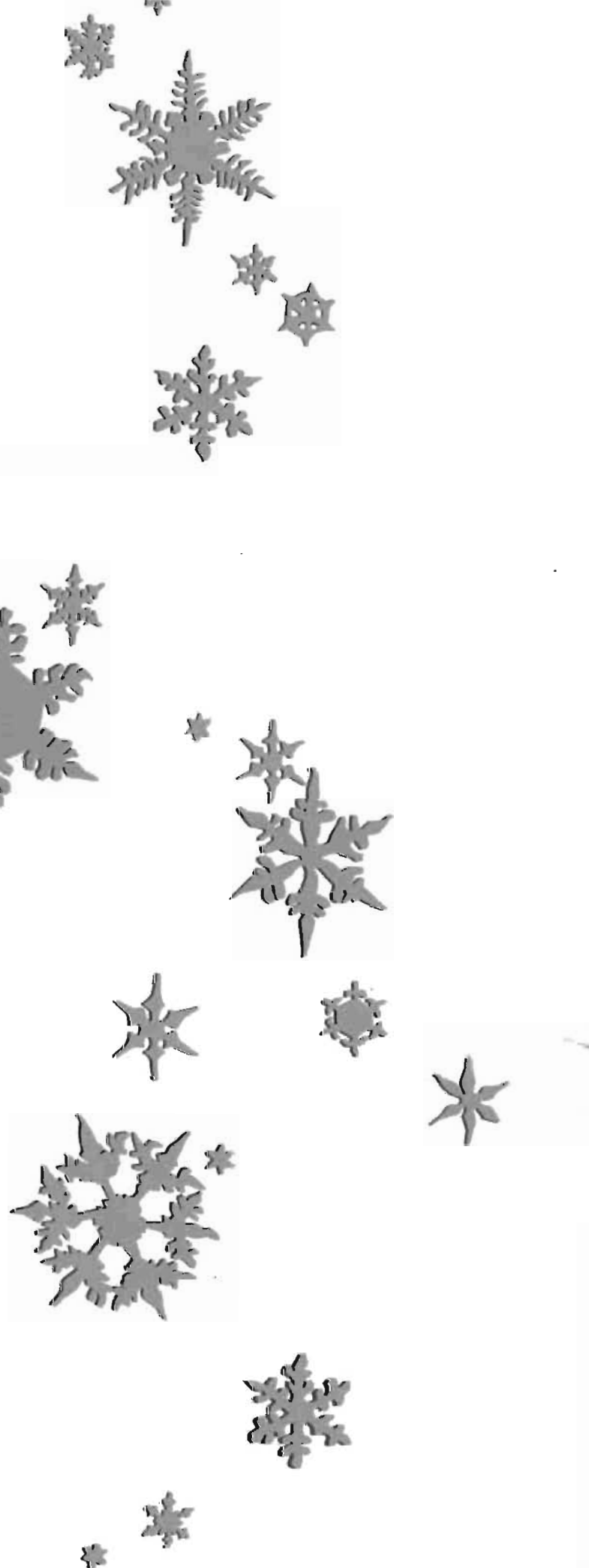
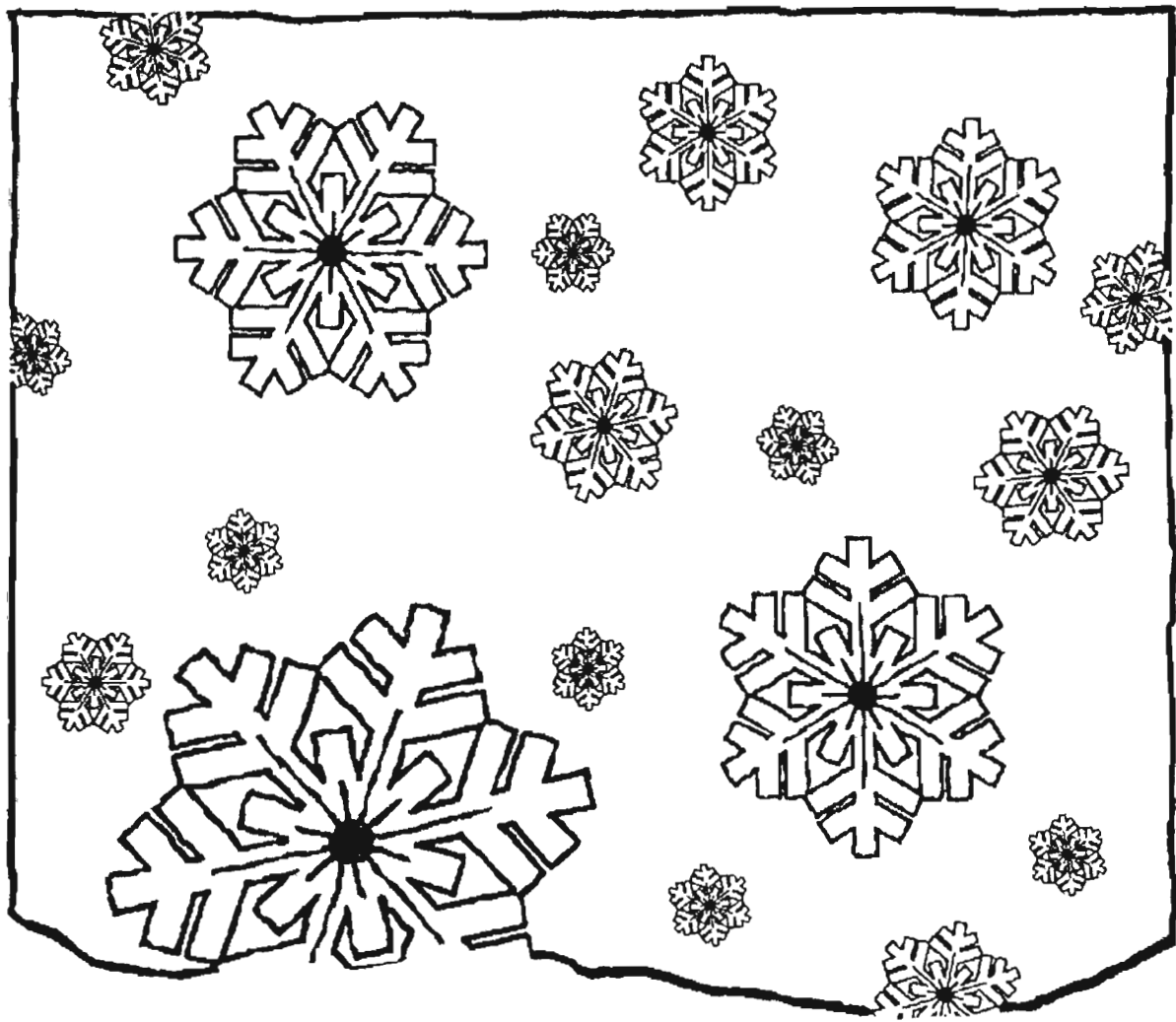


Eastern
Snow
Conference

*Proceedings of the
2006
Annual Meeting*





Proceedings of the
63rd ANNUAL

EASTERN SNOW CONFERENCE

7-9 June 2006
Newark, Delaware, USA

FOREWORD

This proceedings volume contains papers presented at the 63rd Eastern Snow Conference (ESC) held 7–9 June 2006 at the University of Delaware in Newark, Delaware, USA. Sessions covering snow–climate interactions, snow processes, ground ice and periglacial processes, and remote sensing of snow were convened.

The ESC is a joint United States and Canadian forum for discussing recent work on operational, applied, and scientific issues related to snow and ice. It also retains an increasing interest as a symposium where novel approaches to cryospheric science of international significance are presented. The ESC has published an annual series of proceedings since 1952. Typical topics include studies of snow and ice as materials, snow removal, meteorological forecasting, river ice control, snow hydrology, snow chemistry, glaciology, remote sensing of snow and ice, and snow ecology. Membership in the ESC is open to all interested individuals and corporations. Additional copies of the current proceedings and all back issues can be obtained from the Secretary. More information about the Eastern Snow Conference may be found at <http://www.easternsnow.org/>.

We continue with an optional review process and authors may submit extended abstracts or full papers to the proceedings. Participants in the Western Snow Conference (WSC) (<http://www.wcstcmnsnowconference.org/>) have been invited to join the ESC participants in the option of submitting papers relevant to winter hydrology to the international journal *Hydrological Processes*. These papers have gone through a formal journal review, revision, and referee process, and many appear both in these proceedings and in the December 2006 issue of the journal. John Pomeroy (University of Saskatchewan), Kelly Elder (USDA Forest Service, Fort Collins, Colorado), and Andrew Klein (Texas A&M University) edited this special issue of *Hydrological Processes* dedicated to ESC/WSC papers.

We thank the editors at ERDC–CRREL. Over the years this group has contributed considerable time to this publication and has enhanced the quality of these proceedings.

The 2006 meeting of the Eastern Snow Conference and these proceedings were made possible by sponsorship and corporate memberships by the following:

Campbell Scientific (Canada) Corporation
Edmonton, Alberta, Canada
<http://www.campbellsci.com/offices/csc.html>

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Hanover, New Hampshire, USA
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Newark, Delaware, USA
<http://www.udel.edu>

GEONOR
Milford, Pennsylvania, USA
<http://www.geonor.com>

Cryospheric Specialty Group of the Association of American Geographers (AAG)
Washington, DC, USA
http://www.geo.hunter.cuny.edu/AAG_CrSG

We look forward to seeing many of you at the 64th Eastern Snow Conference meeting to be held jointly with the Canadian Geophysical Union, Canadian Meteorological Society, and the American Meteorological Society, 28 May–1 June 2007 at Memorial University, St. John's Newfoundland, Canada. The 2007 meeting theme is “Air, Ocean, Earth, and Ice on the Rock.” It should be exciting, especially with the addition of the other groups.

Robert Hellström and Susan Frankenstein
ESC Proceedings Co-Editors
Bridgewater State College and ERDC–CRREL

Climate Variability, Snowmelt Distribution, and Effects on Streamflow in a Cascades Watershed

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GORDON GRANT³, AND CHRISTINA TAGUE⁴

EXTENDED ABSTRACT

Cascades Range rivers provide critical water supply for agriculture, ecosystems, and municipalities in the Pacific Northwest, and they derive much of their water from snowmelt filtered through groundwater aquifers. Recent analyses show that this region is particularly sensitive to current and projected climate warming trends, specifically reduced snow accumulation and earlier spring melt (Mote, 2003; Stewart *et al.*, 2005). By 2050, Cascades snowpacks are projected to be less than half of what they are today (Leung *et al.*, 2004), potentially leading to major water shortages. Broad regional-scale characterizations identify climatic gradients as the most important controls on spatial variability in streamflow regimes, but the potential for other hydrological factors, particularly groundwater, to influence this response has received much less attention. Our objective is to develop an understanding of how discharge from a groundwater-dominated watershed is controlled at the event, seasonal, and interannual scales by snowpack dynamics, antecedent conditions, and global climate signals.

The study watershed is that of the McKenzie River at Clear Lake (Figure 1), in the central Oregon Cascades, includes extensive areas of high permeability Quaternary (High Cascade) basalts that result in a substantial groundwater system, as well as runoff-dominated Tertiary (Western Cascades) landscapes (Sherrod and Smith, 2000; Tague and Grant, 2004). This 239 km² watershed has long-term records of streamflow from United States Geological Survey gage #14158500. It also has record of precipitation, snow, and temperature from three Natural Resources Conservation Service SNOTEL sites: Hogg Pass (1451 m, 21E05S), Santiam Junction (1143 m, 21E06S) and Jump Off Joe (1067 m, 22E07S). Annual precipitation in the watershed ranges from ~1.8 to 3 m, and 70% falls between November and March. 47% of the watershed lies between 918 and 1200 m, in the transient snow zone. From 1200 m to the peak elevation (2051 m), seasonal snowpacks occur from November through June. Peak snow water equivalent (SWE) occurs around April 1st at Hogg Pass, and around March 1st at Santiam Junction and Jump Off Joe.

In order to examine relationships between hydrological variables in space and time, we performed Pearson's correlations, autocorrelations, and cross-correlations using 42 parameters derived from discharge, precipitation, SWE, and temperature from the stations listed above. We also correlated discharge and SWE with monthly values of the Niño 3.4 index of sea surface

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temperature (Trenberth and Stepaniak, 2001). A simple water balance was constructed for the 2001–2004 water years, using values for the average basin elevation (1215 m) interpolated from precipitation and SWE values at Jump Off Joe and Hogg Pass. Basin-averaged evapotranspiration was calculated in RHESys (Tague and Band, 2004). Predictive models of September–November minimum discharge were developed using stepwise regression in SAS 9.1.

Fluctuations in discharge are muted relative to daily variability in the recharge (rain plus snowmelt) signal (Figure 2). Summer streamflows are sustained by groundwater, not snowmelt. There is a high degree of discharge auto-correlation for ~2.5 months, and there is a strong cross-correlation between the previous year's precipitation and the current year's discharge at a 1 year lag. The El Niño–Southern Oscillation is a reasonably good predictor of SWE and a moderate predictor of annual discharge. Interannual variability in the 26-year SNOTEL record masks any long-term trends in precipitation or SWE, but the longer discharge records suggests that climate warming is altering the streamflow regime at Clear Lake. The hydrograph temporal center of mass (Stewart *et al.*, 2005) has moved earlier by a statistically significant 15 days since 1950, which is probably a function of relatively more winter rain and earlier snowmelt. This finding is in line with other watersheds throughout the mountainous west (Stewart *et al.*, 2005). September–November minimum flows have declined since 1947, probably as a result of longer summer recession periods resulting from earlier snowmelt.

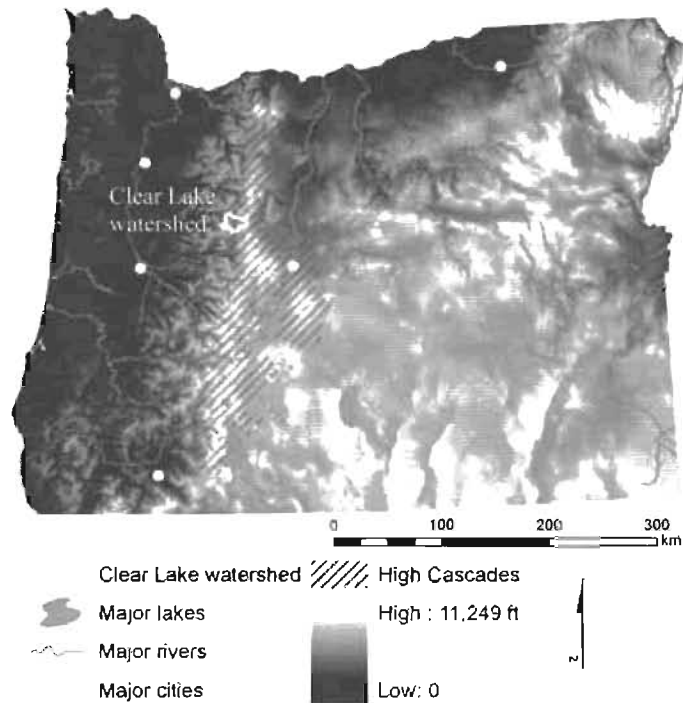


Figure 1. Location map of the study watershed, relative to the topography of Oregon and extent of High Cascades geology.

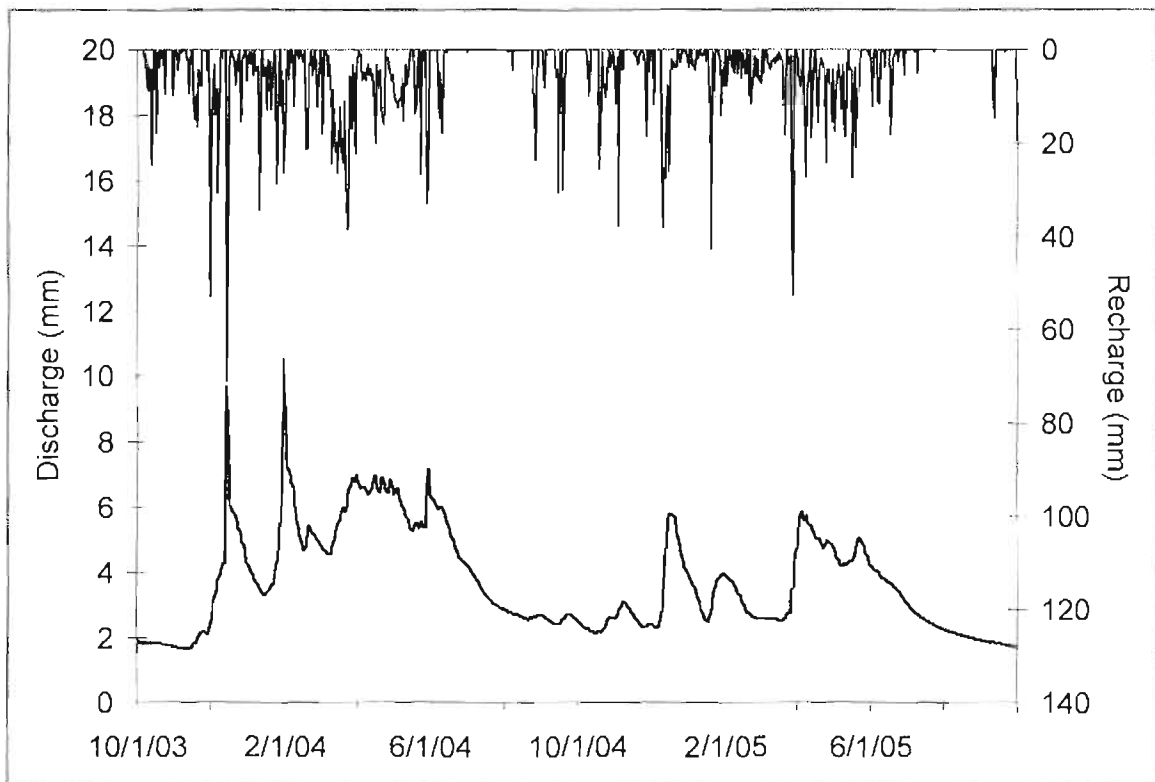


Figure 2. Discharge at Clear Lake for water years 2004 and 2005 (bottom, black line), compared to the interpolated rain + snowmelt time series for the median basin elevation (top, blue line).

The main conclusions of this study are:

1. In the study watershed, pronounced seasonal variability of water inputs is damped by extensive groundwater systems. The study area may serve as a model for other groundwater-dominated watersheds in the mountainous west.
2. Delays between precipitation and discharge are a function of snowpack storage and slow release of groundwater. From July to October, streamflow is sustained by groundwater.
3. Groundwater-dominated watersheds are somewhat buffered from <2-year fluctuations in precipitation, but are susceptible to prolonged droughts or wet periods.
4. Snowpack is more sensitive than discharge to the state of major of climate indices in groundwater-dominated watersheds.
5. Minimum flows are largely controlled by the current year's precipitation, but are also sensitive to the timing of snowmelt and the antecedent conditions in the aquifer.
6. Regional warming of the past several decades has affected the shape of the annual hydrograph, in terms of its temporal center and minimum flows. Continued warming is predicted to lead to loss of snowpack and continued decline in minimum flows.

Keywords: snowmelt, groundwater, climate variability, Oregon, Cascades

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