Using Artificial Barriers to Augment Water Supplies in Shallow Arctic Lakes

presented by Sveta Berezovskaya

Project kick–off meeting, Pittsburgh, Pennsylvania, Feb 19th 2009
OUTLINE

• Introduction to collaborative group
• Relevant background for the project
• Objectives
• Description of the work to be performed
• Expected impact of the project
• Project schedule and milestones
Team Members

Sveta Berezovskaya – PI

Doug Kane - Co-PI

Ken Irving - Research Tech.

Matthew Sturm - Collaborator

Chris Hiemstra - Collaborator

Harvesting Snow to Augment Water Supplies
Snow is central to activities on ANS

Image courtesy: U.S. Department of Energy's Atmospheric Radiation Measurement Program

Harvesting Snow to Augment Water Supplies

Image courtesy of www.morooka.com
RELEVANT BACKGROUND

Petroleum-rich North Slope

National Petroleum Reserve - Alaska

Arctic National Wildlife Refuge

Harvesting Snow to Augment Water Supplies  map is from http://www.anwr.org/
Snow-Net: System for measuring arctic winter precipitation and snow cover, NSF Arctic Observing Network project

This map of Alaska is from the Natural Resources Conservation Service (NRCS) http://www.nrcs.org

SnowNet IPY: SnowNet SITES in Alaska
RELEVANT BACKGROUND

Difficulties in domestic water supplies are associated with

- Short open-water seasons
- Engineering problems encountered with water storage and distribution systems in permafrost terrain
- Severe winter climates
- High operational costs

Low mean annual air temperatures

Polar desert – low precipitation, shallow snow

Mean duration of snow cover (days) over the 1972-94 period as computed from satellite-derived maps of weekly snow cover extent.

Snow is there to harvest during these 9 months!
Accumulating Snow to Augment Water Supply in Barrow, 1975

By Slaughter, C. W.; Mellor, M.; Sellmann, P. V.; Brown, J.; Brown, L., 1975. CRREL, Hannover, Special report.

• The ability to accomplish increased snow deposition by fencing was clearly demonstrated

• There remains a question of optimal snow fence location and number of fences

• Recommendation to concentrate a drift adjacent to stream channel
Design of Reservoirs and Snow Fences


Snow Fence on dike upwind of pond
Snow Fence upwind of pond and dike
A 1:30 scale model of the snow fence-pit-berm combination

The combination that maximizes snow drift storage
“Snow fence may deposit a large quantities of snow, but the reservoir is often dry by the time water is needed.”

By David Sturges, 57th Western Snow Conference, 1989
What are the recognized obstacles for delivering snow drift water to the reservoir on the coastal plain?

• Low gradient terrain - water stays where it melts and evapotranspirates during the summer
• Evaporation from the reservoir surface
• Seepage loss – in some cases water moves through continuous permafrost (i.e. talik zone)
OBJECTIVES

1) Enhance snow drift formation in the area surrounding water source
2) Assess the effects of artificial barriers on 'new' water available due to reduced sublimation losses from blowing particles
3) Find optimum location for the snow drift to ensure that melt water reaches the reservoir
4) Assess the reservoir-volume net increase and the cost of additional water
OBJECTIVE 1

Enhance snow drift formation in the area surrounding water source.

*Drift volume is 8 tonnes of SWE or 27.8 cubic m of snow per 1m of snow drift*
OBJECTIVE 2

Assess the effects of artificial barriers on 'new' water available due to reduced sublimation losses from blowing particles.

"Reassessment of winter precipitation on Alaska’s Arctic" by Carl Benson, 1982
## Sublimation in Arctic, literature review

<table>
<thead>
<tr>
<th>Location</th>
<th>Sublimation min ($S$, mm/yr)</th>
<th>Sublimation max ($S$, mm/yr)</th>
<th>Precipitation ($P$, mm/yr)</th>
<th>Min S/P (%)</th>
<th>Max S/P (%)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tiksi (tundra)</td>
<td>33</td>
<td>96</td>
<td></td>
<td></td>
<td></td>
<td>Hirashima et al., 2004</td>
</tr>
<tr>
<td>Yakutsk (tundra)</td>
<td>12</td>
<td>74</td>
<td>16</td>
<td></td>
<td></td>
<td>Pavlov, 1984</td>
</tr>
<tr>
<td>Kuparuk Basin</td>
<td>0</td>
<td>47</td>
<td>140</td>
<td>0</td>
<td>34</td>
<td>Bowling et al., 2004</td>
</tr>
<tr>
<td>Kuparuk Basin</td>
<td>20</td>
<td>95</td>
<td>180</td>
<td>18</td>
<td>50</td>
<td>Liston and Sturm, 2004</td>
</tr>
<tr>
<td>Western Canada</td>
<td></td>
<td></td>
<td>15</td>
<td>40</td>
<td></td>
<td>Woo et al., 2000</td>
</tr>
</tbody>
</table>

*Courtesy of Anna Wagner and Mathew Sturm, CRREL*
OBJECTIVE 3

Find optimum location for the snow drift to ensure that melt water reaches the reservoir.
OBJECTIVE 4

Assess the reservoir-volume net increase and the cost of additional water.

\[
\text{Cost of installation} / \text{Reservoir-volume net increase} = \text{Cost of additional water}
\]
WORK TO BE PERFORMED

- Estimation of Pretreatment Water Balance
- Artificial Barrier Design and Location
- Assessment of Hydrologic Response
- Assessment of Environmental Impact
- Feasibility Study
Pretreatment Water Balance

\[ V_t = V_{t-1} + \text{Inflow} + P - \text{Outflow} - E - \text{Seepage} \]

\( V \) – water volume in the reservoir, \( P \) – precipitation, \( E \) – evaporation from the water surface, ET – evapotranspiration, SWE – Snow Water Equivalent

\[ P = Q + E + \Delta S \]

Snowmelt Inflow = SWE – Storage – ET

Summer Inflow = \( R - \text{Storage} - \text{ET} \)

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Snow Water Equivalent (SWE)

Snowmelt Inflow = SWE – Storage – ET

Field work: End-of-winter snow survey and snowmelt

- Snow Survey: April 25 – 26, 2009
- Snowmelt: May 20 - June 5, 2009
Pretreatment Water Balance

Summer Inflow = P – Storage - ET

Weather stations through NSF Arctic Observing Network project:
Long-term observations in the Kuparuk River Basin.
PI Douglas L. Kane
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Pretreatment Water Balance

\[ V = f \text{(depth)} \]

\[ ET = f \text{(E)} \]

\[ V_t - (V_{t-1} + \text{Inflow} + \text{Rain} - \text{Outflow} - \text{Evap}) = \text{Seepage} + \text{Error} \]
WORK TO BE PERFORMED

- Estimation of Pretreatment Water Balance
- Artificial Barrier Design and Location
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Artificial Barrier Design


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Artificial Barrier Location: SnowModel


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Artificial Barrier Location: SnowModel

Implementation using approach suggested
By Robert Jairell and Ronald Tabler, 53rd Western Snow Conference, 1985
and Robert Jairell and R.A. Schmidt, 58th Western Snow Conference, 1990

Snow Fence on dike upwind of pond
Snow Fence upwind of pond and dike
SnowNet Barrow Instrumentation: Sublimation

Flux Tower 1
eddy covariance method

Flux Tower 2
aerodynamic method

(Box and Steffen, 2001; Stull 1988)

Photo by Art Gelwin
WORK TO BE PERFORMED

- Estimation of Pretreatment Water Balance
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Assessment of Hydrologic Response

Snow Drift Water Equivalent

Reservoir-volume Net Increase
Snow Drift Water Equivalent

Reservoir snow depth profile, WITHOUT snow fence (A)

- Reservoir
  - $W = 100 \text{ m}$
  - $D = 2 \text{ m}$
  - Water volume per 1 m of length $V = 200 \text{ m}^3$

- Lake width $W$
- Lake depth $D$

- Natural drift

Reservoir snow depth profile, WITH snow fence (B)

- Snow Drift
  - $H = 2.4 \text{ m}$
  - $20H = 48 \text{ m}$
  - $p = 450 \text{ kg/m}^3$
  - Water volume per 1 m of length $V = 53 \text{ m}^3 = 26%$

- Depletion Zone
- Accumulation Zone
- Fetch
- Fence height $H$

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Assessment of Hydrologic Response

Snow Drift Water Equivalent

Reservoir-volume Net Increase

\[ V_{\text{net\_increase}} = V_{\text{with\_drift}} - V_{\text{without\_drift}} \]

\[ V = f (\text{Inflow, Rain, Outflow, ET}) \]

How to find reservoir volume without drift?
Experimental and Natural Reservoirs

2009

\[ V_{\text{exp}} = f(V_{\text{nat}}) \]

\[ V_{\text{without\_drift}} = f(V_{\text{nat}}) \]

\[ V_{\text{net\_increase}} = V_{\text{with\_drift}} - V_{\text{without\_drift}} \]
WORK TO BE PERFORMED

• Estimation of Pretreatment Water Balance
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Assessment of Environmental Impact

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WORK TO BE PERFORMED

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Feasibility Study

1. Cost of additional water

2. Practical recommendations on using snow fences for ANS water resources management
Expected impacts

- creating 'new' water by reducing sublimation losses from blowing particles
- prolonging snowmelt runoff due to increased snow depth
- lowering the costs for additional water by recharging a local source
Expected impacts

- applications of the depletion zone of the snow fence could be to enhance frost penetration
- accumulation zone of the snow fence could increase initial snow accumulation for the road
- our data will be available to committee decision makers and researchers
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Schedule

Theoretical preparation
Practical Solutions
Interpretations
Feasibility

Pretreatment water balance
Assessment of Hydrologic Response

Snow Fence Design and Location
Environmental impact

SnowModel sensitivity simulations to define optimum snow fence location
Stage relationship between control and experimental lakes
Snow fencing effect on partitioning of the lake water balance, increased duration of snow melt recharge and 'net' lake-volume change.
Assessment of impact on land cover and permafrost
Cost of additional water

Field work

2009
Jan-Mar Apr-Jun Jul-Sep Oct-Dec

2010
Jan-Mar Apr-Jun Jul-Sep Oct-Dec

2011
Jan-Mar Apr-Jun Jul-Sep Oct-Dec
## MILESTONES

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Initiation Date</th>
<th>Completion Date</th>
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<tbody>
<tr>
<td><strong>YEAR 1</strong></td>
<td></td>
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<tr>
<td>We are planning to allocate experimental and control reservoir (1), provide recommendation on optimum snow fence location (2) and set-up observational program (3, 4).</td>
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<tr>
<td>1 Allocate experimental and control reservoir. To evaluate changes in experimental, the control and experimental lakes have to have similar natural water balances.</td>
<td>October 1&lt;sup&gt;st&lt;/sup&gt;, 2008</td>
<td>April 1&lt;sup&gt;st&lt;/sup&gt;, 2009</td>
</tr>
<tr>
<td>2 Run SnowModel sensitivity simulation to define prime snow fence location.</td>
<td>January 1&lt;sup&gt;st&lt;/sup&gt;, 2009</td>
<td>August 31&lt;sup&gt;st&lt;/sup&gt;, 2009</td>
</tr>
<tr>
<td>3 Initiate spring melt observational program, which includes work in the field to measure end-of-winter snow survey and snowpack ablation (April-May, 2009). First year data would reflect natural conditions for experimental lake.</td>
<td>April 20&lt;sup&gt;th&lt;/sup&gt;, 2009</td>
<td>June 30&lt;sup&gt;th&lt;/sup&gt;, 2009</td>
</tr>
<tr>
<td>4 Purchase, test and install instrumentation to monitor water balance, soil temperatures and vegetation length at the experimental and control sites. Build snow fence at the experimental lake and install snow depth sensors on the leeward side of the drift.</td>
<td>April 1&lt;sup&gt;st&lt;/sup&gt;, 2009</td>
<td>September 30&lt;sup&gt;th&lt;/sup&gt;, 2009</td>
</tr>
<tr>
<td>5 Work with DOE manager on documentation required by DOE to manage the project.</td>
<td>September 1&lt;sup&gt;st&lt;/sup&gt;, 2008</td>
<td>September 30&lt;sup&gt;th&lt;/sup&gt;, 2009</td>
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</tbody>
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*Harvesting Snow to Augment Water Supplies*
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Thank you