Observed hydrological changes in partially glacierized catchments

Kerstin Stahl

Motivation
Timing and quantity of streamflow changes from partially glacierized catchments as a response to climate warming can vary widely and are difficult to quantify.

Measures of change
Some typical response signatures exist. Heck et al. (2005) summarize glacier runoff characteristics that may be observed in streamflow from glacierized catchments, separating initial response and long-term response to warming.

<table>
<thead>
<tr>
<th>Signature</th>
<th>Initial - Later response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt-season runoff concentration</td>
<td>Decrease ▲</td>
</tr>
<tr>
<td>Inter-annual runoff variability</td>
<td>Increase △</td>
</tr>
<tr>
<td>Runoff correlation with Temperature</td>
<td>Increase ▲ - Decrease ▼</td>
</tr>
<tr>
<td>Specific runoff</td>
<td>Increase ▲ - Decrease ▼</td>
</tr>
</tbody>
</table>

Changes in these signatures were mapped as the difference in streamflow characteristics between an earlier period and a later period, S(1968-1988) : S(1989-2008)

Dataset
The assembled dataset of catchments from Canada, Norway and the European Alps reflects general differences in data availability in these regions. While all countries monitor partially glacierized catchments:
- catchment areas for gauges above the first reservoir or major regulation are much larger in Canada than in Europe,
- mean catchment elevations are higher in the Alps than in Norway and Canada
- European records are longer, but more likely influenced by regulation.

Conclusion
Results of trends and changes largely confirm directed recent changes in Canada and the Alps. Glacial rivers show changes towards prolonged melt seasons, increasing variability and decreasing specific discharge in August. Norwegian glacial rivers, however, show increasing trends in summer streamflow, though some catchments with low glaciation show decreases when correcting for the direct effects of climate variability. The dataset provides opportunities to elucidate the complex drivers of change across a range of conditions.

Acknowledgements
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August streamflow sensitivity (graphs above) to climate was used in a trend analysis of August streamflow corrected for the influence of temperature, precipitation and carry-over storage (through regression) to filter out the signal of change due to glacier loss (Stahl and Moore, 2006).

August streamflow trends (graphs above) are mostly negative in Canada, mostly positive in Norway, and mixed in the Alps. After correction for climate sensitivities, most trends in the Alps and some in Norway become negative, indicating progressive influence of glacier loss.