Colorado Silver Jackets
River Ice Workshop
River Ice Processes

CRREL Ice Engineering Group

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Introduction to River Ice

Objective: Develop an understanding of ice processes
► Formation of river ice and ice covers
► River Ice breakup and melt-out
► Ice Jams

Why?
► Design needs
► Assess flood risks
► Ice Observations
► Hazard mitigation and disaster response
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Ice Formation

River ice formation scenarios:

- No ice formation
  - High velocity
  - Warm water input (e.g. groundwater inflow, industrial discharge)

- Calm water
  - Thermally grown ice formation in lakes, ponds, slow-moving rivers.

- Turbulent water
  - Frazil ice formation in steep, fast-moving rivers.
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Ice Formation: Thermally grown

Columnar ice
- Persistent sub-freezing/cold temperatures
- “Black” ice
- Transparent, allows solar penetration,
- “candle ice”
- Tends to occur in more quiescent flow
- Referred to as Thermally Grown Ice
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Ice Formation: Thermally grown

- Static Ice Cover Formation
  - Typical of ponds, small lakes, and slow flowing rivers
  - Dominated by thermal growth

![Diagram of ice formation with heat transfer]

Interface temperature always at the ice/water equilibrium temperature: 0°C for freshwater.
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Ice Formation: Thermally grown

\[ AFDD = \sum(T_f - T_a) \]

\[ t_i = \alpha \left( AFDD \right)^{\frac{1}{2}} \]

**Table**

<table>
<thead>
<tr>
<th>Ice Cover Condition</th>
<th>( \alpha^* )</th>
<th>( \alpha^\dagger )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windy lake w/no snow</td>
<td>2.7</td>
<td>0.80</td>
</tr>
<tr>
<td>Average lake with snow</td>
<td>1.7-2.4</td>
<td>0.50-0.70</td>
</tr>
<tr>
<td>Average river with snow</td>
<td>0.4-0.5</td>
<td>0.12-0.15</td>
</tr>
<tr>
<td>Sheltered small river</td>
<td>0.7-1.4</td>
<td>0.21-0.41</td>
</tr>
</tbody>
</table>

* AFDD calculated using degrees Celsius. The ice thickness is in centimeters.

† AFDD calculated using degrees Fahrenheit. The ice thickness is in inches.
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Ice Formation: Thermally grown

Snowshoe Lake, AK

\[ y = 1.2202x + 4.7228 \]
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Ice Formation: Thermally grown

Post Pond, NH

\[ y = 2.0879x - 3.8334 \]
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Ice Formation: Thermally grown

[Map of the United States showing average maximum accumulated degree days (°F Days) for ice formation.]
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Ice Formation: Frazil ice

- Formed only in areas of open water
- Formed in turbulent water
  - Flow velocity
  - Wind mixing
- Formed in supercooled water
  - -.01°C to -.02°C
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Ice Formation: Frazil ice

<table>
<thead>
<tr>
<th>PHASE:</th>
<th>Formation</th>
<th>Transformation and Transport</th>
<th>Stationary Ice Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE TYPE:</td>
<td>Seed Crystals</td>
<td>Disk Crystals</td>
<td>Flocs and Anchor Ice</td>
</tr>
<tr>
<td>PROCESS:</td>
<td>Seeding</td>
<td>Frazil Ice Dynamics</td>
<td>Flocculation and Deposition</td>
</tr>
</tbody>
</table>

![Diagram](image)

*Figure 3. Evolution of frazil ice in natural water bodies.*
Frazil Slush
Surface slush and Anchor Ice
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Ice Formation: Anchor ice

Frazil deposited on underwater objects in often referred to as “anchor ice”

Photos from Benoît Turcotte, Ph.D., P. Eng.
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Ice Formation: Anchor ice

Properties of Anchor ice
- Deposition of crystals
- Thermal growth can occur
- Can be highly transitory
- Most stable in shallow, fast flowing streams
- Formation of anchor ice is influenced by flow velocity
- Anchor ice dams raise upstream water levels
Slush and small floes
Frazil ice
- Formed from tiny particles in supercooled water
- Tends to occur in dynamic, turbulent flow
- Can form anchor ice, ice pans, and eventually solid ice cover

Flow
Floe Floe Floe
Slush and small floes
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Ice Formation: Border Ice

• The first ice to appear on a river usually forms along the banks where the velocity is low
• grows vertically and also laterally toward mid-stream
• Lateral growth can take place even with the main water temperatures slightly above freezing
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Ice Formation: Sheet Ice

- River is completely covered it is referred to as sheet ice.
- Can form by
  - border ice meeting in the center
  - a more rapid freeze up of the pancake/frazil ice
- Ice thickens
- Sheet ice may have thin spots.
  - Walking on river ice demands paying attention to areas where this thin ice is likely to occur.
River Ice Thermal Meltout
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Thermal Melt out

• Ice melts in place
• Long gradual warming period with no significant rain
• Ice cover thins, weakens and melts in place, or forms minor jams
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Mechanical Breakup

- Increase in flow
  - Rain, snowmelt, dam release
  - The faster the rate of rise the more effective the increase in fracturing ice
- The ice cover connection with banks is fractured
- The channel geometrical constraints are overcome – sinuosity, constrictions, barriers
- Channel ice begins to move – feedback with flow
- Fractures into smaller and smaller pieces
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Mechanical Breakup
Introduction to River Ice

Ice Jams

Definition: An ice jam is a stationary accumulation of fragmented ice or frazil that restricts flow (IAHR Working Group on River Ice Hydraulics)

Ice Jam classification by season of occurrence:
- Freeze up Jam
- Breakup Jam
- Midwinter Jam
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Ice Jams

Common Locations for ice jams:

- Solid Ice cover
- Bend
- Bridges or other infrastructure
- Channel constrictions
- Islands
- Changes in channel slope
Freezeup Jam
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Ice Jams: Freeze-up Jams

- Early to mid-winter formation
- Subfreezing air temperatures
- Frazil, surface, and broken border ice
- Unlikely to release until air warms
- Fairly steady/declining water flow
- Smooth to moderate surface roughness
Cross Section of Freezeup Jam

- Drained Frazil
- Refrozen Surface Layer
- Border Ice Pieces
- Primary Flow Area
- Frazil
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Ice Jams: Freeze-up Jams

Freezeup Jam
Shear Walls

Shear walls provide cross section view of composition

Frazil ice jam on the Fox River after warm weather and rain opened channel, February 1961. (Photo by R.W. Gerdel.)
Breakup Jam
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Breakup Jams

- Mid to late winter formation
- Near-freezing air temperatures
- Broken sheet and border ice
- Highly unstable, releasing suddenly
- Unsteady water flow (surges)
- Negligible cohesion
- Moderate to extreme surface roughness
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Breakup Jams

- Breakup ice jam forms when ice flow transport capacity exceeded

- Locations:
  - Intact ice sheet
  - Dramatic change in slope
  - Sharp bends
  - Constrictions
  - Barrier – bridge piers
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Breakup Jams

Yellowstone River
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Breakup Jams

Allegheny River
Shear walls stranded on bank following jam failure; can provide a good estimate of jam thickness

Erosion caused by an ice jam
Midwinter Break-up

Winooski River, VT (NAN)

Mohawk River, Schenectady, NY (NAN)

Skunk River, Augusta, IA (MVR)
- 6 homes evacuated
- Froze in place with onset of cold weather, remained till March thaw.
Summary

Topics covered:
- Ice Formation
- Ice melt out and breakup
- Ice jams
Questions?