

**NORTH COAST AND CASCADES NETWORK
GLACIER Protocol Summary Format**

Title: Glacial mass balance, contribution to streamflow and hazards

Parks: Mount Rainier, Olympic, North Cascades

Justification: Glaciers are a significant resource of many mountain ranges of the world, including the three large parks in the NCCN. Combined, the glacial resources of this network are extensive, covering 235 km². They are integral components of the region's hydrologic, ecologic, and geologic systems, and they are retreating rapidly. At NOCA, geologic mapping data and a 1998 inventory (Granshaw, 2001) indicate that glacier area has declined 44% in the last 150 years. Glaciers were rated by NCCN as the fourth priority for monitoring, and were listed as important Vital Signs for OLYM, NOCA and MORA.

Glaciers effect the distribution of aquatic and terrestrial habitat through their advance and retreat. Many of the subalpine and alpine plant communities in the NCCN flourish on landforms and soils created by glaciers within the last century. Glaciers directly influence aquatic habitat by the amount of cold, turbid melt water and fine-grained sediment they release. Glaciers also indirectly influence habitat through their effect on nutrient cycling and microclimate.

The influence of glaciers on NOCA and regional hydrology is immense in both the quantity and timing of discharge of glacial melt water. Post and others (1971) estimate that glaciers contribute 800 million cubic meters to streamflow annually in the North Cascades alone. In the Thunder Creek watershed (250 km² area) glaciers contribute as much as 45% of the total summer runoff (NOCA unpublished data) during the hot, dry summers in the Pacific Northwest, buffering the region's aquatic ecosystems from seasonal and interannual droughts. Aquatic ecosystems, endangered species such as salmon, bull trout and western cutthroat trout, and the hydroelectric and agricultural industries benefit from the stability glaciers impart to the region's hydrologic systems.

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

Monitoring Objectives:

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

- 1) Monitor range of variation and trends in volume of NOCA glaciers;

- 2) Relate glacier changes to status of aquatic and terrestrial ecosystems and hazards;
- 3) Link glacier observations to research on climate and ecosystem change;
- 4) Share information on glaciers with the public and professionals

To meet the primary goal of monitoring the range of variation and trends in the volume of several hundred glaciers covering $>300 \text{ km}^2$, monitoring must occur at multiple spatial and temporal scales, and at variable levels of intensity. Objectives identified to reach this goal include:

- Identify index glaciers to represent larger population of NOCA, OLYM and MORA glaciers;
- Seasonally monitor the mass balance of index glaciers;
- Measure the geometry of index glaciers every 10 years;
- Monitor variation of the area and volume of the entire population of glaciers with a comprehensive inventory at MORA every 5 years and at NOCA and OLYM every 20 years.

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

- winter balance at index glaciers;
- summer balance at index glaciers;
- net mass balance at index glaciers;
- assess surface cover in late fall for each index glacier;
- assess surface features (lakes, crevasse patterns, debris cover) changes related to glacial hazards;
- glacier volume/area for index glaciers at 10-year intervals;
- glacier volume/area for all glaciers at 20 year intervals;
- glacial contribution to summer runoff for four watersheds at NOCA, two at MORA and one at OLYM.

Monitoring Approach:

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

The primary indicator is detailed annual mass balance monitoring of a small sample of the glaciers at each park. This “index glacier” approach has been used in most glacier monitoring programs, due to cost and logistical problems associated with sampling an extensive population in rugged terrain. Mass balance also provides direct links to weather and streamflow. USGS used this approach in designing its Benchmark Glacier Program, and in the selection of South Cascade Glacier (Figure 1) to represent the larger population of glaciers in the North Cascades. Recent research has supported use of the

index glacier approach (Fountain, 2001). At NOCA four index glaciers are being monitored, while there are two index glaciers at MORA and one at OLYM.

Glacier area changes are the second indicator and provide a direct measure of the advance and retreat of all glaciers, and the concomitant creation and destruction of terrestrial and aquatic habitat. Area changes of all park glaciers are accomplished via repeated inventories. These inventories are based on IKONOS satellite or stereo aerial photographs, and will occur at varying frequencies depending on the park. At MORA, where glaciers contribute to hazards on an active volcano, glacier inventories are scheduled for every five years. At OLYM and NOCA these inventories are scheduled for 20 year intervals.

Glacier area changes are directly related to changes in volume and are used to monitor the third indicator – glacier meltwater discharge. Meltwater discharge provides a seasonal estimate of water accumulation, storage, and loss, as well as an estimate for extrapolation to the larger population of glaciers in the park. These measurements will be undertaken at three watersheds at NOCA, two watersheds at MORA and one at OLYM.

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Status, Development Schedule, Budget, Deliverables:

(1) Status - Glacier monitoring at NOCA is entering its 15th year, while this is the first year glacier at MORA will be monitored. University of Washington monitors Blue Glacier at OLYM using a model that relies on input from the Quillayute weather balloon. Complete protocol for monitoring glaciers at NOCA and MORA will be completed by the end of March, 2007. The NOCA protocol was peer-reviewed as a study plan and by reviewers with Earthwatch. The MORA protocol will be peer reviewed, while a summary of the current approach to monitoring Blue Glacier at OLYM will be completed in 2008.

(2) Schedule:

- Spring 2007: Implement NOCA glacier protocols and draft MORA protocol, begin to enter legacy data into relational database
- Spring - Summer 2007: Peer review of MORA glacier protocol.
- Winter 2007-2008: Adjust MORA protocol as per peer review and finalize. Begin to write OLYM glacier protocol.
- Winter 2008: Complete OLYM protocol
- Summer 2008: Implement all three protocols

(3) Budget notes:

Protocol development:

- NOCA protocol is completed, cost was about \$30,000. Developmental costs were incurred before the Natural Resource Challenge was funded.
- MORA protocol is in draft form and ready for peer review. Total cost for development was about \$45,000, and the protocol took 4 years to complete.
- OLYM protocol is estimated to cost \$15,000. Funding will be spread over two FYs; with \$5,000 in FY08 for development and \$10,000 in FY 09 for peer review contract and protocol writing. OLYM is relatively low cost due to reliance upon existing University of Washington model for annual measurements, which is simpler than field work at NOCA and MORA. OLYM can use NOCA protocol for glacier inventory.

(4) Deliverables 2007

A) Digital

- =updated GIS maps of NOCA and MORA index glaciers
- =winter accumulation, summer melt, and net mass balance data for ~30 sites on 6 index glaciers
- =metadata files updated annually
- =estimates of glacial contribution to streamflow for five valleys (3 NOCA, 2 MORA)

B) Documents

- =final NOCA glacier monitoring protocol
- =peer-review draft MORA glacier monitoring protocol
- =contribute Washington Snow Survey Runoff Forecast
- =contribute data to World glacier Monitoring Service
- =annual glacier pages for regional streamflow forecast

References

- Davis, G.E., 1993. Design elements of environmental monitoring programs: the necessary ingredients for success. *Environmental Monitoring and Assessment* 26. p.99-105
- Fountain, A.G.2001. Utility of the index glacier approach and glacier response to climate in the North Cascades. Presentation made at the North Cascades Glacier-Climate Symposium, October 10, 2001 Mt. Vernon, Washington.
- Granshaw, F.D, 2001. Glacier Change in the North Cascades National Park Complex, Washington State USA, 1958-1998. Masters Thesis, Portland State University.
- Paterson, W.S.B., 1981. *The Physics of Glaciers*, Pergamon Press, Elmsford, N.Y., 380 p.
- Peterson, D.L., D.G. Silsbee, D.L. Schmoldt, 1995. A Planning Approach for Developing Inventory and Monitoring Programs in National Parks. NPS/NRUW/NRR-95/16.
- Post, A., D. Richardson, W.V. Tangborn and F.L. Rosselot. 1971. Inventory of glaciers in The North Cascades, Washington. US Geological Survey Prof. Paper, 705-A.
- Silsbee, D.G. and D.L. Peterson. 1991. Designing and implementing long-term inventory and monitoring programs for National Park System lands. NPS Natural resources report NPS/NRUW/NRR-91/04.