New Hampshire Silver Jackets
River Ice Workshop

CRREL Ice Engineering Group

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November 2017
Presentation Overview

- River Ice Processes
  - Ice formation
  - River ice breakup
  - Ice jams
- Ice Jam Database and NH Ice Jams
- Mitigation Techniques
- River Ice Observer Training
Introduction to River Ice

Ice Formation

- Two contrasting cases:
  - Lakes, reservoirs, and very slowly moving rivers with no wind mixing
    - Surface ice cover
  - Rivers with a moderate or higher flow velocity, Lakes and reservoirs with strong wind mixing
    - Frazil ice
Introduction to River Ice

Ice Formation: Surface ice

$AFDD = \sum (T_f - T_a)$

$t_i = \alpha \sqrt{AFDD}$

Interface temperature always at the ice/water equilibrium temperature: 0°C for freshwater.
Introduction to River Ice

Ice Formation: Frazil ice

- Formed only in areas of open water
- Formed in turbulent water
  - Flow velocity
  - Wind mixing
- Formed in supercooled water
  - $-0.01^\circ C$ to $-0.02^\circ C$
Frazil Slush
Surface slush and Anchor Ice
Pancake Ice

Mississippi River near St Louis
Slush and small floes
Introduction to River Ice

Ice Jam Categories

- Occur during river ice formation period
  - Freezeup jam
  - Anchor ice dam
- Occur during river ice breakup
  - Breakup jam
  - Midwinter jams
Introduction to River Ice

Ice Jams: Freeze-up Jams

- Early to mid-winter formation
- Subfreezing air temperatures
- Frazil, surface, and broken border ice
- Insidious – no way to stop arriving ice
- Unlikely to release until air warms
- Fairly steady/declining water flow
Cross Section of Freezeup Jam

- Drained Frazil
- Frazil
- Refrozen Surface Layer
- Border Ice Pieces
- Primary Flow Area
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Grand River, Grand Rapids, MI
2006
Introduction to River Ice

River Ice Breakup

- **Thermal Breakup**
  - river ice cover deteriorates through warming and the absorption of solar radiation and melts in place

- **Mechanical Breakup**
  - Mechanical breakup requires no deterioration of the ice cover, but rather results from an increase in flow.
  - The increase in flow induces stresses in the cover, and the stresses in turn cause cracks and the ultimate fragmentation of the ice cover into pieces that are carried by the channel flow.

- Most river ice breakups combine thermal and mechanical breakup.

- Mechanical breakups are more dramatic and dangerous – increased flow + large volume of ice fragments.
Introduction to River Ice

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
Introduction to River Ice

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
Introduction to River Ice Breakup Jams

Extents of a Breakup Ice Jam

Parts of a jam (toe, head):

**Head - Upstream end of jam:**

**Toe – Downstream end of jam:**

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Introduction to River Ice

Breakup Jams

- Breakup ice jam forms when ice floe transport capacity exceeded

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

Allegheny River
Introduction to River Ice

Breakup Jams: Midwinter Breakup

- 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.
Questions?
CRREL Ice Jam Database

- Overview
- Data Sources
- New York Ice Jams
  - Records for NY in IJDB
  - General overview
Ice Jam Database Overview

- Developed at CRREL in 1992
- Provide timely ice jam information to USACE
- Goal to coordinate response to and assist in long-term planning for ice jam flooding
- Over 22,600 ice jams
- Data publically available through Web
  
  https://rsgisias.crrel.usace.army.mil/icejam/
Data Sources for Ice Jam Database

- National Weather Service (NWS) products
  - (review roughly 2,500 products per hour)
- Real-time river water surface elevation, USGS & USACE
- Online news sources
- First hand observers (locals & emergency managers)
Support to Emergency Management

- CRREL can provide technical assistance through a request made to applicable USACE District.

- Typically when an ice jam has occurred, but can also happen before.
  - Advance Measures vs Emergency Measures
Overview of New Hampshire Ice Jams

- 677 New Hampshire ice events documented in the CRREL ice jam database
- 1835-2017
- November to June
- Freezeup and breakup
- 71 rivers & streams
- 141 locations in 101 cities/towns/etc.

Great Chazy River, Coopersville, NY Feb 2017
New Hampshire Ice Jams in IJDB
Questions?
Ice Jam Mitigation

- Advance/Early Warning Measures
- Emergency Measures
- Permanent Measures
Ice Jam Mitigation

Advance Measures

- Goals:
  - Flood protection
  - Reduce ice supply
  - Control breakup sequence
  - Increase conveyance
- Non-structural intervention
- Two weeks to six months lead time
- Can be inexpensive
- Effectiveness difficult to quantify
Ice Jam Mitigation
Advance Measures: Early Warning

- Ice motion detectors
- Trained observers
- Web Cameras
- Provides critical information
- Two weeks to six months lead time
- Inexpensive and invaluable
Ice Jam Mitigation
Advance Measures: Early Warning

Ice Motion Detectors

- Trip wires in ice
  - alarms inform emergency managers
  - select locations to give as much lead time as possible

A CRREL ice jam motion detector installed on the Kennebec River in Maine.
Ice Jam Mitigation
Advance Measures: Early Warning

Trained Observers
- Part of emergency response team
- Track pre-event ice conditions
- Check upstream & downstream during event
- Helpful for after-action assessment, permanent measures
Ice Jam Mitigation
Advance Measures: Mechanical Weakening

- Weaken ice to pass ice run
- Mechanical & thermal methods
- 2-6 weeks before breakup
- Very low cost
- Effectiveness difficult to quantify
- Ice cutting/hole drilling
  - 4WD trencher or auger
  - amphibious ice saw
- Ice breaking
  - amphibious excavator
  - vessels
Ice Jam Mitigation

Advance Measures: Mechanical Weakening
Ice Jam Mitigation

Advance Measures: Mechanical Weakening

Ice Breaking

Icebreakers / towboat to break downstream ice cover in advance of natural breakup or clear channels through jams.

Large hovercraft creates a wave to break thick ice over 3-ft-thick

Amphibex floating backhoe, effective but slower.

Work from downstream to upstream.
Need sufficient current needed to convey ice pieces downstream

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Ice Jam Mitigation
Advance Measures: Thermal Weakening

Dusting on the Platte River
Ice Jam Mitigation
Emergency Measures

- Goals:
  - Flood protection
  - Increase conveyance
  - Remove ice Jam in place
- Cost & effectiveness depend on timing
- Excavation
- Blasting
- Flood Fighting
- Do nothing
Ice Jam Mitigation
Emergency Measures: Excavation

Excavation - Stage Rising

- Immediate flood threat
- Pre-positioned equipment
  - excavator, clam-shell, bulldozer
  - clear channel D/S of toe
  - dislodge key pieces at toe
- Can be inexpensive (& nerve wracking)
Ice Jam Mitigation

Emergency Measures: Blasting

- The Corps does not blast – only local agencies
- Open water downstream, work up from toe
- Most effective charges placed under ice
- Pre-planning needed
- Not suitable for urban area
Ice Jam Mitigation
Emergency Measures: Excavation

Excavation - Stage Falling

- Second flood threat possible
- Bulldozer clears channel
  - from D/S, through toe
- Dislodge key pieces
  - blasting, clam-shell
- Expensive to excavate and remove ice pieces
- Access often difficult
Excavation Examples

- Gorham, NH
- Morrisonville, NY
Ice Jam Mitigation
Emergency Measures: Flood Fighting

- Track upstream conditions (observers)
- Check database, local accounts to identify potential flood areas
- Sandbags (unfrozen sand)
- Temporary dikes
- Evacuation plans (!)
- Combine with ice removal
Ice Jam Mitigation
Emergency Measures: Do Nothing

- Thin, weak ice
- Little remaining ice supply
- Forecast for mild temperatures & no rain
- Late season jam (check records)
- Other constraints
Ice Jam Mitigation
Permanent Measures

- Goals:
  - Flood protection
  - Reduce ice supply
  - Increase conveyance
  - Control breakup sequence
  - Displace jam location

- Structural solutions
- 2-5 year lead time
- Expect high benefits and reliability
- Generally costly although some low-cost solutions under development
Ice Jam Mitigation
Permanent Measures: Ice Control Structures

Freezeup ICS - Ice Boom & Weirs

- Collect ice at a safe upstream location
- Reduce ice supply to downstream problem area
- Requires:
  - low velocity <= about 2.3 ft./s
  - adequate upstream ice storage capacity
- If properly sited and designed booms are reliable & low cost
- Annual installation and removal time and cost, wear and tear, debris management need to be considered
Oil City, PA ICS
Ice Control Weirs

- Same design objectives as booms: retain a freezeup ice accumulation at desirable upstream location to reduce the ice supply to the downstream problem area.
- Success stories include Cherryfield, ME; Oil City, PA; and Lancaster, NH, where weirs designed as freezeup ICS also retain the breakup ice run.
Ice Jam Mitigation
Permanent Measures: Ice Control Structures

Breakup ICS

- Retain ice cover throughout breakup, or
- Arrest ice run in safe location
- Allow flow through or around ice accumulation to decrease stages
Ice Control Structures - Cazenovia Creek, Buffalo, NY
Ice Control Structures – Lamoille River, Hardwick, VT
Ice Control Structures – Salmon River, CT
Ice Control Research at CRREL

Physical model study of ICS with in-channel relief flow for sites where floodplain bypass flow unavailable. Sponsored by Alcoa.
CAZENOVIA CREEK, ICE CONTROL STRUCTURE (ICS) - WEST SENECA, NY

Excessive Debris Build-up
Conclusions

- **Lead time = effectiveness**
  - Emergency measures last resort
  - Early warning and coordination invaluable
  - Higher risk/uncertainty with advance measures

- **Cost-effective ice control technology improving**
  - Freezeup and breakup ICS
  - Reliable performance possible
  - Range of application expanding
Questions?
River Ice Observer Training

Objective: Report ice conditions to provide early warning and help mitigate ice jam damages.

- Local officials and emergency managers
- State agencies
- CRREL

- What to look for, information to record
- Safety First!
# River Ice Observer Training

## Ice Observer Sheet

### ICE REPORT

**Section A**

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>AM/PM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Observers Name and Contact Info**

**River/stream Name:**

**Location of Observation:**

Area/Mile: ___________________________ or Lat: ___________ Long: ___________

Location of nearest bridge/landmark:

Distance to nearest Town: ___________ County:

Is this a changed condition? Yes or No

Is flooding occurring, describe:

Is damaging occurring or has occurred? Describe:

Is there a Photo? Yes or No

Photo description:

**Local Weather**

Temperature: ___________F

Precipitation: Rain ___________ Snow ___________

Wind: Average Speed ___________ mph

**River Condition:**

- [ ] Traditional
- [ ] Estimate less than backflow
- [ ] Nearest gage reading

**Section B**

- [ ] Character of intact ice cover

- [ ] Location of downstream end of ice cover: Lat: ___________ Long: ___________

- [ ] Location of upstream end of ice cover: Lat: ___________ Long: ___________

- [ ] Surface roughness:

  - [ ] Smooth
  - [ ] Rough

- [ ] Evidence of decay:

  - [ ] Yes
  - [ ] No

- [ ] Cracks in ice cover:

  - [ ] Yes
  - [ ] No

- [ ] Evidence of fracturing along banks:

  - [ ] Yes
  - [ ] No

### ICE REPORT. continued

**Breach**

- [ ] Cracks (check one):

  - [ ] Most to shore

- [ ] Distance from shore: ___________ ft

- [ ] Estimate

- [ ] Measured

- [ ] Average distance between cracks: ___________ ft

- [ ] Water on top of ice:

  - [ ] Frozen

  - [ ] Flowing

- [ ] Name:

- [ ] Time water was clear of ice:

  - [ ] AM/PM

- [ ] Post movement:

  - [ ] Height of shear walls along banks: ___________ ft

### Ice Jams

- [ ] Cause (check one):

  - [ ] Freezing

  - [ ] Abandon

- [ ] Condition or jam initiation point:

  - [ ] Breakup

- [ ] Size of ice jam:

  - [ ] Width

- [ ] Length

### Sketches

- [ ] Include approximate scale, illustrate character of ice cover, ice thickness, water level, etc.

**Other Observations/Notes**

Comments on any aspect of ice cover, ice conditions, water level, etc.
River Ice Observer Training

Ice Observations

Ideal Observations

- Location of Observations
  - High elevation
  - More than one good vantage point
  - Ability to observe up and downstream
  - Near a gage station is helpful
  - Near a bridge is helpful for discharge measurements after ice is gone

- Frequency of Observations
  - Correspond to degree of river ice activity.
  - Daily during freeze-up
  - Every 2 - 4 weeks during established ice cover
  - Daily once any melt has been observed or warm-up is predicted
River Ice Observer Training
Ice Observations: General Information

- Observer
- Date, time
- Location
  - River
  - Coordinates
  - Nearby towns
  - Landmarks
- Conditions
  - Flooding
  - Weather
  - Damages
River Ice Observer Training
Ice Observations: General Information

- Taking Photos
  - Location
  - Direction
  - Other relevant details

Penobscot River at Howland looking toward Piscataquis confluence

Pleasant River in Milo

- Water flowing around jam and out of river banks
- Ice jam only ½ mile long and had shifted slightly downstream a couple of hours later. Water is flowing away from the viewer in this photo.
River Ice Observer Training
Ice Observations

CRREL River Ice Guide

River Ice Observer Training
Ice Observations: Ice Formation

- Note type, thickness and extent of border ice
- Characteristics of ice that is passing
  - Frazil concentration
  - Thickness
  - Size of pans
- Method of freeze-up once it occurs
- Final Cover
  - Roughness
  - Estimate thickness
Two Observers, Two Reports

- 60% of channel has moving ice (frazil pans)
- 1-15 ft. size
- Border ice?

- 50% of Channel with Border Ice
- 100% of Open Channel with Moving Ice (very slowly)
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Ice Observations: Ice Cover

- Locations of upstream extent and downstream extent
- Surface characteristics
  - Roughness
    - Is this a jam or a smooth cover?
  - Thickness
  - Decay
  - Cracks
River Ice Observer Training
Ice Observations: Ice Cover

Roughness/Smoothness
River Ice Observer Training

Ice Observations: Ice Cover

Decay
River Ice Observer Training

Ice Observations: Ice Cover

Fracturing along Banks: Fracture formed in an ice cover or floe that does not divide it into two or more pieces

- Displacement
- Distance from shore
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Ice Observations: Ice Cover

**Hinge Crack (parallel):** Typically, hinge cracks form along both banks. In narrow channels, a single crack may form down the middle of the channel.
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Ice Observations: Break up

- Lifted Ice In Place
- Lifted and Shifted Ice
River Ice Observer Training
Ice Observations: Break up

Ice is beginning to shove and move. What time is it? Where is it at?
What time did the channel clear of ice?

How high are the shear walls?
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Ice Observations: Ice Jams

Freeze-up Ice Jams

- Early in season
- Monitor:
  - Stage and discharge trends
  - Extent
  - Conditions
    - head and toe of jam
    - Movement
  - Surface conditions
    - Buckled? Single layers of floes?
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Anchor Ice Jams
- Occur during freezeup
- Active frazil deposits on bed
- Found in shallow and turbulent areas
- Note extent and affect on water levels

River Ice Observer Training
Ice Observations: Ice Jams
Breakup Ice Jams

- Can occur anytime after ice cover forms
- Generally mid to late winter
- Can form more than once
- Can lead to unsteady flow surges

Monitor:

- Stage and discharge
- Extent, coverage
- Conditions at head and toe of jam (thickness, concentration)
- Surface conditions
  - Color and thickness
Midwinter Jams

- Forms with a mid-winter thaw
- Characteristics of breakup jams with thinner ice floes
- Can refreeze in place and cause problems late in the season

Monitor:
- Stage and discharge
- Extent, coverage
- Conditions at head and toe of jam (thickness, concentration)
- Surface conditions
  - Color and thickness
River Ice Observer Training

Ice Observations: Ice Jams

Released Ice Jams

As the water level continues to increase, ice will be lifted until at some point it will be freed from the geometry of the channel and move downstream

► Time of release
► Height of shear walls
Send your Ice Jam Observations to CRREL

- We will add to weekly ice report and IJDB
- Contact and email info:

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Questions?