Valley-scale Landscape Structure as a Component of Hydrologic Response

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Null Hypothesis: underlying landscape structure is not a significant element in characterizing the hydrologic regime of mountain watersheds

Valley-scale Landscape Structure as a Component of Hydrologic Response

• Context
• What are we looking for and how is it useful?
• What is surprising about this research?
• Research design
• Preliminary results
• Conclusion
**Context: A simplified look at how this research intersects with hydrological science in scale and focus**

- **Large-scale streamflow hydrology-climate models - climate forcing:** water supply, prediction

- **Valley scale characterization - run-off and storage mechanisms produced by coupled hillslope, fluvial and glacial processes:** 1 km² to 40 km² sub-basins – stream management for the sustainability of biotic ecosystems

- **Plot-scale:** ~1 m² to 50m² – experimental research to trace actual surface/groundwater flowpaths – basis of hydrological science

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**Context: Relationship between spatial scale, geomorphological influence and biological attributes**

<table>
<thead>
<tr>
<th>Spatial Scale</th>
<th>Climate, Topography, Geology</th>
<th>Biological Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regional/ Physiographic Province</strong></td>
<td>Climate, Topography, Geology</td>
<td>Community Type</td>
</tr>
<tr>
<td><strong>Valley Segment/ Channel Reach</strong></td>
<td>Routing of Sediment, Water and Organic Matter Disturbance Regimes</td>
<td>Community Composition/ Species Abundance</td>
</tr>
<tr>
<td><strong>Channel Unit or Patch</strong></td>
<td>Local Factors/ Disturbance History</td>
<td>Habitat Use by Individuals</td>
</tr>
</tbody>
</table>

Differences in groundwater storage

*Montgomery, 1999*
**What are we looking for and how is it useful?**

*Understanding streamflow patterns* fundamental to successful monitoring of aquatic biota in undisturbed ecosystems

- Range of variability important for evolutionary potential of aquatic ecosystems.
- The *natural flow regime* of a functioning aquatic ecosystem is characterized by the seasonal timing and patterning of flows.
- Data from undisturbed sites allow managers to maintain or restore the range of natural flow variability.
- Various recent articles define stream type by snow, rain-on-snow, etc. Given the variability of such events in one sub-basin over time, structure might be more useful to characterize stream type.

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**What is surprising about this research?**

- Many people believe that headwater streamflow patterns are homogenous when they have similar climate, bedrock type and hardness, topographical range, drainage area, soils and vegetation.
- Research suggests that adjoining sub-basins with similar characteristics can produce very different patterns in their hydrologic response.
What are some different patterns of hydrologic response and how did we find them?

**Research Design**

- Thunder Creek
- MacAllister Creek
- Fisher Creek #6
- Devil’s Club

Mean slope range: 10-15%
Drainage area: 22-32 mi²
Topographical range: 8000’ – 2000’
Bedrock: Skagit gneiss

Mean slope range: 43-45%
Drainage area: .8-.9 mi²
Topographical range: 6000’ – 1400’
Bedrock: Skagit gneiss

**Experimental Organization**

All 8 NOCA sites have similar climate, bedrock type and hardness, slope, topographical range, drainage area and proximity. Groupings according to scale and presence or absence of glaciers.
**Where is the research located?**

North Cascades National Park
Thunder Creek Basin Stream Gage Sites

![Map of Thunder Creek Basin Stream Gage Sites](image)

**Sites Grouped by Potential Storage Mechanisms and Dominant Processes**

<table>
<thead>
<tr>
<th>Stream/subwatershed</th>
<th>Dominate processes</th>
<th>Hydrogeological flow regimes</th>
<th>Valley scale classification</th>
<th>Storage type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fisher Creek</td>
<td>Glacial Debris flow</td>
<td>Snow Rain and snow Stable groundwater Runoff</td>
<td>Glacial valley</td>
<td>Mass movement debris</td>
</tr>
<tr>
<td>MacAllister Creek</td>
<td>Glacial Debris flow</td>
<td>Snow Rain and snow Stable groundwater Runoff</td>
<td>Glacial valley</td>
<td>Glacial fill</td>
</tr>
<tr>
<td>Thunder Creek</td>
<td>Glacial Debris flow</td>
<td>Snow Rain and snow Stable groundwater Runoff</td>
<td>Glacial valley</td>
<td>Wetland</td>
</tr>
<tr>
<td>4th of July</td>
<td>Colluvial Debris flow</td>
<td>Stable groundwater Rain on snow Rain</td>
<td>Colluvial</td>
<td>Mass movement debris</td>
</tr>
<tr>
<td>Devils Club</td>
<td>Colluvial Debris flow</td>
<td>Intermittent Stable groundwater Rain on snow Rain</td>
<td>Colluvial</td>
<td>Mass movement debris</td>
</tr>
<tr>
<td>#6</td>
<td>Bedrock</td>
<td>Runoff Rain on snow Rain</td>
<td>Bedrock</td>
<td></td>
</tr>
</tbody>
</table>
**Thunder Creek Basin**

Endpoints of Overall Pattern – Range of Variability

- Precipitation
  - Snow
  - Snow melt
  - Glacial melt

**Types of Processes and Landforms Found in the Thunder Basin**

- Fluvial Valley
- Glacial Valleys
**Thunder Creek Landform Areas**

<table>
<thead>
<tr>
<th>Landform Type</th>
<th>Area</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valley Wall</td>
<td>165</td>
<td>55</td>
</tr>
<tr>
<td>Cirque</td>
<td>57</td>
<td>19</td>
</tr>
<tr>
<td>Debris Apron</td>
<td>28</td>
<td>9</td>
</tr>
<tr>
<td>Debris Cone</td>
<td>7.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Debris Avalanche</td>
<td>6.3</td>
<td>5.6</td>
</tr>
<tr>
<td>Floodplain</td>
<td>5.6</td>
<td>1.8</td>
</tr>
</tbody>
</table>

**Thunder Creek Landforms**

**Valley Wall (VW)**
- Too steep to hold a significant amount of slope debris
- Largest single mapping unit in each watershed
- Lower elevation boundary is typically debris cone (break in slope)
- Heavily vegetated or exposed bedrock
Glacial melt is the dominant influence during the summer months

Klawatti Glacier, Thunder Basin

Thunder Creek Landforms: Alternating Canyon and Glacial Valley Morphology Found within Sub-Basins

Upper Fisher

Upper MacAllister
Glacial-dominated Fisher – MacAllister Hydrological Pattern

Fisher has smaller drainage and glacial contributing areas

Thunder Creek Landforms

Debris Torrent (MM-DT)
- Always within a DC, usually at the base of a river canyon, and has a fresh appearance
- Given a unique number and corresponds to the landslide inventory
Fisher and Thunder Basins – Patterns differ as a result of debris torrent activity and wetlands

Post-glacial melt streamflow pattern
**Thunder Creek Landforms**

**Debris Cone (DC)**
- Usually covered by thick alder (young cones)
- Conical shape
- Well defined on topographic maps

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**Rain-dominated response:**

![Graph showing stage in feet over time with markers for Bedrock and Stable Groundwater]

- Bedrock
- Stable Groundwater

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Later slide with data points and graphs showing hydrological responses.
### Mt. Rainier National Park Sites

Residence time, storage characteristics not complicated by glaciers

<table>
<thead>
<tr>
<th>Stream/subwatershed</th>
<th>Drainage area</th>
<th>Mean slope</th>
<th>Analysis Methods</th>
<th>Dominate processes</th>
<th>Hydrogeological flow regimes</th>
<th>Valley scale classification</th>
</tr>
</thead>
</table>
| Crystal             | 1.58          | 22%        | Pressure Transducer Temperature
18O Deuterium       | Colluvial Debris flow | **Stable groundwater**
Snow, Rain on snow, Rain | Colluvial |
| Lost                | 5.4           | 10%        | Pressure Transducer Temperature
18O Deuterium       | Colluvial Debris flow | **Stable groundwater**
Snow, Rain on snow, Rain | Colluvial |
| Deer                | 5.6           | 14%        | Pressure Transducer Temperature
18O Deuterium       | Fractured bedrock | **Runoff – “Old” Water Displacement**
Snow, Rain on snow, Rain | Bedrock |
| Laughingwater       | 5.5           | 9%         | Pressure Transducer Temperature | Fractured bedrock | **Runoff – “Old” Water Displacement**
Snow, Rain on snow, Rain | Bedrock |

### Rain-dominated response:

![Graph showing rain-dominated response with Fractured Bedrock and Stable Groundwater]

- **Fractured Bedrock**
- **Stable Groundwater**

![Bar chart showing index values for the different streams/subwatersheds]

- **Index values**
- **Legend:** Deer, Crystal, Lost
Preliminary Results

- Valley structure appears to be a determinant of streamflow pattern
- Residence time, groundwater storage are important in these systems
- If true, length of residence time should be evident in stable isotope signatures and temperature
How do the preliminary results apply to monitoring aquatic systems?

- If streamflow is not dominated by Hortonian overland flow, but is composed of varying ages of "old" water, the temperature and geochemical signature of these creeks will vary significantly. This is likely to affect the aquatic community found in the system.

- Hydrogeologic stream classification schemes that define stream type by snow, rain-on-snow, rain and groundwater-dominated systems will not produce meaningful stream indices in mountainous basins.

Many thanks to:
Susan Bolton and Dave Montgomery, UW, John Riedel, Mike Larrabee, Jeanna Probala, NOCA, Paul Kennard, Barbara Samora, MORA, Andrea Woodward, USGS, Dan Ribeiro, Leslie Wall, CWWS. Funding provided by the National Park Service and USGS.