved for the purposes of this review. The figures and tables will need to be included in a TOC before publication however. This will be a long term benefit to the park in being able to locate protocol information.
Q2. There was no response to this comment. Please check with your data managers and respond.
Q3. There is still no information regarding cleaning and storage of equipment after the field season in either an SOP or the narrative.

Figure J.7. Document of Revised Mount Rainier Glacier Monitoring Protocol review "acceptable with minor revisions", 4/20/09, pp. 1–5 (continued).

Q12. While the authors include a Job Hazard Analysis as part of the supplemental materials, I have the uneasy feeling that the content of this JHA underemphasizes the risks associated with this monitoring. There is no separate Safety SOP – only the JHA. I would suggest that the authors consider if they have adequately covered hazards associated with this monitoring protocol before finalizing it. At the recent NOCA HR for Managers training there was a section devoted to Safety that was quite comprehensive. The NOCA Data Manager also attended this training. I would suggest discussing additional safety documentation that was discussed in this training with Ron. This is not your average monitoring activity. I will expect some response to this question.

Section 3. Supplemental Material
Q4. It is not clear where the information listed in the Administrative Record (Appendix K) can be found.

Editorial Comments for your information not requiring a response.
Some of the areas where organization could be improved might be to consider combining SOPs 21-23 at some point. I also thought there was some confusion about the type of information included in the Sampling Design section vs. the Field Methods section. For example, Section B of the Sampling Design section includes information on “where” measurements are taken and “how often” combined with a detailed discussion of “how” that is done. The “how” might better be placed in the Methods section. There is also some overlap with Data Analysis. But overall, the intent of the monitoring is clear and the protocol organization is acceptable.

- Fig. 1. For final publication, it would be helpful to change the color of the met stations to something other than blue so it is easier to distinguish them from streams and glacier areas which are all in different shades of blue. (Optional but recommended.)
- Pg. 15, Fig. 5. Sentence 2 of caption is a fragment.
- Pg. 20. Bottom paragraph. I think you mean “respectively” instead of “respectfully”.
- Pg. 41. There is a Riedel 2003 citation at the top of the page. The References section has Riedel 2001 and Riedel and Burrows 2003.
- Pg. 281 appears on a blank page that is actually pg. 44
- Pg. 47, Table 3. What do BST and PST stand for?
- Pg. 62, SOP1, Table 1. Include units for Altitude.
- Pg. 88, Fig. 2. In the caption a space is needed between Scientific and Engineering. This happens a couple of times in the document so you might search for it.
- Pg. 133, SOP8, Table 1. The table on this page which is a continuation of the table on the previous page, does not have a header row.
- Some of the tables and figures in the SOPs do not have numbers or captions associated with them, e.g. the uncertainty calculations on pgs. 142-144. You will need to fix this before publication in the series but will probably need to decide how you will handle including SOP

Figure J.7. Document of Revised Mount Rainier Glacier Monitoring Protocol review “acceptable with minor revisions”, 4/20/09, pp. 1–5 (continued).

figures in the table of contents before assigning new table/figure numbers. There are also line numbers on the first page of this table (I believe it occurs in two places) that should be removed.

- Another example occurs on pg. 231 in SOP21. The table for the Product Delivery Schedule and Specifications does not have a table number or caption. There are other instances where this occurs. I would also suggest placing this table so that more of it appears on one page initially.
- Pg. 142 is numbered pg. 200 something (can't see for the hole punch)
- Pg. 148, SOP10, Figure 1. This is a very busy figure. If the objective is to identify air photo centers and flight lines for Emmons and Nisqually, you might consider a) removing the names of glaciers other than Emmons and Nisqually, and b) color coding all areas associated with Emmons differently from those associated with Nisqually. (Optional but recommended.)
- Pg. 151, SOP11. The Hodge citation is listed as 1970 in the text and 1972 in the References section. The SAM, Inc. 2003 citation is missing in References, pg. 153.
- Pg. 156, SOP11, Fig. 1. The legend says that the Nisqually glacier margin is outlined in black. However, it appears to be outlined in blue as opposed to the Emmons Glacier in Fig. 2 on the next page.
- Pg. 171, SOP11, Fig. 17. The scale for this figure is placed inconsistently compared to your other figures.
- Pg. 178, SOP 13. It's not clear why the title of the SOP appears at the top of the page. This is the only page where this occurs. Then on pg. 179, "continued" appears behind the report title as if it were an appendix, figure or table but it has none of these designations. I would consider presenting it as an Exhibit. Again, you could consult our Technical Editor.
- Pg. 277, last sentence. Typo makes sentence unclear.

It was a welcome sight to see consecutive page numbering all the way through the document. It is technically and stylistically very well done. Once you have responded to these comments and the protocol is approved, submission of the protocol for publication in the Natural Resource Report series is next. We recommend that you work with your network coordinator to manage this process.

Sincerely,

James K. Agee
PWR Protocol Review Coordinator

Figure J.7. Document of Revised Mount Rainier Glacier Monitoring Protocol review "acceptable with minor revisions", 4/20/09, pp. 1–5 (continued).

Appendix K. Snow densities from South Cascade and North Cascades Glaciers

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

	Dates																	
Altitude	5/15/1986	5/6/1987	5/19/1988	5/3/1989	5/1/1990	5/1/1991	4/15/1992	5/5/1993	5/4/1994	5/16/1995	5/24/1996	5/9/1997	5/598	5/27/1999	5/7/2000	5/10/2001	5/19/2003	**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	ρ = -0.0002 * z + 0.83
1987	ρ = -0.000255 * z + 0.942
1988	ρ = -0.000277 * z + 0.964
1989	ρ = -0.0002 * z + 0.884
1990	ρ = -0.0002 * z + 0.818
1991	ρ = -0.000468 * z + 0.584
1997	ρ = -0.02 per 100 meters altitude gain

Table L-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 L-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 L-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

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