WILL CLIMATE CHANGE AFFECT THE HYPORHEIC ZONES OF ARCTIC STREAMS?
AN ASSESSMENT OF INTERACTIONS AMONG GEOMORPHOLOGY AND HYDROLOGY IN ARCTIC STREAMS

Pre-project Seminar
by
Jay P. Zarnetske
Overview of Talk

- Background - Context of the study
- Introduction to study
- Central hypotheses
- Approach
- Methods Explained
- Implications of research
Background

- Arctic Environment of Study Site
  - Climate
  - Landscape
  - Climate Change

- Hyporheic Zone (HZ)
  - What is it?
  - Why is it important?
Arctic Climate of North Slope

Average Monthly Air Temperature at Toolik Lake
(1989-1999 Average)

Daily Solar Radiation for 1994

<table>
<thead>
<tr>
<th>Month</th>
<th>Avg. Total Rain (mm) 89-99</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>46.1</td>
</tr>
<tr>
<td>July</td>
<td>70.0</td>
</tr>
<tr>
<td>August</td>
<td>64.2</td>
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<tr>
<td></td>
<td>Max. 61.0</td>
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<tr>
<td></td>
<td>Min. 29.5</td>
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<tr>
<td></td>
<td>Max. 142.0</td>
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<tr>
<td></td>
<td>Min. 12.2</td>
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<tr>
<td></td>
<td>Max. 117.9</td>
</tr>
<tr>
<td></td>
<td>Min. 44.7</td>
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</tbody>
</table>

Yearly average precipitation: 318 mm
North Slope Landscape

- Permafrost Dominates

C. Kennedy, 2004

Zarnetske, 2004

Permafrost

Zarnetske, 2004

Kennedy, 2004

Climate Change

Change in permafrost temperatures at various depths in Fairbanks (Alaska)

Mean annual temperature °C

Soil depth (in meter)
- 0.12 m
- 0.52 m
- 1.01 m

IPCC, 2001

Source: Romanovsky, in Impacts of global climate change in the Arctic regions, IASC, Tromsø, April 1999.

May 2004
Hyporheic Zone

Alley et al., Science, 2002
Hyporheic Zone

Morphologic Influence

Biogeochemistry

USGS Circular 1139

Gooseff et al. in press
Introduction to Study

- HZs do exist in Arctic (Edwardson et al., 2003)
  - Poorly understood
  - Arctic HZs have a unique existence
    - Seasonal evolution limited by climate
    - Spatially limited by permafrost
- Study is part of larger Arctic HZ investigation
- Aim to describe Arctic HZs via an assessment of:
  - Stream geomorphology
  - Changes in sub-stream thaw
- Each component expected to control HZ evolution
- Improve ability to project broader climate change impacts to Arctic streams
  - Seasonal thaw dynamics relate to overall climate warming
Hypotheses

- **H₁**: Stream geomorphology (i.e. bed form and material) creates the physical template that controls seasonal sub-stream thaw.

- **H₂**: Sub-stream thaw controls the potential hyporheic zonal extent (i.e. HZ increases as sub-stream thaw increases).
Conceptual Arctic HZ framework

Natural Input $\rightarrow$ Climate $\rightarrow$ Human Input

Climate $\rightarrow$ Stream Geomorphology $\leftrightarrow$ Permafrost and Thaw

Geology
Vegetation
Topography
Glaciology

Hyporheic Zone

HZ ecosystem function

Landscape processes

Total stream ecosystem structure and function

Coastal processes
Approach

- **Objective 1**: Channel Morphologic Variability
  - Locate and characterize stream reaches
  - For each study reach across thaw season:
    - **Objective 2**: Monitor sub-channel thaw dynamics
      - Ground penetrating radar (GPR)
      - Sub-surface temperature measurements
    - **Objective 3**: Repeated hyporheic exchange studies
      - Stream solute addition experiments
      - Flow models – groundwater and surface water flow simulation
  - Two field seasons
Objective 1: Channel Morphology

- Objective 1
  - Stream Geomorphology
  - Permafrost and Thaw
  - Hyporheic Zone
    - HZ ecosystem function
  - Total stream ecosystem structure and function
  - Coastal processes

- Natural Input
- Climate
- Human Input

- Geology
- Vegetation
- Topography
- Glaciology

- Landscape processes

- H1
- H2
Site Selection

- 12 study reaches identified in Toolik Lake Region
- Primary criterion
  - Channel morphology
    - Morphotypes: Alluvial, Peat, and Alluvial-peat
    - Plan form
    - Bed Material
- Secondary criteria
  - Stream order (focus on low-order)
  - Placement in watershed (e.g. lake inlet or outlet)
  - In-channel winter ice conditions
- Refine site selection based on 1st field season data
  - Intensify work on refined sites
Study Area: Toolik Lake Region

TOOLIK LAKE INLET WATERSHED, ALASKA
ARCTIC LTER

KUPARUK RIVER WATERSHED, ALASKA
ARCTIC LTER

OKSRUKUYIK CREEK WATERSHED, ALASKA
ARCTIC LTER

Toolik Lake Station

A. Hershey, 2004
Alluvial Morphotype

- Similar to temperate mountain streams
  - Moderate meandering,
  - Cobbly substrate,
  - Pool-riffle or step-pool,
  - 1st – 5th order,
  - Relatively steep gradients.
  - Relatively large width to depth ratios
Peat Morphotype

- Typically beaded streams form via thermal erosion
  - Deep pools connected by short stream segments in plan and cross-sectional form,
  - No regular meandering,
  - Organic substrate,
  - low-order and shallow gradients
  - Small W : D
Alluvial-peat Morphotype

- Combination of alluvial and peat characteristics
  - Moderate meandering,
  - Cobbly substrate residing within a larger peat channel,
  - Large pools connected by short, narrow riffles and runs
  - Varied gradients and orders.
  - Moderate W : D
Further Reach Characterization

- Further classified according to Montgomery and Buffington, 1997
- 3-D survey and graphically processing channel and water features
- Collecting additional data for potential incorporation
  - Identify placement in watershed
    - Stream order
    - Lake inlet or outlet
  - Identify in-channel winter ice conditions
    - Cap-ice, bed-ice, ice-free (spring fed)
Objective 2: Depth of Thaw

- Natural Input
- Climate
- Human Input
- Stream Geomorphology
- Permafrost and Thaw
- Hyporheic Zone
- HZ ecosystem function
- Landscape processes
- Total stream ecosystem structure and function
- Coastal processes

- Geology
- Vegetation
- Topography
- Glaciology
Monitoring Depth of Thaw

- **GPR imaging of sub-surface**
  - Channel longitudinal and cross-section profiles
    - Provides 3-D imaging and quantification of sub-surface thaw
    - Primary responsibility of Boise State University (BSU) research team
      - John Bradford, Geophysicist, PhD
      - Troy Brosten, Graduate Student, PhD candidate

- **In-situ Thermistor cross-section profiles**
  - Validation of GPR and broader temporal view
    - Primary responsibility of BSU
      - James McNamara, Hydrologist, PhD
Preliminary GPR data

Modified from Bradford et al., in press

2004 data
Preliminary Temperature Data

Alluvial Reach

Temperature (°C)

Date, 2004

20 cm deep
40 cm deep
60 cm deep
80 cm deep
100 cm deep

Alluvial Reach

2004 data
Objective 3: Monitor Hyporheic Hydraulics

Natural Input \rightarrow Climate \rightarrow Human Input

Geology
Vegetation
Topography
Glaciology

Stream Geomorphology \leftrightarrow Permafrost and Thaw

Geology

Hyporheic Zone

HZ ecosystem function

Landscape processes \rightarrow Total stream ecosystem structure and function \rightarrow Coastal processes

H_1

H_2
Stream Tracer Experiments

Example: Sawtooth Mtns, Idaho

Non-toxic, Fluorescent Rhodamine Dye Injection
Tracer Experiment Analysis

- Models produce reach average surface and HZ hydraulic characterization (e.g. velocity, water residence time, storage zones: transport zone, etc.)
**Simplified Analysis**

- Permafrost boundaries effectively remove subsurface inflow

(after Harvey et al., 1996)
HZ flow and Particle Tracking

- Use reach stream bed and water surface profiles to parameterize a GW flow model
  - MODFLOW *(Harbaugh et al., 2000)*
    - creates flow paths
  - MODPATH
    - MODFLOW tool
    - examines particle transport through flow paths

*based on Gooseff et al., in press*
Investigation Summary

- Climate
- Permafrost and Thaw
- Hyporheic Zone
- HZ ecosystem function
- Total stream ecosystem structure and function
- Coastal processes
- Landscape processes
- Natural Input
- Human Input
- Geology
- Vegetation
- Topography
- Glaciology
- H1
- H2
Implications of Research

- **Increase understanding of Arctic HZ processes**
  - Initial look at spatial and temporal relationships
    - Geomorphology
    - Hydrology
    - Permafrost

- **Expected climate warming will alter these stream components**
  - Help predict trajectory of stream changes and downstream impacts to oceans

- **Assist policy makers, resource managers, and scientists**

- **Provide data for future investigations**
Acknowledgements

- My committee
  - Dr. Michael N. Gooseff
  - Dr. Michelle A. Baker
  - Dr. John C. Schmidt

- Field assistance:
  - Ken Hill and Rob Payn (USU) & Dr. Breck Bowden and Morgan Johnston (UVM)

- BSU team
  - Dr. James McNamara, Dr. John Bradford, Troy Brosten

- Logistical assistance: Arctic LTER, Toolik Field Station & Crew, and Univ. of AK-Fairbanks

- Funding: NSF Arctic Program (grant 03-27440)
Questions?

Field Improvisation

Toolik Lake 2:15AM

Flock of “state birds”