New Hampshire Silver Jackets River Ice Workshop

ERDC
Engineer Research and Development Center

CRREL Ice Engineering Group

Presented by,

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US Army Corps of Engineers®

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


US Army Corps of Engineers® Cold Regions Research & Engineering Laboratory

Ice Engineering

U.S. Army Engineer Research and Development Center, Hanover, New Hampshire

Method to Estimate River Ice Thickness Based on Meteorological Data

Some knowledge of ice thickness is required for the design of structures—such as bridges, dams, weirs, locks, piers, intakes, channel stabilization measures, and coastal shoreline protection—in ice-affected rivers. One recent case illustrating the need for considering ice in the design of riverine structures is the failure of the McKeesport (Pennsylvania) Marina on the Youghiogheny River in January 2001 (Fig. 1 [Silver and Fuoco 2001] and 2). The marina was constructed in 1997 at a cost of more than $2 million. According to the ERDC-CRREL Ice Jam Database sources (National Weather Service 2001a, b; Veltri 2001), ice jam breakup, jamming, and failure resulted in the complete destruction of the marina by chunks of ice measuring up to one foot thick. Contemporary reports estimated that the damage began around 6:30 p.m. on 31 January, and by 8:37 p.m., the marina was torn away. Reconstruction costs for the marina have been estimated at more than $1 million.

Figure 1. Twisted docks at McKees Point Marina on the Youghiogheny River, Pennsylvania. Photo by Darrell Sapp, Post-Gazette.

Ice covers and ice jams can cause rapid increases in stage that can cause flooding and damage (Fig. 3). Numerical models of rivers to develop stage-frequency information required for modeling ice jams for flood damage reduction measures, flood insurance studies, and changes to the ice regime that occur from development in the floodplain or dam removal also require that ice thickness be estimated. Analyses of ice-induced scour and erosion in ice-affected rivers must include knowledge of ice thickness.

Unlike discharge or stage measurements, observations of ice thickness can be challenging to locate. The USGS does record ice thickness as part of its winter discharge measurements, but these records are often archived in paper form and can be difficult to access. Some local flood warning systems measure ice thickness. A good example is the Nebraska Ice Warning System (http://dnrdata.dnr.state.ne.us/Icejam/index.asp), which contains seasonal ice thickness measurements.

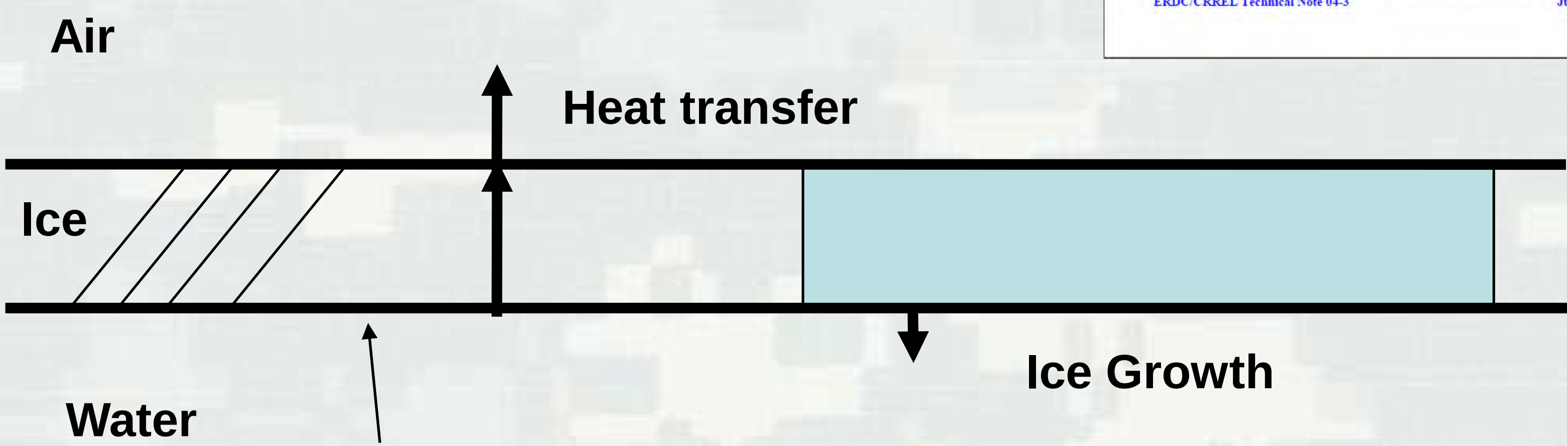
Given the lack of existing data, ice thickness must often be estimated. Because ice covers result from complex physical processes, there is not yet a method to account for all factors affecting thickness. This technical note presents a method to estimate ice thickness that results from heat transfer processes based on meteorological data.

Figure 2. Debris from the McKeesport Marina trapped above Emsworth Locks and Dam on the Ohio River about six miles downstream from Pittsburgh. Photo by Andy Tuthill, ERDC-CRREL.

ERDC/CRREL Technical Note 04-3 June 2004

$$AFDD = \sum (T_f - T_a)$$

$$t_i = \alpha\sqrt{AFDD}$$



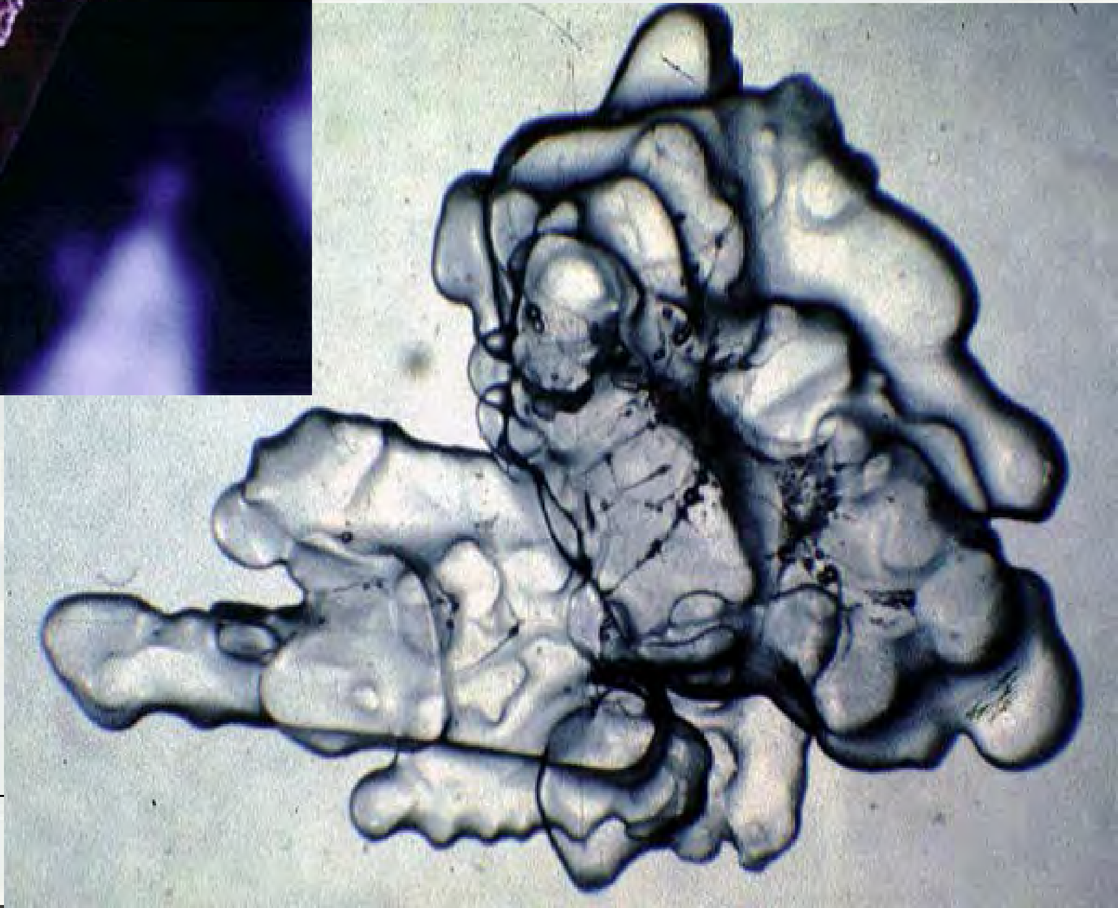
Interface temperature always at the ice/water equilibrium temperature: 0C for freshwater.

Introduction to River Ice

Ice Formation: Frazil ice

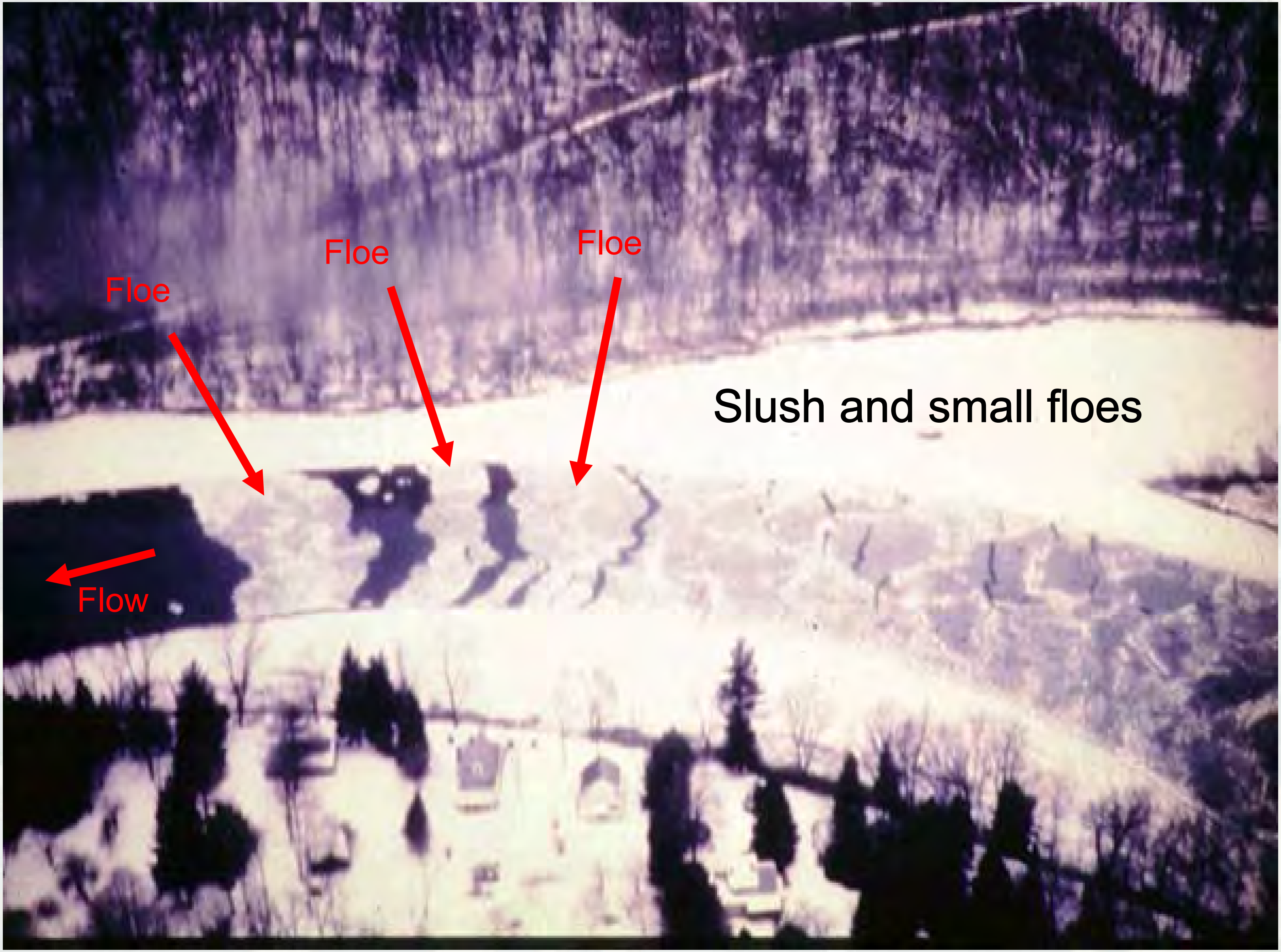
- Formed only in areas of open water
- Formed in turbulent water
  - Flow velocity
  - Wind mixing
- Formed in supercooled water
  - -.01°C to -.02°C

Frazil Slush



Surface slush and Anchor Ice


Pancake Ice
Mississippi River near St Louis


Floe
Floe
Floe
Slush and small floes
Flow

Introduction to River Ice

Ice Jam Categories

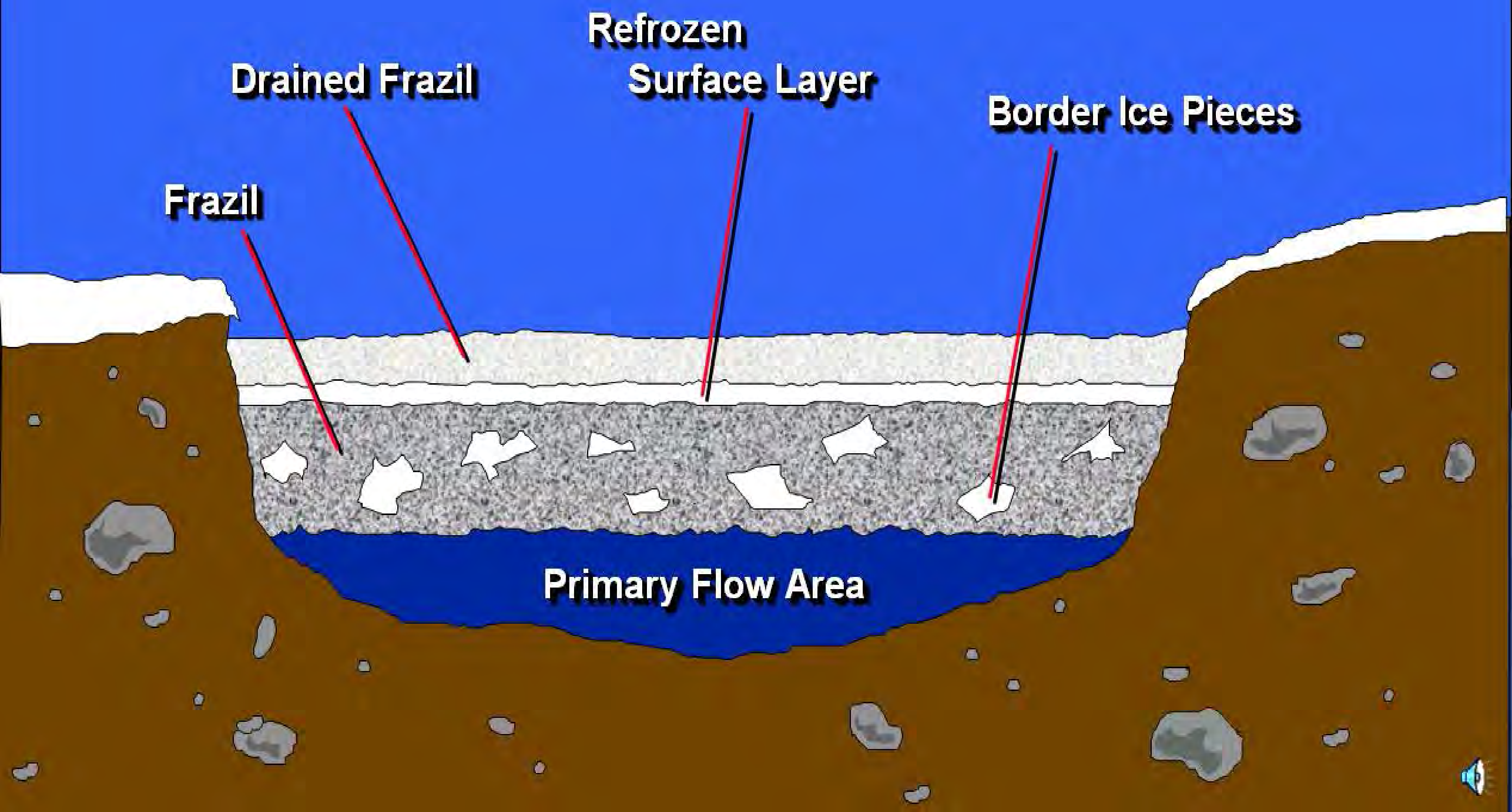
- Occur during river ice formation period
  - Freezeup jam
  - Anchor ice dam
- Occur during river ice breakup
  - Breakup jam
  - Midwinter jams

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



Grand River, Grand Rapids, MI
2006

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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

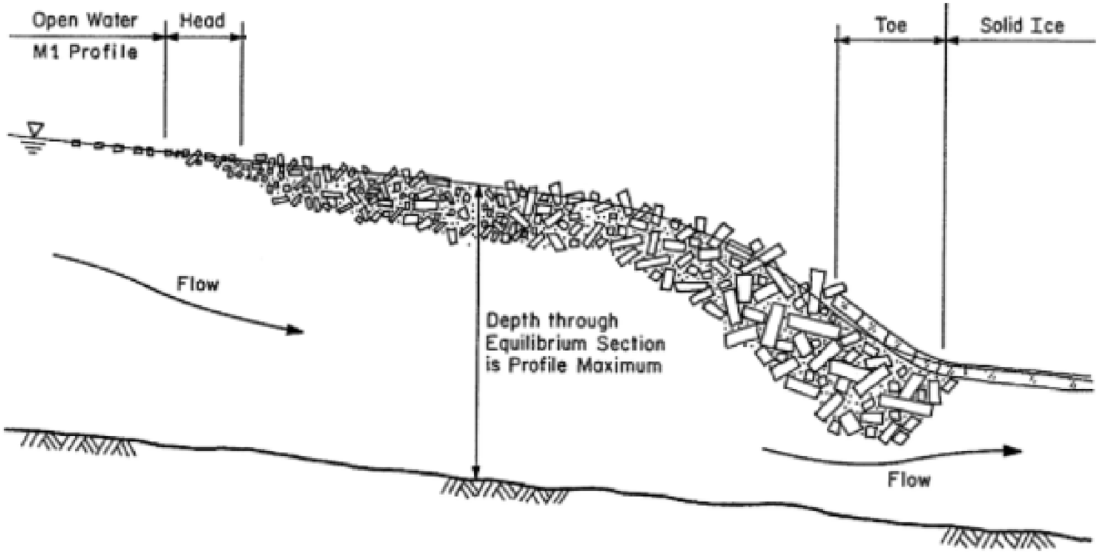
- Increase in flow
  - Rain, snowmelt, dam release
  - The faster the rate of rise the more effective the increase in fracturing ice
- The ice cover connection with banks is fractured
- The channel geometrical constraints are overcome – sinuosity, constrictions, barriers
- Channel ice begins to move – 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):

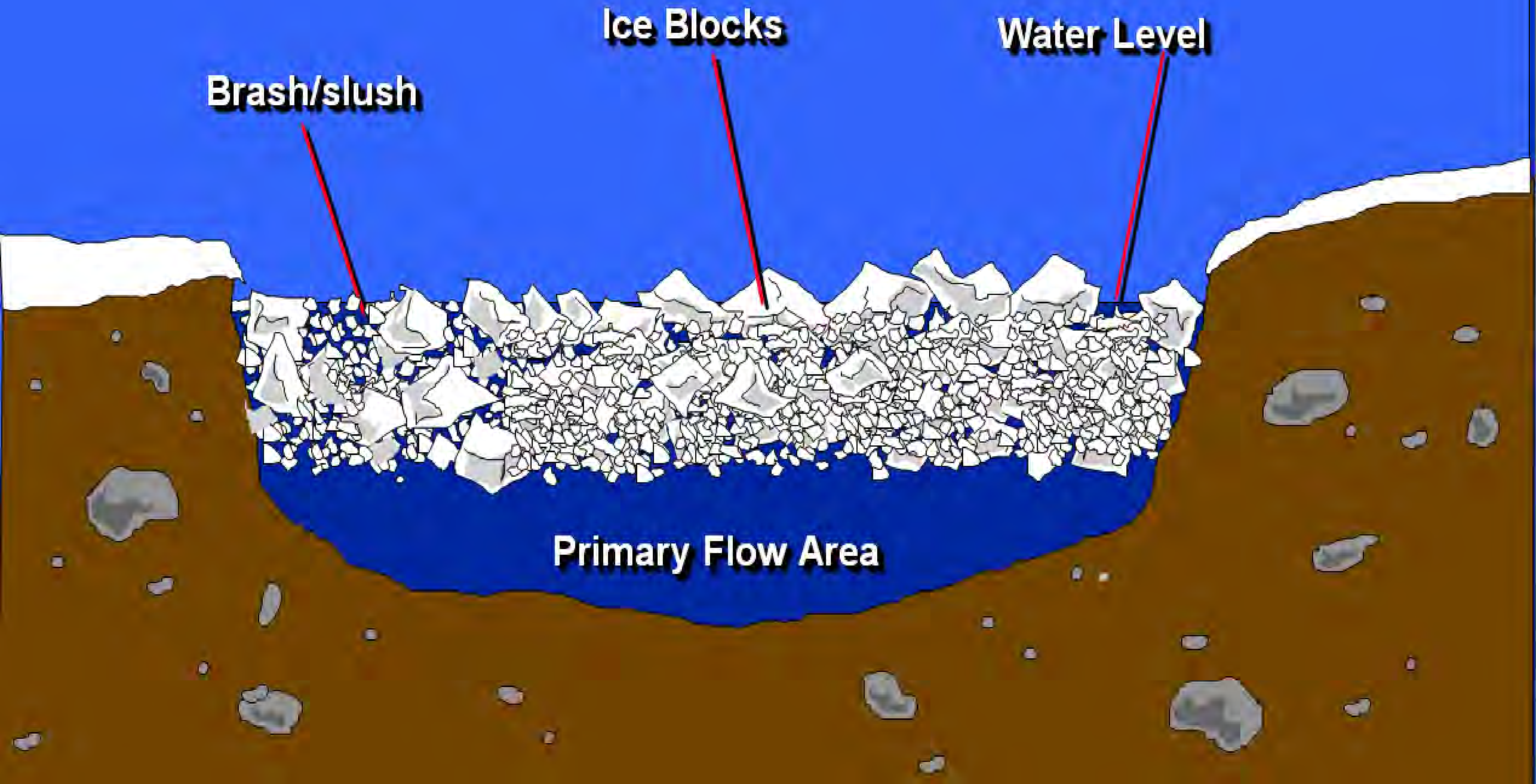


Head - Upstream end of jam:

Toe – Downstream end of jam:

Breakup jam.

Cross Section of Breakup Jam



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

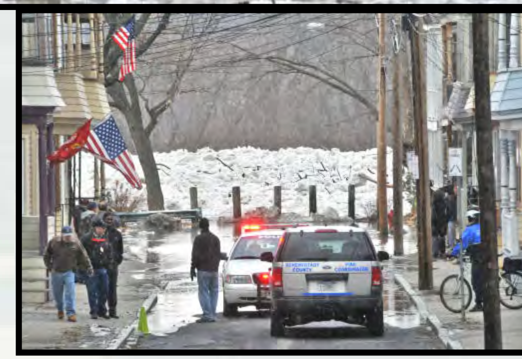
Allegheny River

Introduction to River Ice

Breakup Jams: Midwinter Breakup

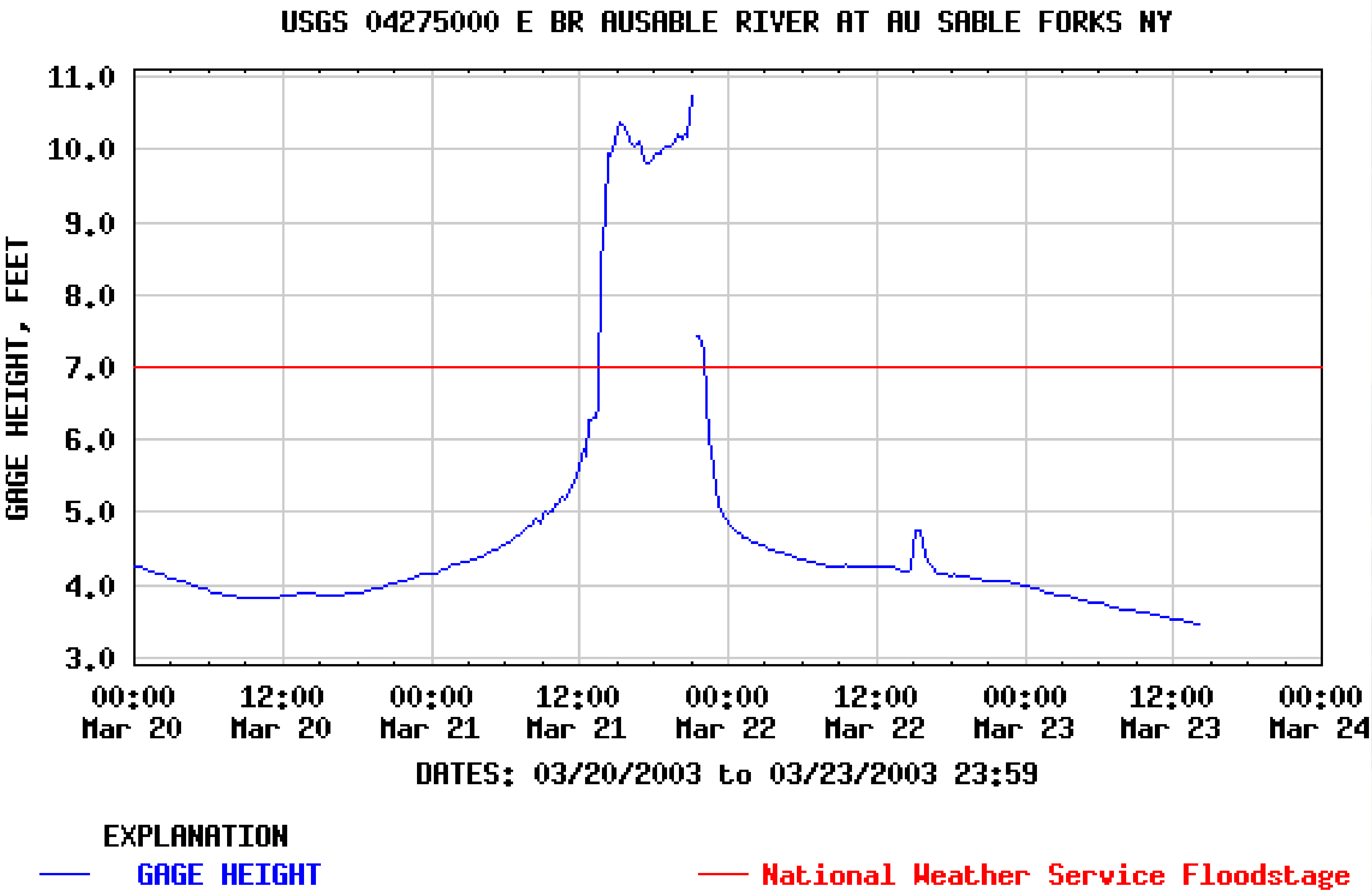
Winooski River, VT (NAN)

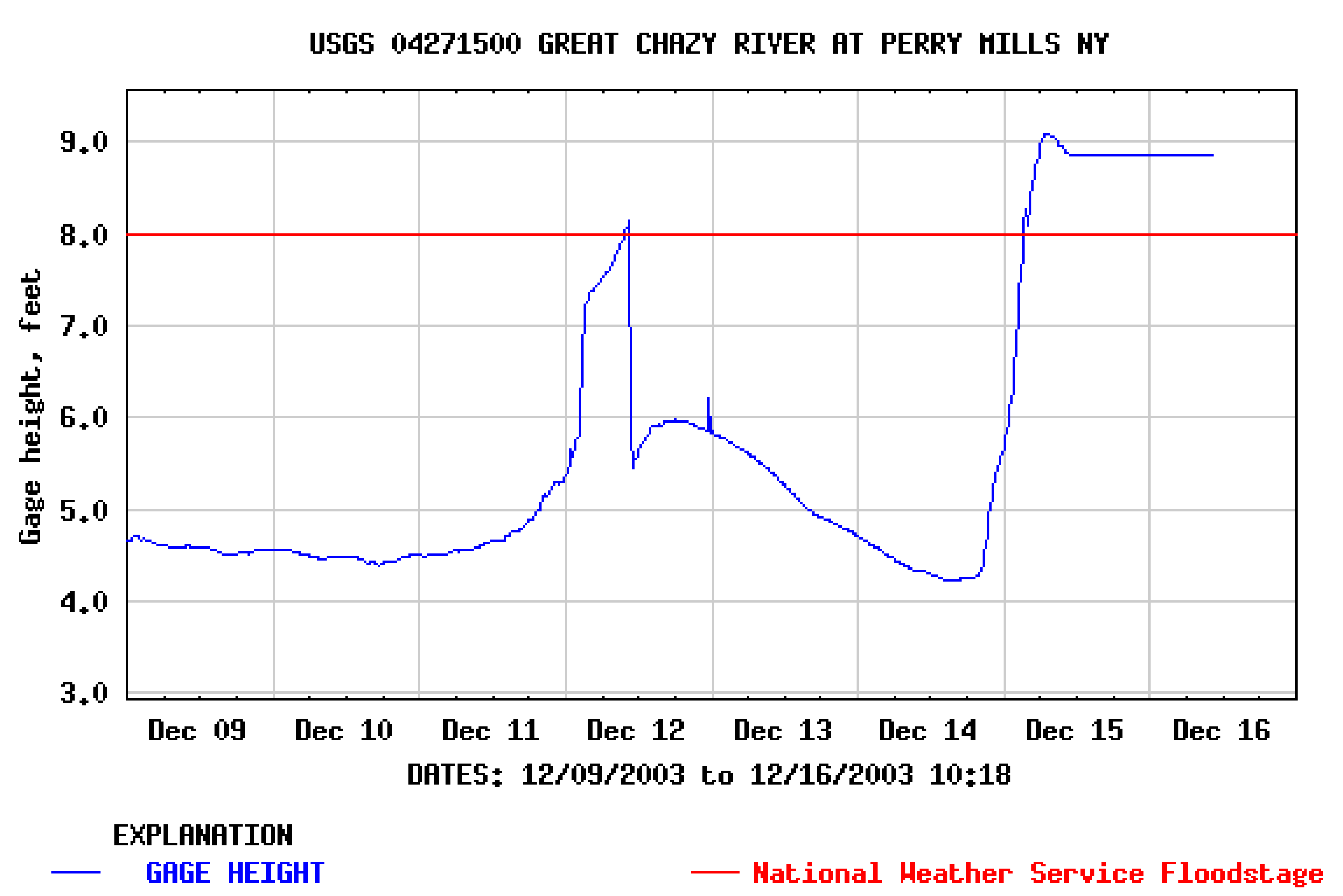
Mohawk River, Schenectady, NY (NAN)



Skunk River, Augusta, IA (MVR)

- 6 homes evacuated
- Froze in place with onset of cold weather, remained till March thaw.


USGS 04275000 E BR AUSABLE RIVER AT AU SABLE FORKS NY
GAGE HEIGHT, FEET
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
00:00 Mar 20
12:00 Mar 20
00:00 Mar 21
12:00 Mar 21
00:00 Mar 22
12:00 Mar 22
00:00 Mar 23
12:00 Mar 23
00:00 Mar 24
DATES: 03/20/2003 to 03/23/2003 23:59
EXPLANATION
GAGE HEIGHT
National Weather Service Floodstage



USGS 04271500 GREAT CHAZY RIVER AT PERRY MILLS NY
Gage height, feet
9.0
8.0
7.0
6.0
5.0
4.0
3.0
Dec 09
Dec 10
Dec 11
Dec 12
Dec 13
Dec 14
Dec 15
Dec 16
DATES: 12/09/2003 to 12/16/2003 10:18
EXPLANATION
GAGE HEIGHT
National Weather Service Floodstage

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

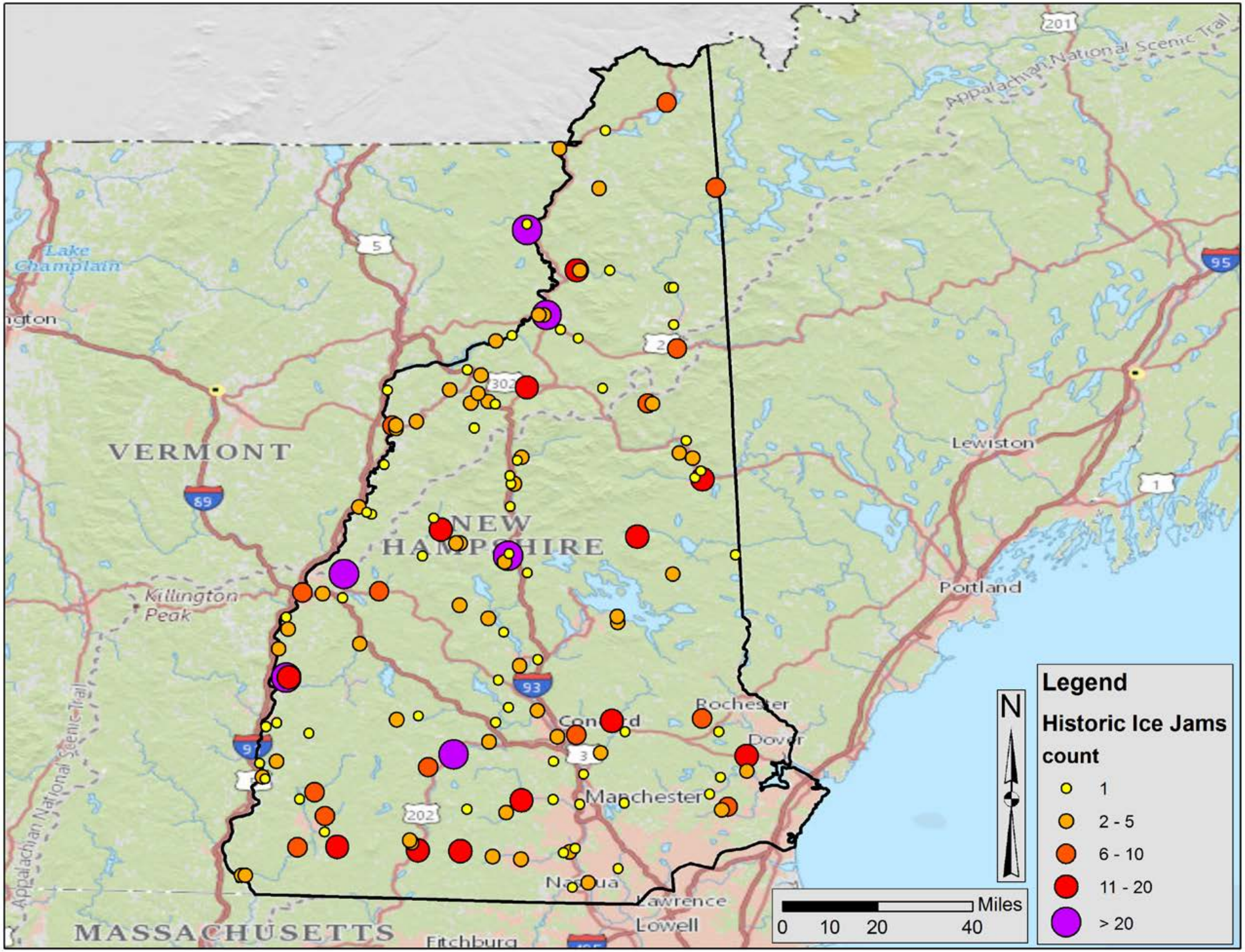
- CRREL can provide technical assistance through a request made to applicable USACE District.
- Typically when an ice jam has occurred, but can also happen before.
  - Advance Measures vs Emergency Measures

Overview of New Hampshire Ice Jams

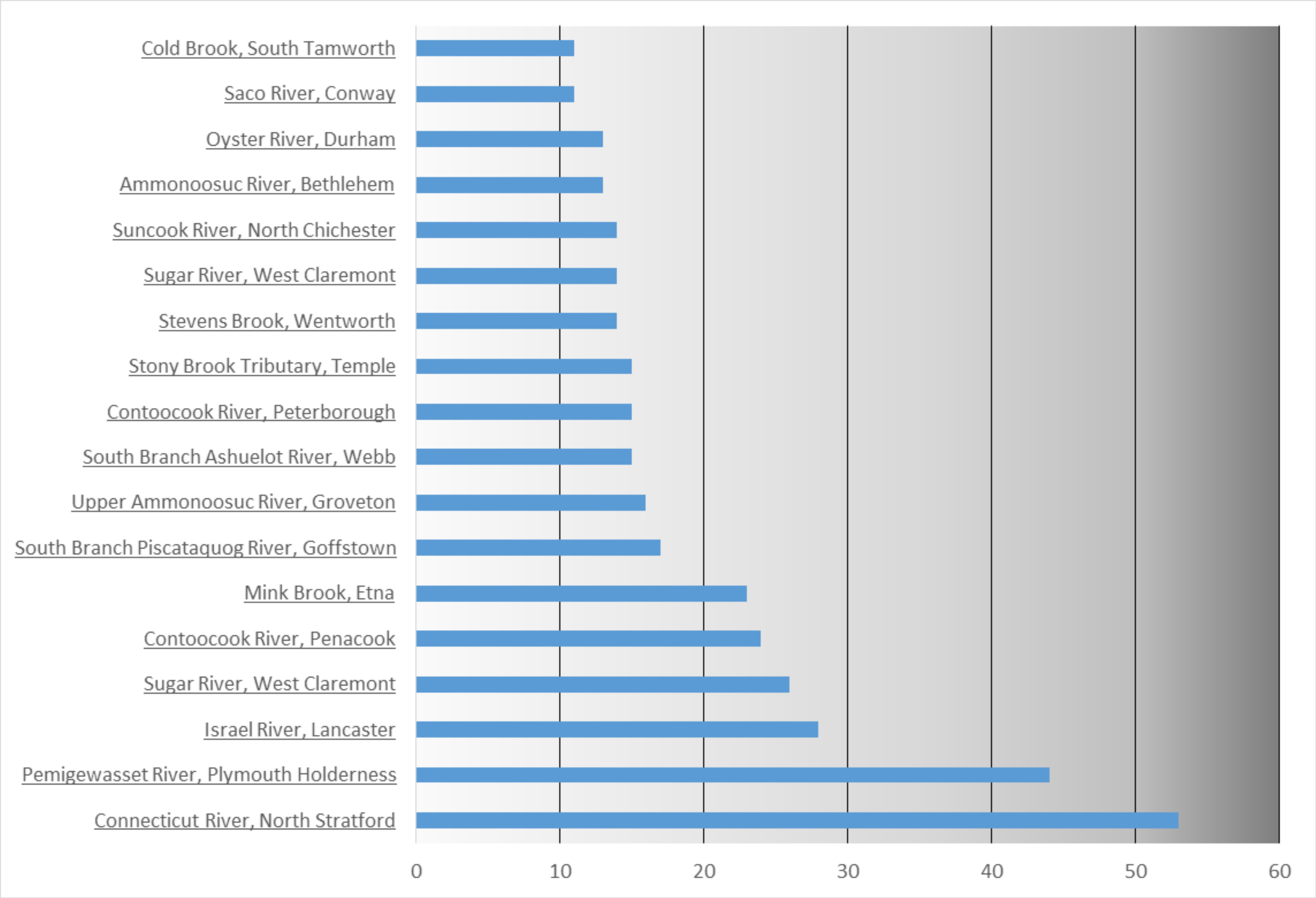
- 677 New Hampshire ice events documented in the CRREL ice jam database
- 1835-2017
- November to June
- Freezeup and breakup
- 71 rivers & streams
- 141 locations in 101 cities/towns/etc.

Great Chazy River, Coopersville, NY Feb 2017

New Hampshire Ice Jams in IJDB



New Hampshire Ice Jams by River, City



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

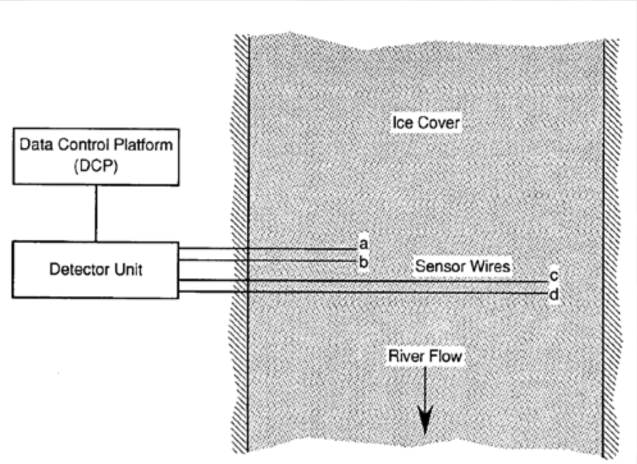
- Ice motion detectors
- Trained observers
- Web Cameras
- Provides critical information
- Two weeks to six months lead time
- Inexpensive and invaluable

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

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

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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

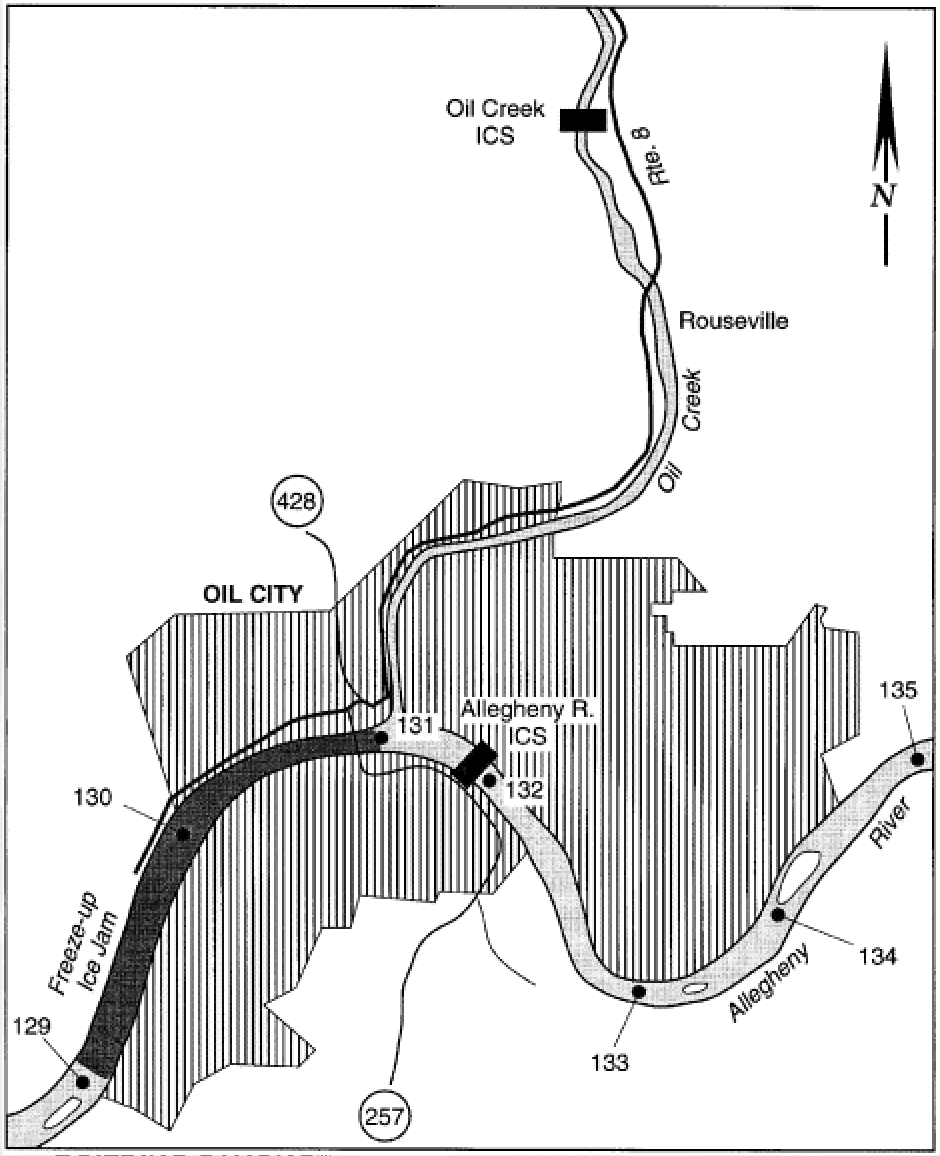
Ice Jam Mitigation

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

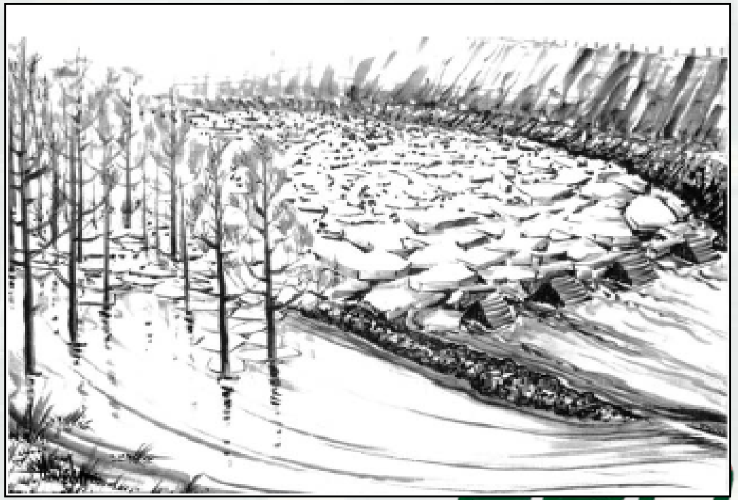
Permanent Measures: Ice Control Structures

Breakup ICS

- Retain ice cover throughout breakup, or
- Arrest ice run in safe location
- Allow flow through or around ice accumulation to decrease stages

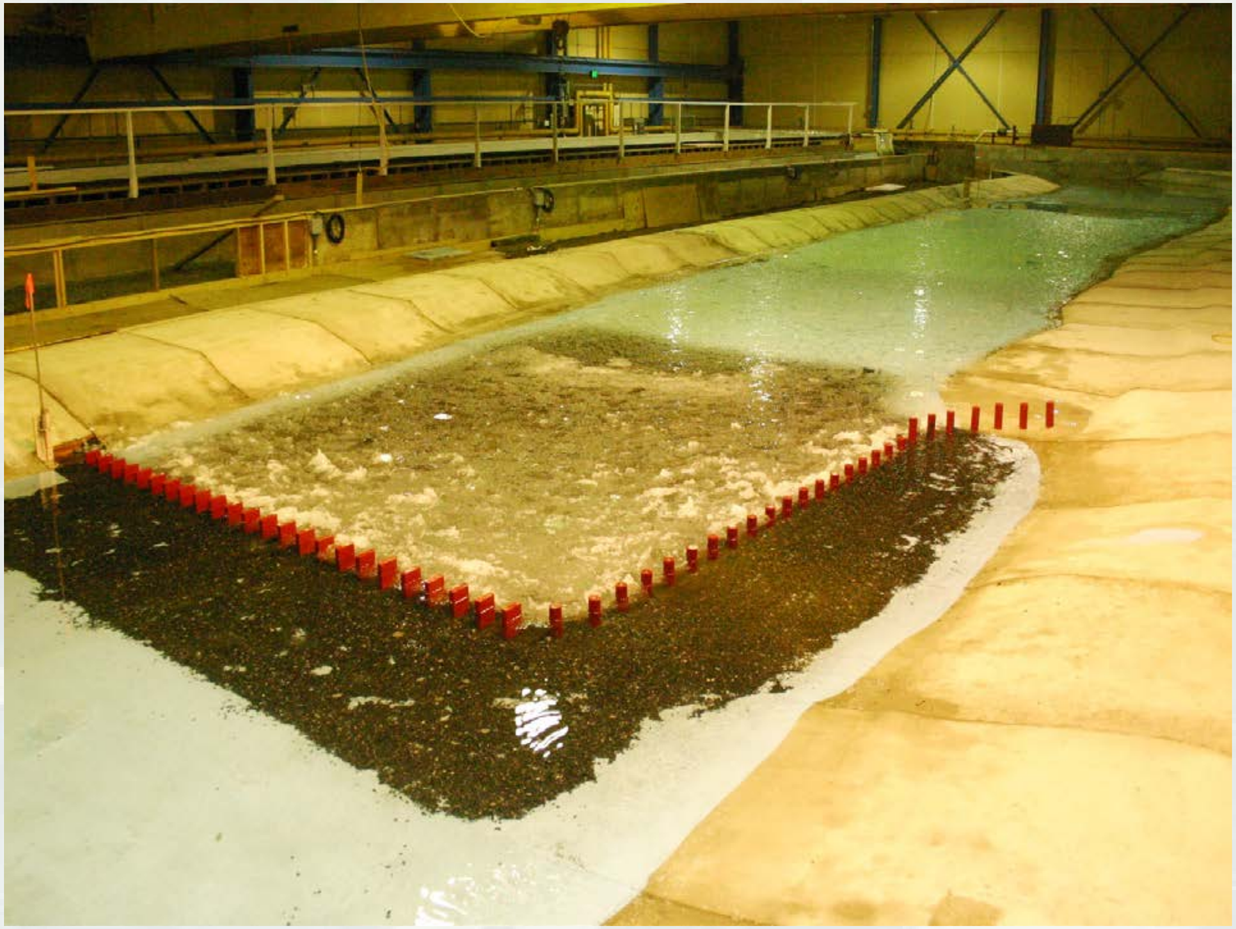
Ice Control Structures - Cazenovia Creek, Buffalo, NY

Ice Control Structures – Lamoille River, Hardwick, VT



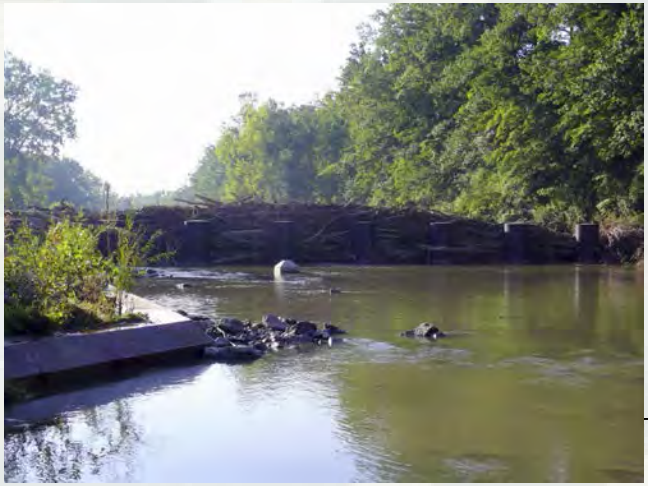
Ice Control Structures – Salmon River, CT

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

DATE: ______ mm/dd/yy TIME: ______ AM/PM
OBSERVERS NAME and CONTACT INFO: ______
RIVER/STREAM NAME: ______ NEAREST TOWN: ______
LOCATION OF OBSERVATION: (attach a map if desired)
Area/Site# ______ or Lat: ______ Long: ______
Location of nearest roads: ______
Location of nearest bridge/landmark: ______
Distance to nearest Town: ______ County: ______
Is this a changed condition: ◯Yes ◯No
Is flooding occurring, describe: ______
Is damaging occuring or has occurred? Describe: ______
Is there a Photo? ◯Yes ◯No File: ______
Photo description: ______

LOCAL WEATHER

Temperature: Air: ______ °F Water: ______ °F
Precipitation: Rain: ______ in Snow: ______ in
Wind: Average Speed ______ mph Direction(pick one) NW N NE W E SW S SE

RIVER CONDITION:
☐Bankfull ______ ft. ☐Estimate less than bankfull ______ ft. ☐Nearest gage reading ______ ft.

Section B

☐**CHARACTER OF INTACT ICE COVER**
Location of downstream end of ice cover: Lat: ______ Long: ______
or River mi: ______ or Distance from observation location: ______ mi
Location of upstream end of ice cover: Lat: ______ Long: ______
or River mi: ______ or Distance from observation location: ______ mi
Surface roughness (check one):
☐Smooth ☐< 0.5 ft. ☐< 1.0 ft. ☐<1.5 ft. ☐> 1.5 ft.
Evidence of decay ☐Yes ☐No ☐Snow covered
If yes, check: ☐Melting snow ☐Melting ice ☐Candled ice
Cracks in ice cover: ☐Yes ☐No
If yes, check: ☐Parallel to shore, Distance from shore: ______ ft. ☐estimate ☐measured
☐Perpendicular to shore
Evidence of fracturing along banks: ◯Yes ◯No
If yes, check: ☐(a) Ice thickness when fracture occurred: ______ ft. ☐ estimate ☐measured
☐(b) Displacement: ______ ft. ☐estimate ☐ measured
☐(c) Distance from shore ______ ft. ☐estimate ☐ measured

River Name: ______ ***ICE REPORT**, continued* Page 2

☐**BREAKUP**
Cracks (check one): ☐Parallel to shore, Distance from shore ______ ft. ☐estimate ☐measured
☐Perpendicular to shore
Average distance between cracks ______ ft.
Water on top of ice: ☐Pooled ☐Flowing ☐None
Time ice started to move: ______ AM/PM ______ mm/dd/yy
Time water was clear of ice: ______ AM/PM ______ mm/dd/yy
Post movement: Height of shear walls along bank: ______ ft.

☐**ICE JAMS**
Cause (check one): ☐Freezeup ☐Aufeis ☐Anchor Ice ☐Breakup
☐Combination ☐Frozen-in-place ☐Released ☐Unknown
Condition at jam initiation point (check all that apply)
☐Solid ice sheet ☐Bend ☐Bridge ☐Island ☐Constriction
☐Reduction in water slope ☐other: ______
Jam length: ______ mi (approx.)
Location of toe of jam (downstream end): Lat: ______ Long: ______
or River mi: ______ or Distance from observation location: ______ mi
Location of head of jam (upstream end): Lat: ______ Long: ______
or River mi: ______ or Distance from observation location: ______ mi
Estimated time of jam formation: ______ AM/PM ______ dd/mm/yy
Estimated time of jam release: ______ AM/PM ______ dd/mm/yy
Height of shear walls along bank after jam release: ______ ft.
Can you estimate ice thickness: ______ in. How: ______
Can you identify a high water mark ______

Section C

☐**SKETCHES**: Include approximate scale, illustrate character of ice cover, ice coverage, water level, etc.

OTHER OBSERVATIONS/NOTES
Comments on any aspect of ice quantity, quality, freezeup, breakup or jamming, weather, etc.

Please email to: icejams@usace.army.mil or mail to Ice Jam Database Manager, CRREL, 72 Lyme Road, Hanover, NH 03755

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

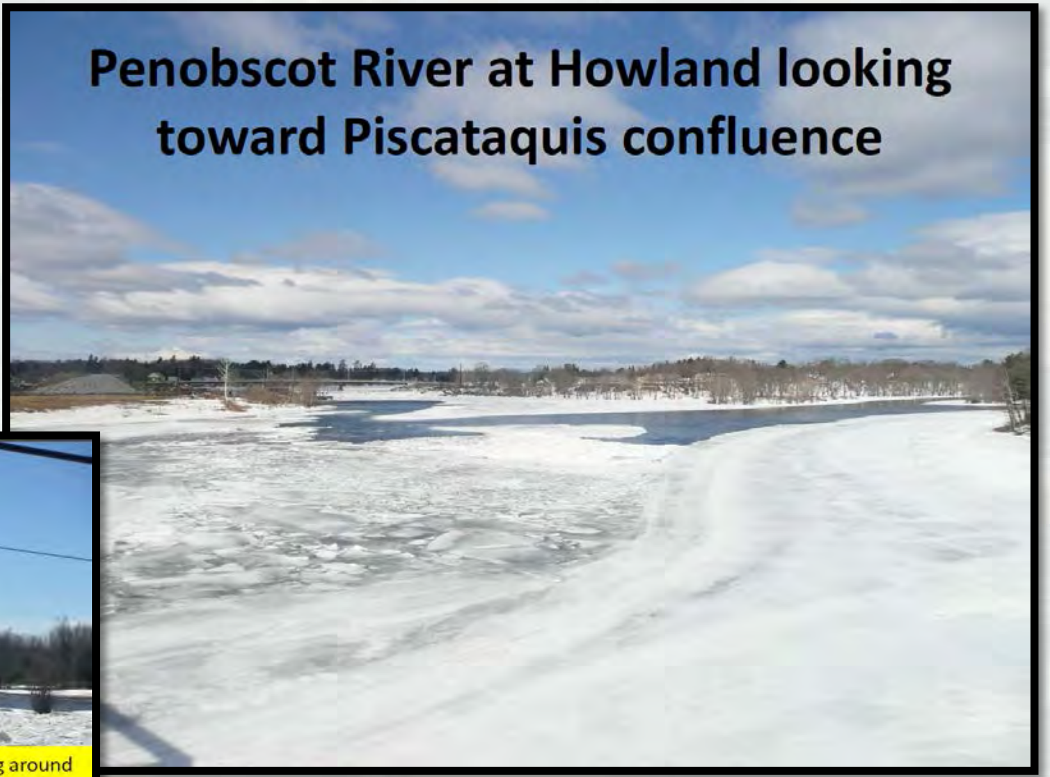
Ice Observations: General Information

- 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



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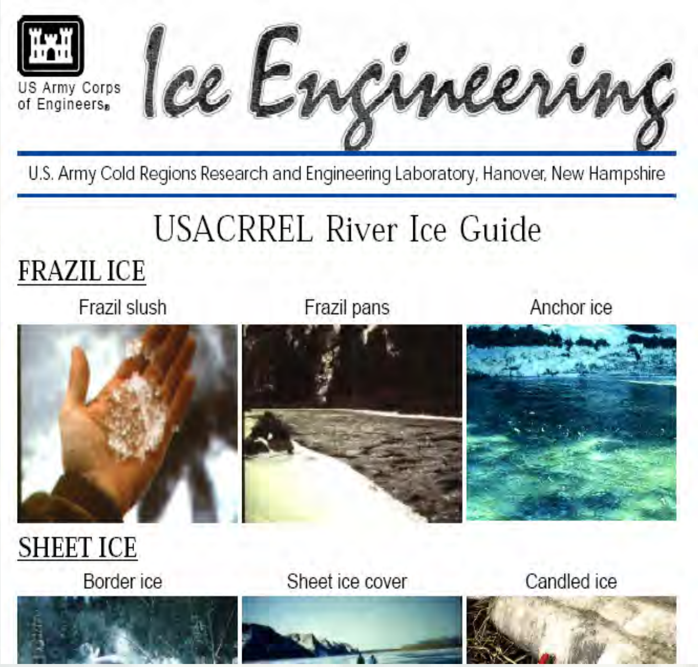
River Ice Observer Training

Ice Observations

CRREL River Ice Guide

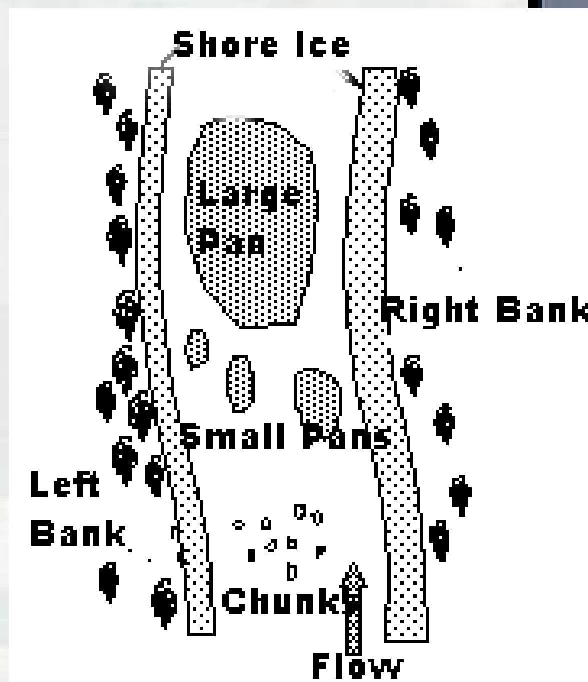


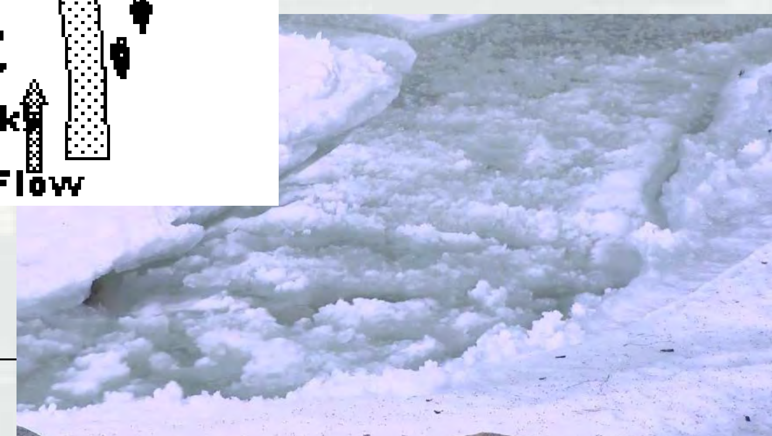
http://icejams.crrel.usace.army.mil/tectran/IEnews15.pdf

River Ice Observer Training

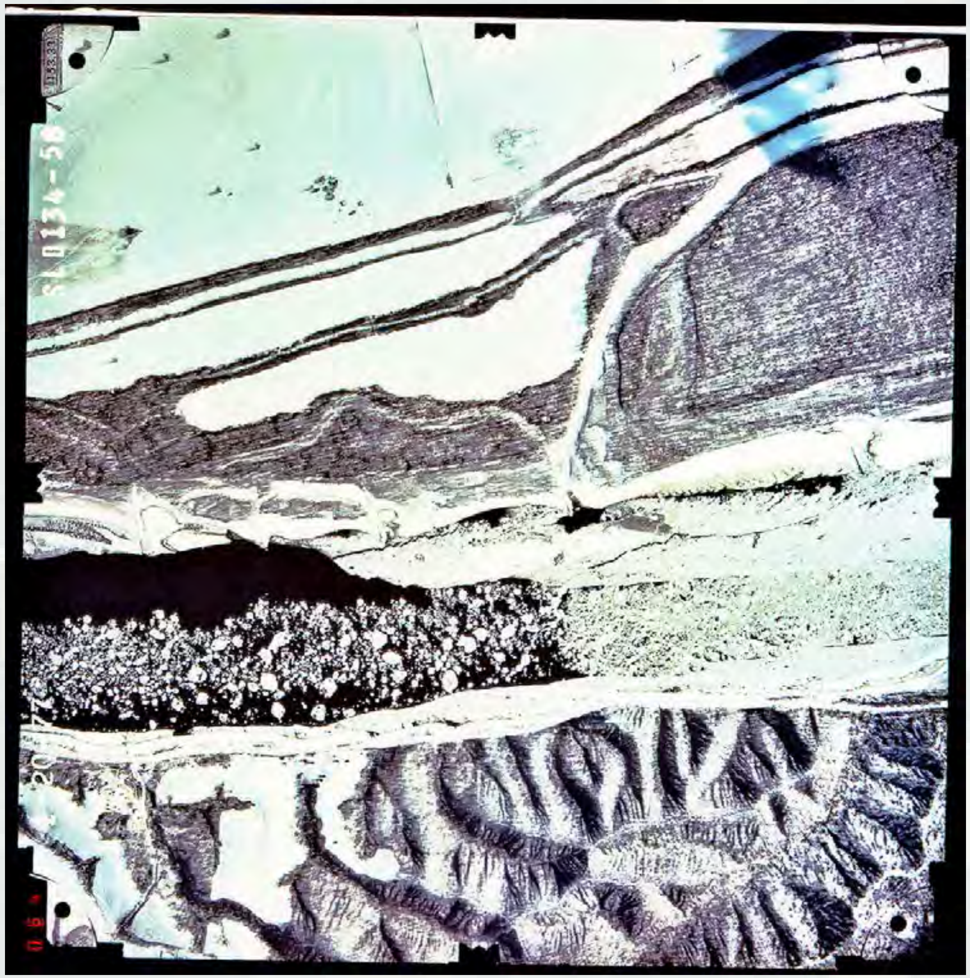
Ice Observations: Ice Formation

- 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)

River Ice Observer Training

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

River Ice Observer Training

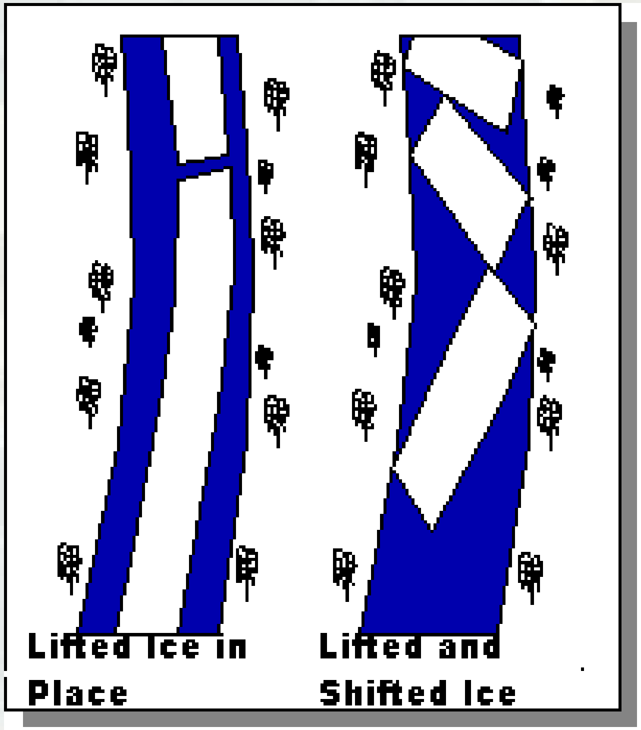
Ice Observations: Ice Cover

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

River Ice Observer Training

Ice Observations: Break up

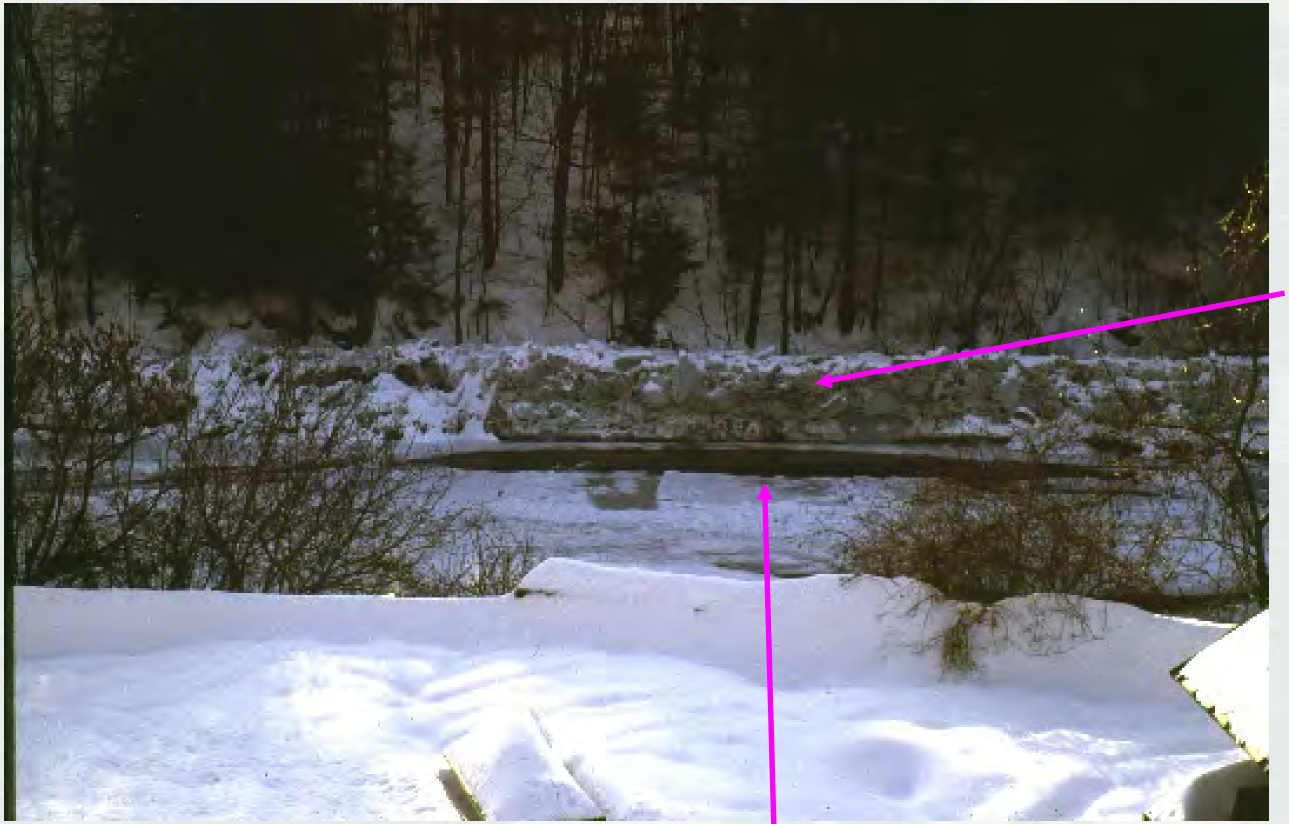
- Lifted Ice In Place
- Lifted and Shifted Ice



River Ice Observer Training

Ice Observations: Break up

Ice is beginning to shove and move. What time is it?
Where is it at?



How high are the shear walls?

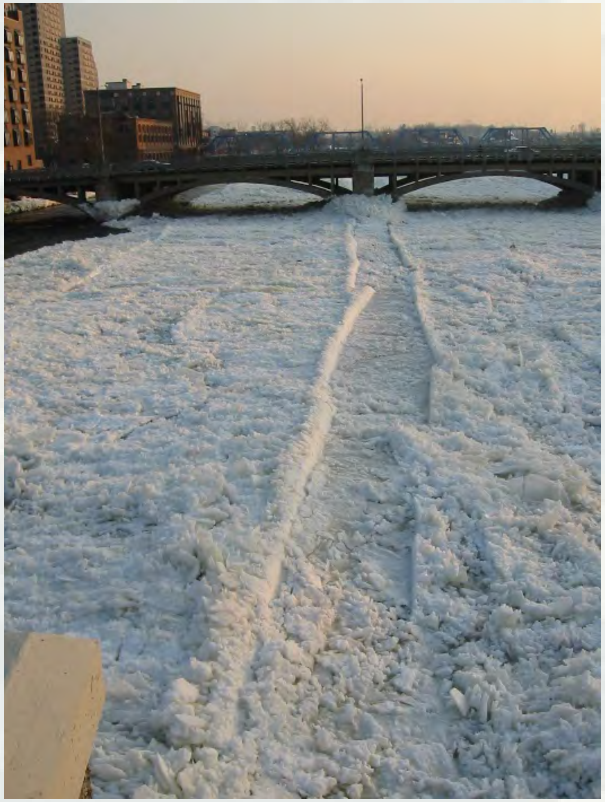
What time did the channel clear of ice?

River Ice Observer Training

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?



River Ice Observer Training

Ice Observations: Ice Jams

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

River Ice Observer Training

Ice Observations: Ice Jams

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

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

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?