Ice Jam Mitigation

Kathleen D. White, PhD, PE
Research Hydraulic Engineer
Associate Technical Director
USA Army Corps of Engineers Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
Hanover, NH 03755-1290
Kathleen.D.White@erdc.usace.army.mil

3 December 2005

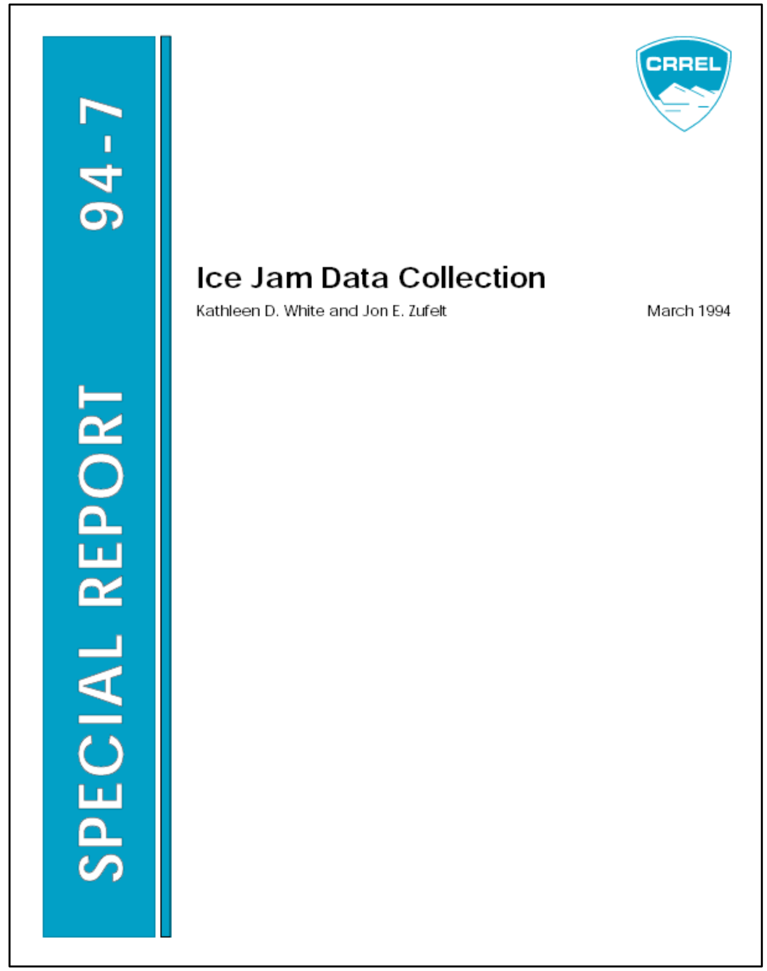
Ice Jam Disaster Preparedness

- Monitoring
  - Observations to identify problem areas early
- Early warning
  - Alert system: Evacuation
- Mitigation:
  - In many states, mitigation plan must be in place prior to taking actions that will dislodge ice jam
  - Ice weakening/thinning/removal
  - Equipment placement
  - Supplies:
    - Source of unfrozen sand
    - Sandbags
    - Jersey barriers
    - Polyethylene sheeting

- Permanent Measures
  - Freezeup Jam Control
    - Control production and transport of frazil ice
    - Displace jam initiation location
  - Breakup Jam Control
    - Control timing of ice breakup
    - Displace jam location

Monitoring

- Visual
- NWS/USGS sources via web
- What are the present ice conditions?
- How does the ice cover form?
  - Thermally grown?
    - Estimate ice thickness from AFDD
  - Is there likely to be deposition?
    - If so, where?
    - Increase coefficient used to estimate thickness
- What ice conditions might affect future mitigation measures?
- What is the forecast?


SPECIAL REPORT 94-7

CRREL

Ice Jam Data Collection

Kathleen D. White and Jon E. Zufelt

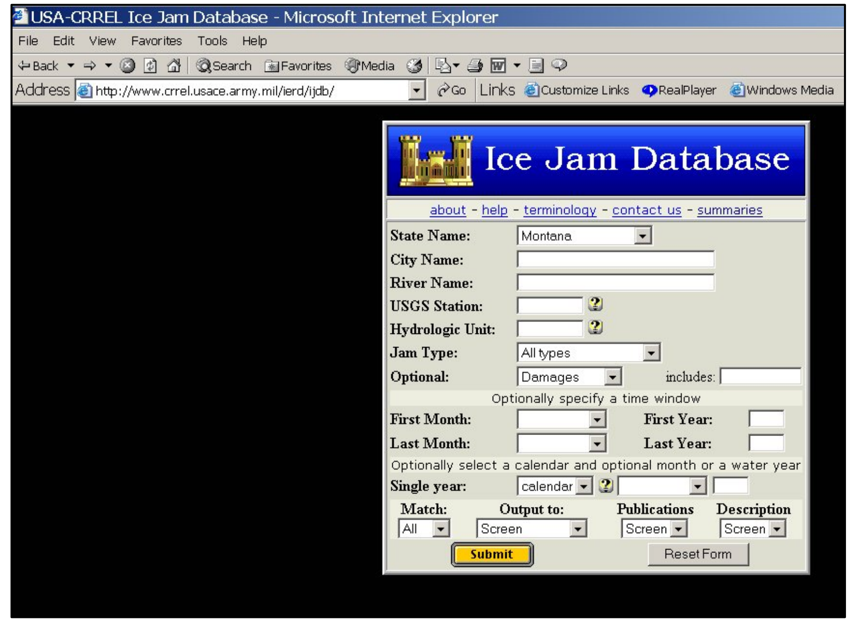
March 1994

http://www.crrel.usace.army.mil/techpub/CRREL_Reports/html_files/Cat_D.html

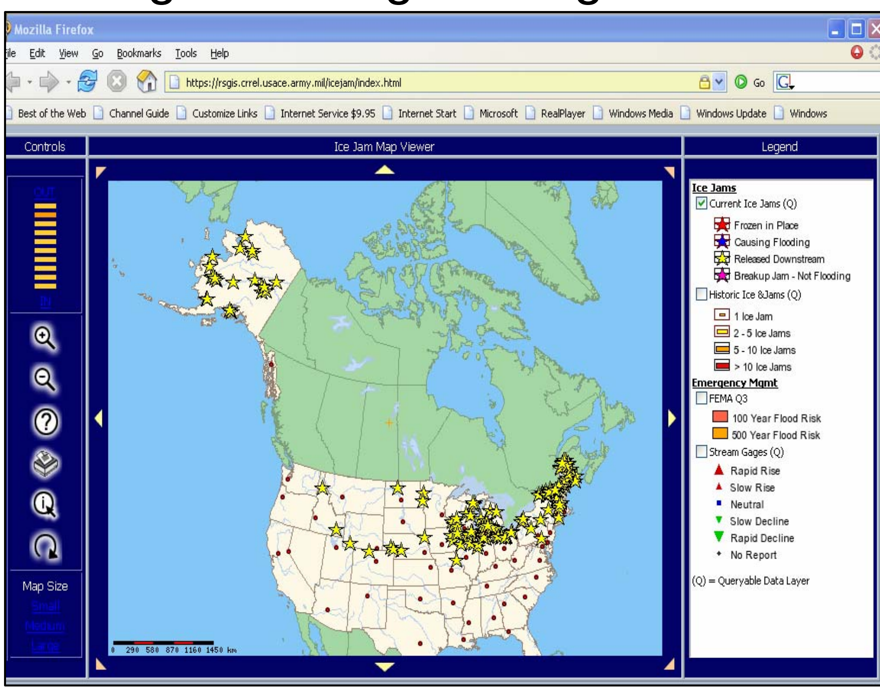
CRREL Ice Jam Database

Major source of data: CRREL Ice Jam Database

- Database begun 1990
- Now >14,700 events
- 1785-2005
- Ice information available from text-based database or rapid mapping tool
- Emergency management, design and engineering studies

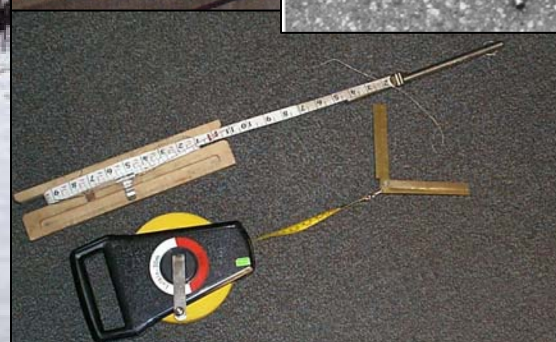


http://www.crrel.usace.army.mil/ierd/ijdb/

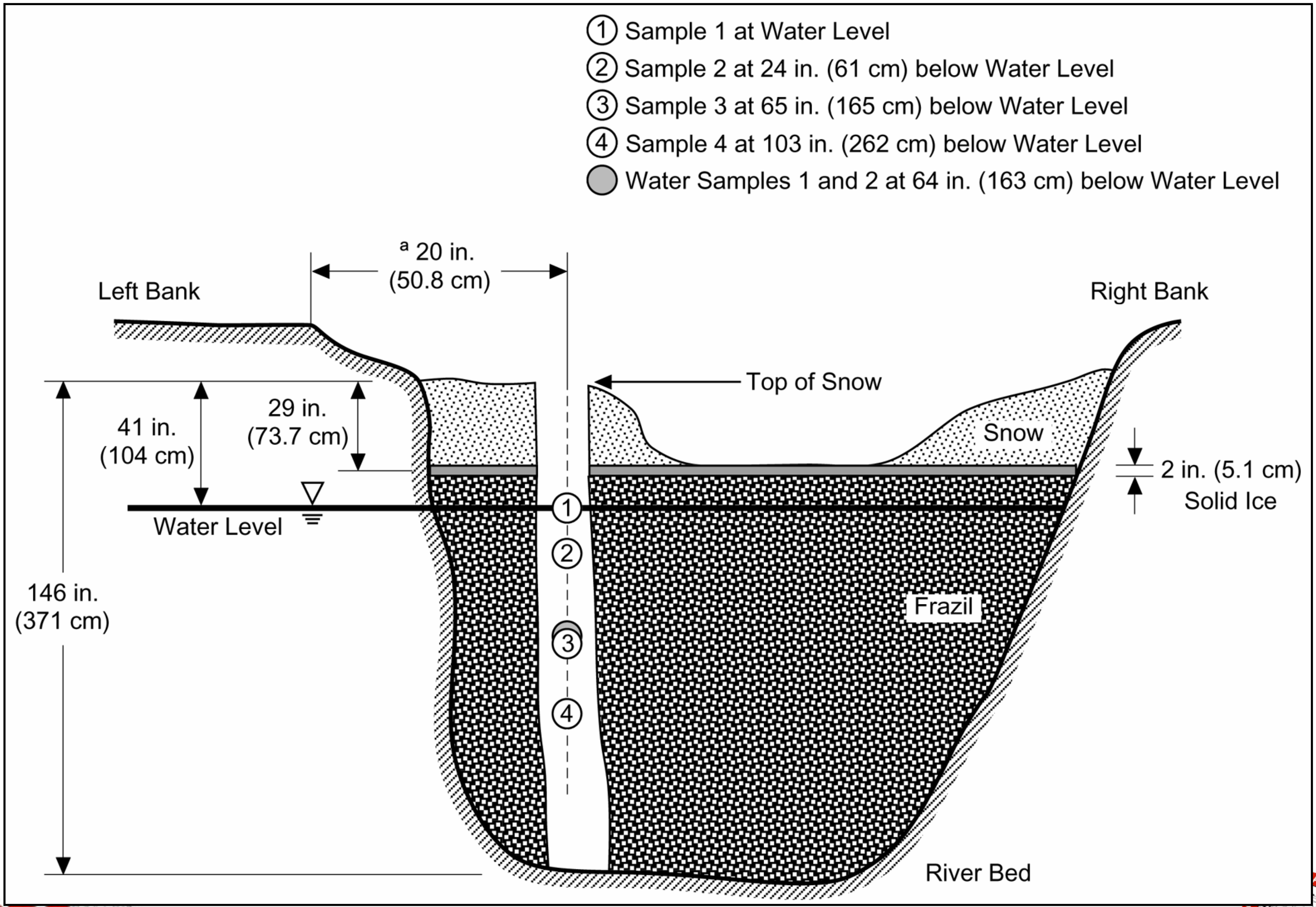


Select “Current ice jams” from
http://www.crrel.usace.army.mil/icejams/index.htm

Ice Thickness Measurement – only for the pros!



Ice Thickness Measurement – only for the pros!



Early Warning

- Provides critical information
- Two weeks to six months lead time
- Inexpensive and invaluable
  - Trained observers
    - Part of emergency response team
    - Track pre-event ice conditions and during event
    - Helpful for after-action assessment
  - Ice motion detectors
    - Trip wires in ice
      - Alarms inform emergency managers
      - Select locations to give days/hours warning
      - Can be remote
  - Automated stage alarms
    - Useful for open-water events also
    - Remote packages available
  - Web cameras

US Army Corps of Engineers

Ice Engineering

U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

Remote Ice Motion Detection

The potential exists for property damage (Fig. 1), serious injury, and fatalities during ice-related flooding, evacuations, and other ice mitigation operations. A review of the CRREL Ice Jam Database indicates that most ice-jam-related deaths have occurred during evacuations. Because of their unpredictability and danger, communities that experience damaging ice jams should develop warning systems so that emergency operations can begin as soon as possible.

Presented here is a method for detecting ice motion at remote locations that do not have power or telephone service. An ice monitoring program on the Kennebec River at Augusta, Maine, is presented as a case study.

Background

Winter in northern rivers is characterized by ice cover formation, growth, and breakup. Ice covers form because of thermal or mechanical processes, or a combination thereof. Thermal processes dominate in slower-moving reaches of rivers, where ice crystals form as water temperature loses heat to the atmosphere. Heat transfer processes can also result in the formation of frazil ice in turbulent, supercooled, open-water reaches. Mechanical processes resulting from the interaction of ice floes dominate in higher velocity areas. These processes include juxtaposition of floes to form a single layer ice accumulation, and, where velocities are higher, collapse and shoving of floes to form multiple-layer ice accumulations.

Once an ice cover forms, it can thicken because of thermal processes or by deposition of frazil or ice pieces beneath the ice cover. Frazil deposits under ice (sometimes called hanging dams) can become thick enough to decrease flow area and increase flow velocity beneath the ice. Frazil often deposits at the upstream end of an impoundment, creating a natural impediment to the downstream movement of broken ice or ice runs later in the season.

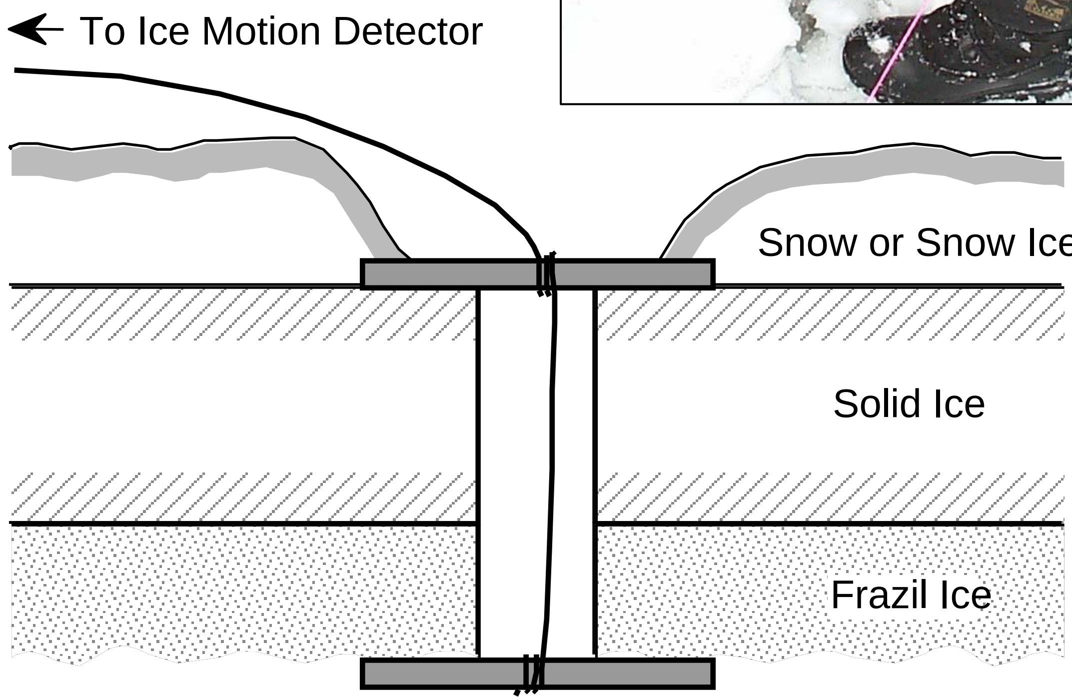
Thermal and mechanical processes also cause ice cover breakup. Thermal breakups that occur when the cover melts and thins as a result of warming air and water temperatures are largely benign. They can, however, result in the movement of ice pieces that later jam. Mechanical breakup occurs when the downstream-acting forces on the ice cover become larger than the resisting forces, causing the ice to fail. This usually results from increases in flow caused by sudden rapid snowmelt, often combined with rainfall. The resulting stage rise lifts the ice cover, cracking it along the shorelines (or the centerline for a narrow channel) and breaking it from the banks.

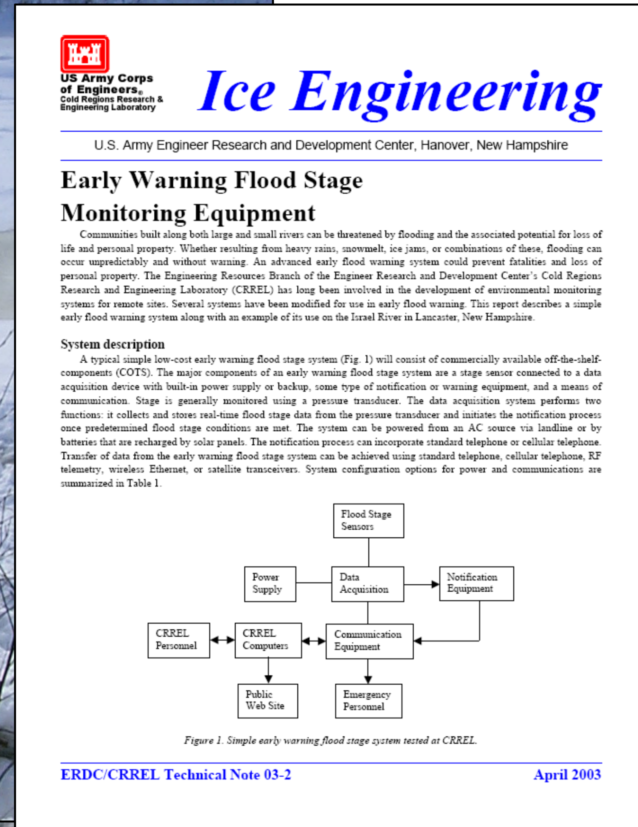
Once the ice cover has lifted and begins moving, it rapidly breaks into smaller pieces that move downstream until the river's ice transport capacity is exceeded. This may occur because the moving ice rubble has reached an intact ice cover or other obstacles that resist movement, such as islands, sand bars, bends, or channel constrictions. Ice runs commonly stop in reaches where the water slope changes from

Figure 1. This breakup ice jam, which occurred in March 1992 on the Winooski River in Montpelier, Vermont, resulted in damages of about $20M. Following this jam, a monitoring system that includes ice motion detectors was utilized for early warning.

Number 25 September 2000

http://www.crrel.usace.army.mil/ierd/tectran/IERD25.pdf


To Ice Motion Detector
Snow or Snow Ice
Solid Ice
Frazil Ice



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Ice Engineering

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

Early Warning Flood Stage Monitoring Equipment

Communities built along both large and small rivers can be threatened by flooding and the associated potential for loss of life and personal property. Whether resulting from heavy rains, snowmelt, ice jams, or combinations of these, flooding can occur unpredictably and without warning. An advanced early flood warning system could prevent fatalities and loss of personal property. The Engineering Resources Branch of the Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (CRREL) has long been involved in the development of environmental monitoring systems for remote sites. Several systems have been modified for use in early flood warning. This report describes a simple early flood warning system along with an example of its use on the Israel River in Lancaster, New Hampshire.

System description

A typical simple low-cost early warning flood stage system (Fig. 1) will consist of commercially available off-the-shelf-components (COTS). The major components of an early warning flood stage system are a stage sensor connected to a data acquisition device with built-in power supply or backup, some type of notification or warning equipment, and a means of communication. Stage is generally monitored using a pressure transducer. The data acquisition system performs two functions: it collects and stores real-time flood stage data from the pressure transducer and initiates the notification process once predetermined flood stage conditions are met. The system can be powered from an AC source via landline or by batteries that are recharged by solar panels. The notification process can incorporate standard telephone or cellular telephone. Transfer of data from the early warning flood stage system can be achieved using standard telephone, cellular telephone, RF telemetry, wireless Ethernet, or satellite transceivers. System configuration options for power and communications are summarized in Table 1.

Figure 1. Simple early warning flood stage system tested at CRREL.

ERDC/CRREL Technical Note 03-2 April 2003

Stage Detectors/Alert Systems

ERDC Engineer Research and Development Center

http://www.crrel.usace.army.mil/ierd/tectran/ieieb.htm

Israel River at Lancaster NH - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address https://webcam.crrel.usace.army.mil/lancaster/

USACE Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory

Web Camera Images at ERDC/CRREL Real-time Data from the Israel River, Lancaster NH

Latest Information and Recent images from active cameras

The water temperature and stage in the Israel River at Lancaster NH are being monitored as part of a test of an early warning flood system for use in ice-affected rivers. The plots shown below are from the site and should automatically update every 2 hours. We are also testing a new web camera system and transmission modes. The camera images below are hourly images. For further information, please contact Dr. Kate White at Kathleen.D.White@erdc.usace.army.mil

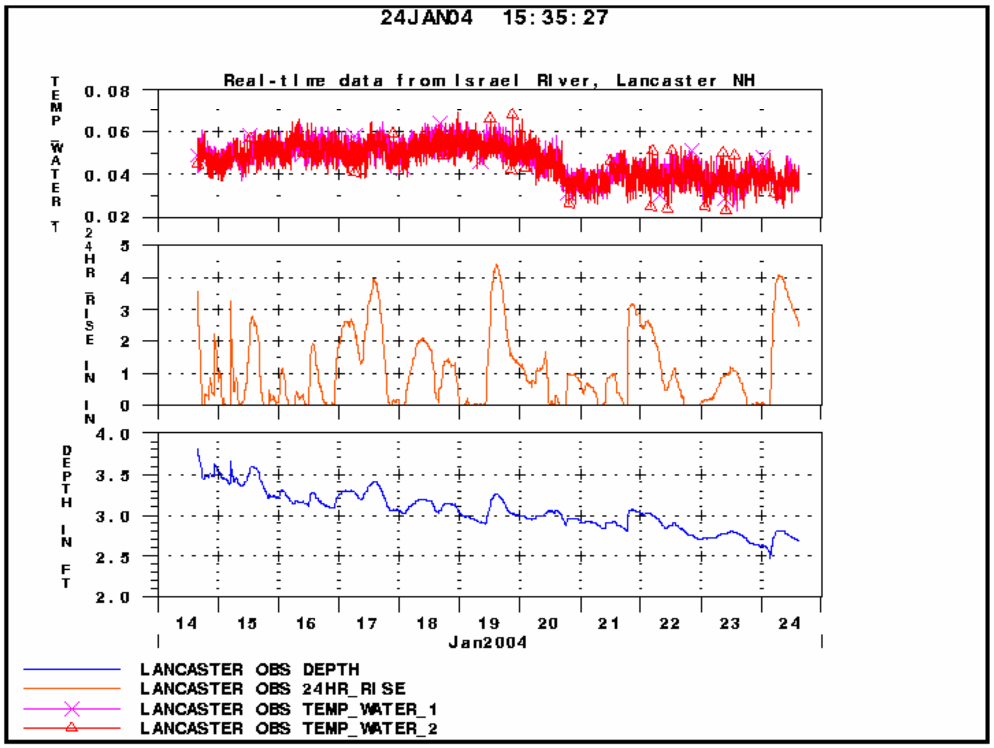

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Image from Camera 1 Table of images from above camera or Animation of images

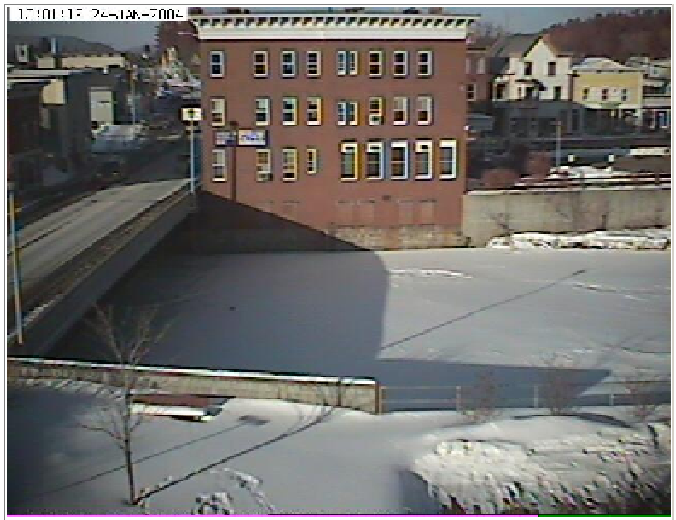
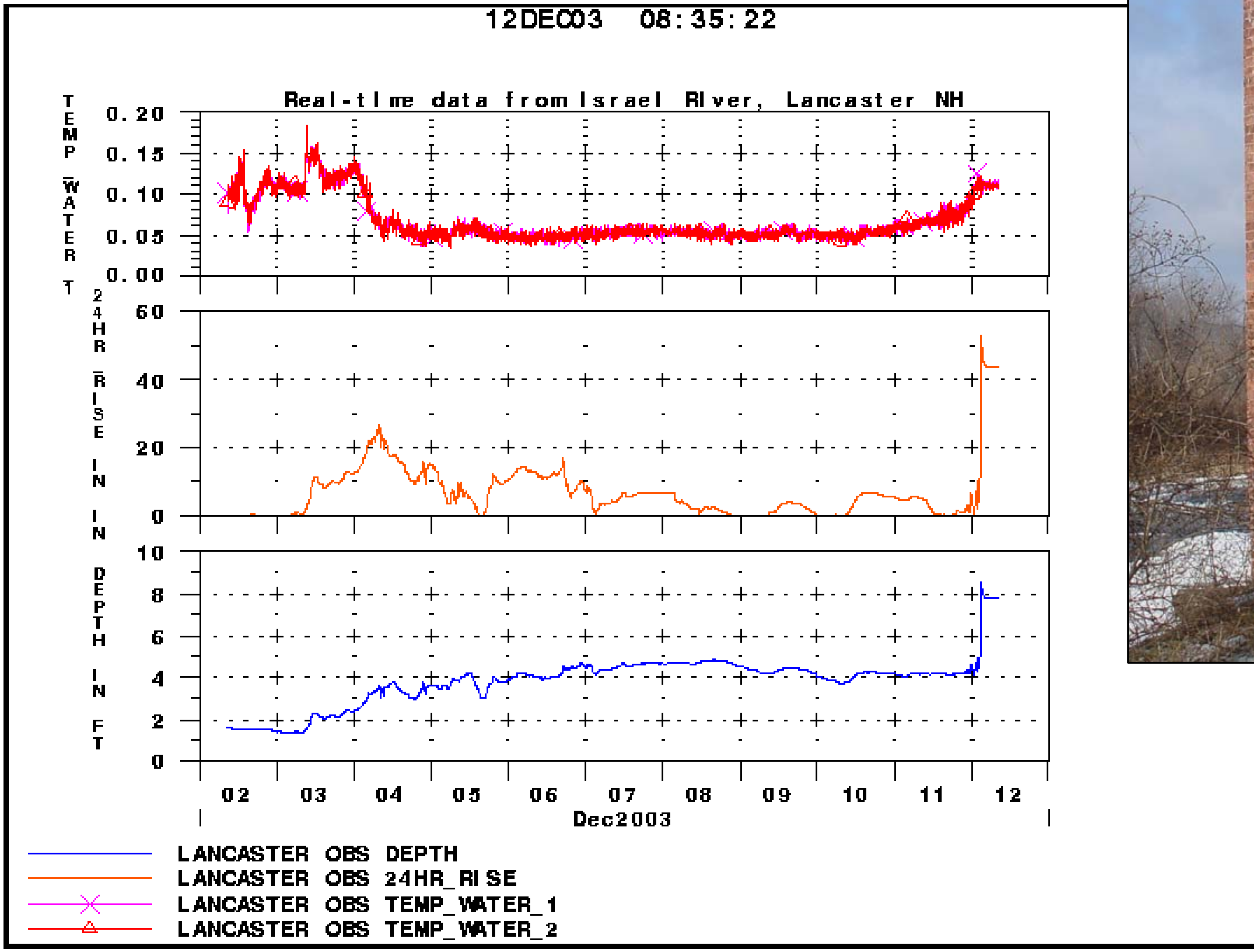


Image from Camera 2 Table of images from above camera or Animation of images

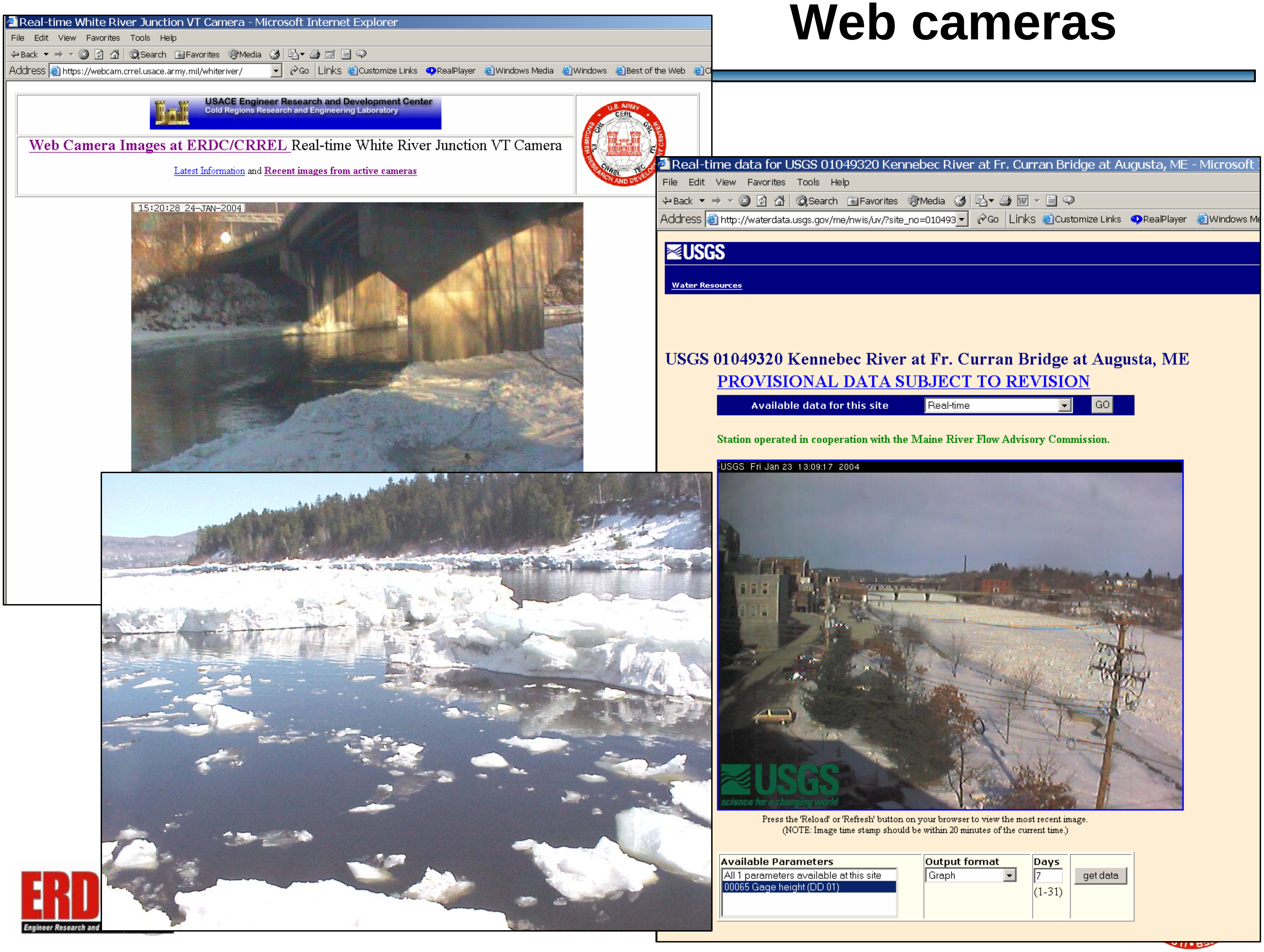
Image from Camera 3 Table of images from above camera or Animation of images

For more information, contact webcam@crrel.usace.army.mil or 603-646-4186

Page last updated on Sat Jan 24 15:36:21 EST 2004


12DEC03 08:35:22
Real-time data from Israel River, Lancaster NH
TEMP_WATER T
0.20
0.15
0.10
0.05
0.00
24HR_RISE IN IN
60
40
20
0
DEPTH IN FT
10
8
6
4
2
0
02
03
04
05
06
07
08
09
10
11
12
Dec2003
LANCASTER OBS DEPTH
LANCASTER OBS 24HR_RISE
LANCASTER OBS TEMP_WATER_1
LANCASTER OBS TEMP_WATER_2

Web cameras

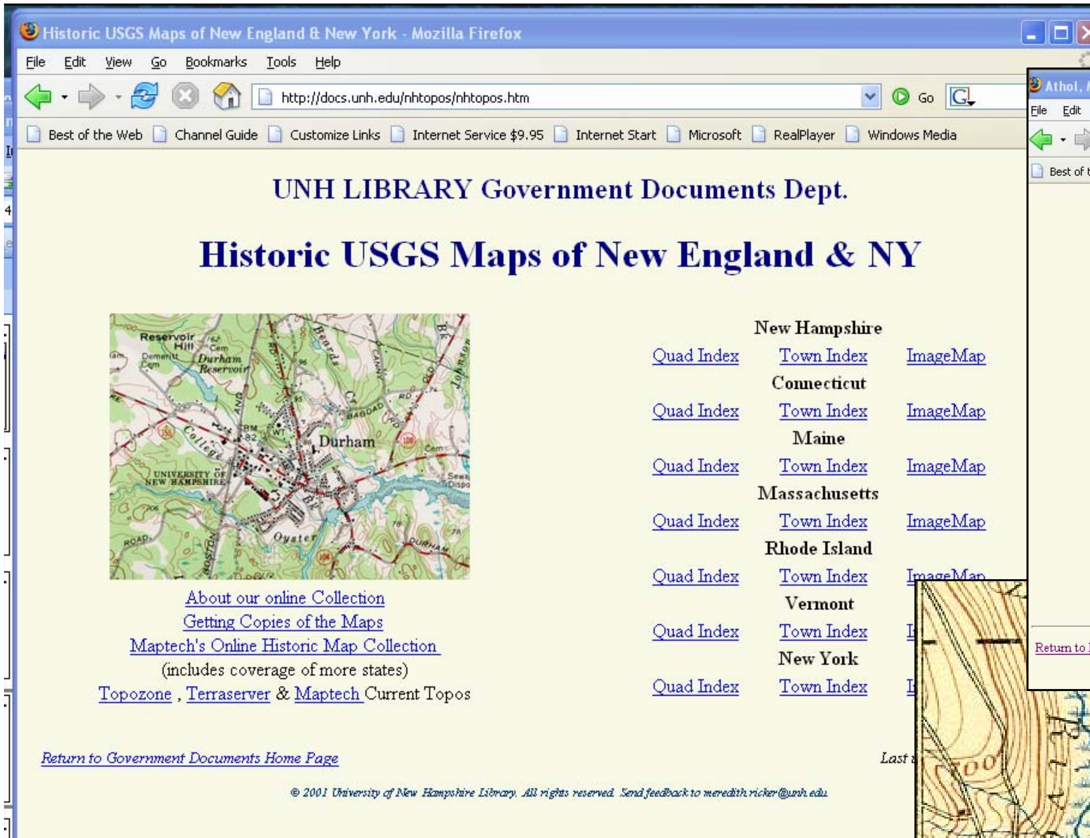

Real-time White River Junction VT Camera - Microsoft Internet Explorer
File Edit View Favorites Tools Help
https://webcam.crrel.usace.army.mil/whiteriver/
USACE Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
Web Camera Images at ERDC/CRREL Real-time White River Junction VT Camera
Latest Information and Recent images from active cameras
15:20:28 24-JAN-2004
Real-time data for USGS 01049320 Kennebec River at Fr. Curran Bridge at Augusta, ME - Microsoft
http://waterdata.usgs.gov/me/nwis/uv/?site_no=010493
USGS
Water Resources
USGS 01049320 Kennebec River at Fr. Curran Bridge at Augusta, ME
PROVISIONAL DATA SUBJECT TO REVISION
Available data for this site
Real-time
GO
Station operated in cooperation with the Maine River Flow Advisory Commission.
USGS Fri Jan 23 13:09:17 2004
USGS
science for a changing world
Press the 'Reload' or 'Refresh' button on your browser to view the most recent image.
(NOTE: Image time stamp should be within 20 minutes of the current time.)
Available Parameters
All 1 parameters available at this site
00065 Gage height (DD 01)
Output format
Graph
Days
7
(1-31)
get data
ERD
Engineer Research and

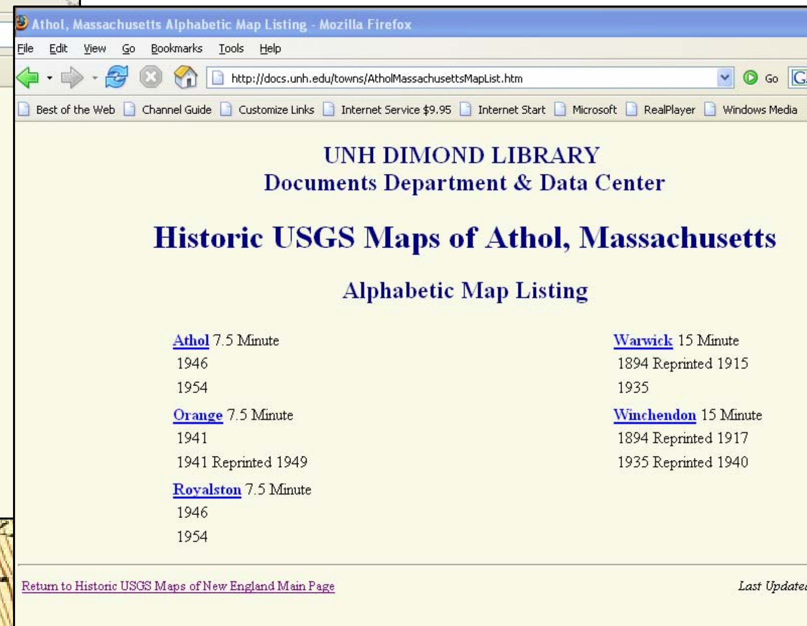
Aerial photography

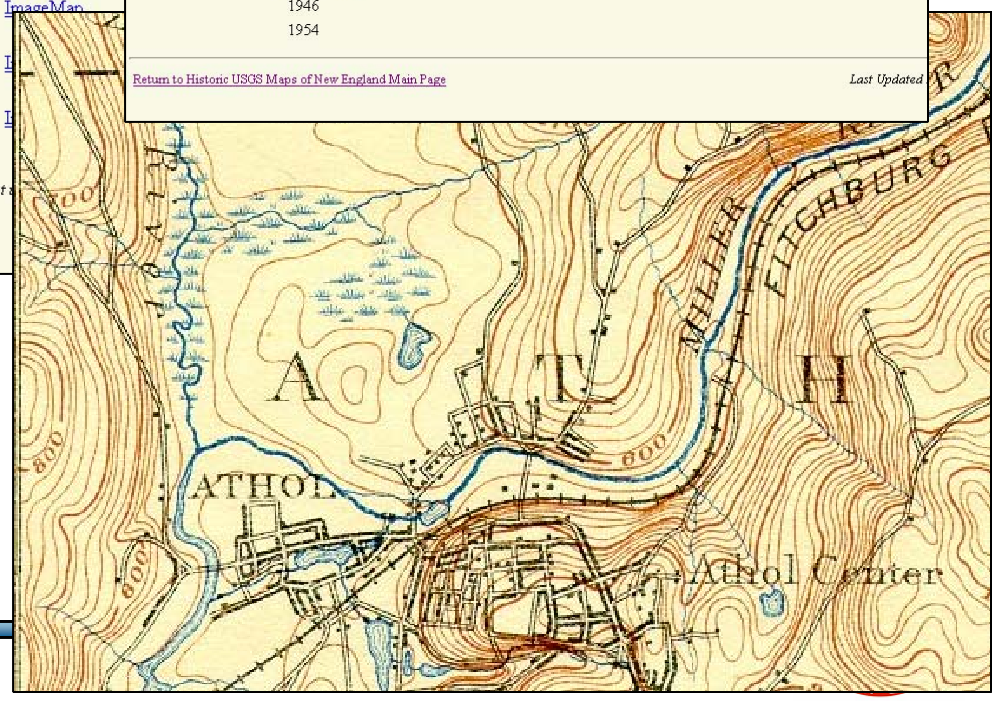
Freezeup ice jam, flow from top to bottom

Topographic Maps

Historical Topographic Maps

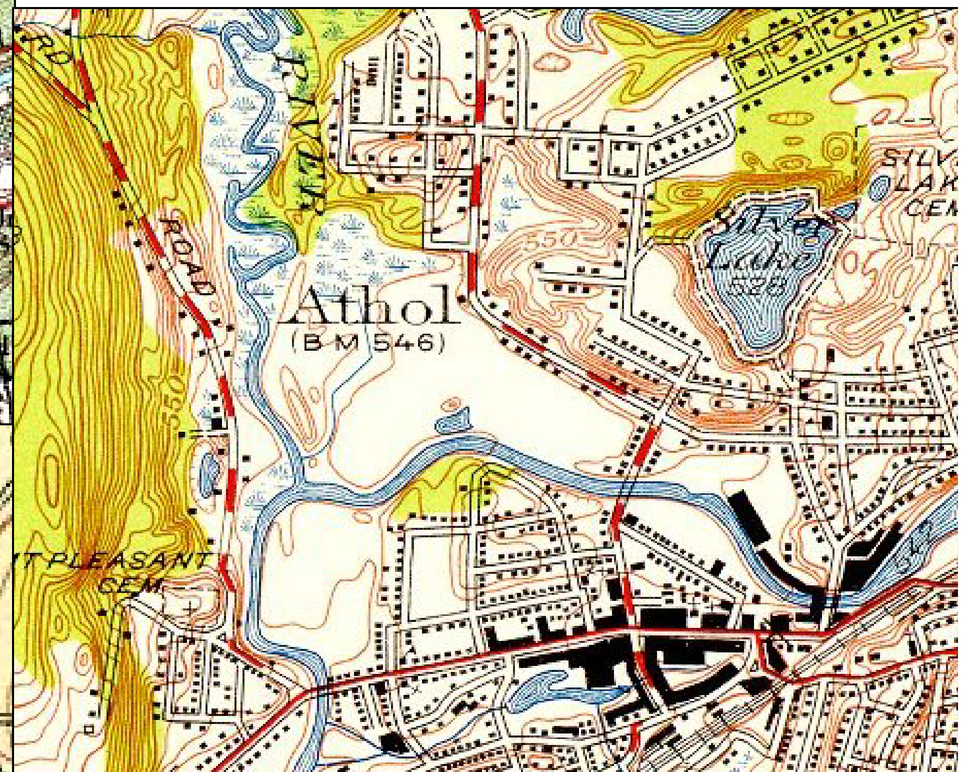


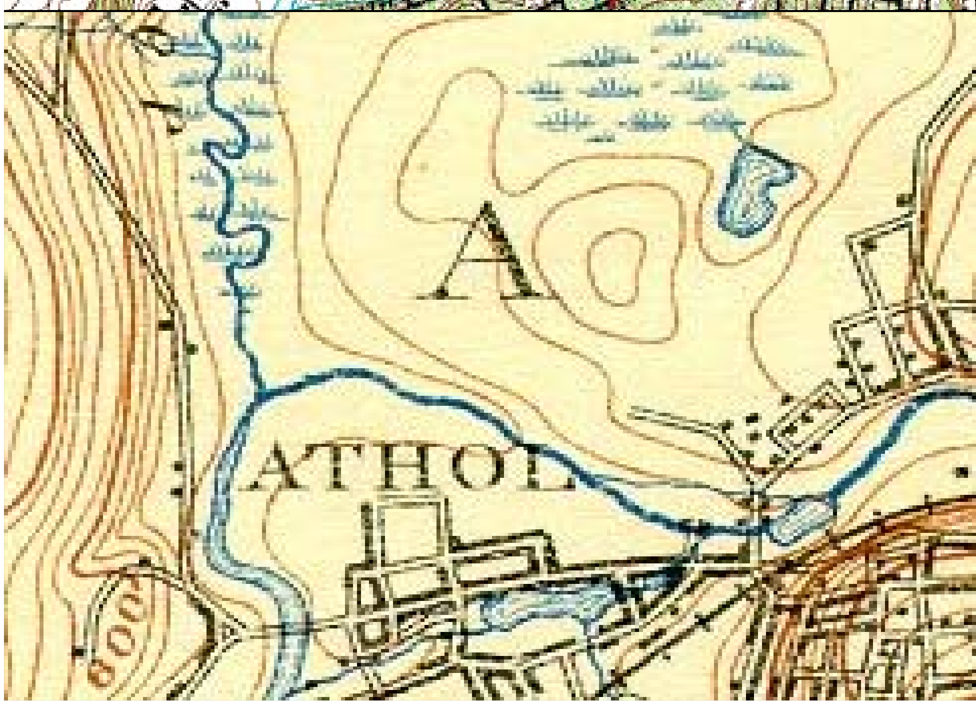




Winchendon NW 1894
(surveyed 1887)

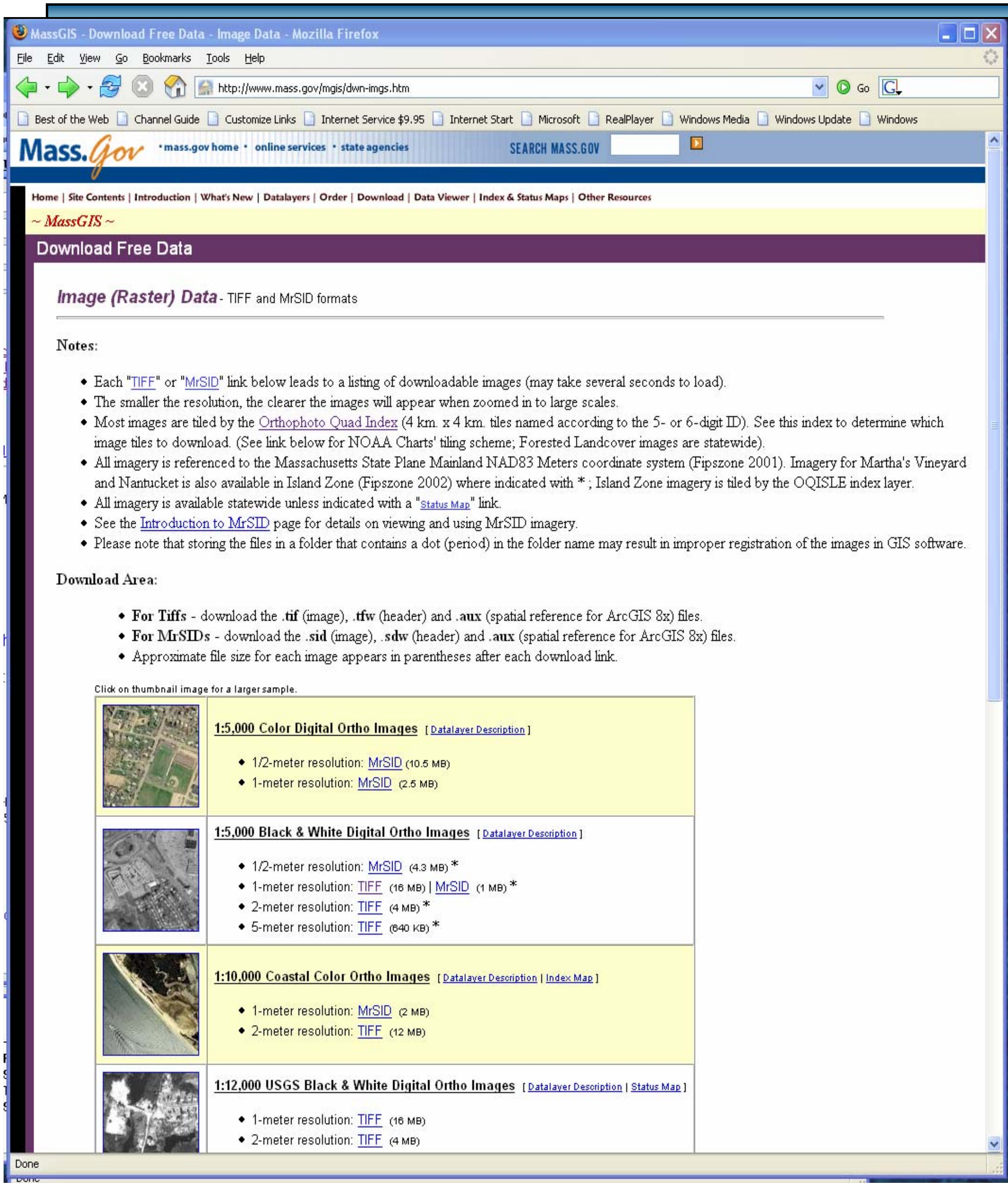
1954, surveyed 1944





1894, surveyed 1887

Digital Orthophotos



http://www.mass.gov/mgis/dwn-imgs.htm

Digital Orthophotos

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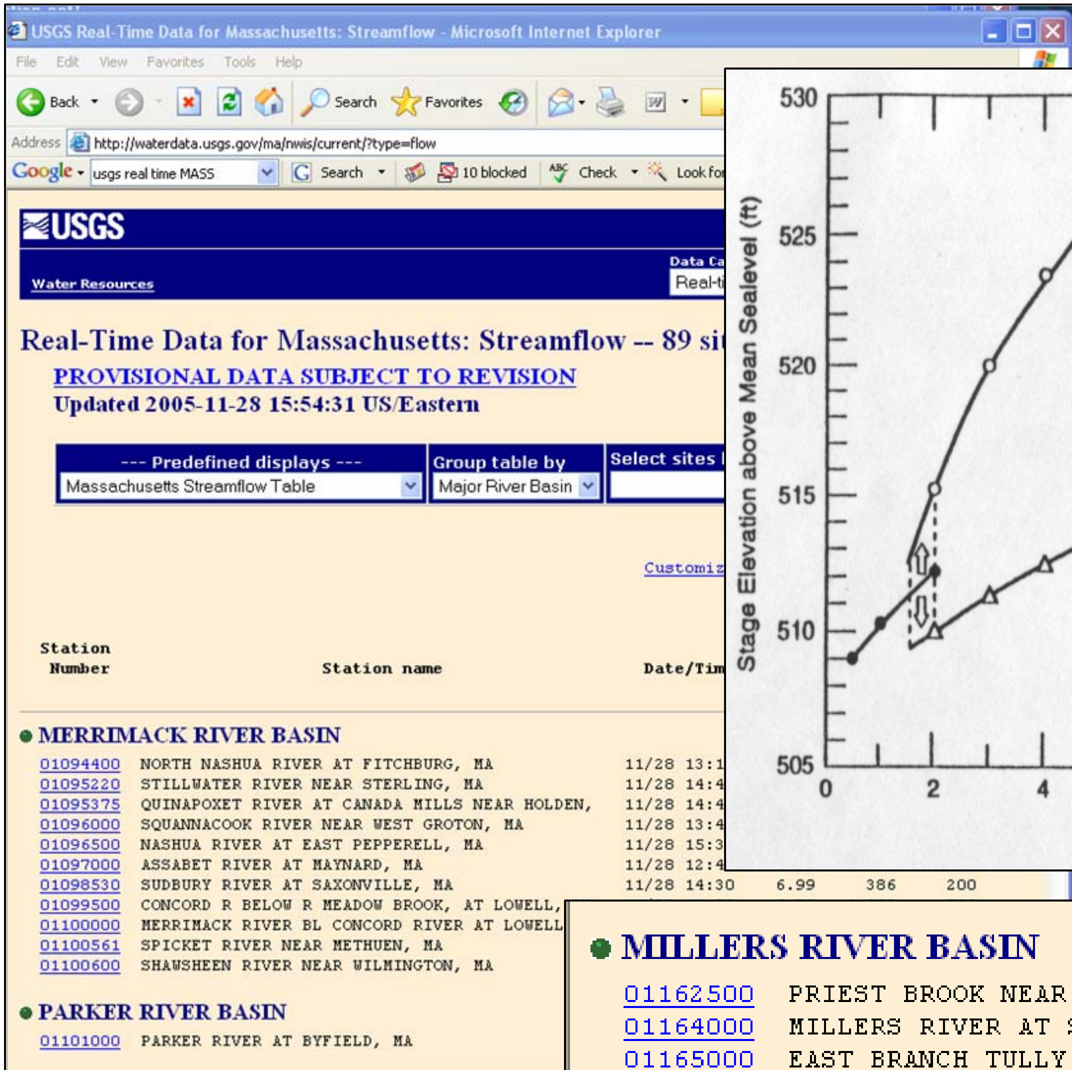
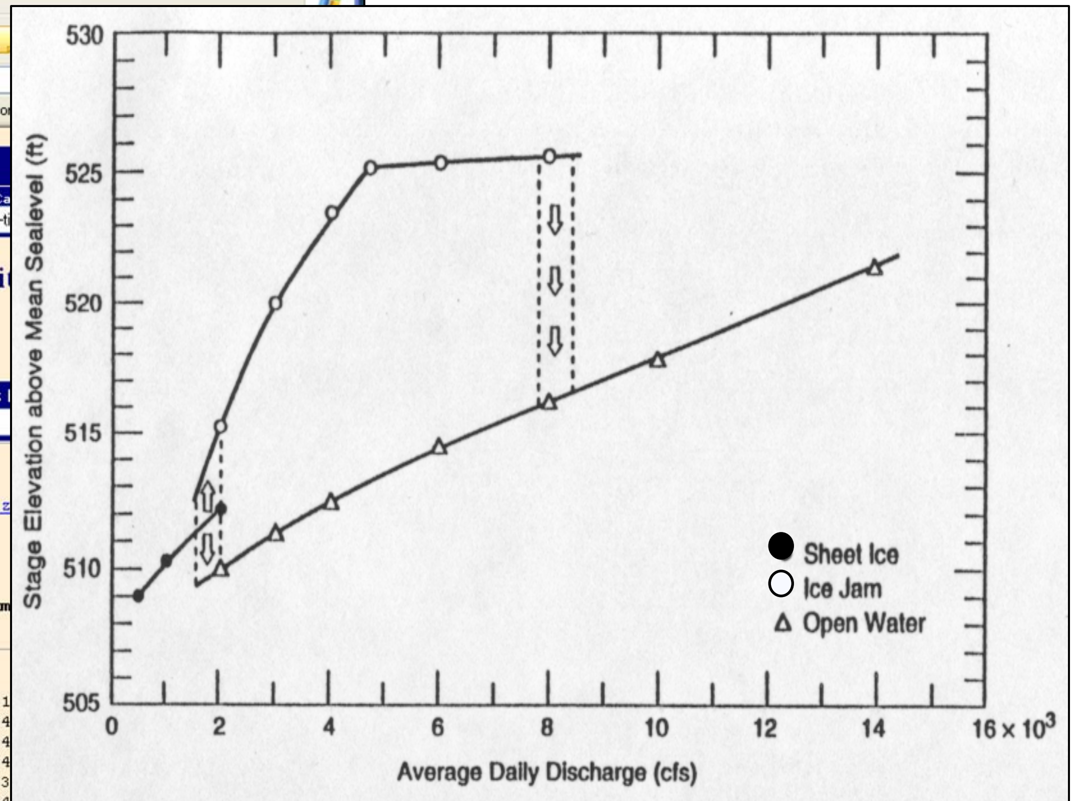
Assessing Real-Time USGS Gage Data for Ice-Affected Stages

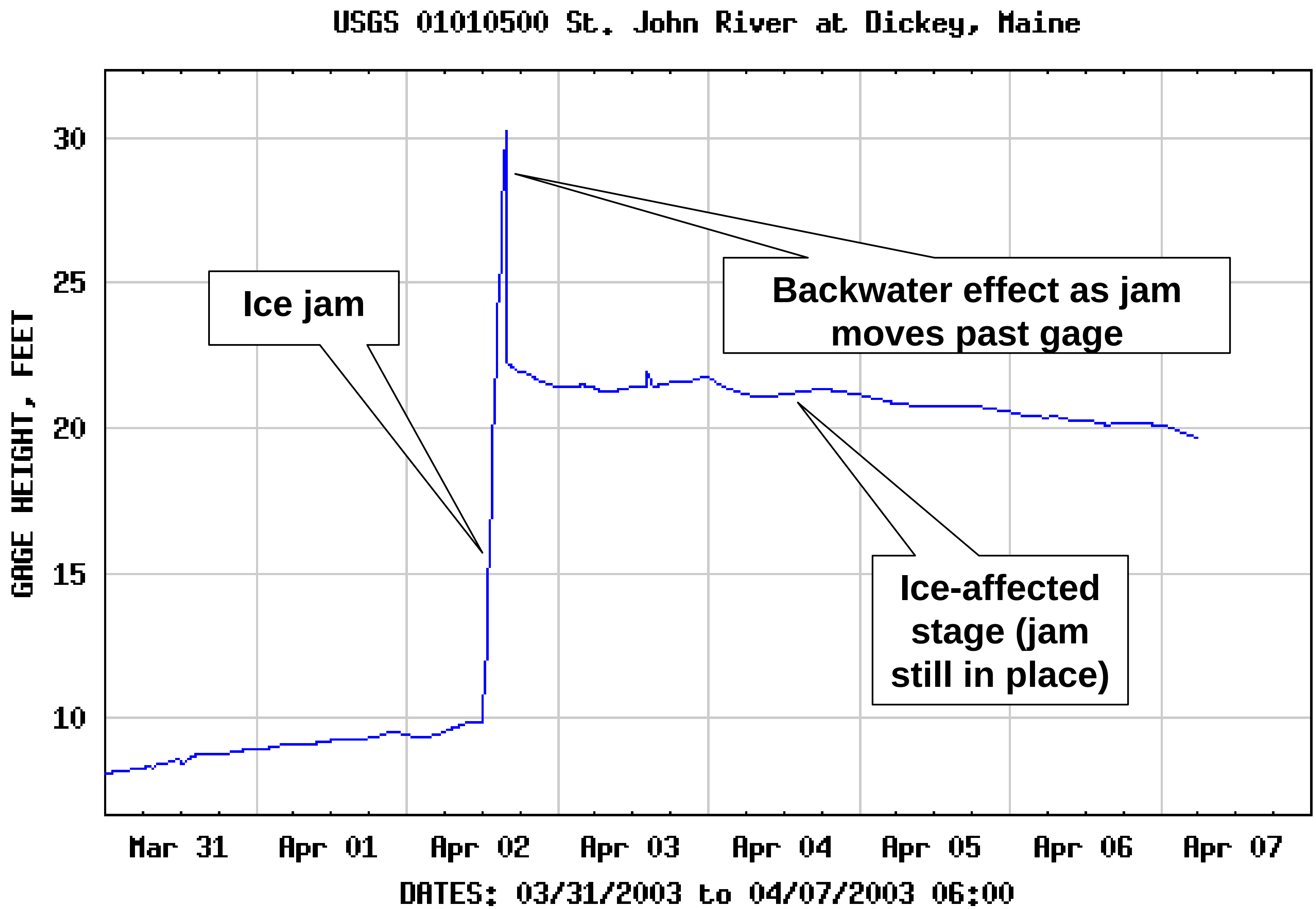




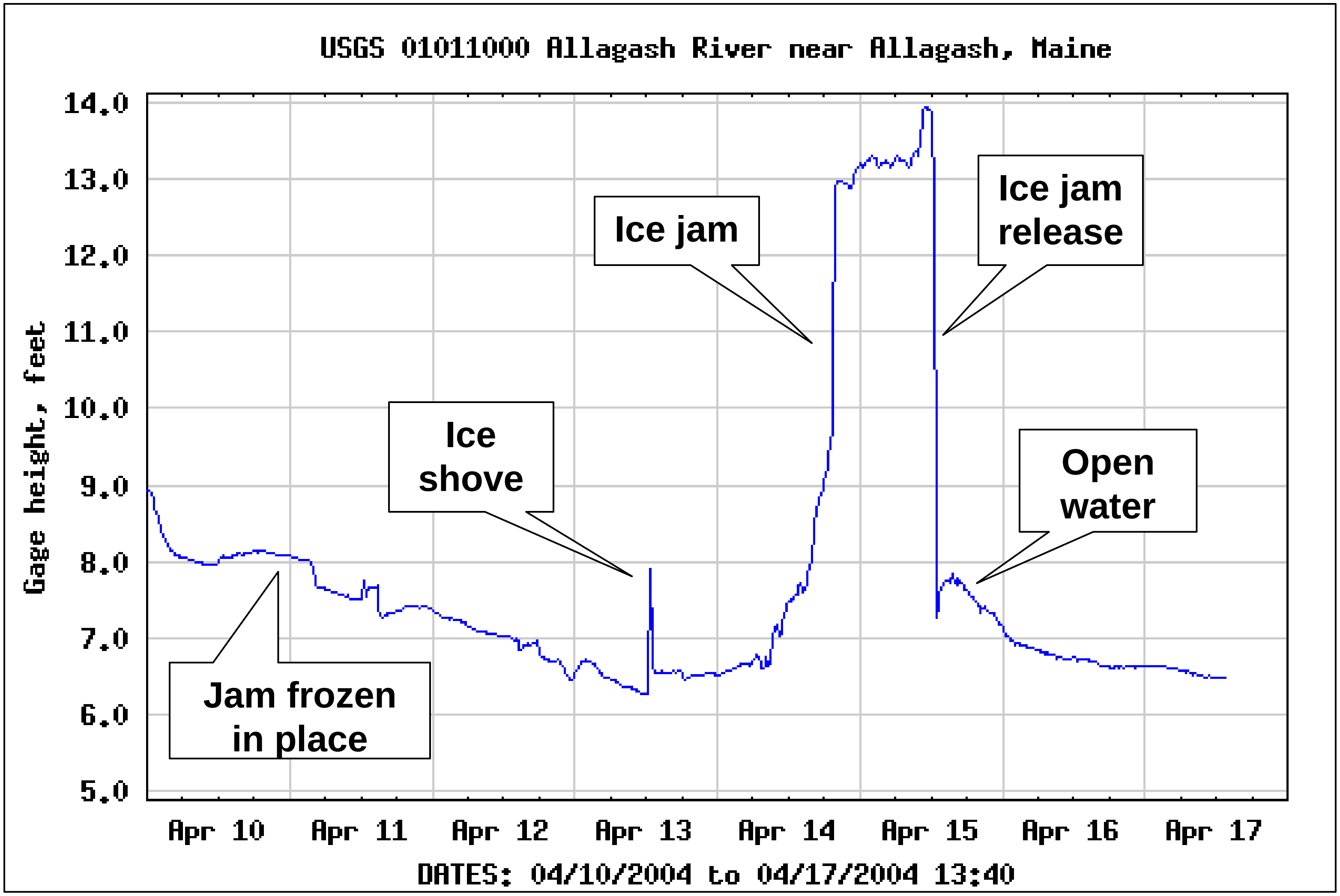
MILLERS RIVER BASIN

01162500	PRIEST BROOK NEAR WINCHENDON, MA
01164000	MILLERS RIVER AT SOUTH ROYALSTON, MA
01165000	EAST BRANCH TULLY RIVER NEAR ATHOL, MA
01166500	MILLERS RIVER AT ERVING, MA

Typical Hydrographs of Ice Jams

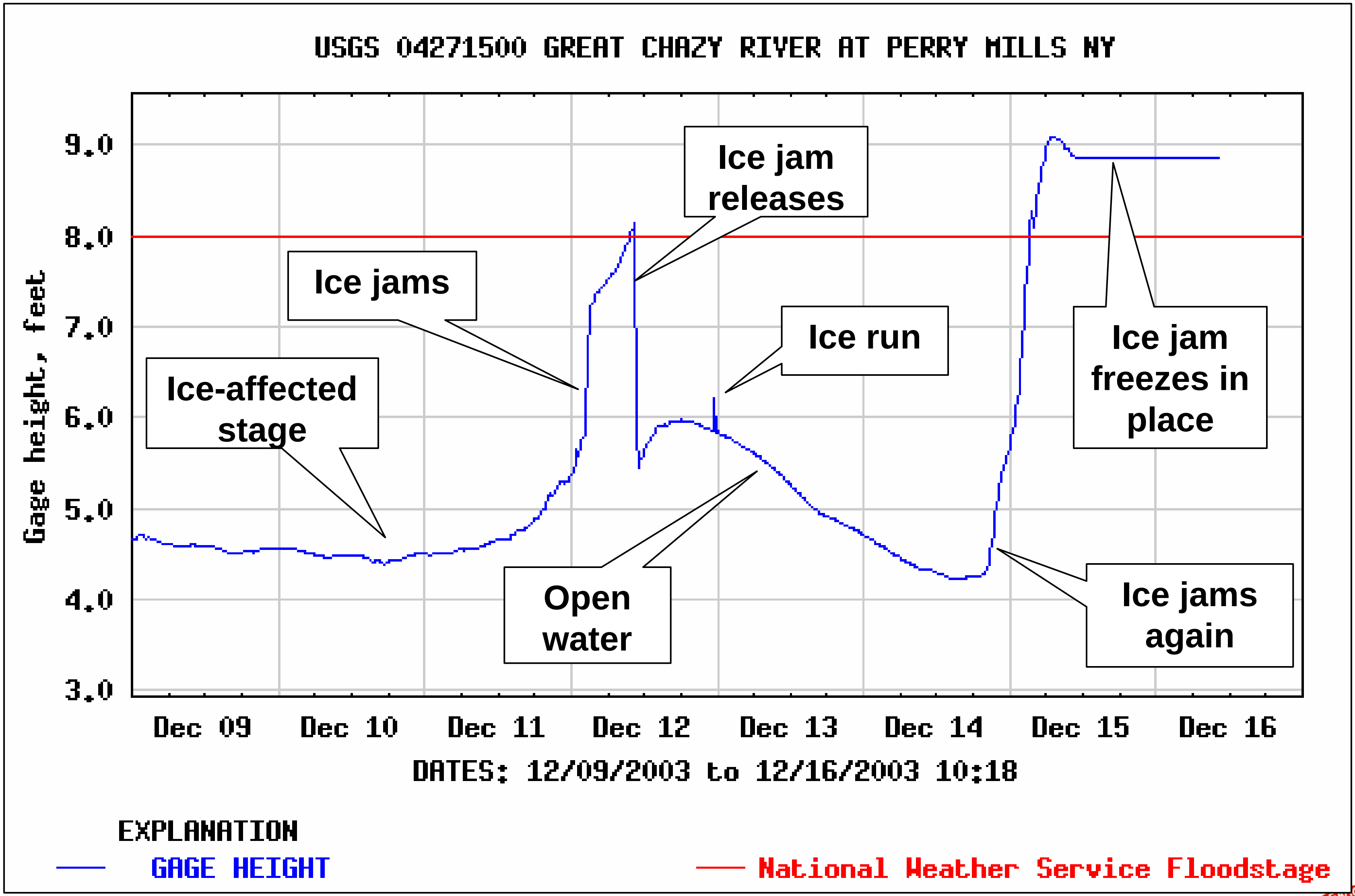


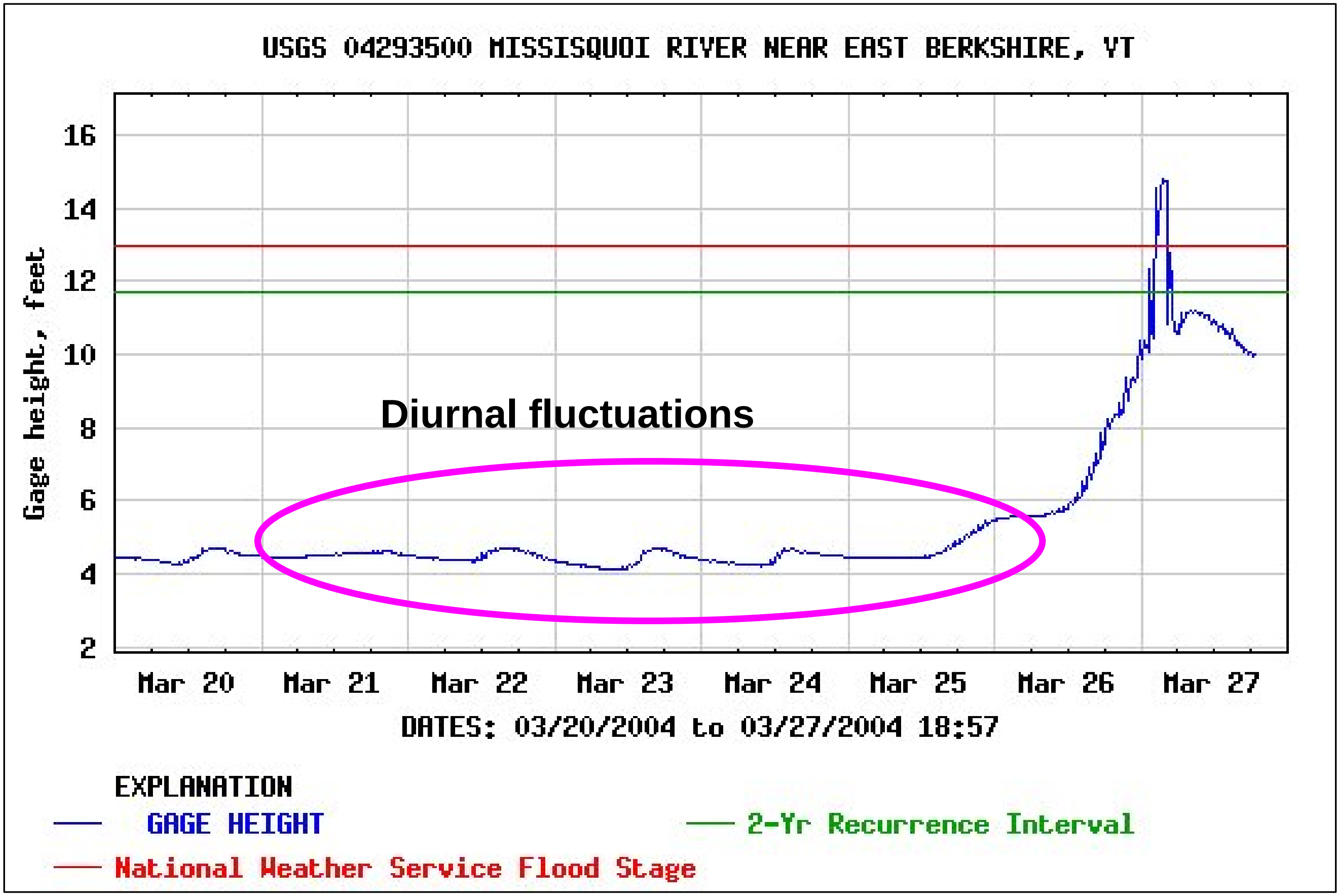
Breakup Jam



USGS 01011000 Allagash River near Allagash, Maine
Gage height, feet
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
Apr 10
Apr 11
Apr 12
Apr 13
Apr 14
Apr 15
Apr 16
Apr 17
DATES: 04/10/2004 to 04/17/2004 13:40
Ice jam
Ice jam release
Ice shove
Open water
Jam frozen in place

Breakup Jam Followed by Freezeup Jam





USGS 04293500 MISSISQUOI RIVER NEAR EAST BERKSHIRE, VT
Gage height, feet
16
14
12
10
8
6
4
2
Diurnal fluctuations
Mar 20
Mar 21
Mar 22
Mar 23
Mar 24
Mar 25
Mar 26
Mar 27
DATES: 03/20/2004 to 03/27/2004 18:57
EXPLANATION
GAGE HEIGHT
2-Yr Recurrence Interval
National Weather Service Flood Stage

Diurnal Fluctuations

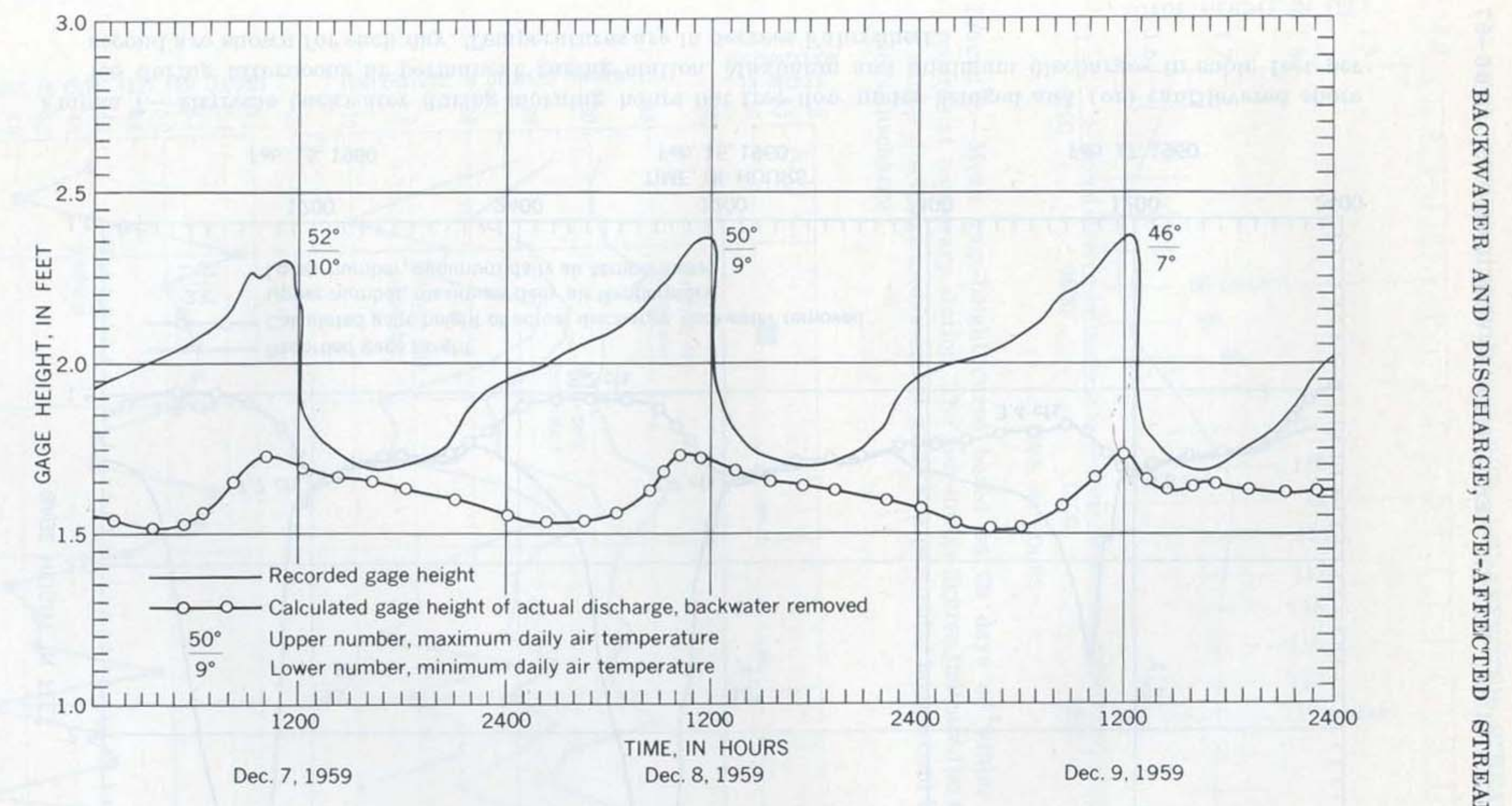


FIGURE 6.—Pattern of backwater from ice at permanent station. Calculated gage height of open water was obtained from data collected at supplementary gaging station. Maximum and minimum temperatures, in degrees Fahrenheit, are from the recording thermograph operated at the supplementary station.

From Cook, R.E. and Cerny, E.E. (1968) "Patterns of backwater and discharge on small ice-affected streams." IN Selected Techniques in Water–Resources Investigations, 1966-1967, USGS Water –Supply Paper 1892, p. 114-125.

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Ice Jam Mitigation Measures

Advance Measures:
Potential for Ice Jam

- Cost depends on method
- Effectiveness difficult to quantify
- Monitoring
- Early Warning
- Ice Weakening
  - Drilling holes
  - Dusting
  - Blasting

Emergency Measures:
Ice Jam in place

- Cost & effectiveness depend on timing
- Estimate time to thin/melt
- Traditional Flood Fighting
  - Sandbagging
  - Jersey barriers
  - Diversion channel
- Excavation
- Blasting
- Do nothing

Lead Time ⇒ Increased Effectiveness

Effect of Flow on Thinning of Jam

- Jam thinning or melting can be significant if incoming water temperature is above freezing
- Observations indicate that almost all available heat is transferred to ice melting within the upper 1 mile of jam
- As jam shortens or preferential flow paths develop, jam failure may occur
- Very rough rule of thumb per Δ° F: $\dot{V}_m(cfs) = 0.01Q(cfs)$

Table 5. Measurements of water temperature entering breakup ice jams. The heat-transfer length is the distance from the head of a jam to the point where the water has lost > 90% of its sensible heat.

Reference	*River*	*Entering water temp., ΔT (°F–32)*	*Heat-transfer length (miles)*	*Comments*
Calkins (1984)	Ottauquechee R.	1.3	0.8	Upstream of refrozen jam, time between breakup and measurement unknown.
Prowse and Marsh (1989)	Liard R.	3.1	2	Measured during breakup event.
Beltaos et al. (1998)	Matapedia R.	4.5	0.2	Time between breakup and measurement unknown.

From Lever et al. (2000)" Cazenovia Creek ice control structure" ERDC/CRREL Technical Report 00-14

Effect of Flow on Thinning of Jam

- Example **(remember, this is very rough estimate!)**:
- Assume incoming water temperature is 32.4 ºF, Q=20,000 cfs
- Estimated ice jam volume:

  Ice Volume = avg. length x avg. width x avg. thickness x (1 - ice jam porosity)

  = 1 mile x 400 ft x 10 ft x (1- 40%)

  = 12 million ft^3
- Estimated melt rate :

  Melt rate = 1% x avg. river discharge in cfs x water temp in deg F above 32. ºF

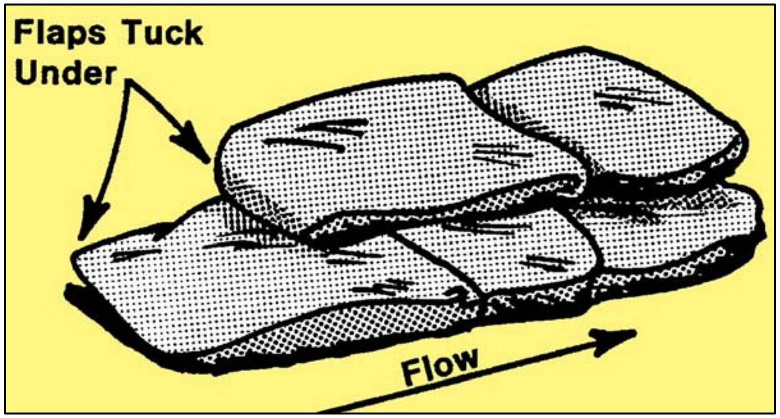
  = 1% x 25,000 cfs x 0.4 ºF

  = 100 cubic feet of ice melted per second
- Time required to melt out jam = ice volume in jam / melt rate

  = 12 million ft^3 / 100 cfs = 120,000 sec = 33 hours

Sand Bagging Review

- Use bags about 14-18" wide, and 30-36" deep
- Materials:
  - –Burlap sacks
    - Empty bags can be stockpiled for emergency use
    - Will be serviceable for several years if properly stored
    - Filled bags of earth material will deteriorate quickly



  - –Polypropylene
    - Can be stored for a long time with minimum care
    - Not biodegradable, must have disposal plan
  - –Garbage bags are too slick to stack
  - –Feed sacks are too large to handle
- Fill between one-third (1/3) to one-half (1/2) of bag capacity
- Prefer heavy bodied or sandy soil; gravels and larger usually too permeable

Sand Bagging Review

- Fold the open end of the unfilled portion of the bag to form a triangle
  - Can tie, but this takes time and is not more effective
  - If tied bags are used, flatten or flare the tied end
- Place lengthwise and parallel to the direction of flow, with the open end facing against the water flow
  - Tuck the flaps under, keeping the unfilled portion under the weight of the sack
  - Offset bags by 1/2 the filled length of the adjoining bag
  - Stamp into place to eliminate voids, and form a tight seal
- Stagger the joints when multiple layers are necessary
- For unsupported layers over 3 layers high, use the pyramid placement method

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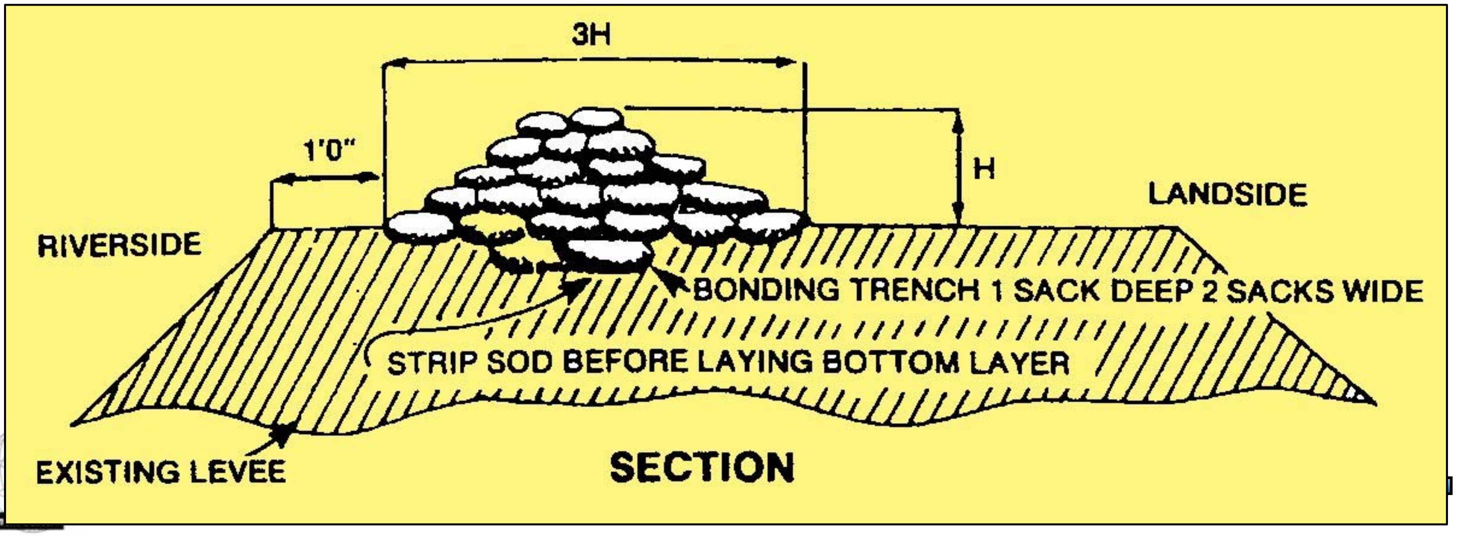
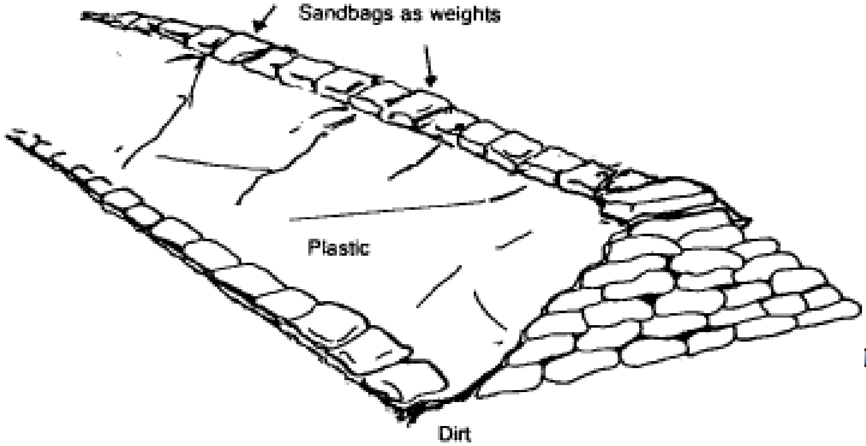
Sand Bagging Review

- Pyramid Placement (> 3 high)
  - Place the sand bags to form a pyramid by alternating header courses (bags placed crosswise) and stretcher courses (bags placed lengthwise)
  - Stamp each bag in place
  - Overlap sacks
  - Maintain staggered joint placement
  - Tuck in any loose ends
- Quantity of sand bags for 100 linear feet of dike is estimated as:
  - 800 bags for 1-foot-high dike
  - 2,000 bags for 2-foot-high dike
  - 3,400 bags for 3- foot-high dike



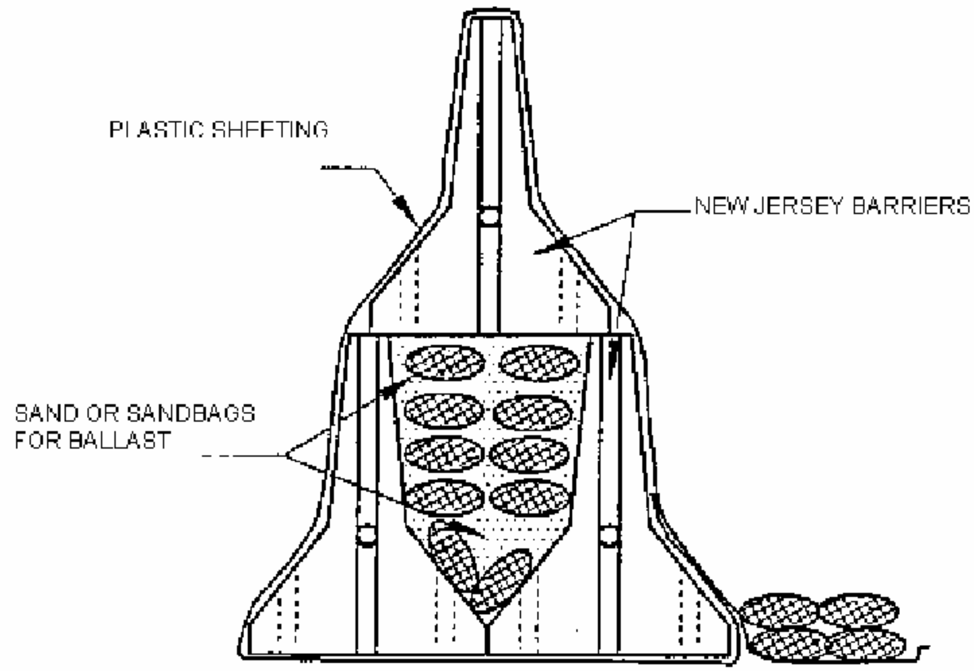
Sand Bagging Review

- Polyethylene sheeting
  - Will improve the performance of any sand bag barrier
  - > 6 mils thick
  - 3 times as wide as the intended height of the sand bag barrier
  - Don't stretch tightly
  - Stair step up or cover bags as shown below
  - Seal with sand bags at base of levee and at crown



Jersey Barriers

- Double row with staggered joints preferred to single row
- Fill between with sand, sandbags
- If permeable material used to fill, wrap with plastic sheeting
- May be stacked but single height preferable for stability



Diversion Channels

Can use snow, snow with sheeting, sand/gravel/rock alone or with sheeting, sandbags, jersey barriers….

Ice Weakening

- Mechanical: Immediate strength reduction
  - Ice cutting
    - 4WD trencher
    - Ditch Witch
  - Ice breaking
    - Amphibious excavator
    - Vessels
- Thermal: Accelerate natural ice deterioration
  - Hole drilling
  - Dusting
  - Flow effects

Aerial Dusting

- Sand or other dark material increases solar absorption and enhances ice deterioration
- High sun angle and longer hours of sunlight required for optimum results (i.e., after mid-February)
- Difficult to assess effectiveness
- Potential environmental issues
  - Permitting required well ahead of time

Hole Drilling

- Oconto River, WI
  - 10 ft grid, central 2/3 of channel
  - Holes expand to weaken sheet
  - Weakens ice in jam location to increase conveyance, transport capacity of channel

Excavation

- Most efficient when stage rising
- Potential safety issues
- Potential environmental issues
- Pre-positioned equipment helpful
  - excavator, clam-shell, bulldozer
  - clear channel D/S of toe
  - dislodge key pieces at toe
- Expensive to excavate ice pieces after stage falls
- Can be combined with blasting (excavate where safe, blast upstream end of jam)

Excavation - Examples

Hardwick, VT

Baltic, CT

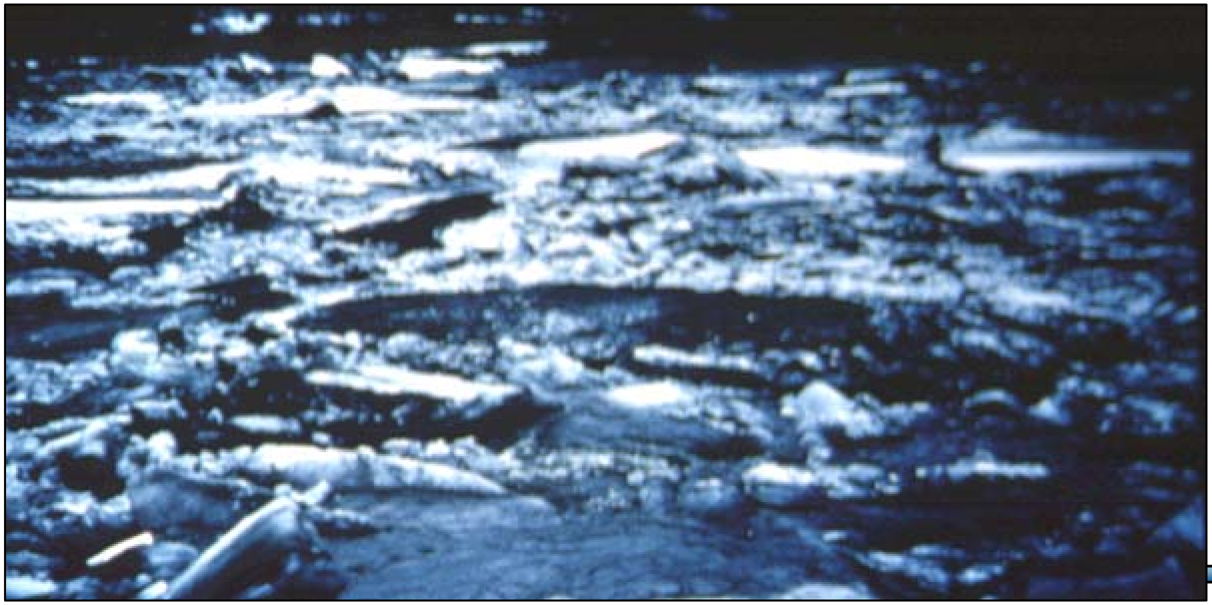
Morrisonville, NY

Blasting

- Requires open water downstream
- Work from downstream to upstream
- Charges should be placed just under ice
- Pre-planning needed (liability issues, rapid response)
- Not suitable for urban area

Do Nothing

- Estimate melt rate
- Thin, weak ice
- Little remaining ice supply
- Continued mild temperatures
- Late season jam (check records)
- Other constraints

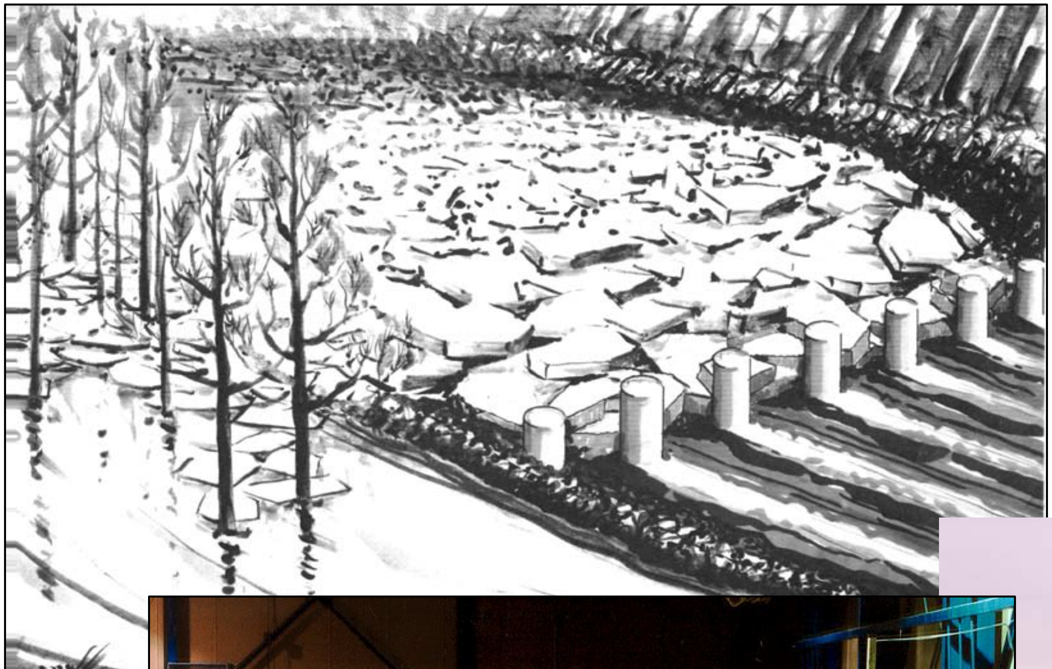


Permanent Measures

- Structural solutions
  - Ice control structures (ICS's)
  - Diversion channels
  - Flow control
  - Thermal discharge
  - Levees, floodwalls
  - Flood proofing
  - Land management
- 2-5 year lead time
- Expect high benefits and reliability
- Generally costly although some low-cost solutions are under development

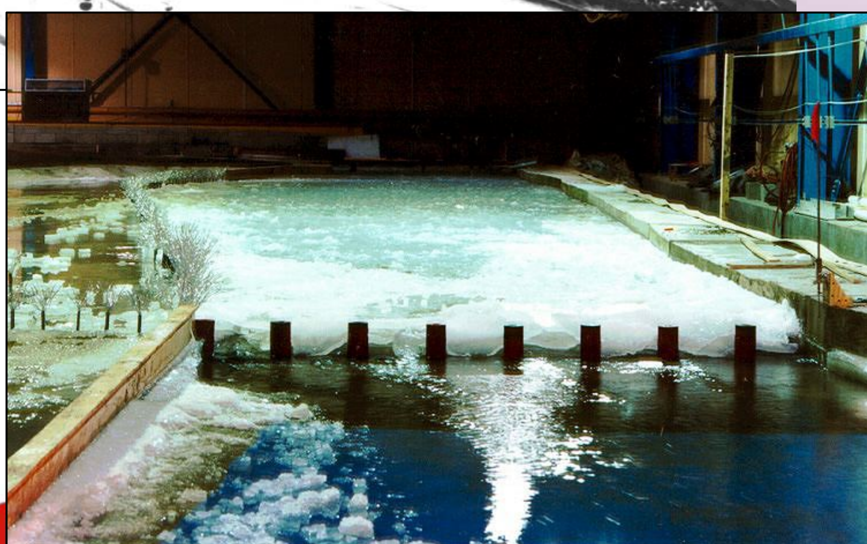
Ice Control Structure, Lamoille River, Hardwick, VT

Cylindrical Pier ICS



Greater ice-holding capacity than sloped Blocks

- **Cazenovia Creek Structure (Currently under construction)**



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Summary

- Monitoring ice conditions leads to better understanding of ice processes
  - Trained observers with common understanding of descriptive terms aid in pre-, during, and post-jam monitoring
  - Real-time stage data from USGS can be invaluable
- Early warning enhances effectiveness of other emergency response measures
- Ice jam emergency response depends on type of ice jam and formation mechanisms, as well as other constraints:
  - Safety
  - Budget
  - Time
- Permanent ice control methods are available
  - Requires site-specific knowledge of ice processes