Ice Jam Mitigation Part 1: Introduction to River Ice

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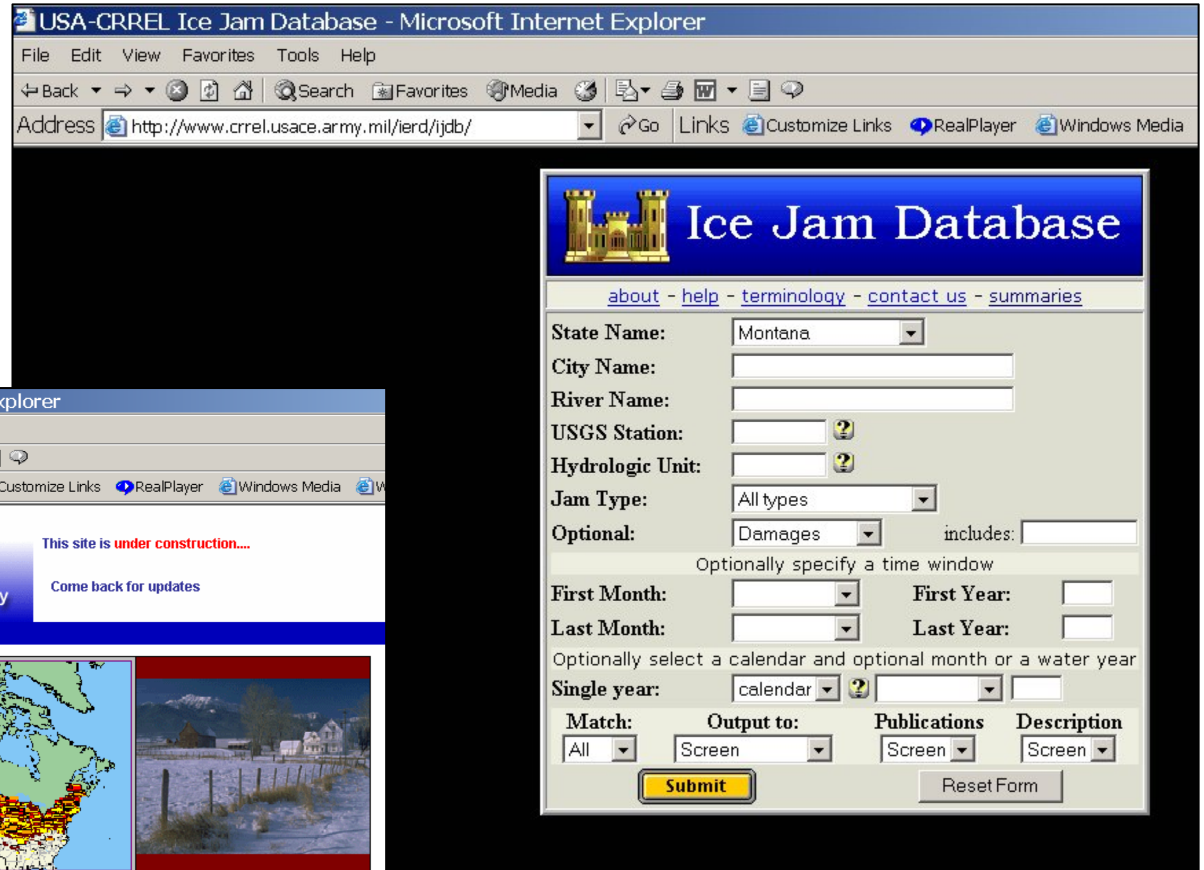
Overview of Montana Ice Jams*

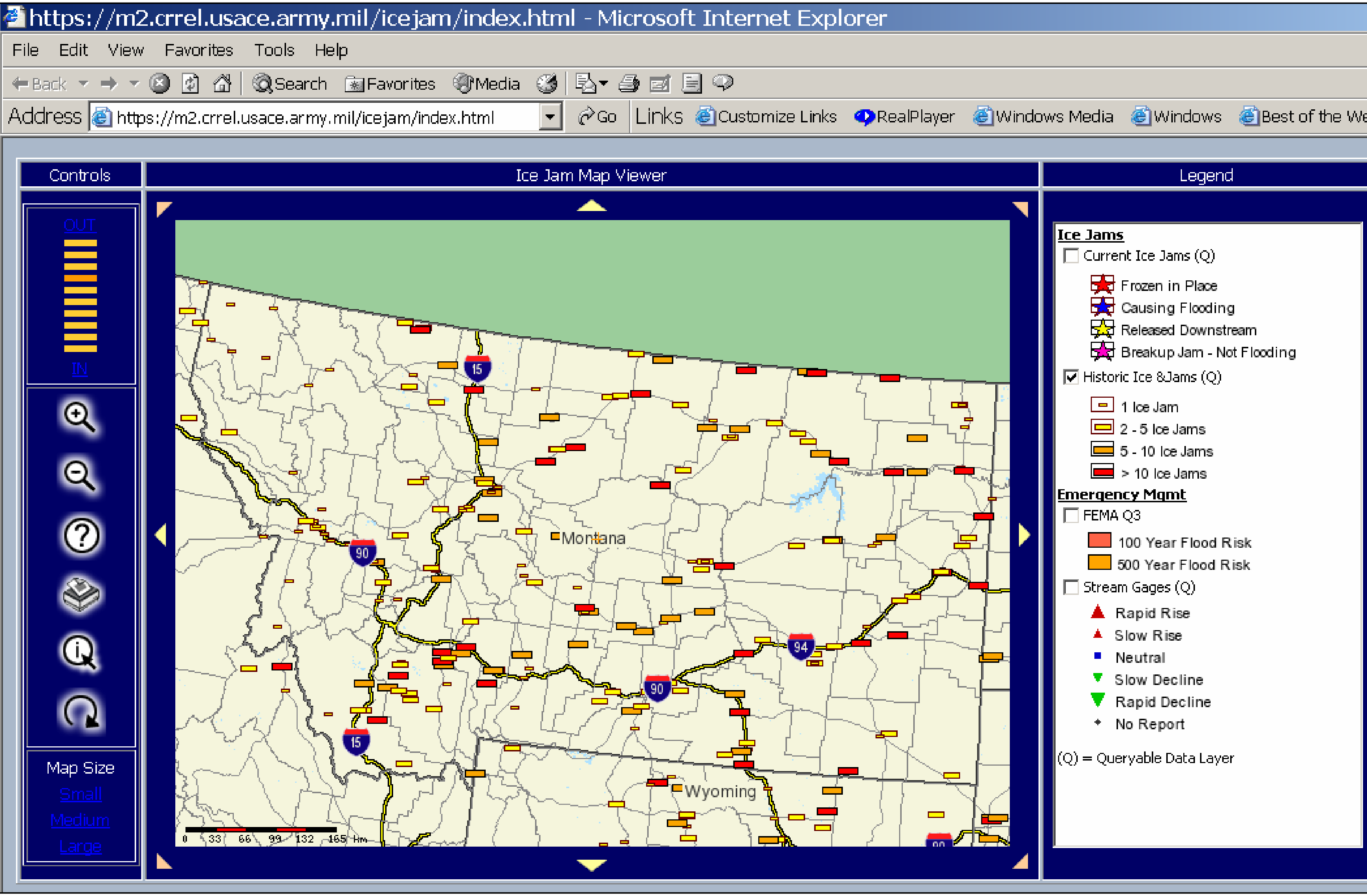
- Highest number of reported ice events – and related deaths (18) in the US
- 1419 Montana ice events documented in the CRREL ice jam database (>10% of 13,750)
- 1894-2003
- October to July
- Freezeup and breakup
- 143 rivers & streams
- 170 locations (including 17 on Int'l Boundary)

* As of January 24, 2004

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



http://www.crrel.usace.army.mil/icejams/index.htm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File Edit View Favorites Tools Help
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Address https://m2.crrel.usace.army.mil/icejam/index.html
Go Links Customize Links RealPlayer Windows Media Windows Best of the Web
Controls
Ice Jam Map Viewer
Legend
OUT
IN
Map Size
Small
Medium
Large
Montana
Wyoming
15
90
94
0 33 66 99 132 165 km
Ice Jams
Current Ice Jams (Q)
Frozen in Place
Causing Flooding
Released Downstream
Breakup Jam - Not Flooding
Historic Ice &Jams (Q)
1 Ice Jam
2 - 5 Ice Jams
5 - 10 Ice Jams
> 10 Ice Jams
Emergency Mgmt
FEMA Q3
100 Year Flood Risk
500 Year Flood Risk
Stream Gages (Q)
Rapid Rise
Slow Rise
Neutral
Slow Decline
Rapid Decline
No Report
(Q) = Queryable Data Layer

US Army Corps of Engineers

Ice Engineering

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

Ice Jams in Montana

An ice jam is an accumulation of ice in a river that restricts water flow and may cause backwater that floods low-lying areas upstream from the jam. Downstream areas also can be flooded if the jam releases suddenly, sending excessive water and ice downstream. Damages resulting from ice jams can affect roads, bridges, buildings, and homes, and can cost the affected community thousands to millions of dollars. More common, however, are jams that result in highly localized, yet serious damages (Fig. 1). In these cases, it is often difficult to obtain the types of disaster assistance that are available for large-scale flooding typical of open-water flood events.

Engineers at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) have been working to develop and optimize low-cost structural and nonstructural techniques to prevent or alleviate damages caused by ice jams. Many of these methods, such as early warning systems, ice dusting, ice breaking, ice weakening, and ice jam removal techniques, can be carried out by local offices at a reasonable cost (Corps of Engineers 1994). Methods of predicting ice jam occurrence and severity are also being developed.

The latter efforts, partly based on statistics and probability analysis, require the compilation of accurate and reliable data on past ice jam events. The CRREL Ice Jam Database was started in 1990 with the intent of compiling data on freezeup and breakup ice jam events in the United States (White 1996). Currently there are nearly 11,000 records in the database, with the earliest account dating from 1780. For each ice jam event, the database includes the river name, city, state, year, month, jam date, jam type, damages, a short description, a listing of publications, latitude and longitude, U.S. Geological Survey (USGS) hydrologic unit code, and USGS gage number, if available.

CRREL also has an Ice Jam Archive that contains hard copies of CRREL trip reports, National Weather Service (NWS) reports, newspaper articles, and other reports used as sources for ice-jam-related information (Herrin and Balch 1995). The information can be borrowed or photocopied.

Figure 1. Severe flooding on the Milk River in Glasgow, Montana, March 1986. (Photo courtesy of the Glasgow Courier, *Glasgow, Montana; used with permission.)*

Montana ice jams

This bulletin provides a brief summary of information in the CRREL Ice Jam Database for rivers in Montana. This is the second in a series that will characterize every state affected by ice jams using the CRREL Ice Jam Database.

Despite Montana's sparse population, with only 5.7 persons per square mile (Edstrom 1993), ice jams have a frequent and destructive history in the state. In 1992 there were 24,800 farms in Montana; ice jam floods often have left them inundated,

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

Billings Gazette
Sunday March 12, 2000

MAGAZINE

Section **E**

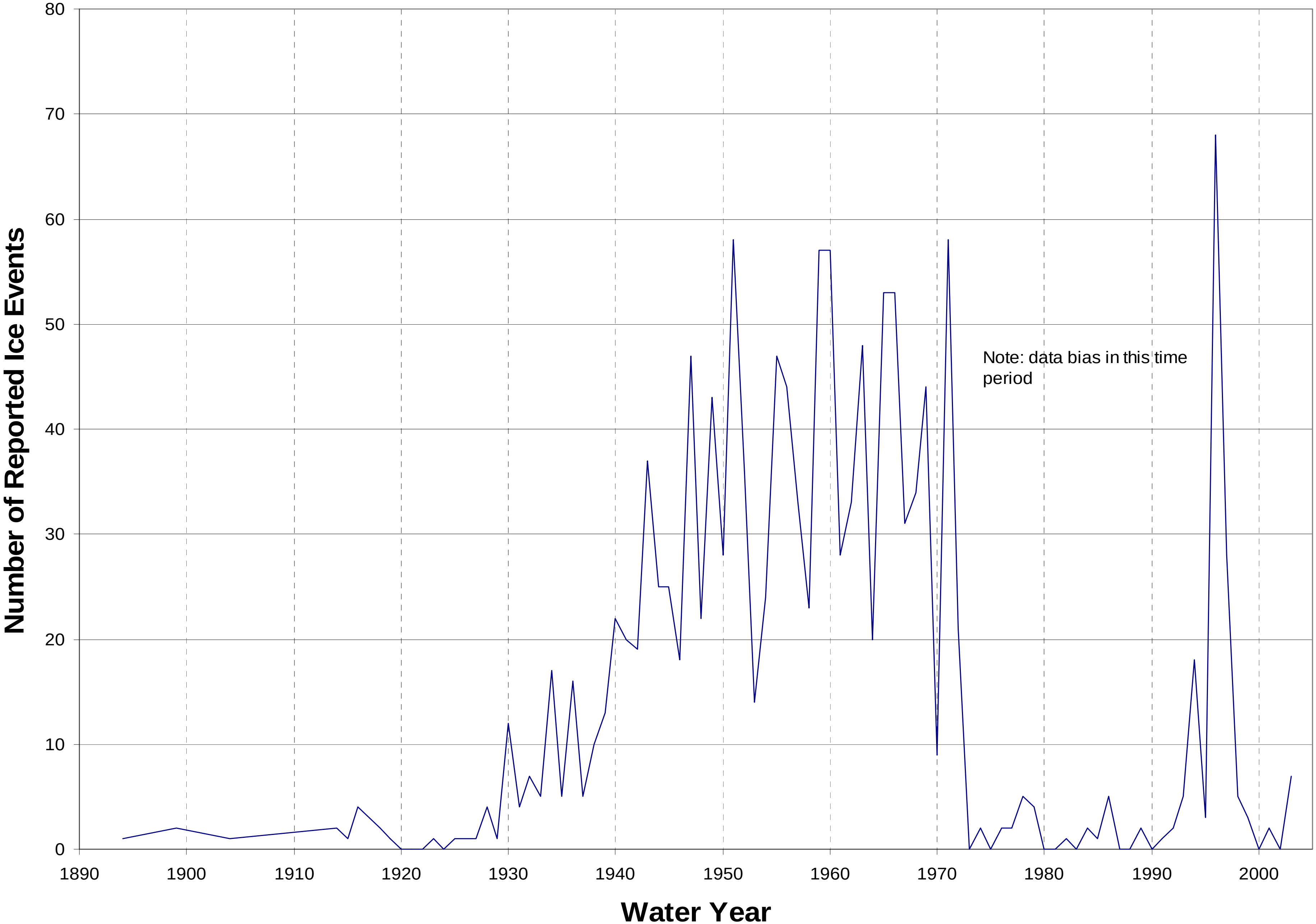
Sunday, March 12, 2000

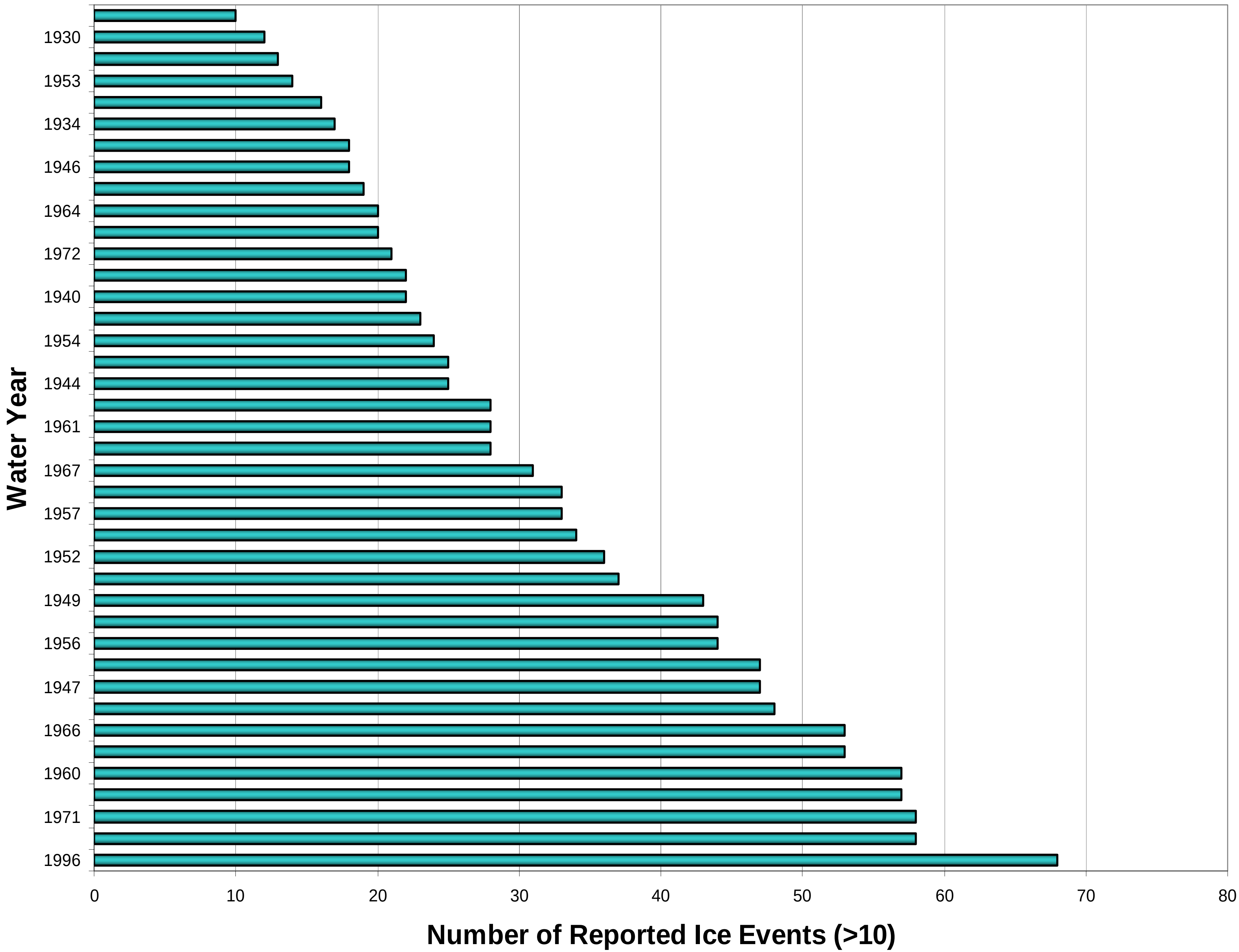
Of ice jams *and* raging rivers

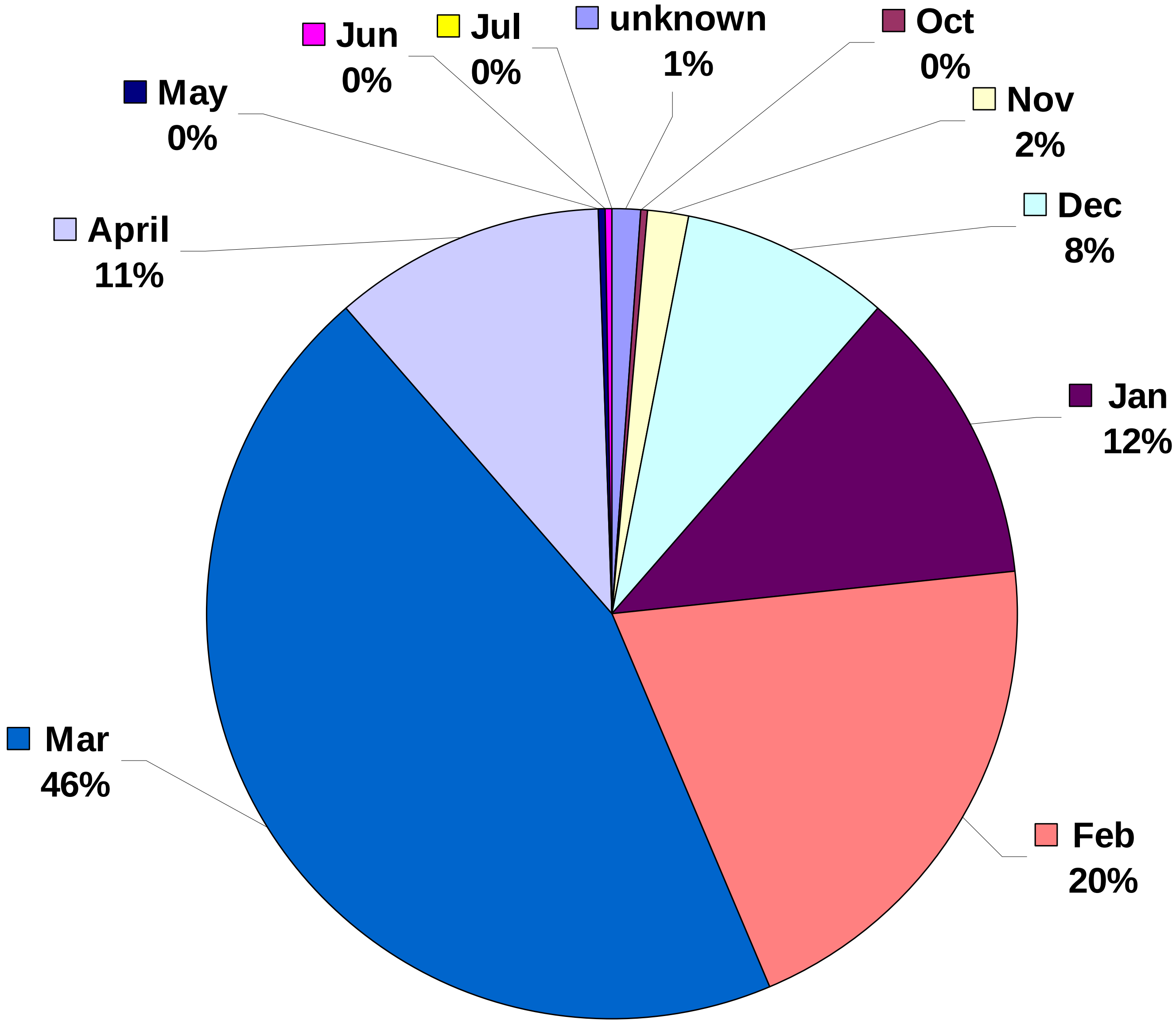
TOP JAM SITES

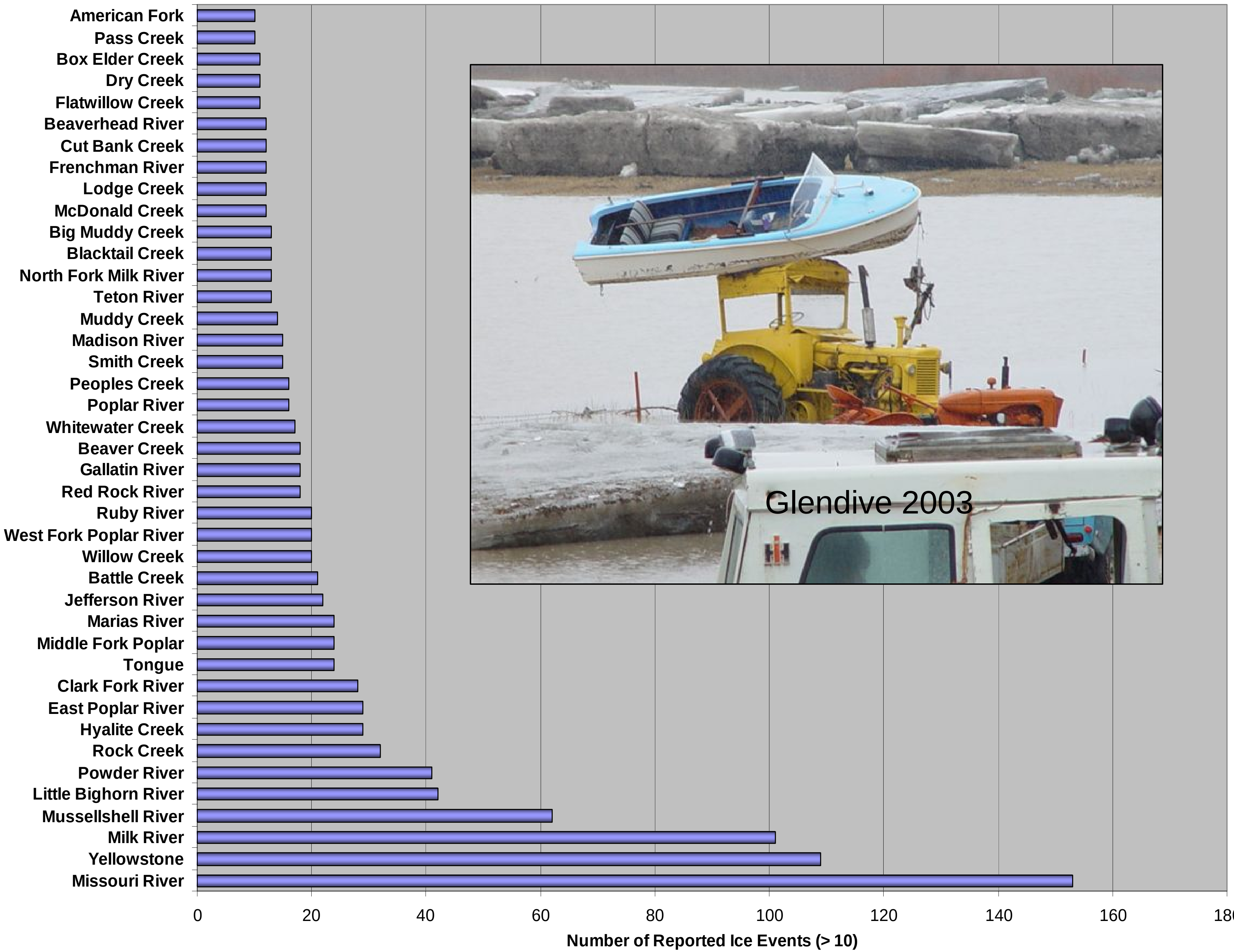
TOP ICE JAM YEARS

FIND OUT MORE

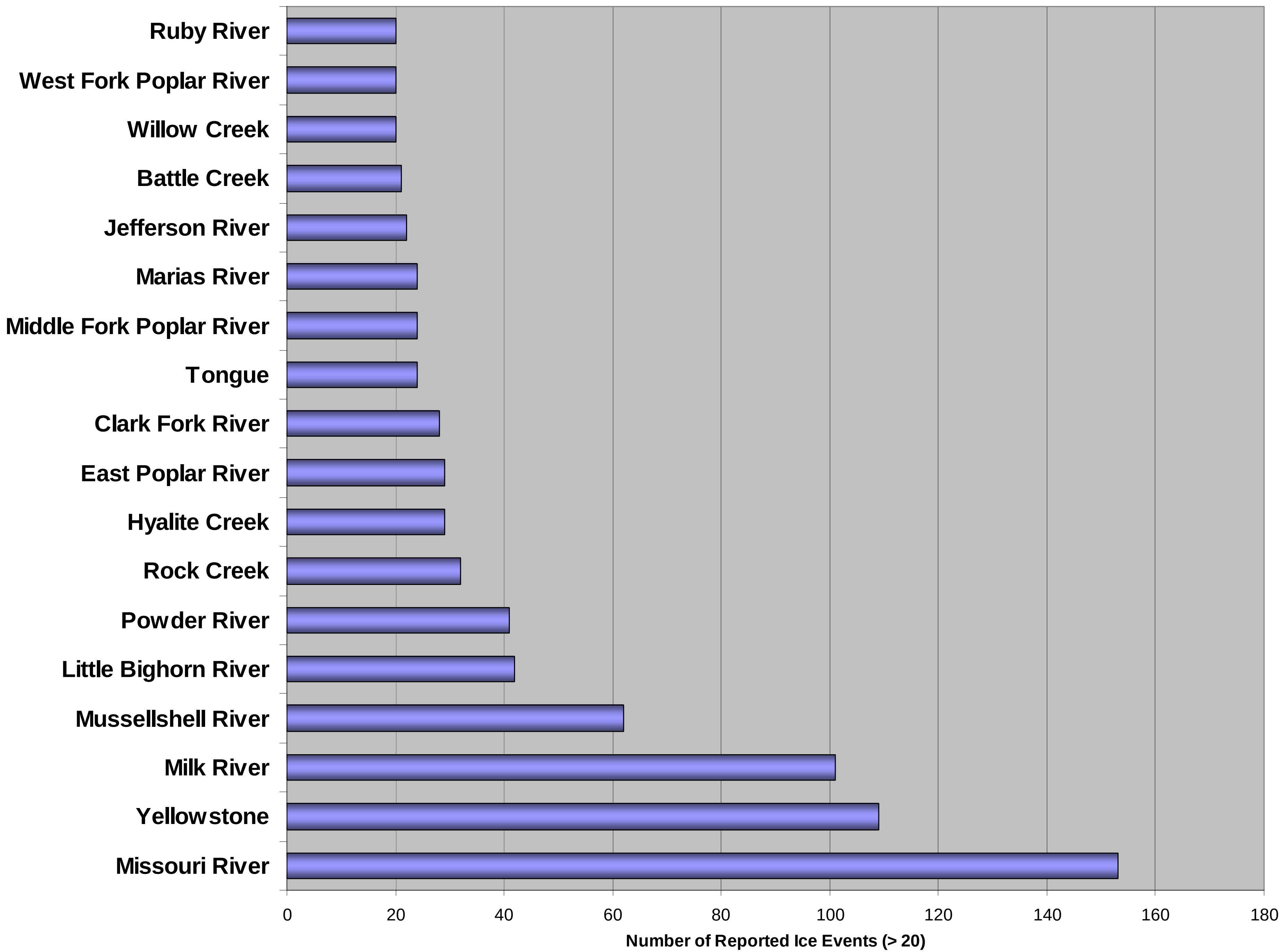

Number of Reported Ice Events
Water Year
0
10
20
30
40
50
60
70
80
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Note: data bias in this time period


1930
1953
1934
1946
1964
1972
1940
1954
1944
1961
1967
1957
1952
1949
1956
1947
1966
1960
1971
1996
Water Year
0
10
20
30
40
50
60
70
80
Number of Reported Ice Events (>10)

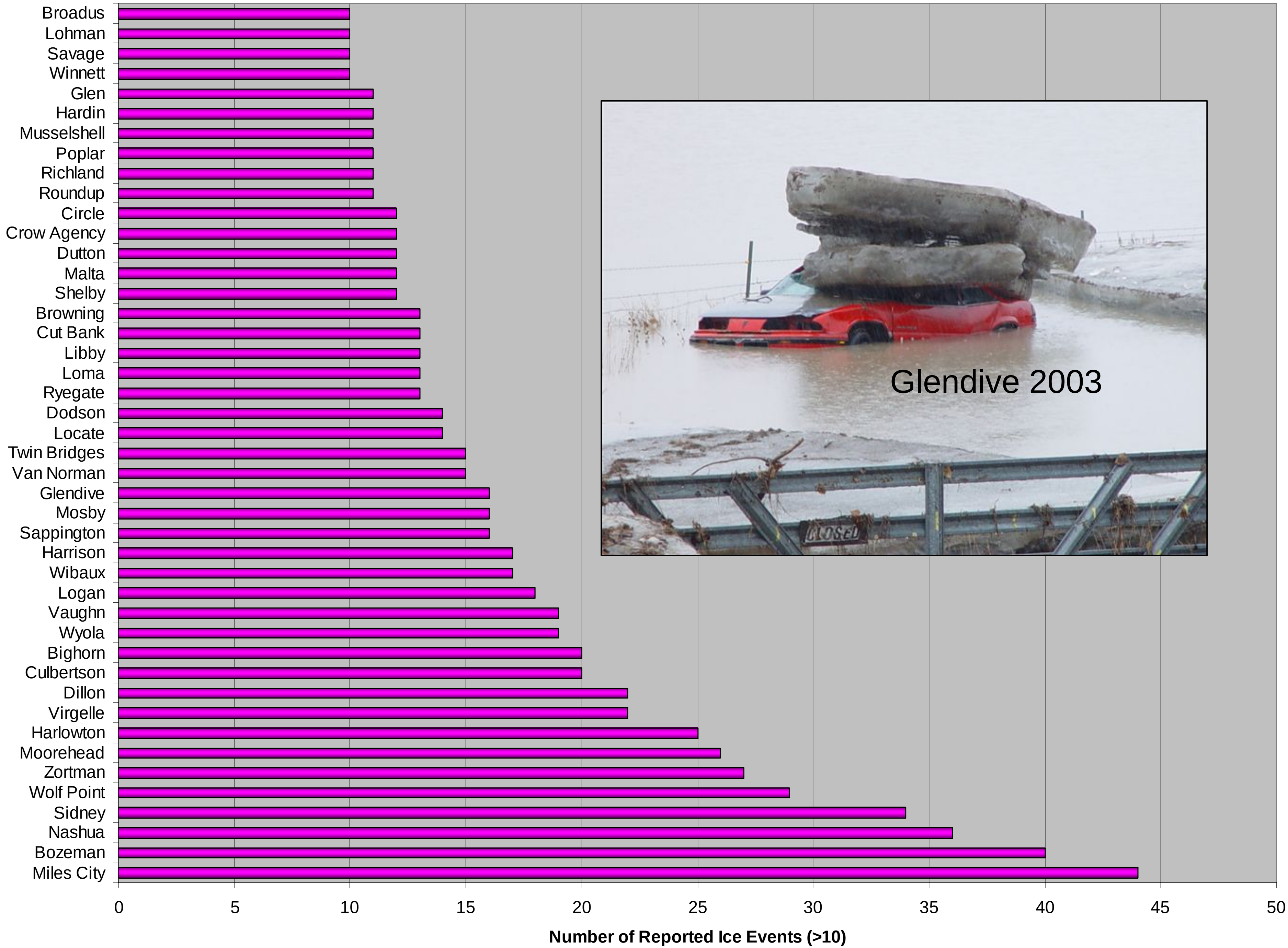

Jun
0%
Jul
0%
unknown
1%
Oct
0%
May
0%
Nov
2%
Dec
8%
April
11%
Jan
12%
Mar
46%
Feb
20%

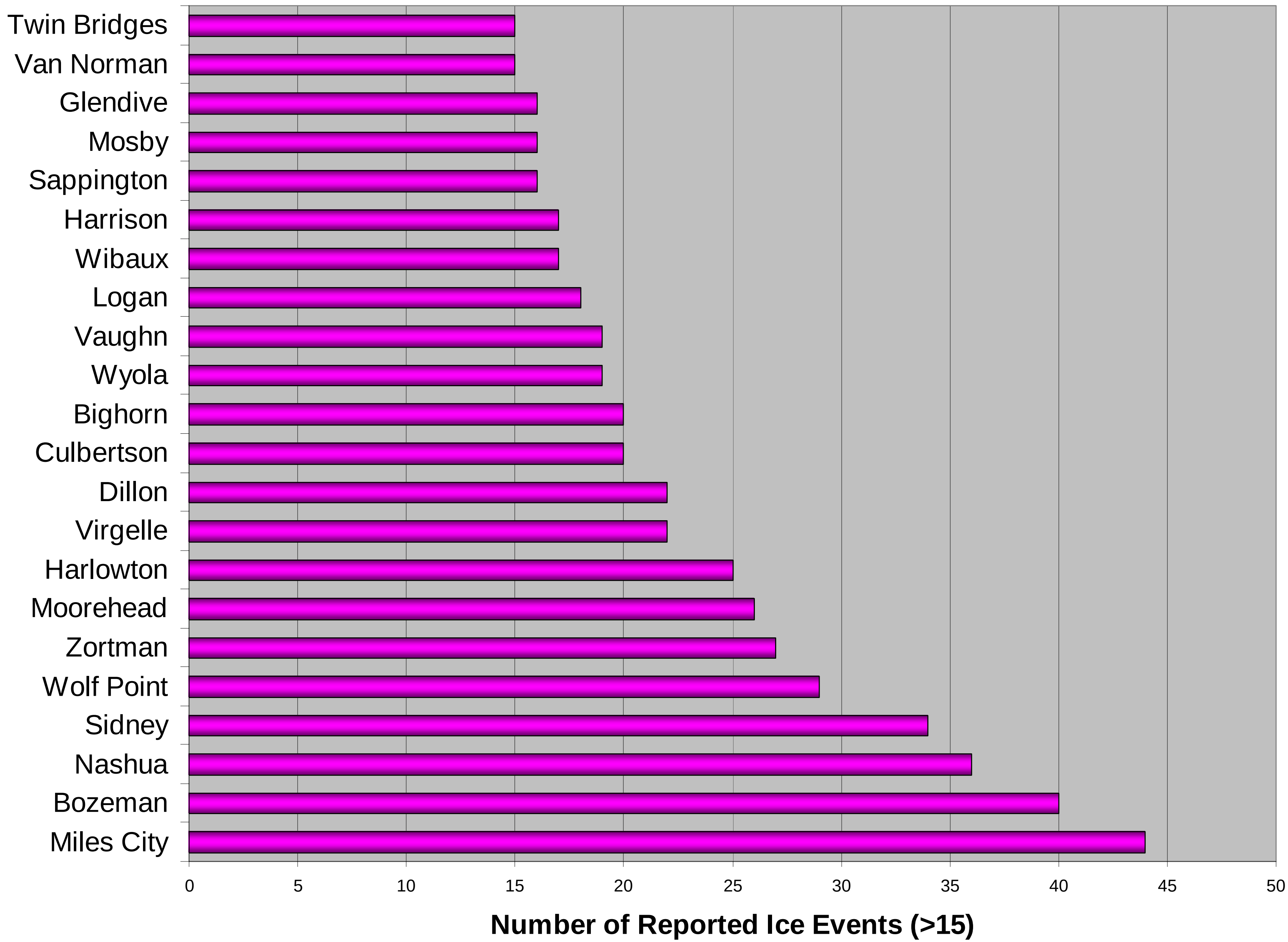


American Fork
Pass Creek
Box Elder Creek
Dry Creek
Flatwillow Creek
Beaverhead River
Cut Bank Creek
Frenchman River
Lodge Creek
McDonald Creek
Big Muddy Creek
Blacktail Creek
North Fork Milk River
Teton River
Muddy Creek
Madison River
Smith Creek
Peoples Creek
Poplar River
Whitewater Creek
Beaver Creek
Gallatin River
Red Rock River
Ruby River
West Fork Poplar River
Willow Creek
Battle Creek
Jefferson River
Marias River
Middle Fork Poplar
Tongue
Clark Fork River
East Poplar River
Hyalite Creek
Rock Creek
Powder River
Little Bighorn River
Mussellshell River
Milk River
Yellowstone
Missouri River
0
20
40
60
80
100
120
140
160
180
Number of Reported Ice Events (> 10)
Glendive 2003



Ruby River
West Fork Poplar River
Willow Creek
Battle Creek
Jefferson River
Marias River
Middle Fork Poplar River
Tongue
Clark Fork River
East Poplar River
Hyalite Creek
Rock Creek
Powder River
Little Bighorn River
Mussellshell River
Milk River
Yellowstone
Missouri River
0
20
40
60
80
100
120
140
160
180
Number of Reported Ice Events (> 20)


Broadus
Lohman
Savage
Winnett
Glen
Hardin
Musselshell
Poplar
Richland
Roundup
Circle
Crow Agency
Dutton
Malta
Shelby
Browning
Cut Bank
Libby
Loma
Ryegate
Dodson
Locate
Twin Bridges
Van Norman
Glendive
Mosby
Sappington
Harrison
Wibaux
Logan
Vaughn
Wyola
Bighorn
Culbertson
Dillon
Virgelle
Harlowton
Moorehead
Zortman
Wolf Point
Sidney
Nashua
Bozeman
Miles City
0
5
10
15
20
25
30
35
40
45
50
Number of Reported Ice Events (>10)
Glendive 2003
CLOSED

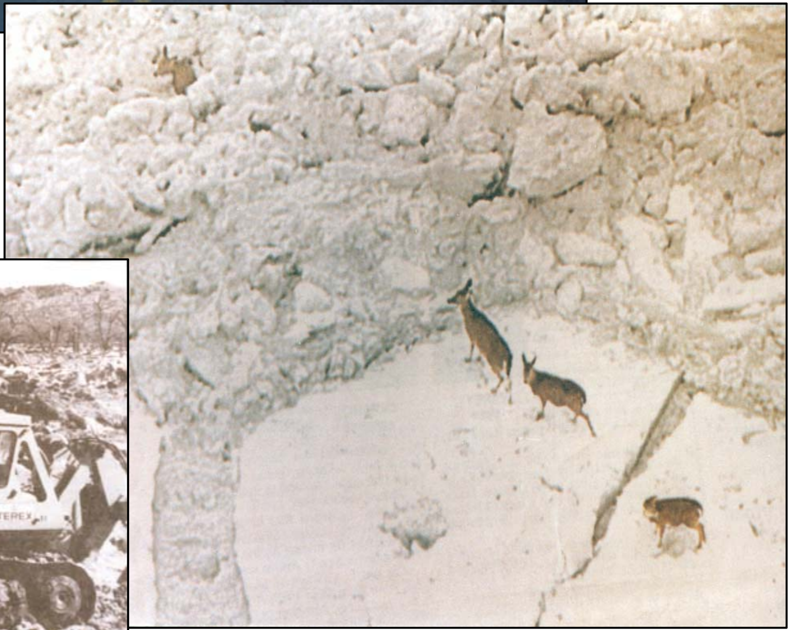

Twin Bridges
Van Norman
Glendive
Mosby
Sappington
Harrison
Wibaux
Logan
Vaughn
Wyola
Bighorn
Culbertson
Dillon
Virgelle
Harlowton
Moorehead
Zortman
Wolf Point
Sidney
Nashua
Bozeman
Miles City
0
5
10
15
20
25
30
35
40
45
50
Number of Reported Ice Events (>15)

Summary of Montana Jams

- **Montana experiences both freezeup and breakup ice jams, although breakup jams predominate**
- **Jams occur most often in March (46%), followed by February and January**

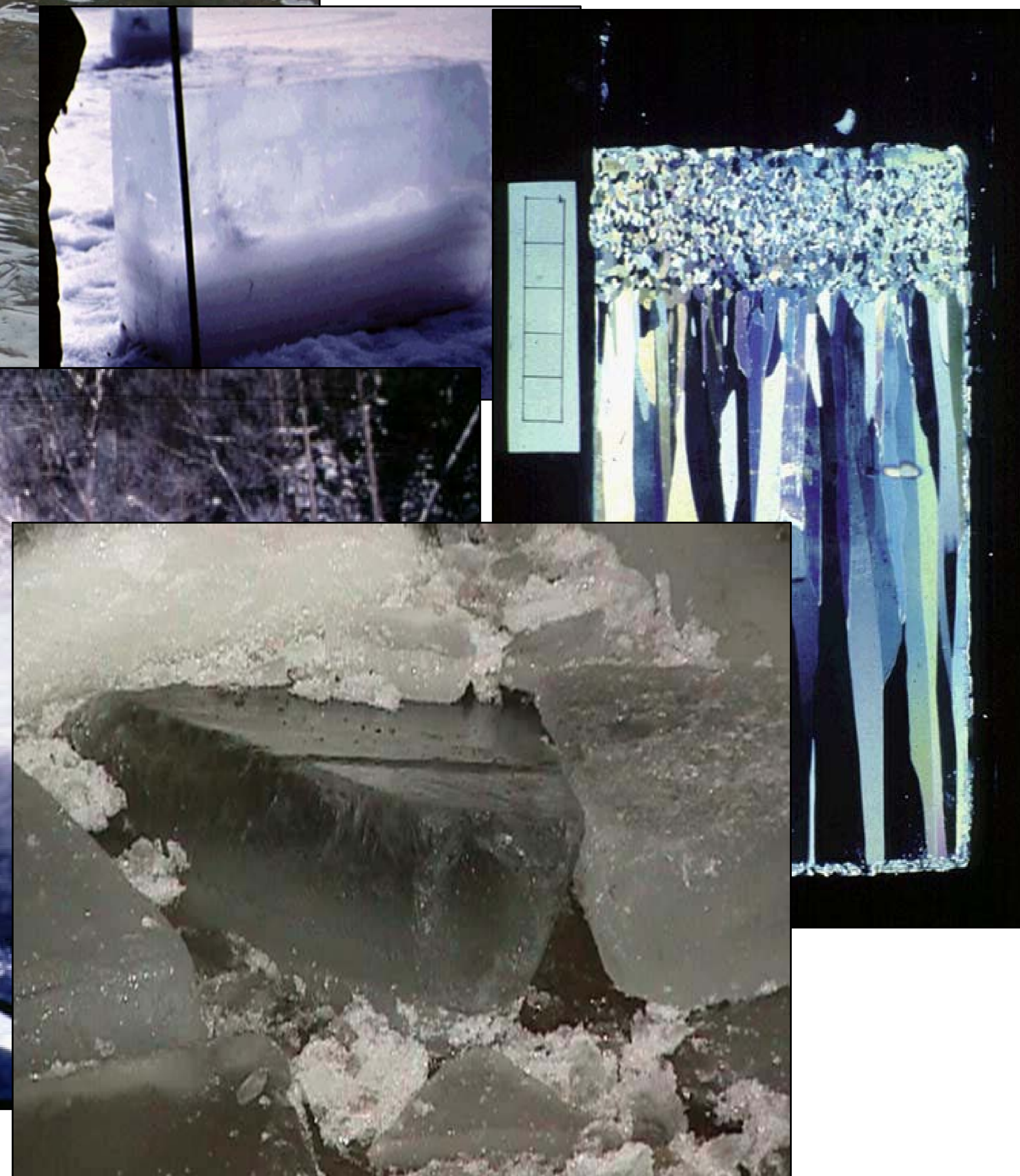
Introduction to River Ice

- **Purpose: Common language to describe ice results in more effective emergency response**
- **Objective: Develop an understanding of ice processes so that observers will be able to identify potential reasons why the ice problem exists and how the ice problem may respond to natural or human-induced interventions**
- **Goal: Efficient, effective emergency response**



- **There are 2 basic ice types, classified according to their ice crystal structures**
  - **Fine grained ice**
    - **Frazil or snow**
    - **“White” ice**
    - **Resists solar penetration**
    - **Tends to occur in dynamic, turbulent flow**
    - **We call this Frazil Ice**
  - **Columnar ice**
    - **Thermally grown**
    - **“Black” ice**
    - **Transparent, allows solar penetration,”candle ice”**
    - **Tends to occur in more quiescent flow**
    - **We call this Thermally Grown Ice**

Thermally-grown ice



Ice Cover Growth

We can estimate thermal ice growth from modified Stefan equation

$$t(in) = \alpha\sqrt{AFDD(\circ F)}$$

Ice Cover Condition	α*	α †
Windy lake w/no snow	2.7	0.80
Average lake with snow	1.7-2.4	0.50-0.70
Average river with snow	0.4-0.5	0.12-0.15
Sheltered small river	0.7-1.4	0.21-0.41

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

† AFDD calculated using degrees Fahrenheit. The ice thickness is in inches.

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

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

Ice Engin

U.S. Army Engineer Research and Development Center, Hanov

Method to Estimate River Ice Thick
Based on Meteorological Data

River ice can damage riverine structures such as bridges, locks, dams, dikes, groins, lev
forms of bank protection, and can block hydropower and water supply intakes. Ice jams
stoppages, or damage to tows, barges, and mooring/fleeting areas. Ice-induced scour may
banks, with adverse affects on fish and wildlife habitat, as well as the exposure of utilities
presence of river ice can result in wintertime oxygen deficits that impair water quality.

Removal of dams in ice-affected rivers can result in changes to the riverine ice regim
or more severe ice jamming. Emergency and medical relief to flooded areas may be limit
and erosion of roads resulting in road closures, or by the closure of bridges weakened
exists for death or serious injury during ice-related flooding, evacuations, and other ice miti

The planning, engineering, and design of ice jam mitigation measures designed to
described above generally require some estimate of ice cover thickness. Ice covers can
cesses. This Ice Engineering Technical Note discusses a method of estimating ice thick
processes based on meteorological data.

Figure 1. Hydraulic modeling of ice jams requires some estimate of i

ERDC/CRREL Technical Note 03-4

http://www.usace.army.mil/inet/usace-docs/eng-manuals/cecw.htm

CECW-EH

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

EM 1110-2-1612

Manual
No. 1110-2-1612

Engineering and Design
ICE ENGINEERING

1. Purpose. This manual, composed of three parts, presents in Part I the cu
planning, design, construction, and operation and maintenance of ice control
measures for Corps of Engineers projects; provides in Part II the current guid
jams and the resultant flooding, including preventive measures; and gives in P
for engineering and operational solutions to ice problems on rivers used for na

2. Applicability. This manual is applicable to all USACE commands havin
works design, construction, operations, and maintenance.

3. Distribution statement. Approved for public release, distribution is un

4. References. Bibliographic material is included at the end of each chapt

5. Discussion. All Corps projects subjected to freezing temperatures have
buildup on lock walls, hydropower intakes, and lock approaches; ice accumul
channels; ice passage over spillways that scours the downstream channels; an
structures and shorelines, etc. Therefore, ice control measures should be consi
existing projects to improve operations and safety in cold regions. In Part I, th
discussion of ice formation processes, physical properties, and potential soluti
Part II considers the problem of ice jams and ice jam flooding, and discusses
measures. Part III of this manual addresses the considerations that arise from
waterways, including the conduct of river ice management studies and the pre
management plans.

FOR THE COMMANDER:

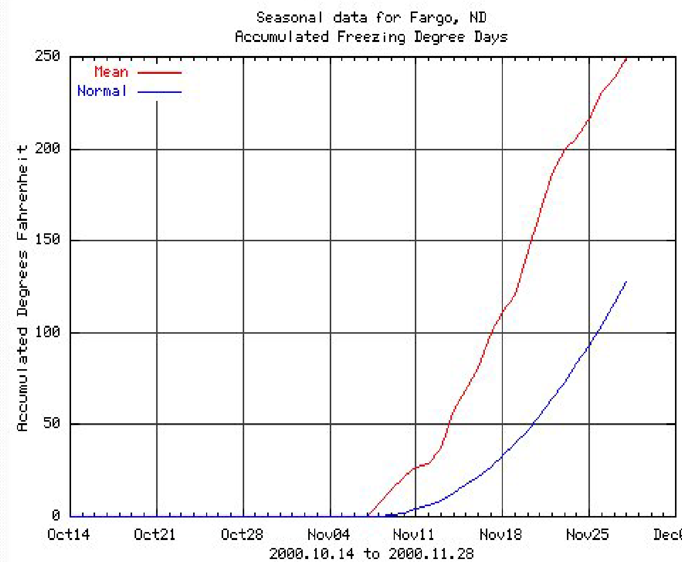
3 Appendices
(See Table of Contents)

JOSEPH SCHROEDEL
Colonel, Corps of Enginee
Chief of Staff

This manual supersedes EM 1110-2-1612, dated 30 April 1999.

EM 1110-2-1612

Seasonal AFDD Query Results

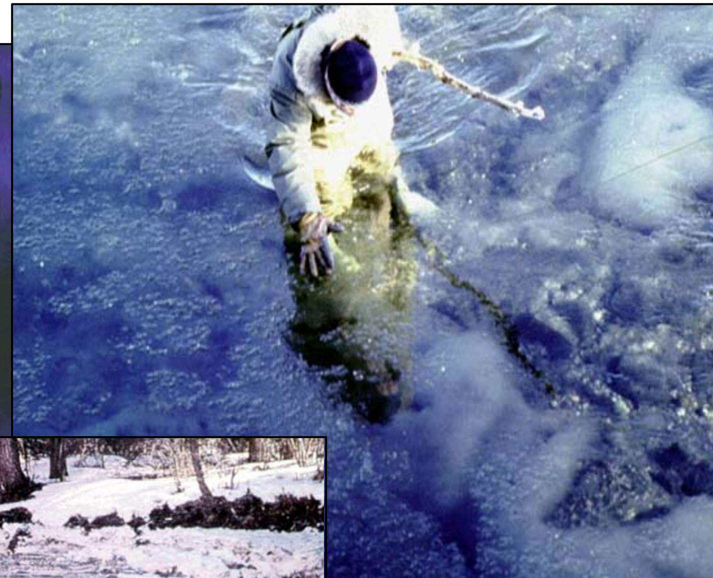


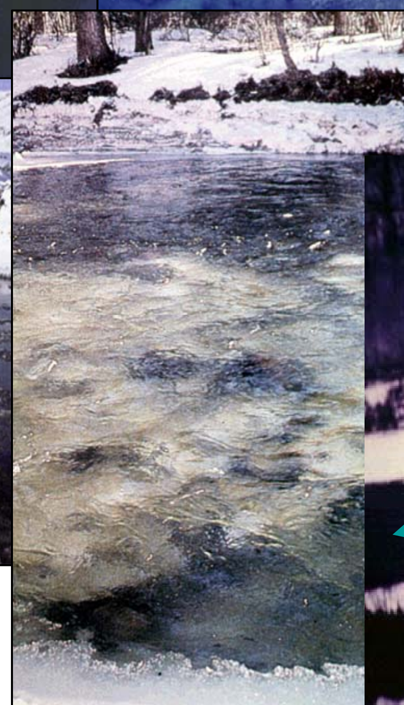
Seasonal AFDD: 249 Fahrenheit Normal AFDD: 128 Fahrenheit
Ice thicknesses for various conditions using the Stefan Formula:

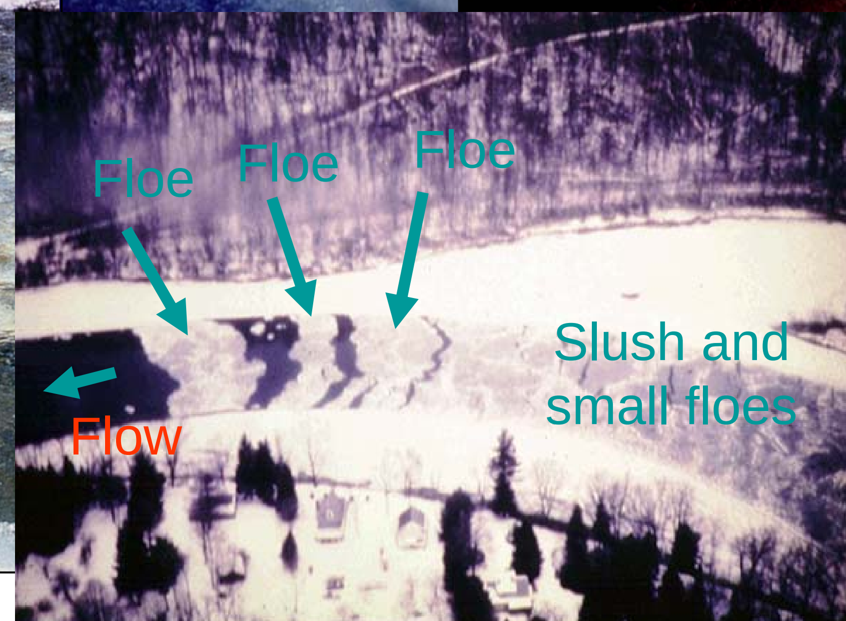
Theoretical value:	16.2 inches or 41.2 cm (*K* = *35*)
Windy lakes with no snow:	12.5 inches or 31.8 cm (*K* = *27*)
Average lake with snow:	9.5 inches or 24.1 cm (*K* = *20.5*)
Average river with snow:	6.7 inches or 17.1 cm (*K* = *14.5*)
Sheltered small river with rapid flow:	4.9 inches or 12.3 cm (*K* = *10.5*)

http://www.mvp-wc.usace.army.mil/ice

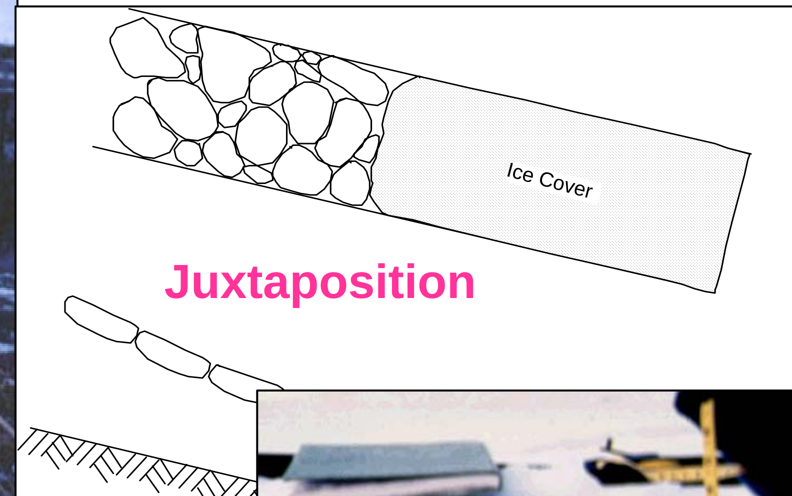
Frazil Ice

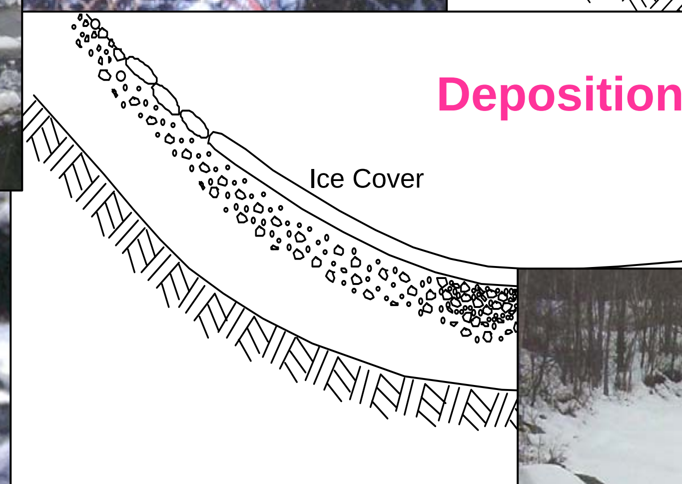






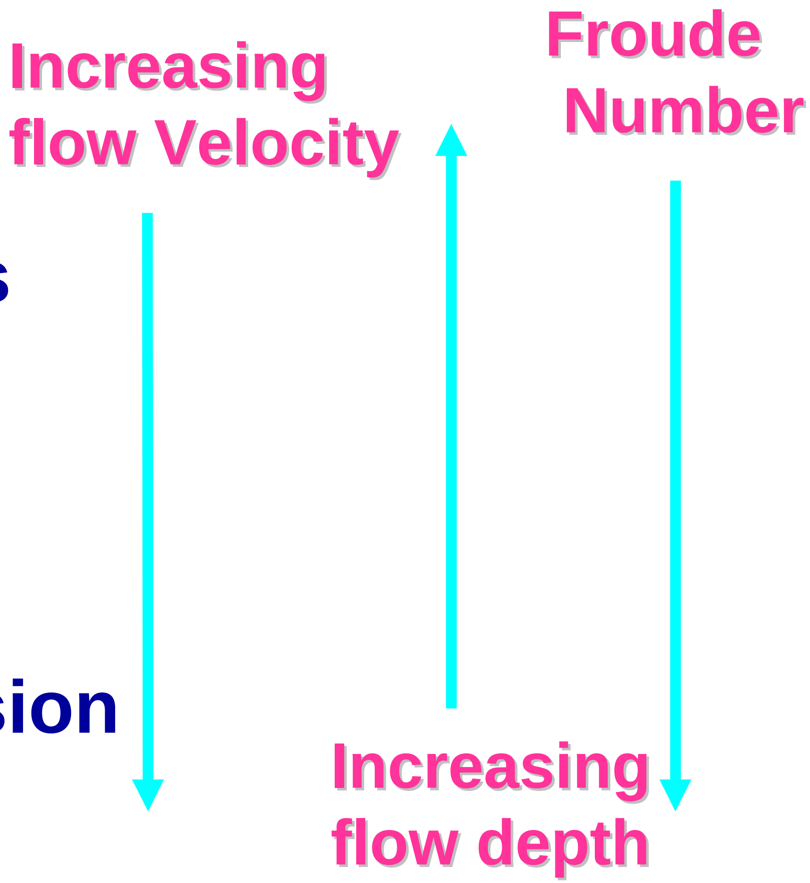
Dynamic Ice Cover Formation



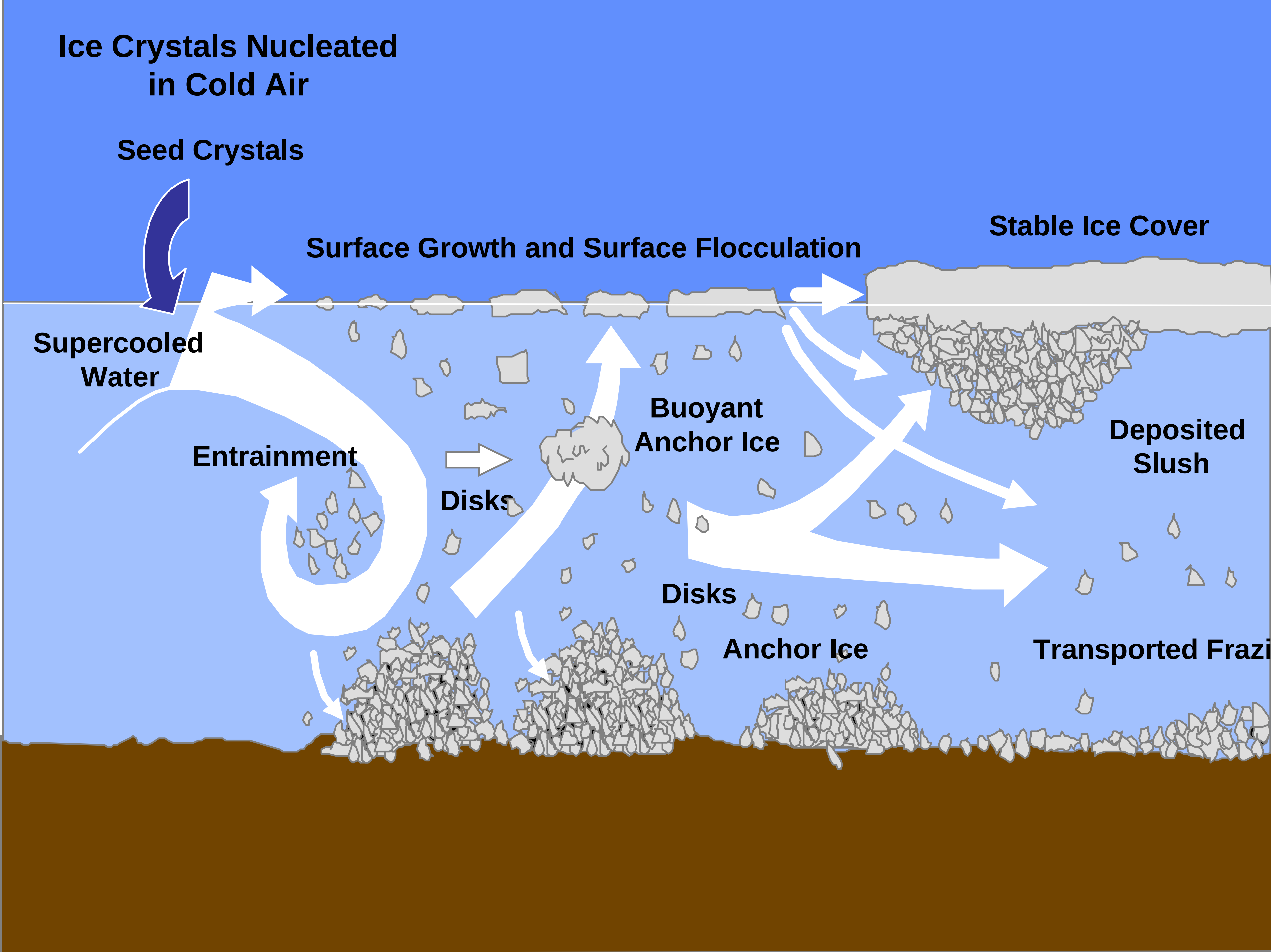


Dynamic Ice Cover Formation

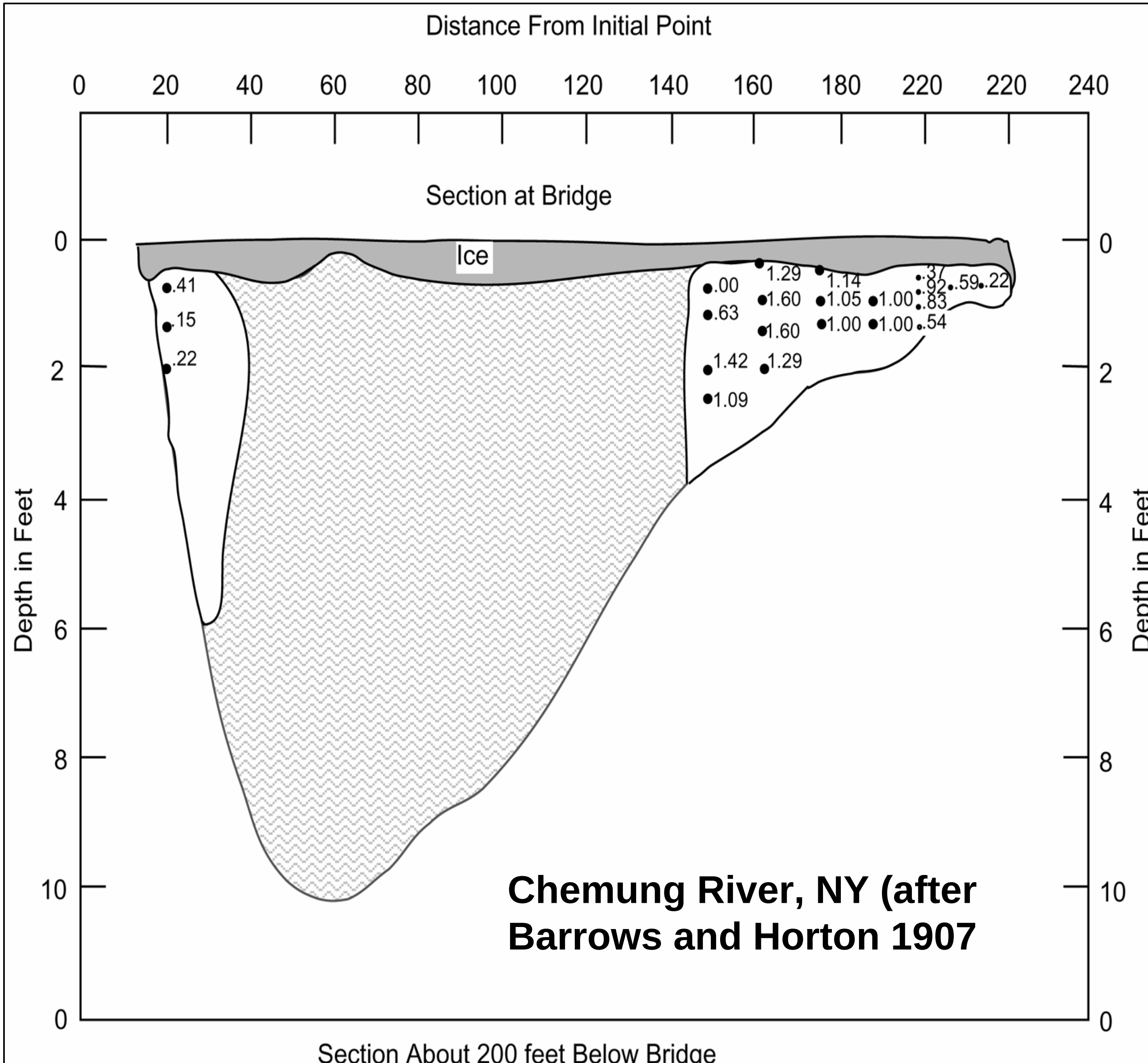
- Bridging
- Juxtaposition of Floes
- Shoving of ice cover
- Underturning of floes
- Under-ice transport
- No ice-cover progression



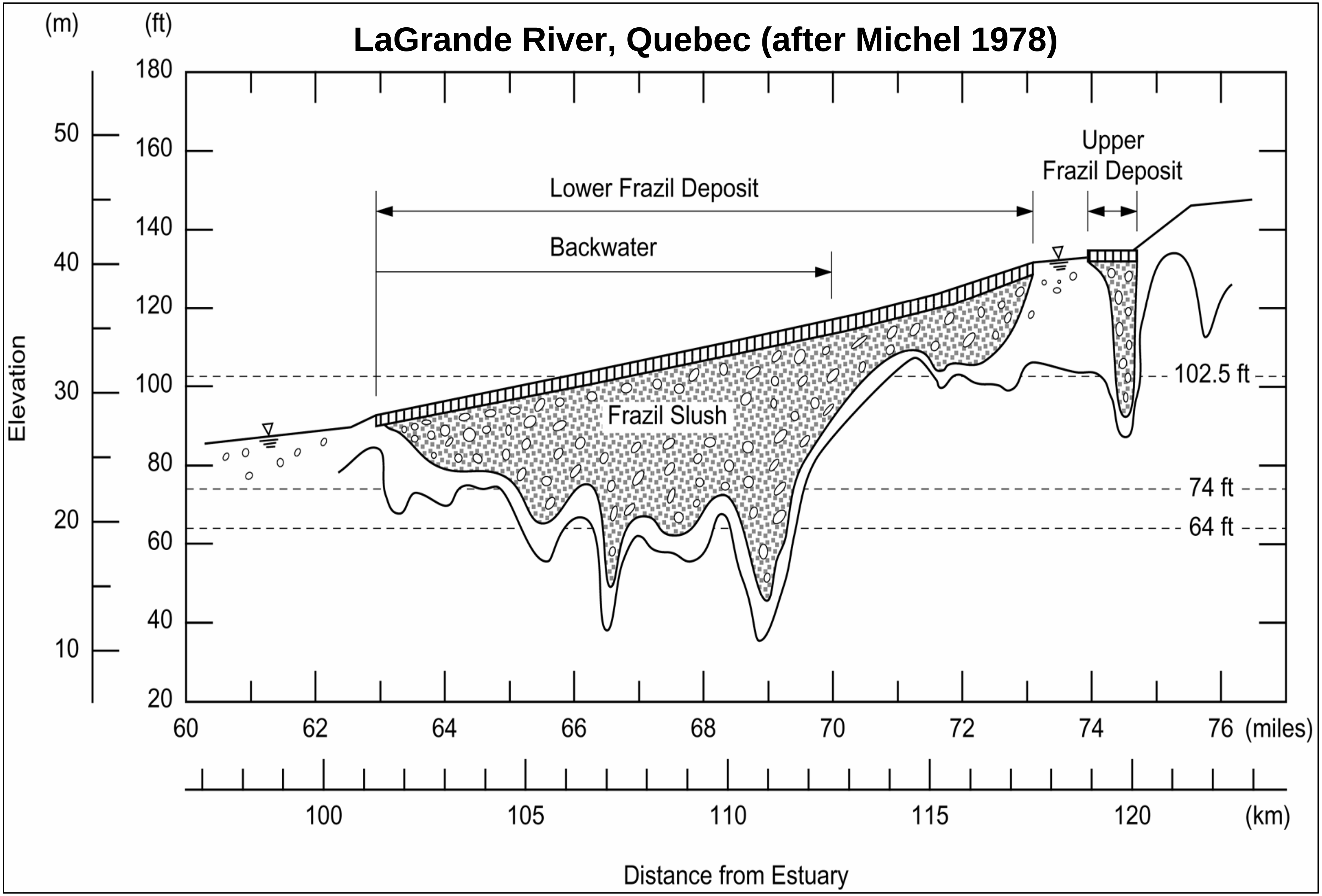
$$F = \frac{v}{\sqrt{gd}}$$



Ice Crystals Nucleated in Cold Air
Seed Crystals
Surface Growth and Surface Flocculation
Stable Ice Cover
Supercooled Water
Entrainment
Disks
Buoyant Anchor Ice
Deposited Slush
Disks
Anchor Ice
Transported Frazi



Distance From Initial Point
0
20
40
60
80
100
120
140
160
180
220
220
240
Section at Bridge
Ice
Depth in Feet
0
2
4
6
8
10
0
.41
.15
.22
.00
1.29
1.14
.37
.92
.59
.22
1.60
1.05
1.00
.83
.63
1.60
1.00
1.00
.54
1.42
1.29
1.09
Section About 200 feet Below Bridge
Chemung River, NY (after Barrows and Horton 1907



LaGrande River, Quebec (after Michel 1978)
(m)
(ft)
Elevation
50
40
30
20
10
180
160
140
120
100
80
60
40
20
Lower Frazil Deposit
Backwater
Upper
Frazil Deposit
Frazil Slush
102.5 ft
74 ft
64 ft
60
62
64
66
68
70
72
74
76
(miles)
100
105
110
115
120
(km)
Distance from Estuary

Ice Cover Breakup

- **Continuum from thermal to mechanical**
- **Thermal Breakup: Ice cover melts in place**
  - **Direct sunlight plays a large role**
  - **Surface color influences absorption of sunlight: Dusting ice promotes melting**
  - **Water on ice decreases reflection, may promote melting**
  - **Open water areas absorb sunlight**
- **Mechanical Breakup: Hydrodynamic forces acting on cover exceed cover strength**
  - **Results from an increase in discharge (=energy to system)**
  - **Precipitation event**
  - **Snowmelt event**
  - **Dam operation (large, sudden increase)**

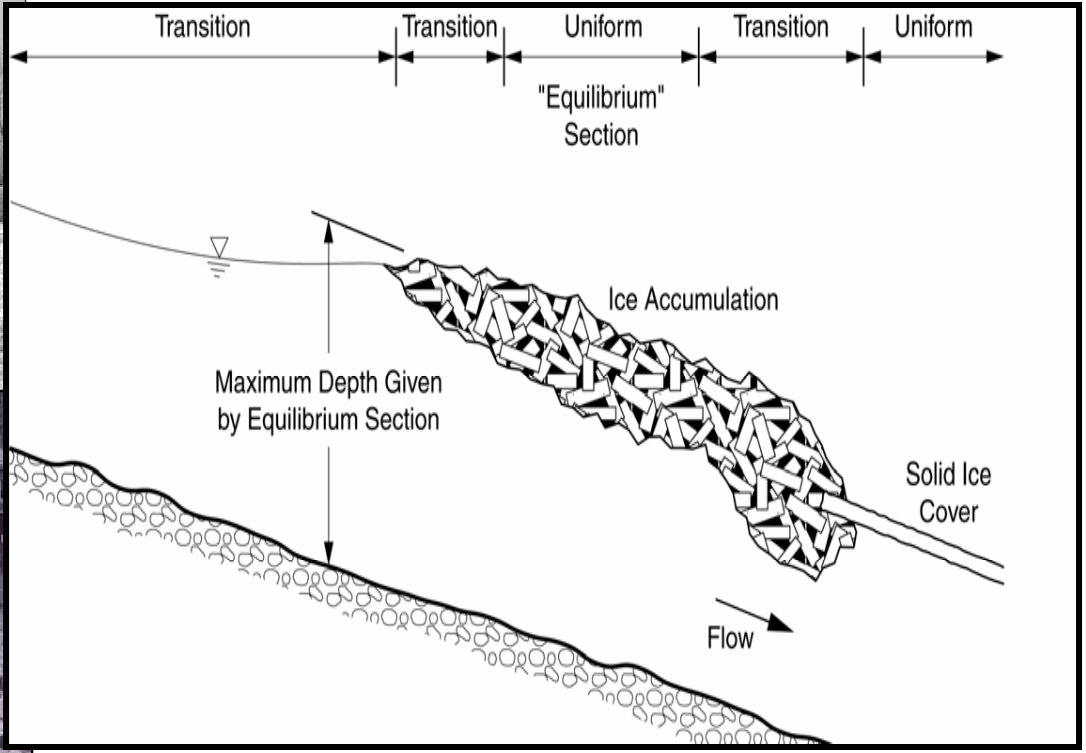
Ice Cover Breakup

- **Rule-of-thumb: stage increase of between 1.5 and 3 times the ice thickness needed to lift, break, and transport ice cover**
- **Often occurs later in impoundments due to damped hydrograph and thicker ice**

Ice cover transport and jamming

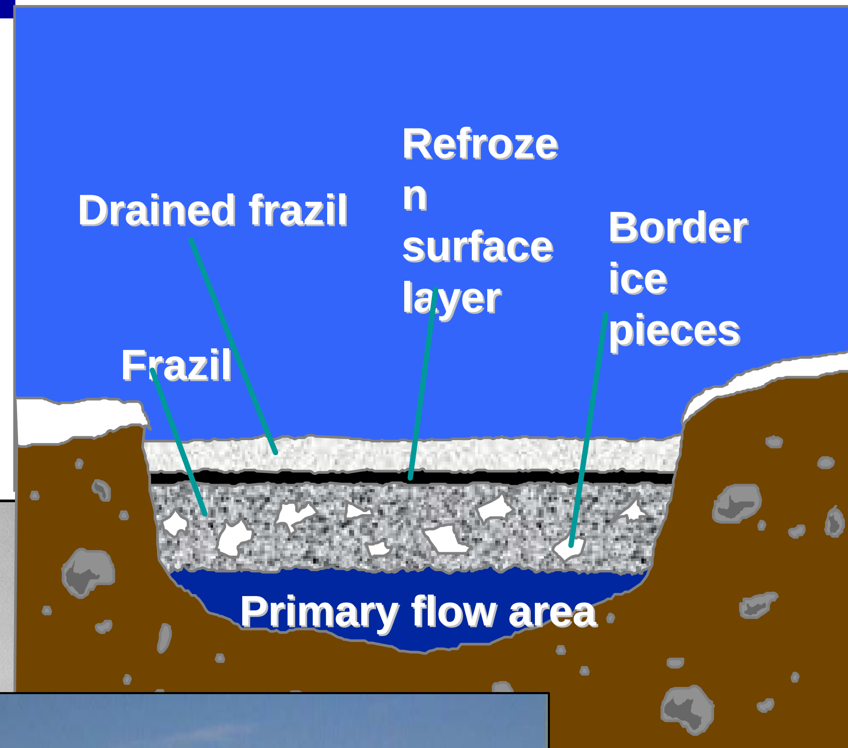
- Broken pieces move downstream until transport capacity is exceeded
  - Decrease in slope
  - Constriction
  - Obstruction (e.g., solid ice cover)
  - Bend, island
- Jam forms quickly
- Underside is very rough, leading to erosion and scour
- Jam failure associated with surges that cause erosion

Ice Jam Formation



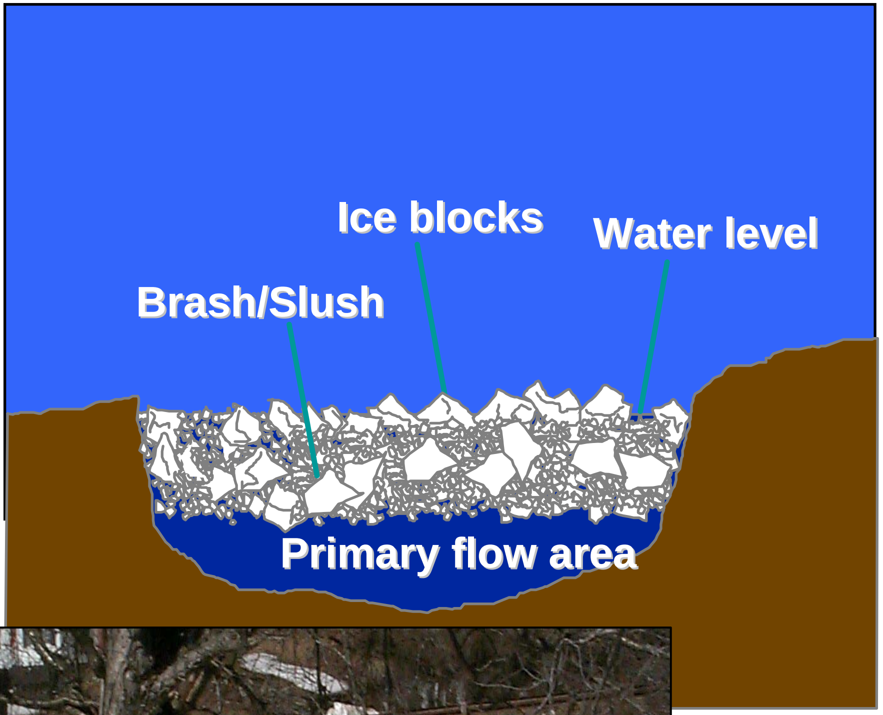
Freezeup Jams

- Early to midwinter formation
- Subfreezing air temperatures
- Fairly steady discharge
- Frazil and broken border ice
- Unlikely to release suddenly
- Smooth to moderate surface roughness

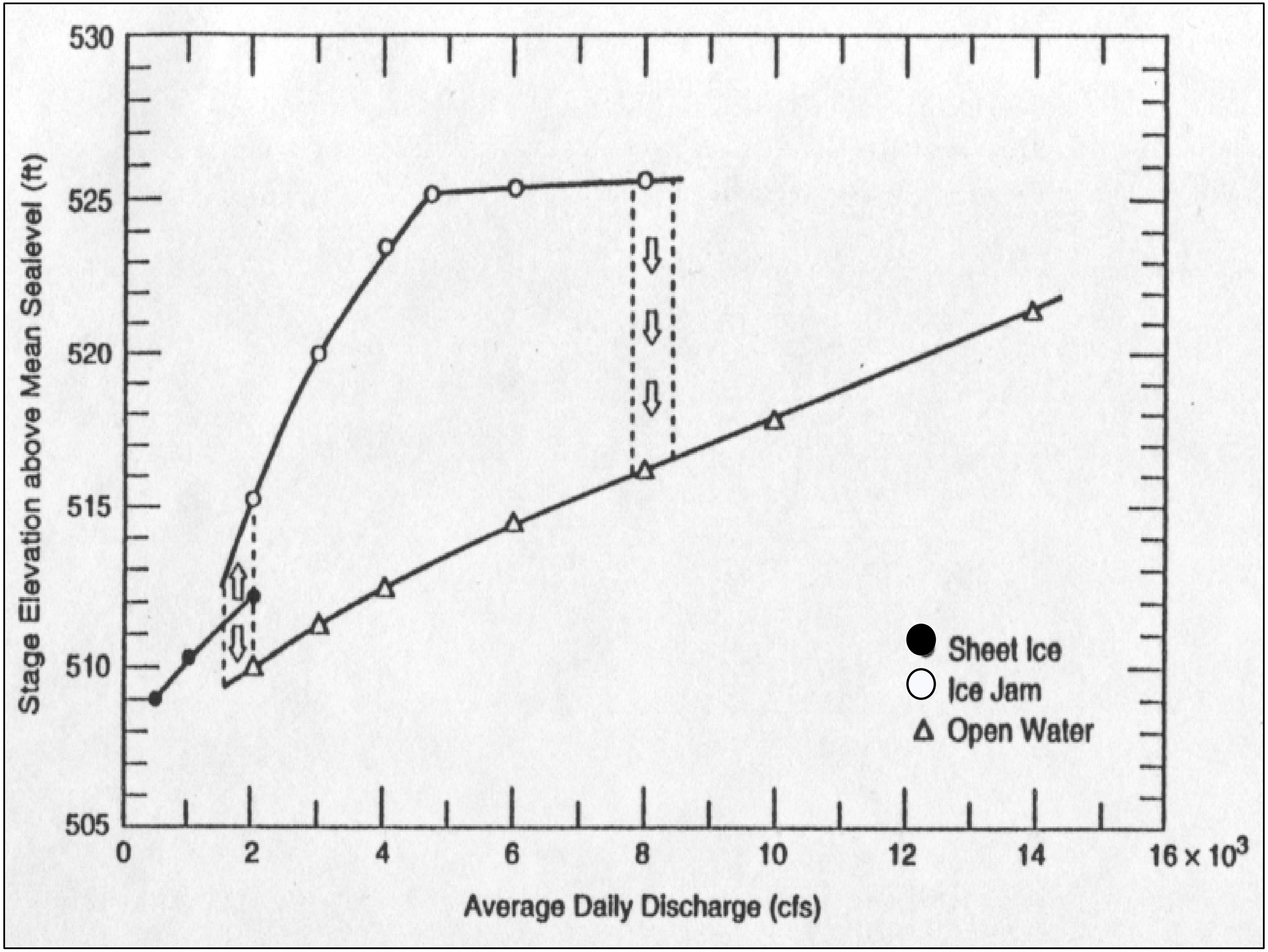


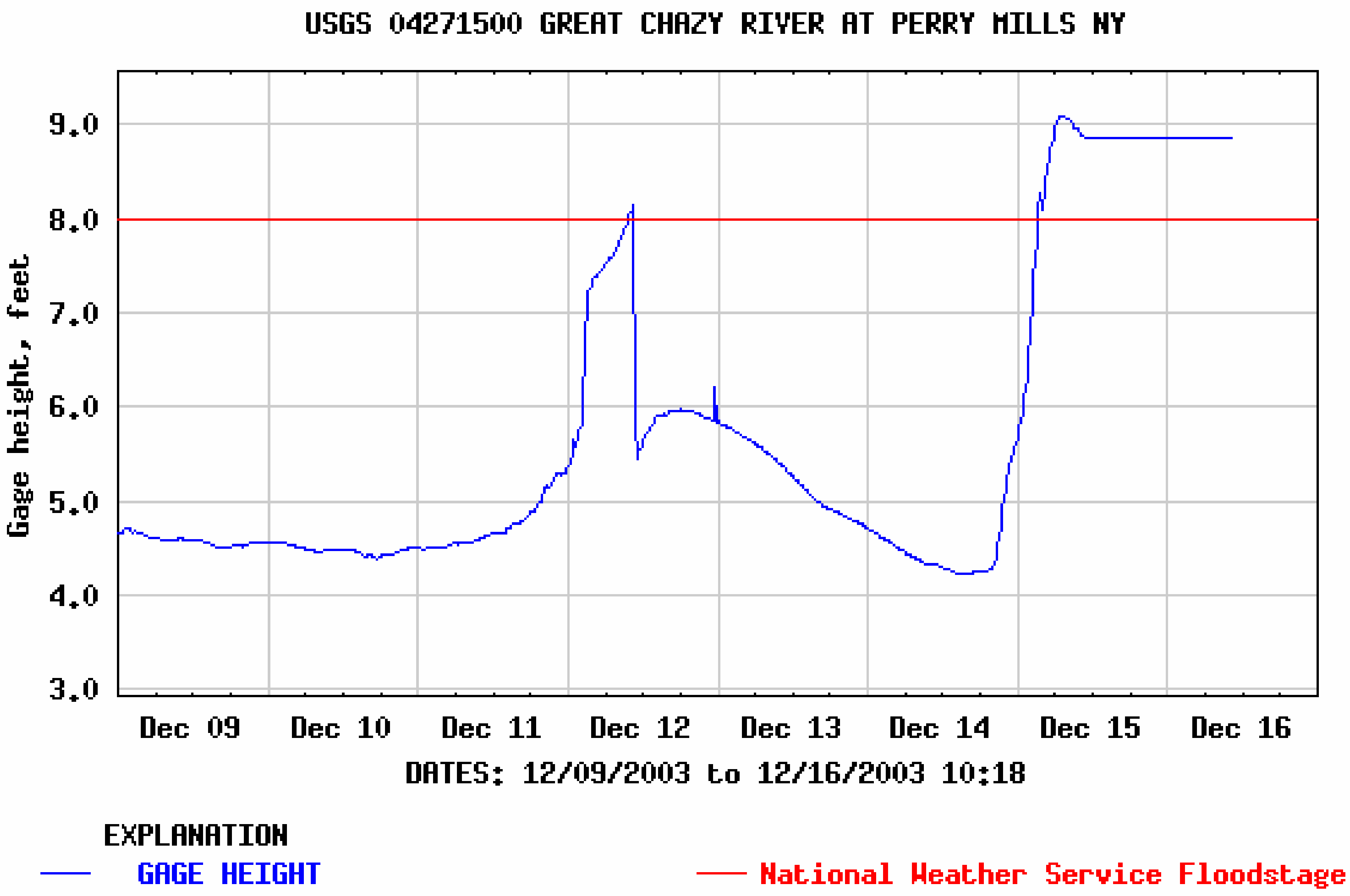
Breakup Jams

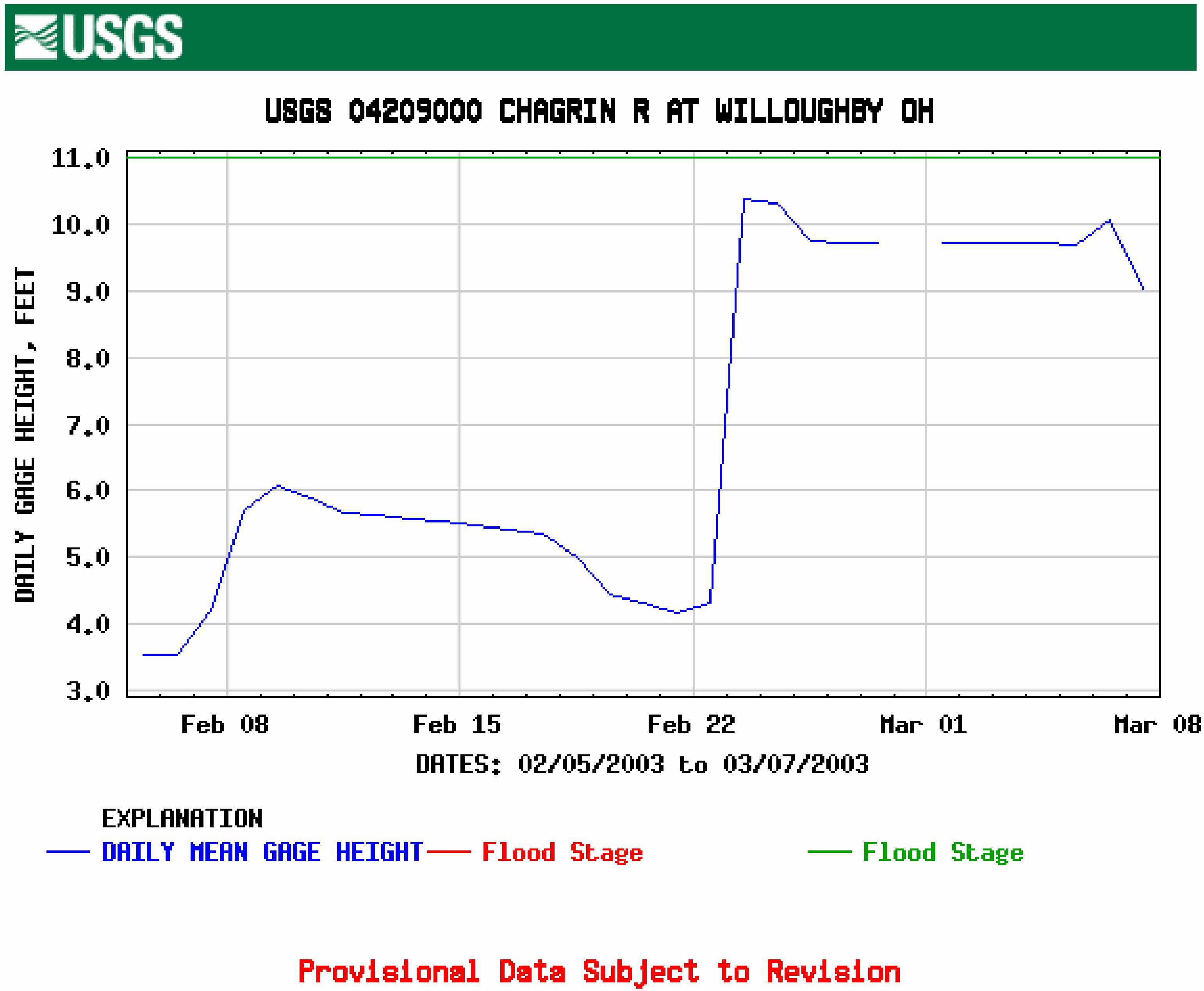
- Can occur any time after ice cover formation but generally mid to late winter
- Can form more than once per season
- Near-freezing air temperatures
- Highly unstable, with sudden failures
- Unsteady water flow (surges)
- Moderate to extreme surface roughness
- Midwinter jams may freeze in place, causing additional problems later in the season

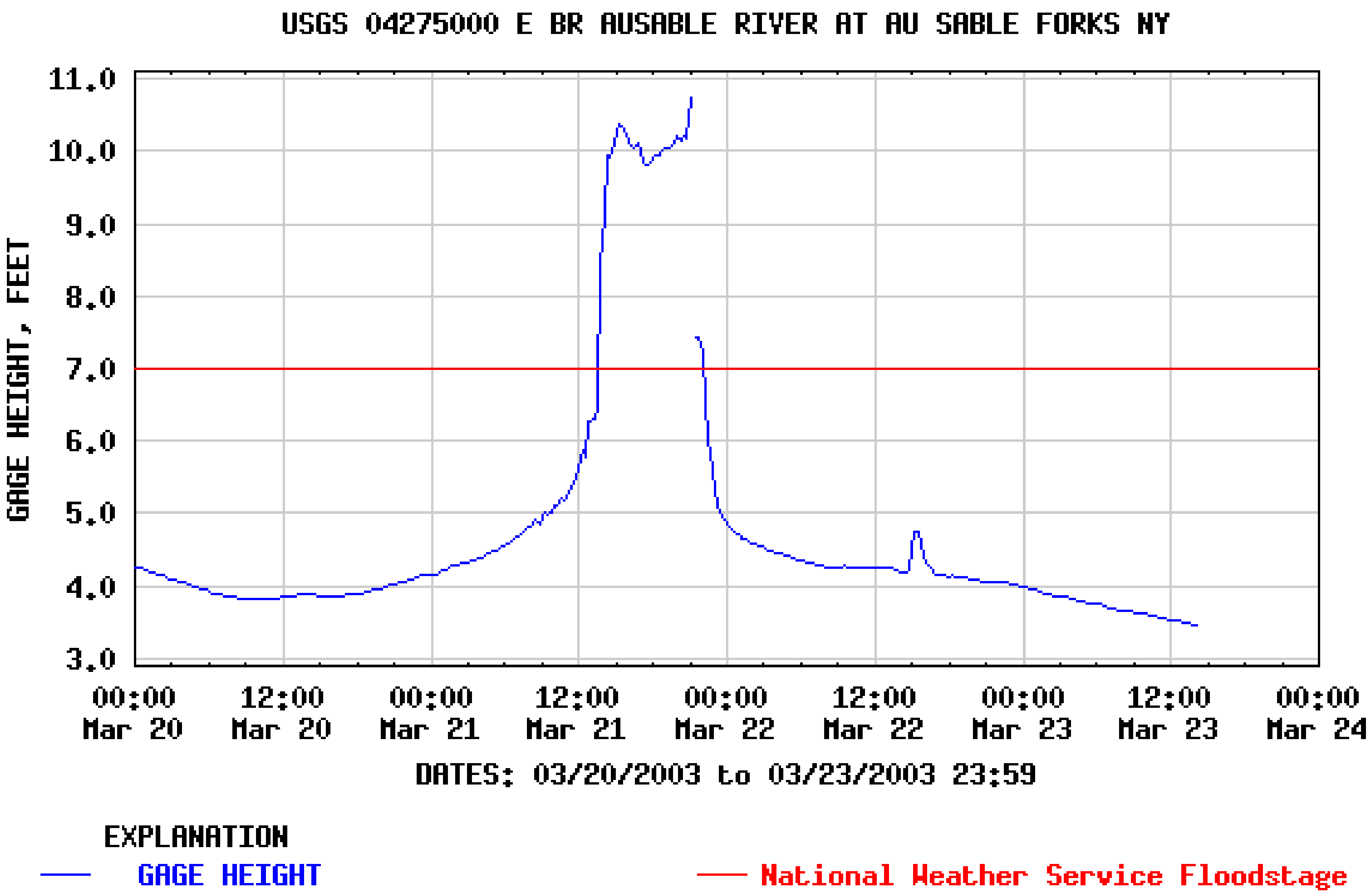


Ice-Affected Stages




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

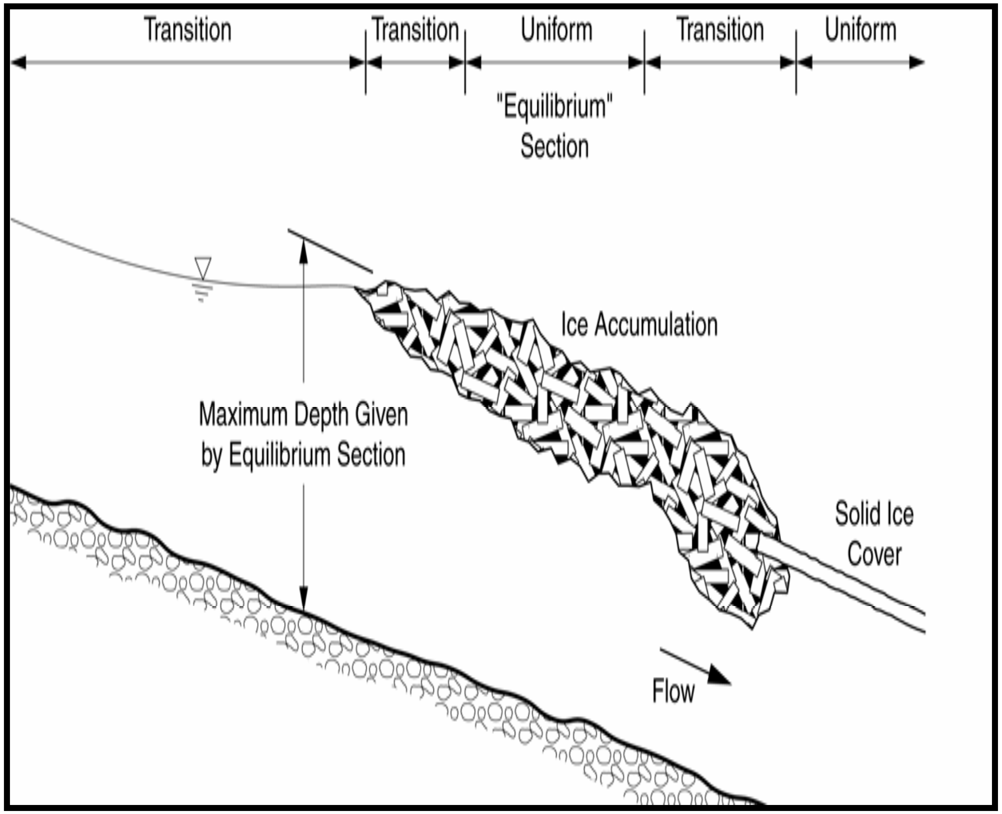

USGS
USGS 04209000 CHAGRIN R AT WILLOUGHBY OH
DAILY GAGE HEIGHT, FEET
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
Feb 08
Feb 15
Feb 22
Mar 01
Mar 08
DATES: 02/05/2003 to 03/07/2003
EXPLANATION
DAILY MEAN GAGE HEIGHT
Flood Stage
Flood Stage
Provisional Data Subject to Revision



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

Modeling Ice-Covered Rivers

- **Steady Flow**
  - **HEC-RAS (HEC-2 is obsolete!)**
  - **1-D steady flow**
  - **Freezeup or breakup**
  - **Can model deposition using iterative process**
- **Unsteady Flow**
  - **UNET**
  - **Discrete Element Models**
- **Zufelt (1999) provides test to determine whether steady flow assumptions are violated to the point that unsteady flow is required**
- **2 Dimensional Flow**
  - **Currently in development**



Note: Flood insurance studies and re-studies at locations with frequent ice jams should include ice hydraulic modeling, or regulatory floodplain limits may not be conservative enough

Summary

- 2 Types of ice: frazil and thermally grown
- Estimates of thermally grown ice thickness can be used to provide estimate of change in stage required to cause ice cover breakup
- Dynamic ice formation processes provide information on the flow velocity and likelihood of jamming:
  - Bridging
  - Juxtaposition
  - Shoving
  - Underturning of floes
  - Under-ice transport/deposition
  - No ice-cover progression
- Frazil deposition beneath ice can impact breakup jam location