Appendix F1

Contribution of Glacier Melt to Upper Hood River Streamflow and Implications of Climate Change.

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Contributions of Glacier Melt to Upper Hood River Streamflow and Implications of Climate Change

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<u>EXECUTIVE SUMMARY</u>

Glaciers are excellent reservoirs because they serve to moderate variations in runoff and supply reliable flow during drought periods. There therefore needs to be a clear understanding of the influence of glacier runoff at both the basin and catchment scale. This study investigates the contribution of glacier melt to the upper Middle Fork Hood River catchment (50.6 km^2) on the northeast flanks of Mount Hood Oregon. Discharge measurements and isotope samples were used to calculate glacier meltwater contributions to the entire catchment, which feeds into a major diversion used for farmland irrigation. Data was primarily collected in August – September of 2007 because this is a period of little rain and suspected high glacier melt contributions. Discharge measurements taken at the termini of the Coe and Eliot Glaciers indicate a contribution of 40% of the entire catchment's runoff between August 10 and September 7. Isotopic analyses, which include the inputs of all other glacier surfaces in the catchment, show a total glacier contribution of 62 – 74% of catchment discharge at a given time. The Snowmelt Runoff Model (SRM) was calibrated using the 2007 discharge records to quantify August – September glacier runoff in the Middle Fork catchment under a variety of scenarios. SRM simulations indicate that runoff from the catchment glaciers are highly sensitive to changes in glacial area, debris-cover, and air temperatures. The decrease in discharge due to glacier recession is measured to be higher than the effect of forecasted temperature increases, implying that annual glacier runoff is decreasing over time. Applying current glacier recession rates and a 2°C temperature forcing, the model predicts a decrease of 31.3% of late summer glacier runoff by 2059, most of which is lost in August. This study suggests that glaciers currently play a significant hydrological role in the upper catchments of the Hood River Basin at a time when water is needed most, and that these contributions will diminish over time. Complete results are available in Phillippe's Masters thesis.

<u>PROJECT DESCRIPTION AND RESULTS:</u>

The objectives of this work were to determine if glacier meltwater makes a significant contribution to streamflow in the Upper Middle Fork Hood River and how future glacier melt contributions might change on timescales of 10-50 years.

Mount Hood, the stunning, glacier-capped stratovolcano that is Oregon's highest peak, is also the sole source of summer streamflow for the acclaimed agricultural Hood River Valley to the northeast. Five irrigation districts along the East, Middle, and West Forks of the Hood River rely on late summer snow and ice melt from six glaciers, along with reservoir storage of winter rains, to meet heavy water demands during the dry summer months, while maintaining sufficient instream flows and cool water temperatures for threatened fish. However, recent studies document that Mount Hood's glaciers, crucial to the water supply of the region, have decreased as much as 61% over the past century (Lillquist and Walker, 2006). Until this study, there were no monitoring programs to provide measurements of the contributions of Mt. Hood glaciers to streamflow, and therefore, no way to estimate the potential impact of their loss in the face of climate change scenarios. Located on the north side of Mount Hood, Oregon, the Middle Fork Hood River drains into the main stem of the Hood River, which then flows into the Columbia River, and eventually into the Pacific Ocean. The Upper Middle Fork catchment has an area of 50.6 km^2 and glaciers cover about 6.8% of that area. The catchment consists of four creeks that drain the north side of Mount Hood: Eliot, Coe, Clear and Pinnacle. Eliot and Coe Creeks are glacier-fed, whereas Clear and Pinnacle rely solely on lingering snowpacks and groundwater inputs during the summer dry season. Clear and Pinnacle Creeks flow into Laurance Lake Reservoir, which acts as storage and a power supply for the Middle Fork Irrigation District (MFID). Because Coe and Eliot are more sediment-laden, they are diverted directly from the channel to a settling pond, and after sufficient deposition of clays and silts, the water is pumped out by the irrigation district. Discharge was measured from June to September 2007 immediately upstream of the diversions of the four catchment creeks: Eliot, Coe, Pinnacle, and Clear. Runoff at the outlet of Coe and Eliot Glaciers was also measured between August and September 2007 to determine the contribution of flow from the glaciers to the downstream sites. At each site, water height recordings were made at a 15-minute time step using capacitance stage recorders. To relate water height to streamflow, discharge and depth measurements were made over a range of flows during the summer. Eliot glacier is in a narrow drainage and melts into a single, well-defined channel. However, Coe glacier is separated into several parts and melts into several channels. Thus, streamflow monitoring in Coe creek is not an effective estimate of the total glacier contribution. To remedy this problem, isotopic analyses of glacier and non-glacier contributions to streamflow were performed. For this purpose, water samples were collected on three occasions throughout the basin in August, September, and October. Water samples were collected 5 m downstream of the Eliot and Coe Glacier termini. Samples were analyzed for $d^{18}O$ at the Isotope Ratio Mass Spectrometer Facility at Oregon State University (Corvallis, OR). They were run through a Finnigan/MAT 252 (dual inlet) and were reported relative to SMOW (Standard Mean Ocean Water; Craig, 1961) with a precision of +/-0.03‰. Modifying the standard equations for a 2-component mixing model (Sklash and Farvolden, 1979) glacier melt water replaced new water in order to solve for the relative proportions of groundwater (old water) and glacier melt. To compare meltwater composition with glacier ice, four Eliot glacier ice samples were collected and analyzed.

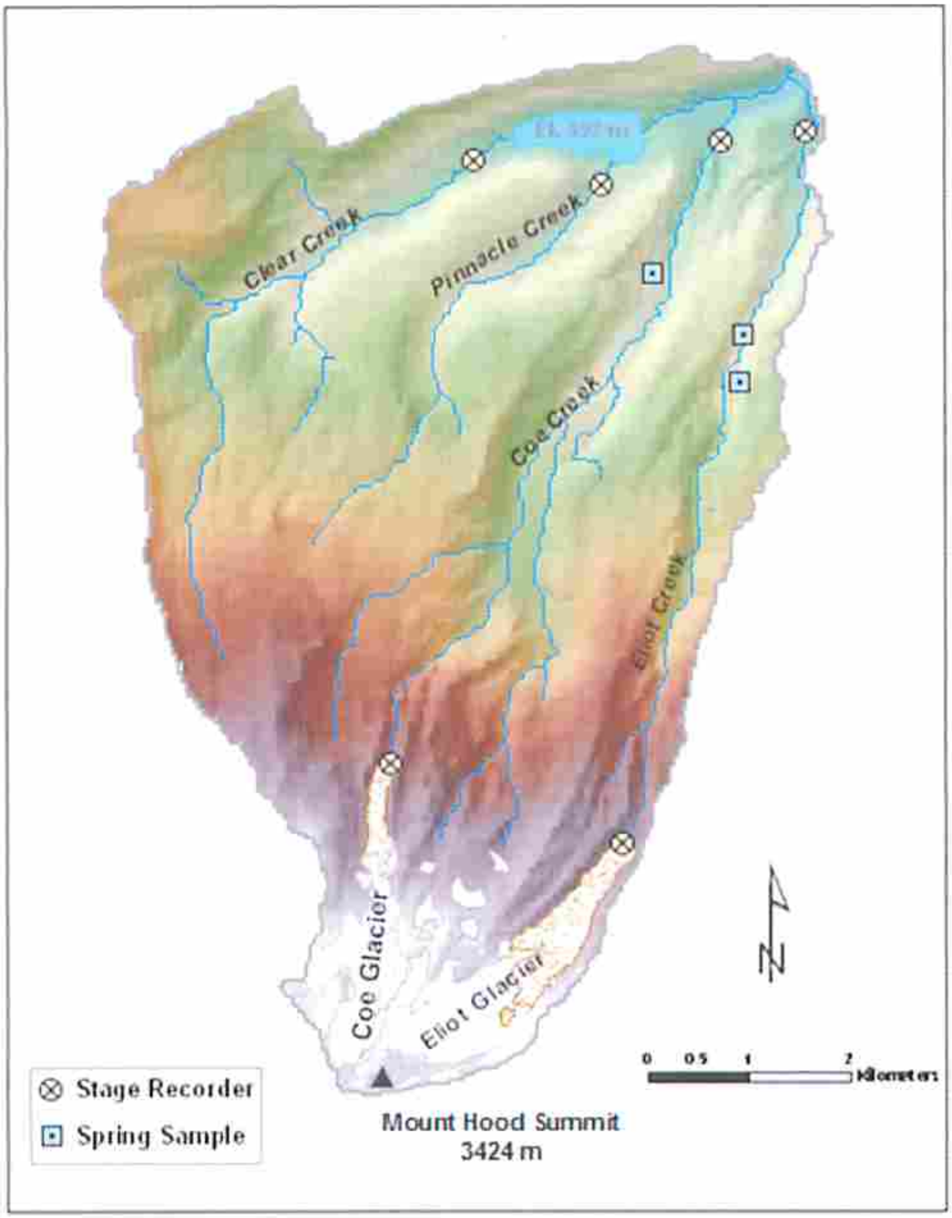

Figure 1. Map of the Upper Middle Fork Hood River watershed showing Coe and Eliot glaciers and the six streamflow measurement sites.

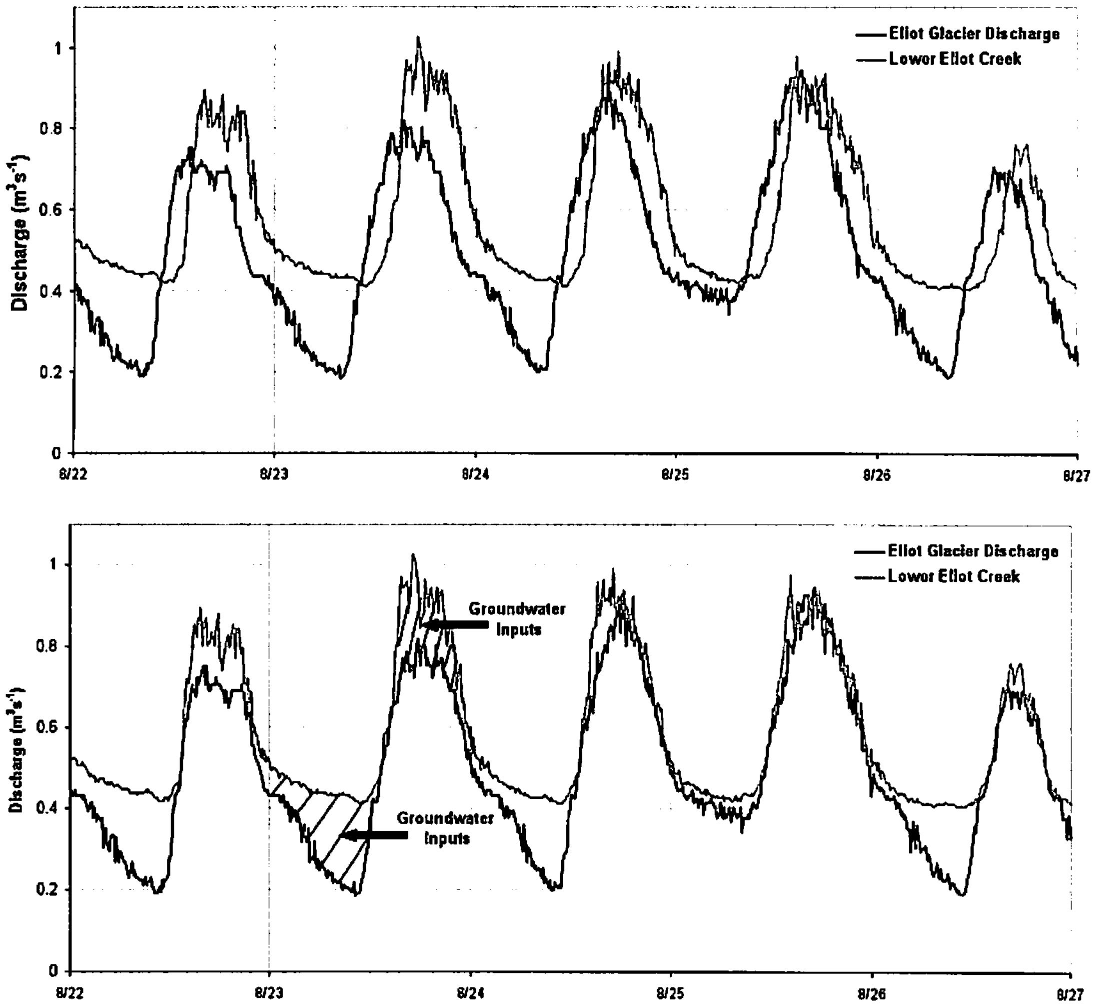

Figure 2. The Diurnal variation in both glacier Discharge and Terminal Flow in Eliot Creek: August 22 – 27, 2007 (top). The lower histogram delays glacier discharge by 2 hours and 18 minutes to compare hydrograph geometries.

Isotopic analyses show that in the Eliot and Coe catchments, glacier ice is most depleted in ^{18}O, followed by surface water and springs. Given the accuracy of isotope reporting ($^{+}/-$ .03 ‰), the differences in ^{18}O compositions are significant. The isotope data show that glacier melt can contribute 76 – 88% of the runoff in Eliot Creek and 70 – 88% in Coe Creek (table 4.1), totaling 62 – 74% of the entire catchment's discharge. The isotopic representation of glacier melt is much higher than that exhibited by the discharge method because the isotopes represent both the Coe Glacier and all of its neighboring glacierettes.

To simulate the effects of continued glacier recession on streamflow in the Upper Middle Fork Hood River, we used a conceptual model that uses air temperature as its primary input. The Snowmelt Runoff Model (SRM, Martinec 1975) is a semi-distributed model and requires variable inputs into specified elevation zones. The basin was divided into eight 200-meter elevation zones for the Eliot and Coe catchments and five zones for the Compass catchment. SRM was calibrated using the 2007 discharge records to quantify August – September glacier runoff. SRM simulations indicate that runoff from the catchment glaciers are highly sensitive to changes in glacial area, debris-cover, and air temperatures. The decrease in discharge due to glacier recession is measured to be higher than the effect of forecasted temperature increases, implying that annual glacier runoff is decreasing over time. Applying current glacier recession rates and a 2°C temperature forcing, the model predicts a decrease of 31.3% of late summer glacier runoff by 2059, most of which is depleted in August.

Table 1. SRM simulations for 2007 and 2059 of total glacier discharge under different glacier area scenarios. SRM simulations for 2007 and 2059 (estimated) under a 2°C forcing.

Scenario	Total Glacier Discharge (m^3)	Decrease in Discharge (%)
2007 Conditions	**$4.34 \times 10^6 m^3$**	-
• August	$2.85 \times 10^6 m^3$	-
• September	$1.49 \times 10^6 m^3$	-
• 9/10-9/29	$7.94 \times 10^5 m^3$	
2059 Conditions	**$2.98 \times 10^6 m^3$**	**31.3**
• August	$1.78 \times 10^6 m^3$	**37.5**
• September	$1.20 \times 10^6 m^3$	**19.5**
• 9/10-9/29	$7.08 \times 10^5 m^3$	**10.8**

SRM simulations show that the Middle Fork Hood River exhibits high sensitivity to changes in the area, debris-cover, and air temperatures of the Eliot, Coe, and Compass glaciers and glacierettes. Using glacier recession rates and established temperature increases, decreases in glacier discharge in total glacier discharge of 31.3% are projected by the year 2059. In this and other scenarios, August undergoes particularly drastic changes in discharge, whereas early September to the end of the water year sees much smaller losses, probably because of the decreased degree-day factor and increases in precipitation inputs at this time. The methods developed in this project serve as a strategy for gauging glacier runoff in the late ablation season in small, ungaged glacierized catchments.

OUTREACH

This project has received attention in the press, by water resources managers, and at Oregon State University. Outreach activities include the following:

- Front page article in The Oregonian: "A region's vitality melting away", (11 Feb 2008)
- Presentation to the Hood River Watershed Group (22 Jan 2008)
- Presentation to the IWW Board of Advisors (4 April 2008)
- Presentation to the Oregon House Interim Committee on Energy and Environment (4 April 2008)
- Presentation at the Oregon State University, Focus the Nation (30 Jan 2008)
- Poster presentation at the Western Snow Conference, Hood River, OR (17 April 2008)

- Presentations to classes at OSU in Environmental Engineering, Climatology, Snow Hydrology in Winter 2007, Winter 2008, Spring 2008
- Presentations to the Middle Fork Irrigation District, Hood River, OR (multiple presentations throughout 2007-2008)

In addition, this investigation trained a graduate student, Jeff Phillippe for whom this constituted his MS thesis.

REFERENCES

Lillquist K., and K. Walker, Historical glacier and climate fluctuations at Mount Hood, Oregon, *Arctic, Antarctic, and Alpine Research*, 38(3), 399-412, 2006.

Martinec, J. (1975). New methods in snowmelt-runoff studies in representative basins. *IAHS Symposium on Hydrological Characteristics of River Basins, Tokyo, Japan*, 117, 99-107, 1975.

Sklash, M. G., and Farvolden, R. N., The Role of Groundwater in Storm Runoff, *Journal of Hydrology*, 43, 45-65, 1979.

Mike Benedict

From: Anne Nolin [nolina@geo.oregonstate.edu]
Sent: Wednesday, August 20, 2008 1:23 PM
To: Mike Benedict
Cc: Jeff Phillippe
Subject: Re: Long Range Water Planning in Hood River County

Dear Mike,

Thank you for your interest in our research on Mt. Hood glaciers and water supply. My graduate student, Jeff Phillippe, recently completed his MS thesis on current and future contributions of glacier melt to the Upper Middle Fork Hood River. I've attached a summary of our findings as well as a proceedings paper. This work was based solely on a single summer, which we believe is reasonably representative of recent years' low flows. However, it would be worthwhile to continue making these measurements and to also examine glacier melt contributions to the East Fork Hood River. We were constrained by funding and so limited our work to sampling runoff from the Coe and Eliot glaciers. It's likely that the Newton Clark and other glaciers on the east side of Mt. Hood are major contributors to summer flows in the East Fork. We are also interested in identifying the relative contributions of snowmelt and glacier melt -- and in quantifying changes in snowpack that may influence groundwater recharge rates and summer low flows. Let me know if you'd like to discuss this further.

In addition to this work on water resources, we are also conducting research on debris flows around Mt. Hood and the climate change impacts on the frequency and size of the debris flows. We are still in the early phase but would be happy to share these results as they become available.

Regards,
Anne

On Aug 19, 2008, at 3:41 PM, Mike Benedict wrote:

Dr. Nolin
I am the land use planning director for Hood River County and I will be helping coordinate a long range water planning project for the county starting in the very near future. I understand that you have been conducting research on a couple of Mt. Hood glaciers that might contribute to our understanding of our water supply and the impact on it from climate change.

Any information that you can share or suggestions for additional research that you feel would be important to gaining a well rounded understanding of the County's beneficial water sources would be greatly appreciated.

Thank you,

Mike Benedict

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