

2003

Cold Climate Considerations in Stream Restoration (2003 Stormwater Management in Cold Climates Presentation)

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STORMWATER MANAGEMENT IN COLD CLIMATES:

Planning, Design and Implementation

November 3-5, 2003, Portland, ME

Cold Climate Considerations in Stream Restoration

Craig Fischenich, PhD, PE

Kate White, PhD, PE

US Army Corps of Engineers

Engineer Research and Development Center

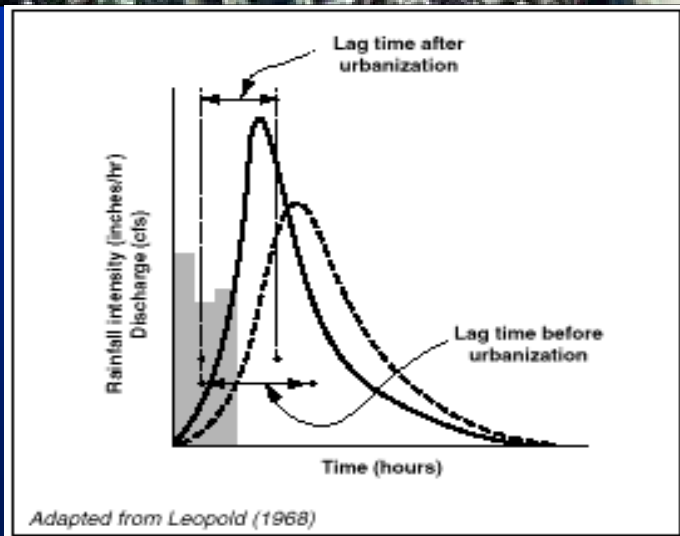
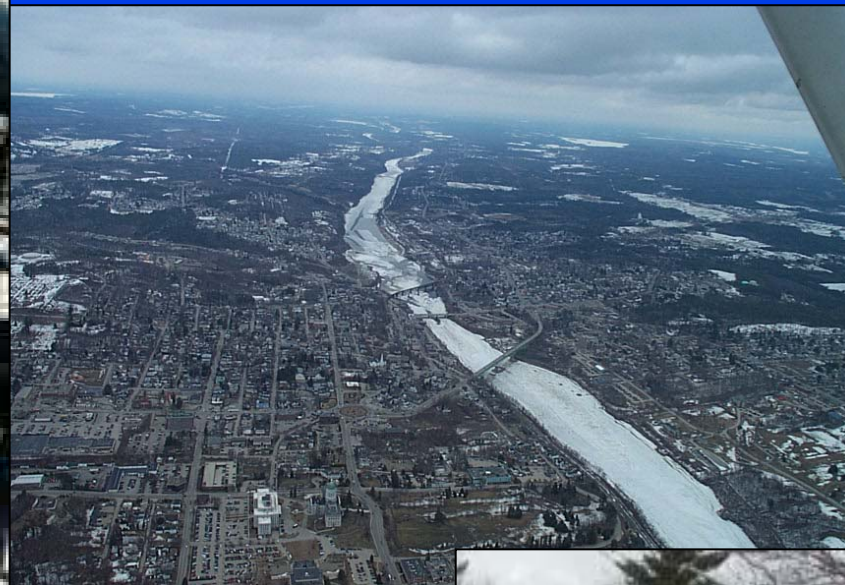
Craig.J.Fischenich@erdc.usace.army.mil

Kathleen.D.White@erdc.usace.army.mil

USACE Environmental Operating Principles

1. Strive to *achieve environmental sustainability*. An environment maintained in a healthy, diverse, and sustainable condition is necessary to support life.
2. Recognize the *interdependence of life and the physical environment*, and consider environmental consequences of Corps programs and activities in all appropriate circumstances.
3. Seek balance and synergy among human development activities and natural systems by designing *economic and environmental solutions* that support and reinforce one another.
4. Continue to *accept corporate responsibility and accountability* under the law for activities and decisions under our control that impact human health and welfare and the continued viability of natural systems.
5. Seek ways and means to assess and mitigate *cumulative impacts* to the environment; bring systems approaches to the full life cycle of our processes and work.
6. Build and share an integrated scientific, economic & social *knowledge base* that supports a greater understanding of the environment and impacts of our work.
7. *Respect* the views of individuals and groups interested in Corps activities; listen to them actively and learn from their perspective in the search to find win-win solutions to the Nation's problems that also protect & enhance the environment.





Sustainable Urban Flood Damage Reduction

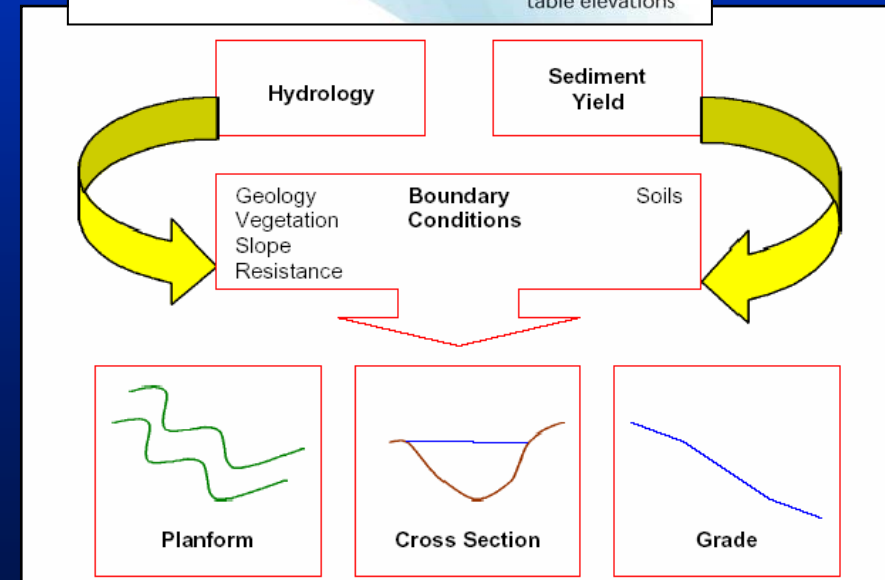
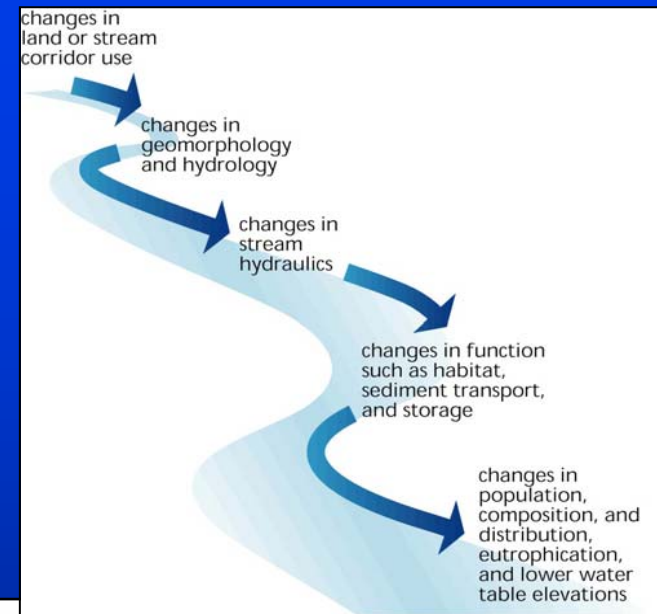
Sustainable Urban FDR

- The impacts of urbanization and the engineering efforts to control urban flooding are not simply local impacts, but are part of system-wide cumulative impacts and may affect the entire watershed
- There is little published guidance for accomplishing restoration of urban channels within a systems context that considers the entire watershed
 - Direct impacts of natural events and human activities
 - urbanization
 - construction of dams, levees, and diversion structures
 - straightening, widening, deepening, clearing of channel systems
 - Indirect impacts through pathways
 - hydrological
 - ecological
 - Cumulative impacts at the system scale



Stormwater Management Issues

- Existing regulations tend to neglect system considerations
- Volume/duration/stability relations poorly understood
- Techniques for multiple benefits needed
- Guidelines for designs related to watershed position needed
- New outlet controls needed
- Efficient stormwater management often includes retention and detention basins to reduce the impacts of development upon runoff characteristics
 - Potential adverse impacts on receiving streams by extending the duration of flows with sufficient energy to induce erosion of the channel's bed and banks
 - Solutions that involve modification to the design of stormwater basins can reduce this impact
 - Methods to enhance or restore the stream and riparian environment are needed as well

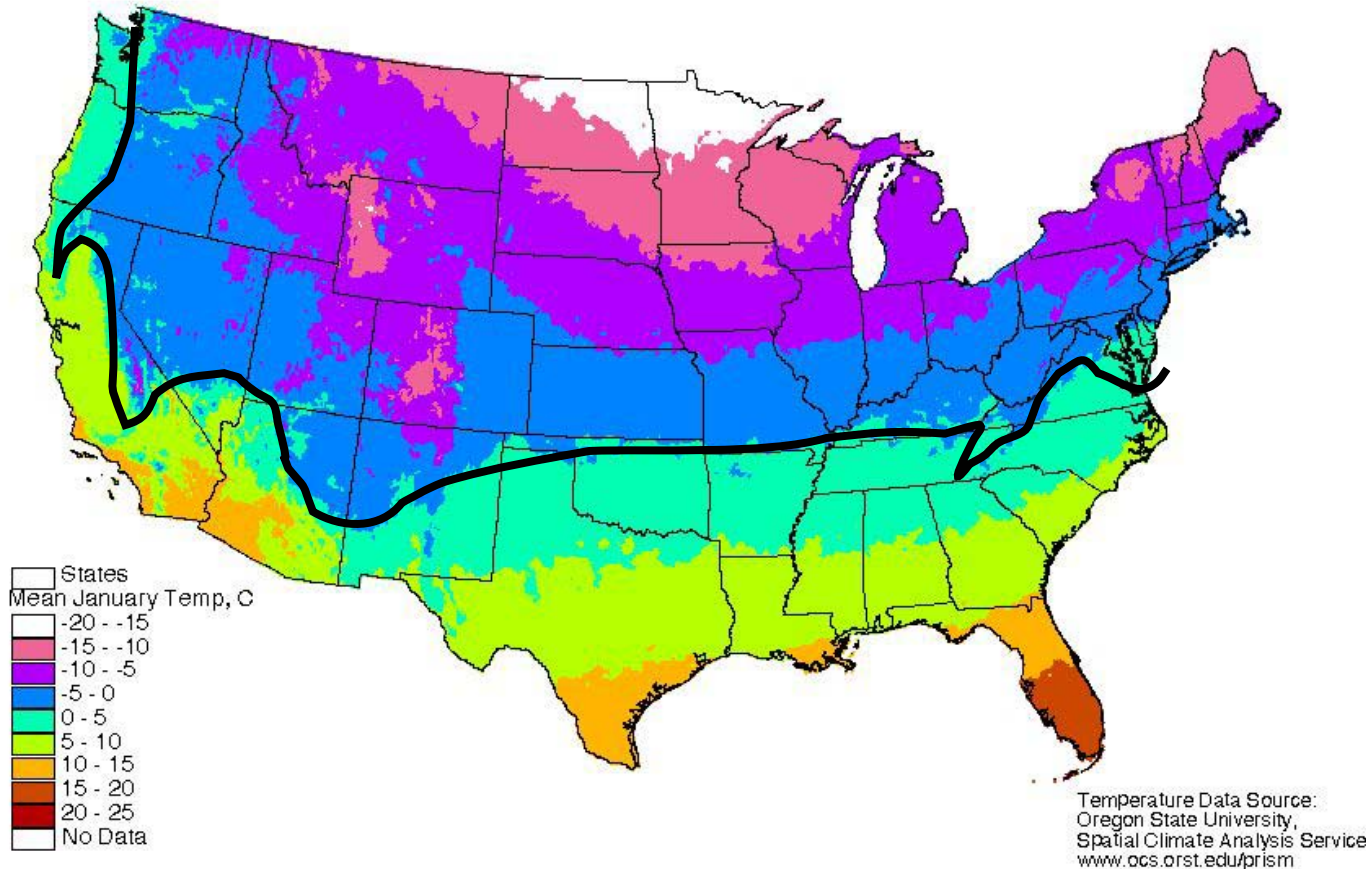


Cold Climate Issues

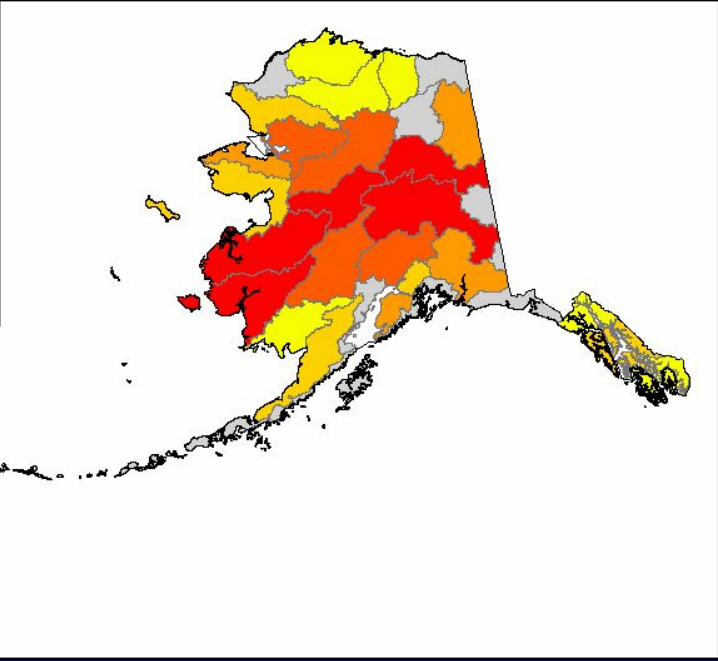
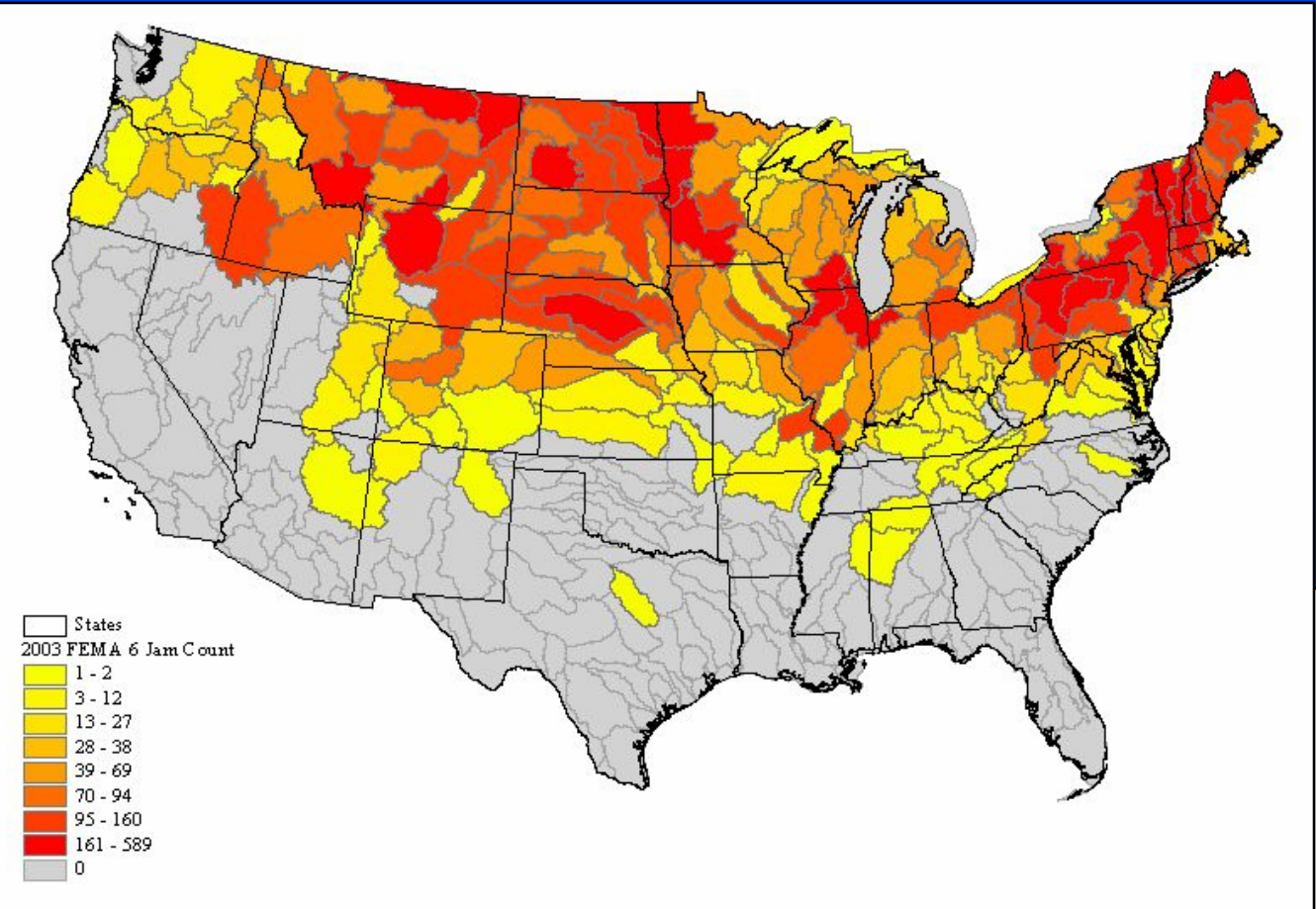
- Snowmelt \Rightarrow pollutant loads (numerous)
- Snow management, deicing techniques \Rightarrow pollutant loads (numerous)
- Stormwater facilities \Rightarrow freezing, pollutant loads, ice covers (e.g., Gary Oberts, MN BMP, Center for Watershed Protection)
- Stream restoration \Rightarrow effective design guidelines
- Impacts of ice on stream restoration design has not been adequately addressed
 - Design of a stable channel slope and channel stabilization measures
 - Ice-affected stage-frequency
- As a result, stream restoration projects in cold climates may not operate as designed
- This presentation will discuss planning and design considerations for stream restoration in cold climates



Mean January Temperature



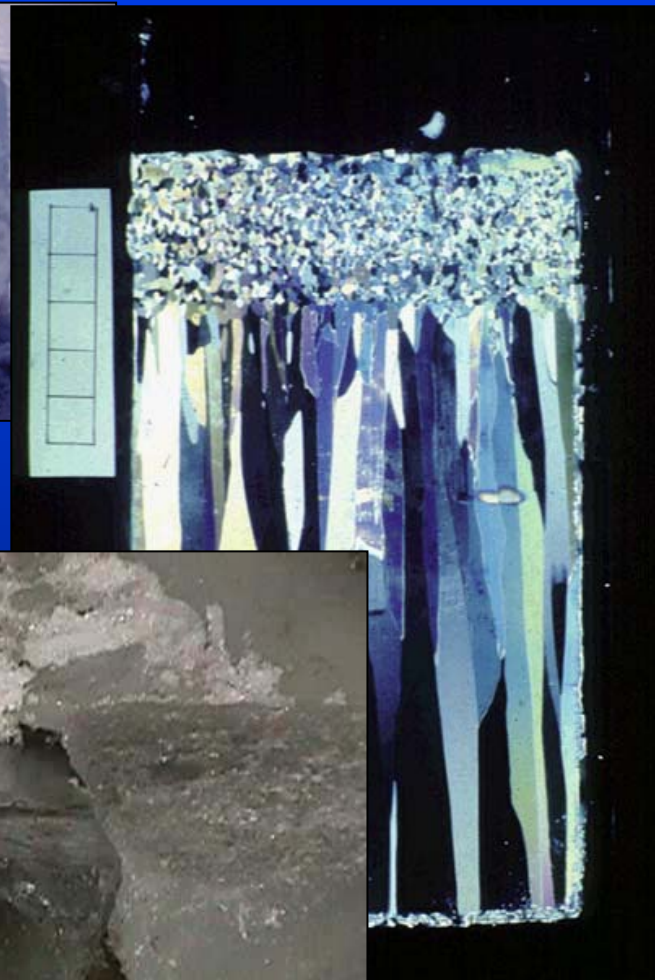
CRREL Ice Jam Database
>13,500 ice events
Currently updating
Wisconsin,
Pennsylvania,
upstate New York



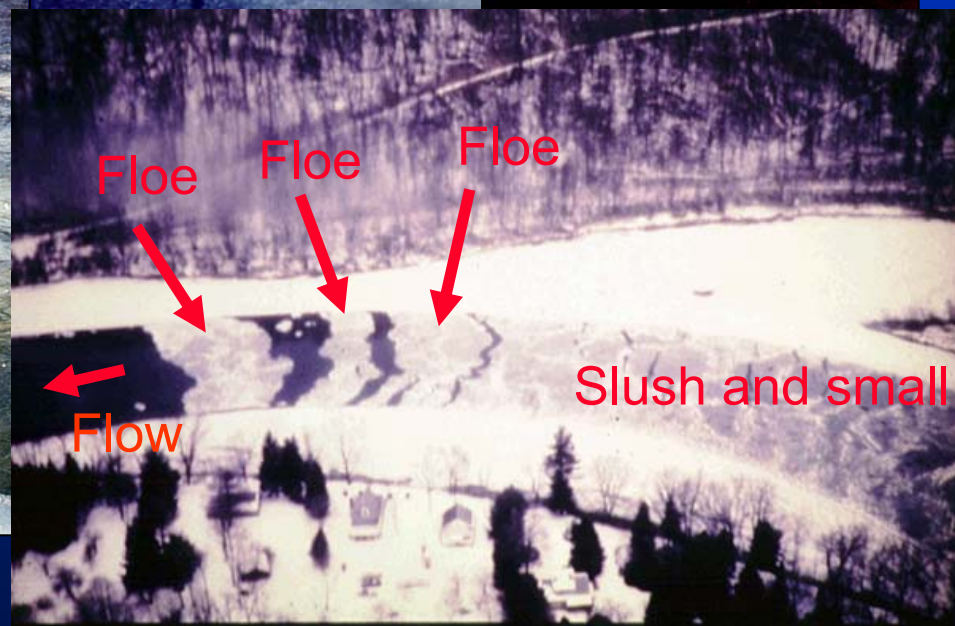
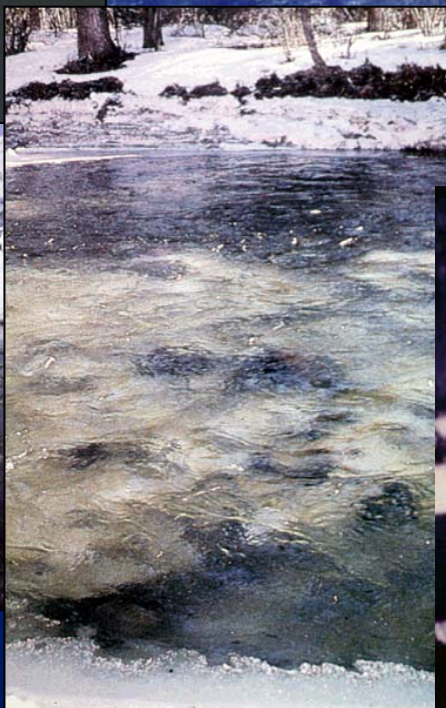
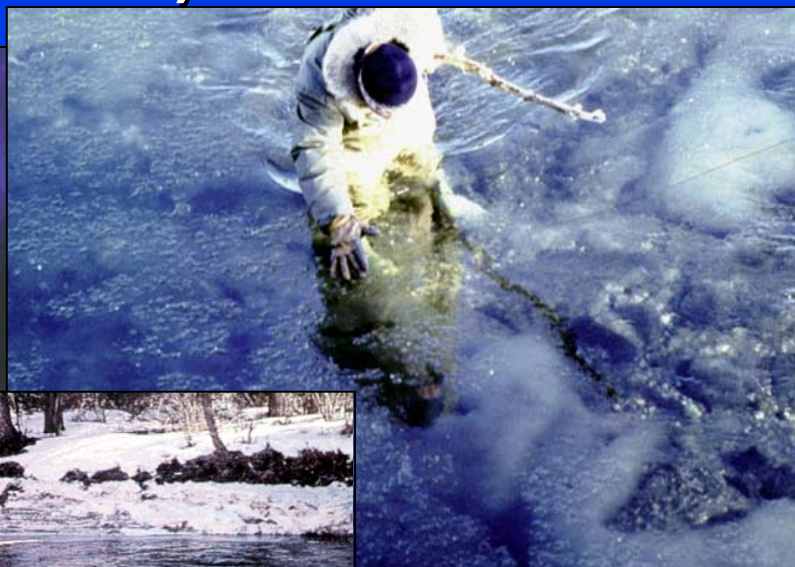
<http://www.crrel.usace.army.mil/ierd/ijdb/>



Thermally-grown ice



Dynamically formed (frazil) ice



Dynamic Ice Cover Formation

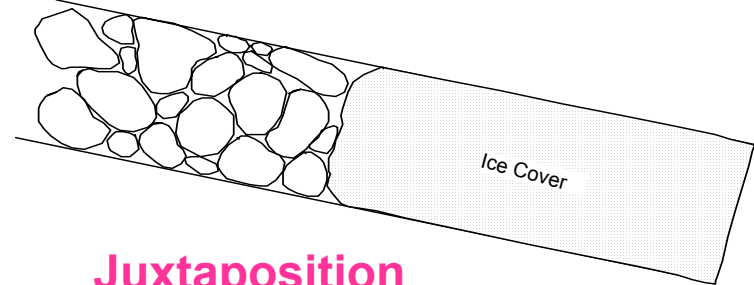
Ice bridging or arching



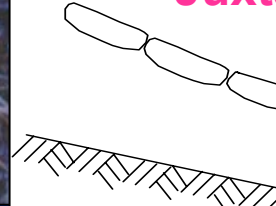
Shoving



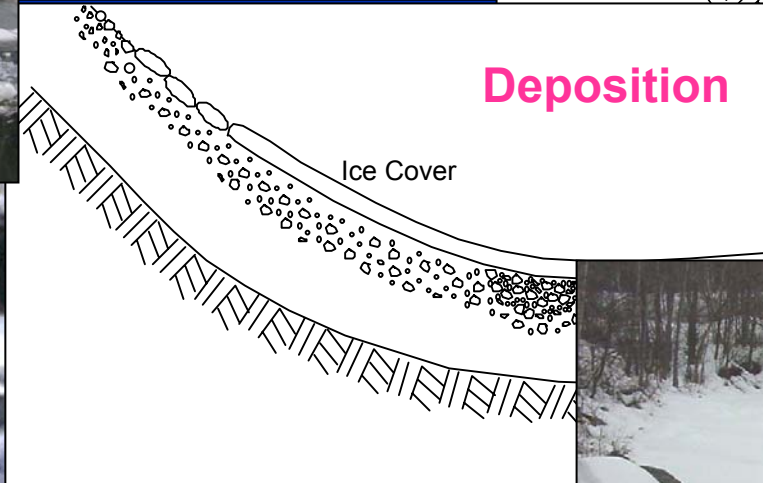
Underturning



Juxtaposition



Deposition



No Ice Cover Possible



Ice Cover Growth

Estimate thermal ice growth from modified Stefan equation

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

<i>Ice Cover Condition</i>	α^*	$\alpha \dagger$
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.





Ice Engineering

U.S. Army Engineer Research and Development Center, Hanover, N

Method to Estimate River Ice Thickness Based on Meteorological Data

River ice can damage riverine structures such as bridges, locks, dams, dikes, groins, levees, rip forms of bank protection, and can block hydropower and water supply intakes. Ice jams affect stoppages, or damage to tows, barges, and mooring/floating areas. Ice-induced scour may cause to banks, with adverse effects on fish and wildlife habitat, as well as the exposure of utilities buried 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 regime that r or more severe ice jamming. Emergency and medical relief to flooded areas may be limited by fl and erosion of roads resulting in road closures, or by the closure of bridges weakened or destr exists for death or serious injury during ice-related flooding, evacuations, and other ice mitigation

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



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

ERDC/CRREL Technical Note 03-4

CECW-EH

Manual
No. 1110-2-1612

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

Engineering and Design ICE ENGINEERING

- Purpose.** This manual, composed of three parts, presents in Part I the planning, design, construction, and operation and maintenance of ice control measures for Corps of Engineers projects; provides in Part II the current gams and the resultant flooding, including preventive measures; and gives i for engineering and operational solutions to ice problems on rivers used fo
- Applicability.** This manual is applicable to all USACE commands ha works design, construction, operations, and maintenance.
- Distribution statement.** Approved for public release, distribution is
- References.** Bibliographic material is included at the end of each cha
- Discussion.** All Corps projects subjected to freezing temperatures ha buildup on lock walls, hydropower intakes, and lock approaches; ice accu channels; ice passage over spillways that scours the downstream channels; structures and shorelines, etc. Therefore, ice control measures should be co existing projects to improve operations and safety in cold regions. In Part I discussion of ice formation processes, physical properties, and potential so Part II considers the problem of ice jams and ice jam flooding, and discuss measures. Part III of this manual addresses the considerations that arise fro waterways, including the conduct of river ice management studies and the management plans.

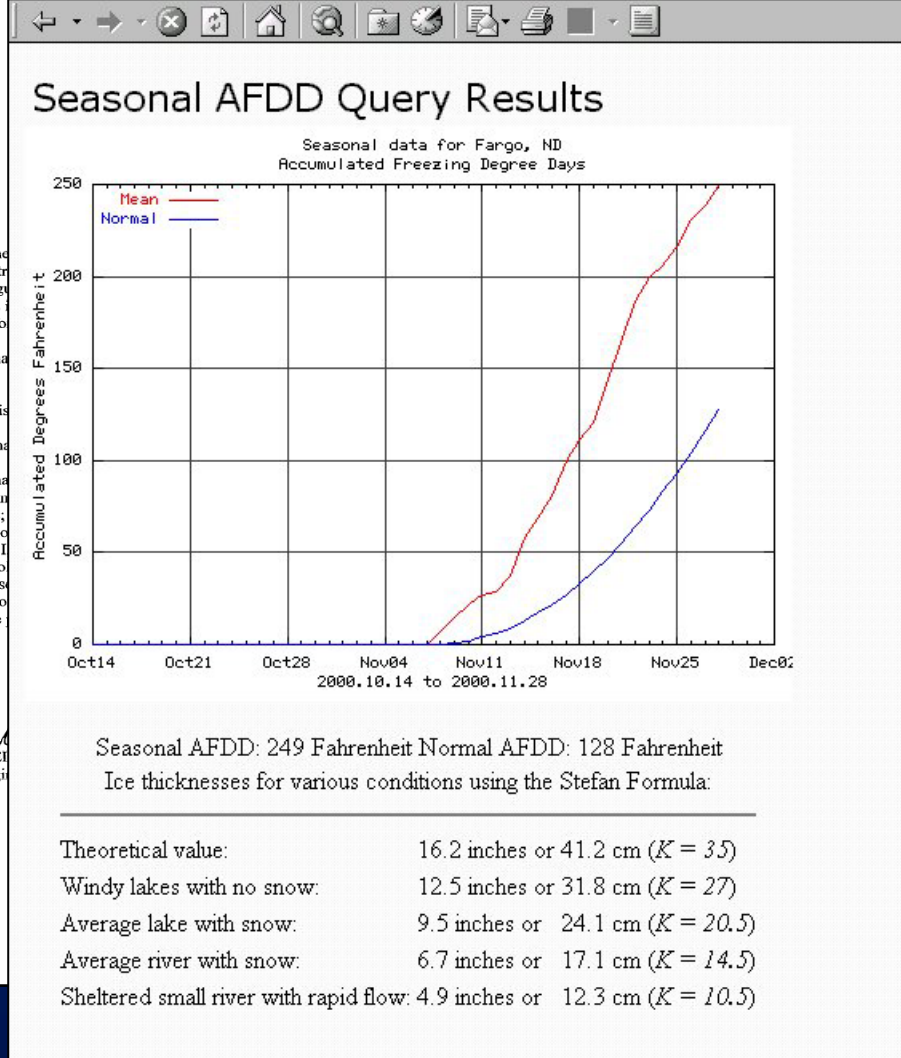
FOR THE COMMANDER:

3 Appendices
(See Table of Contents)

Joseph Schroeder
JOSEPH SCHROEDER
Colonel, Corps of Engi
Chief of Staff

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

EM 1110-2-1612



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
 - 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



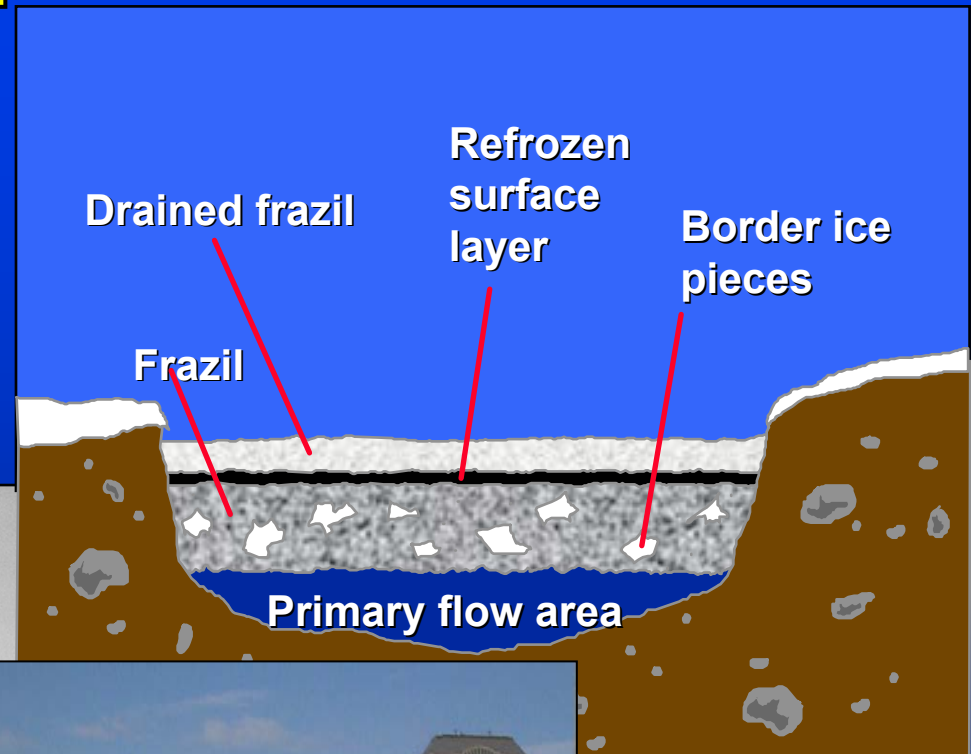
Ice cover transport and jamming

- 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



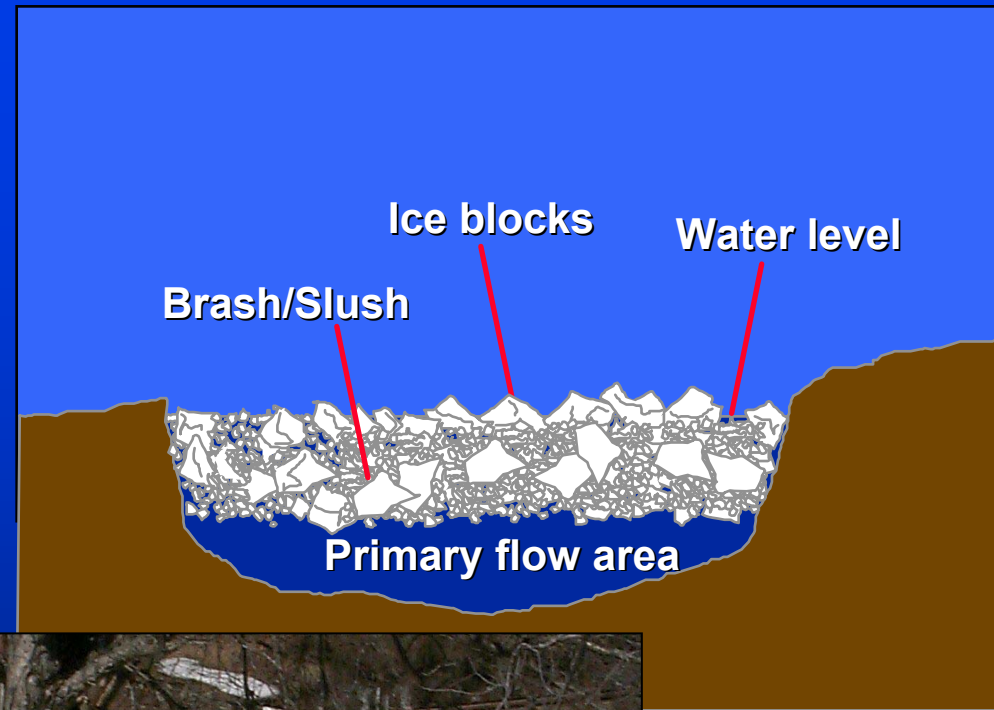
Freezeup Jams

- 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



Manning's Equation with Ice

$$Q = \frac{1.486}{n_c} A_i R_i^{2/3} S_o^{1/2}$$

$1/2$ when $B \gg d$

$$Q = \frac{1.486}{n_c} B d \left[\frac{B d}{2B + 2d} \right]_i^{2/3} S_o^{1/2}$$

$$H = \frac{\rho'}{\rho} \eta + 1.32 \left[\frac{Q n_c}{1.486 B S_o^{1/2}} \right]_i^{3/5}$$

At least 32% increase in total depth due to ice cover at uniform flow

A = cross sectional flow area

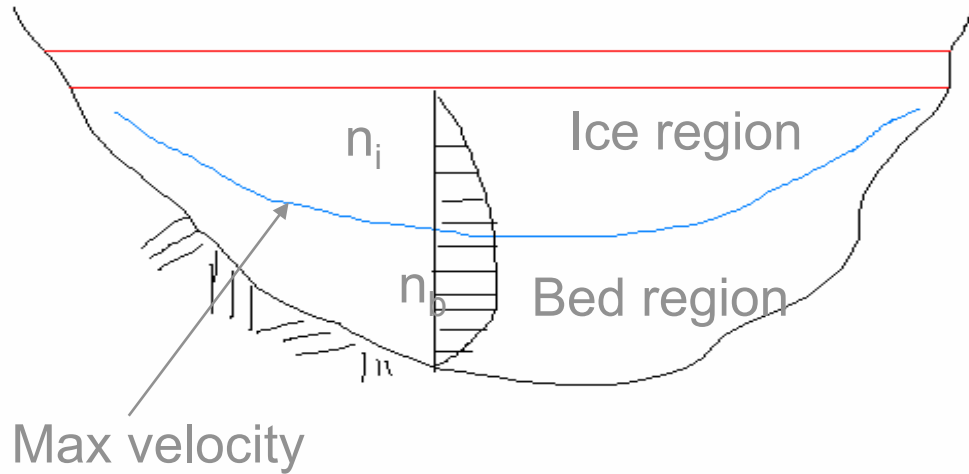
P = wetted perimeter

Δx = distance between cross sections

$R = A/P$ (hydraulic radius)

Velocity profile under steady flow conditions

- assume average flow velocity in the ice region and the bed region are equal
- assume Manning's equation applies to each
- assume the energy grade line is the same in both



$$V_i = \frac{1}{n_i} R_i^{2/3} S^{1/2}$$

$$V_b = \frac{1}{n_b} R_b^{2/3} S^{1/2}$$

$$V_o = \frac{1}{n_c} R_o^{2/3} S^{1/2}$$

$$n_c = \left[\frac{n_i^{3/2} + n_b^{3/2}}{2} \right]^{2/3}$$

Belokon-Sabaneev Formula

Table 1. Values of ice roughness coefficient (n_i) and composite roughness coefficient (n_c) calculated from discharge measurements.

(n_i)	(n_c)	<i>Comment</i>	<i>Reference</i>
	0.010–0.012	Sheet ice, early winter*	Nezhikhovskiy (1964)
	0.008–0.010	Sheet ice, late winter	Nezhikhovskiy (1964)
0.010–0.06†		Ice cover formed from loose frazil*	Nezhikhovskiy (1964)
0.013–0.09†		Ice cover formed from dense frazil*	Nezhikhovskiy (1964)
0.015–0.10†		Ice cover formed from sheet ice*	Nezhikhovskiy (1964)
0.010–0.028**	0.018–0.027	Sheet ice	Carey (1966)
0.004–0.013**	0.015–0.022	Sheet ice	Carey (1967)
0.10	0.090–0.109	Breakup jams	Beltaos (1978)
0.057–0.065, $\bar{n}_i = 0.060$	0.041–0.046	Breakup jam	Andres (1980)
0.010–0.015		Breakup jam	Knowles and Hodgins (1980)
	0.053–0.142	Breakup jams	Michel (1980)
0.013–0.040		Freezeup jam*	Beltaos (1981)
0.033–0.041††		Freezeup jam*	Beltaos (1983)
0.072		Breakup jams	Andres and Doyle (1984)
0.020–0.15		Freezeup jam, frazil deposits	Majewski and Grzes (1986)

*Within three days of formation.

†Higher values for thicker accumulations.

**Lower values earlier in the winter.

††Higher values for thinner accumulations.



Table 4. Stability of Channel Linings for Given Velocity Ranges

Lining	0 – 2 fps	2 – 4 fps	4 – 6 fps	6 – 8 fps	> 8 fps
Sandy Soils	Yellow	Red	Red	Red	Red
Firm Loam	Yellow	Yellow	Red	Red	Red
Mixed Gravel and Cobbles	Green	Yellow	Yellow	Red	Red
Average Turf	Green	Yellow	Yellow	Red	Red
Degradable RECPs	Green	Yellow	Yellow	Yellow	Red
Stabilizing Bioengineering	Green	Yellow	Yellow	Yellow	Red
Good Turf	Green	Green	Yellow	Yellow	Yellow
Permanent RECPs	Green	Green	Green	Green	Yellow
Armoring Bioengineering	Green	Green	Green	Green	Yellow
CCMs & Gabions	Green	Green	Green	Green	Yellow
Riprap	Green	Green	Green	Green	Green
Concrete	Green	Green	Green	Green	Green

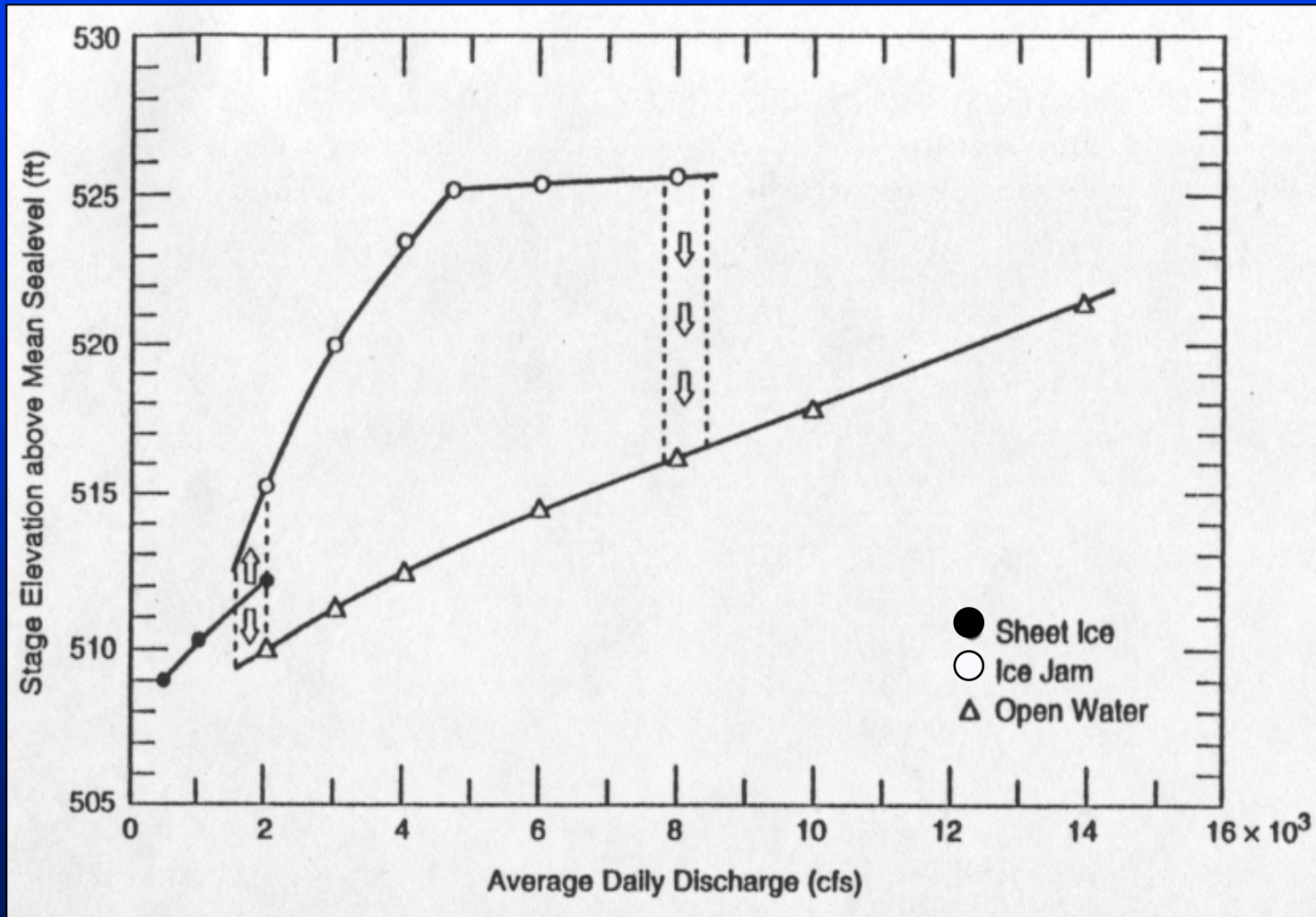
Key:

Green	Appropriate
Yellow	Use Caution
Red	Not Appropriate

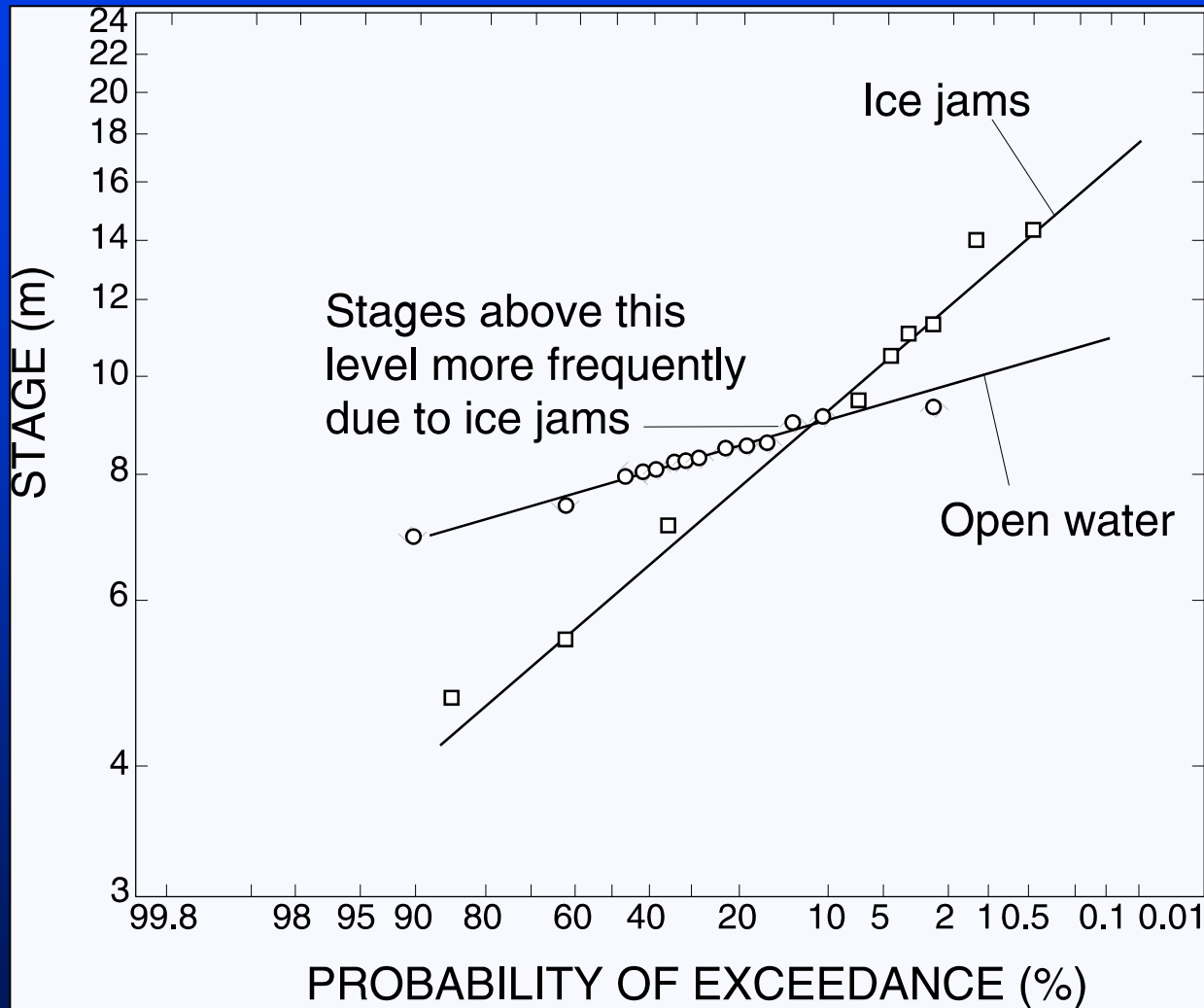
Increased velocity and shear due to ice cover has implications on material selection



Ice-Affected Stage-Frequency



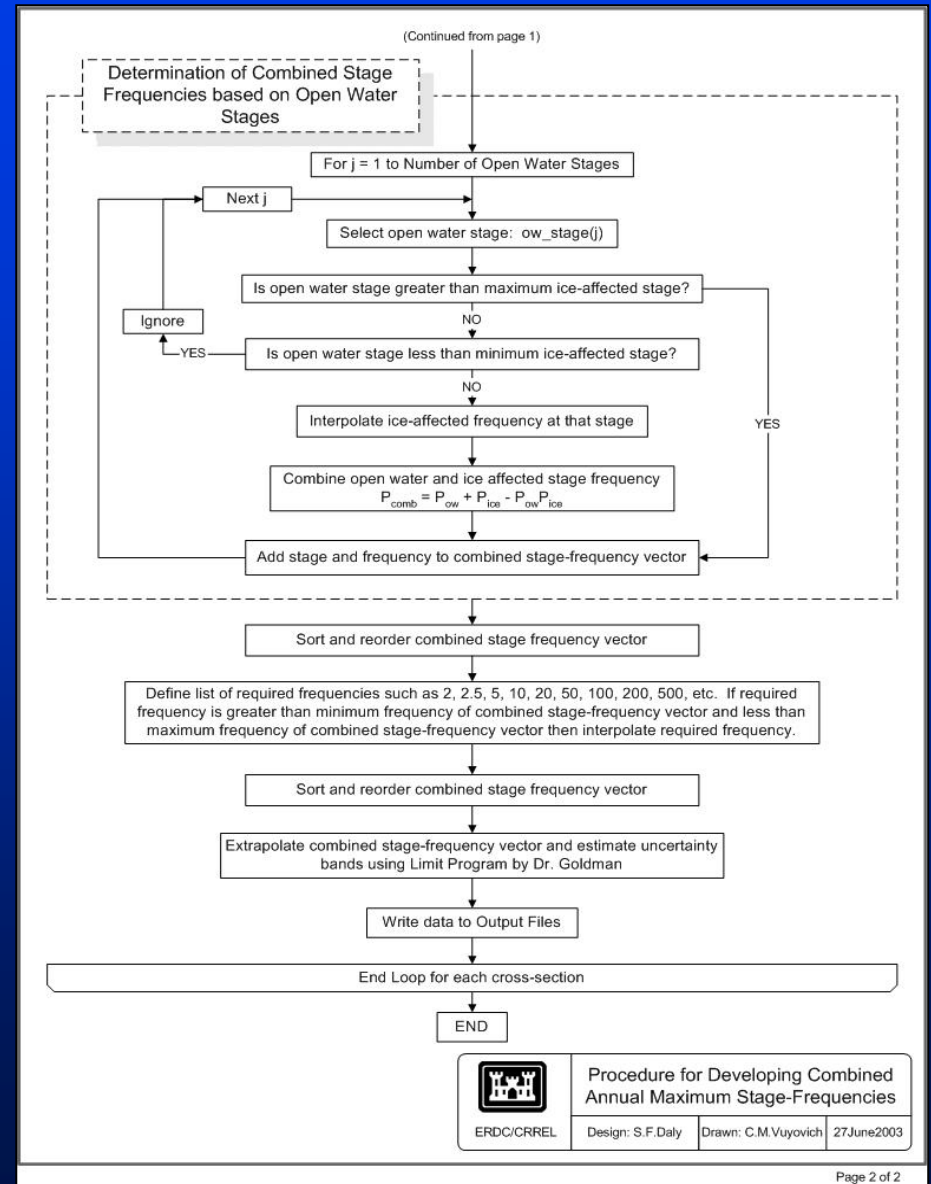
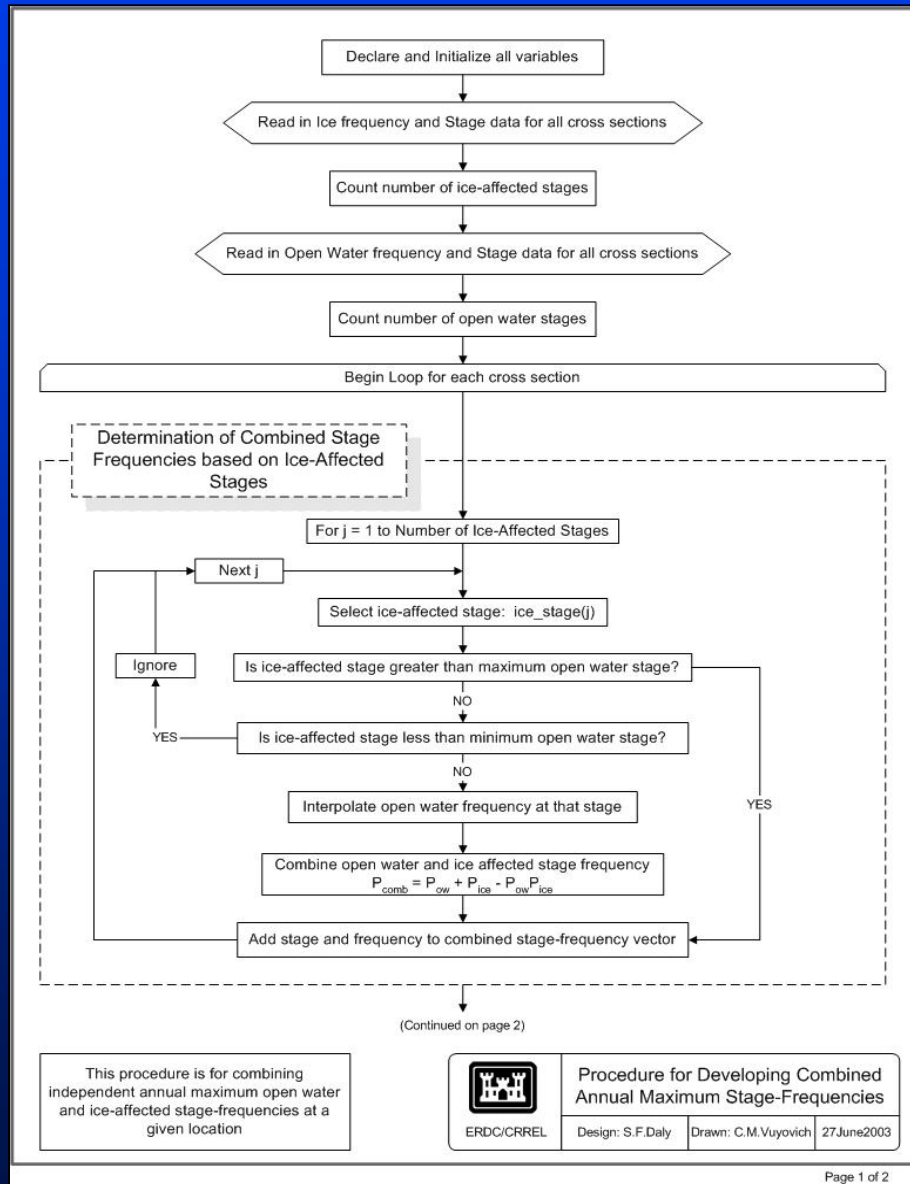
Ice-Affected Stage-Frequency



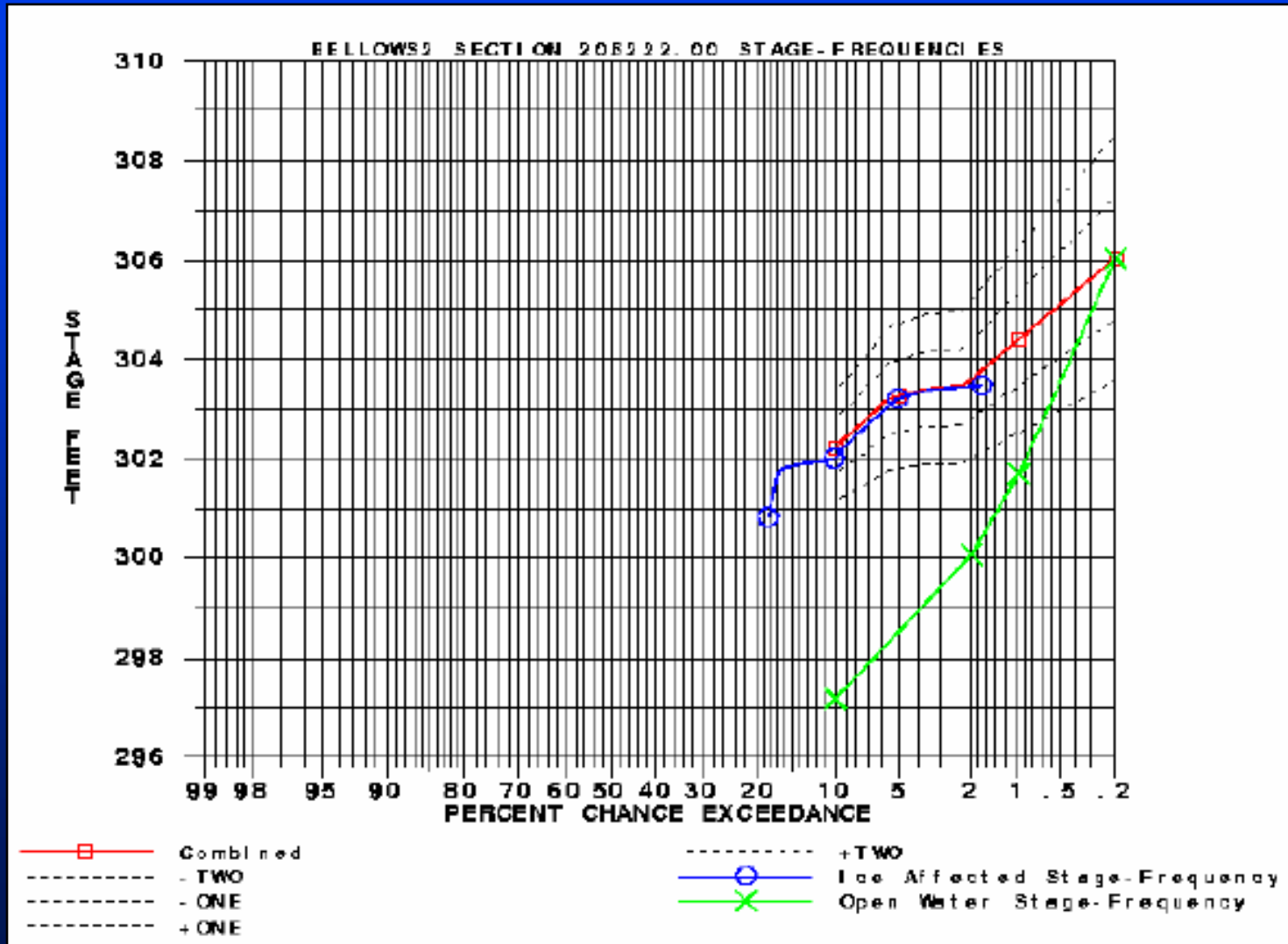
Gerard and Karpuck 1979



Combined Stage Frequency Method



Ice-Affected Stage-Frequency



Summary of river ice regime

- Frazil ice is dominant form of ice in northern rivers
- Ice often forms more quickly in impounded areas than in more turbulent river reaches
- Frazil deposits tend to form at upstream end of impoundments and tributary confluences
- Ice cover thickens due to thermal, deposition, shoving processes
- Thinner ice covers break up sooner than thicker ice covers with implications on jam location/timing
- Jams or rough ice covers increase scour and erosion
- Ice covers, deposits, and jams increase stage >30%



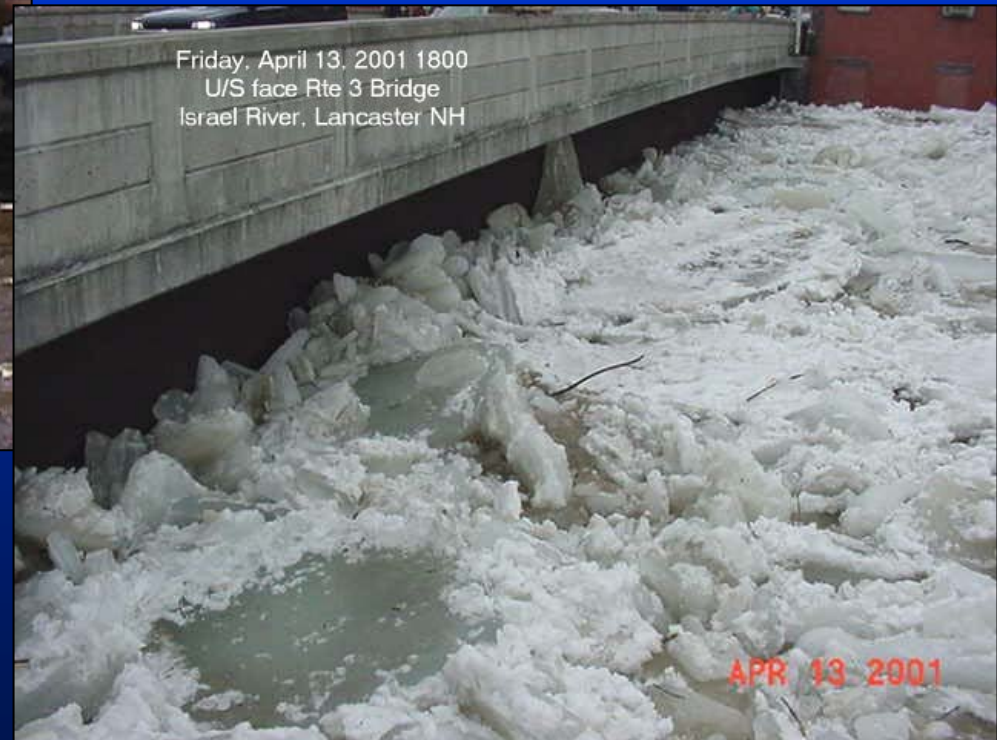


US Army Corps
of Engineers

Replacement bridge: ice-affected stage-frequency not included in design



1999

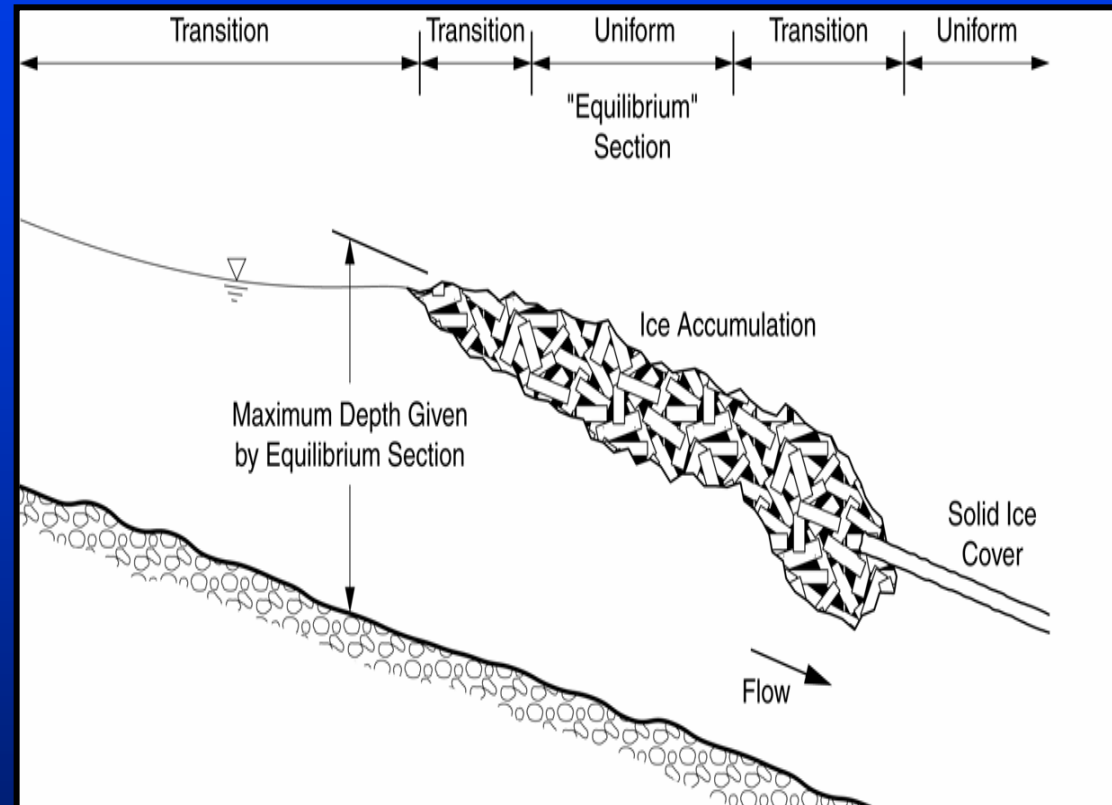


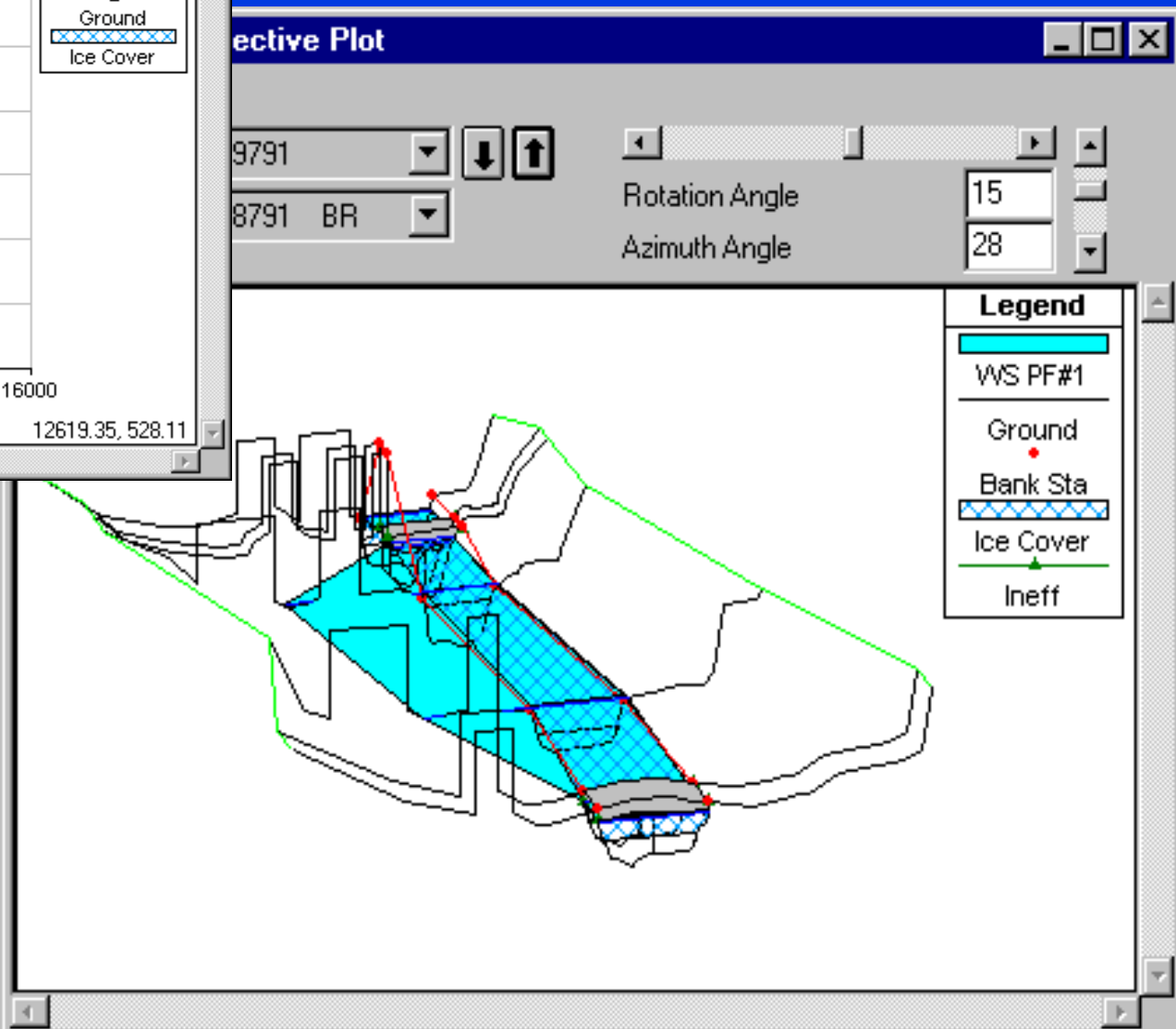
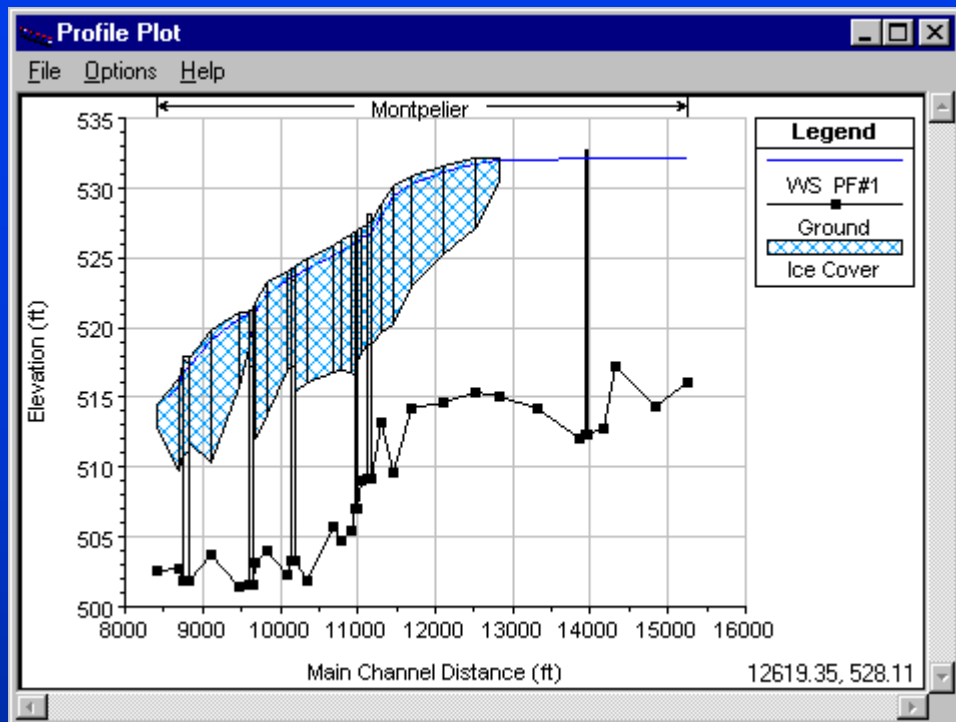
2001



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





Recommendations

1. Characterize existing ice regime

- Ice formation, growth, breakup, transport, jamming
- Sources of information:
 - USGS gage records
 - NWS meteorological records
 - CRREL Ice Jam Clearinghouse, Ice Jam Database
 - Other historic documents (e.g., town histories, newspapers)
 - Anecdotal evidence

CRREL Ice Jam Information Clearinghouse - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Forward Stop Search Favorites Media Print

Address <http://www.crrel.usace.army.mil/icejams/index.htm> Go Links Customize Links RealPlayer Windows Media Window

Welcome to the US Army Corps of Engineers
Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory

This site is under construction...
Come back for updates

Home
Ice Jam Database, Bulletins & Surveys
Flood Conditions and Flood Outlook
Ice and Snow Maps
Related Links
Technical Resources

QuickLooks

Current Ice Jams
Latest Status Report
Emergency Assistance

Ice Jams & Ice Jam Flooding

Advance Measures & Technical Assistance

Overview

This Web Site has been established to integrate current information related to Spring 2002 Ice Jam and Ice Jam Flooding Potential across the United States and to provide links to technical assistance available from the U.S. Army Corps of Engineers.

Expect frequent changes as data sources will be updated daily if possible and new products added as they are completed. Some information resources we hope to make available include:

- Ability to view and query the CRREL Ice Jam Database (map or text based)
- Access to current Spatial Data:
 - Ice thickness (empirical and measured)
 - Snow depth and water equivalence
- Downloadable maps
- Index map to potential ice jam flooding
- Ice Guides, Reports, and Other Information
- Links to other agencies providing ice or snow related Information

Technical Information

Ice Jam Flooding: Causes & Possible Solutions
Engineering & Design

Ice Jam Mitigation
Slide Show of Mitigation Techniques

All about Ice Jams
A short overview of Ice Jams

Contact Us

Site Developed with Funding provided by USACE Headquarters Civil Works Directorate, Civil Emergency Management Branch. Security and Privacy Notice

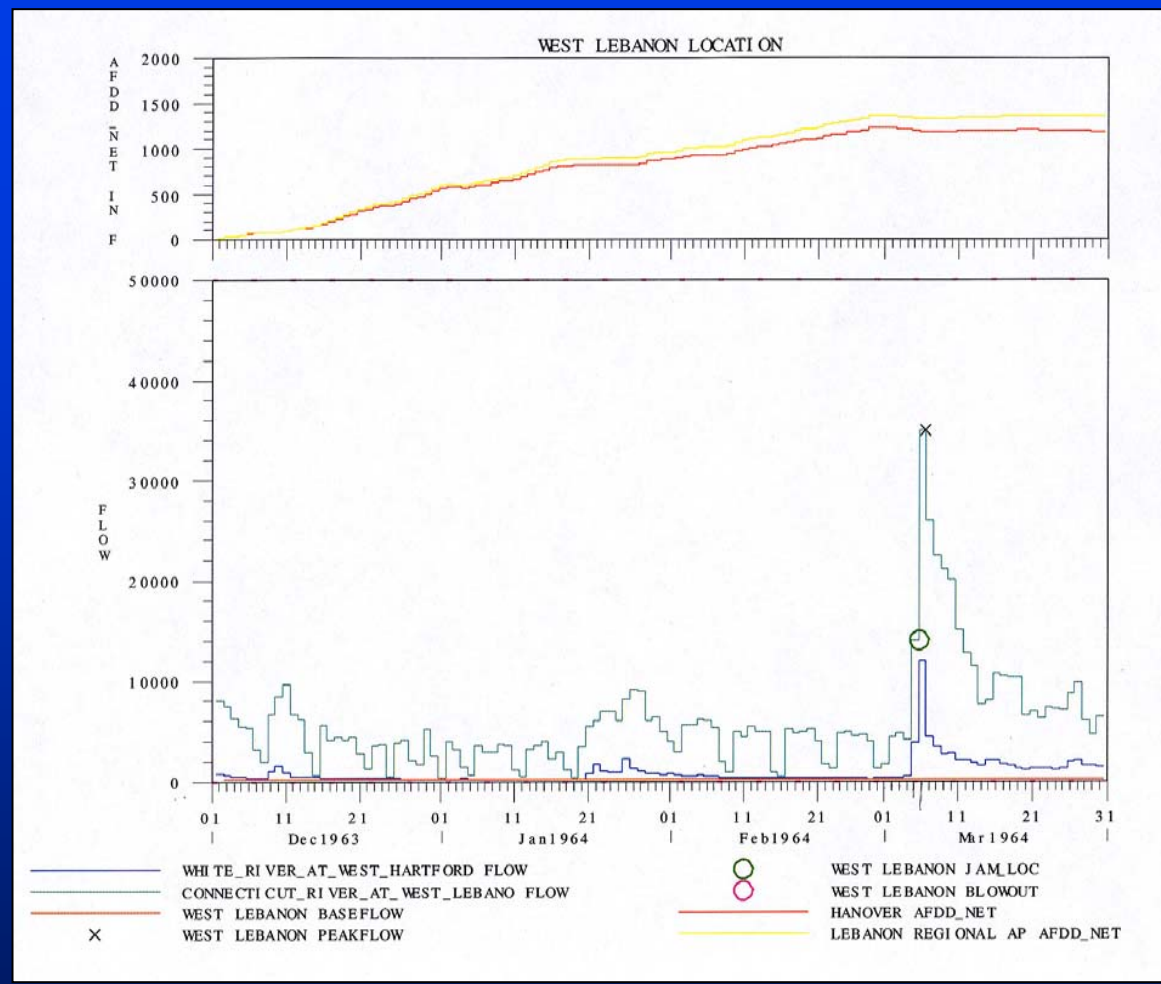
Best viewed with IE or Netscape v6.x

<http://www.crrel.usace.army.mil/icejams/index.htm>



Recommendations

- Review hydrometeorological conditions
 - ID those associated with open-water, ice cover, ice jams
 - Estimate ice cover thickness
 - Estimate ice jam thickness and length
- Perform hydraulic modeling of ice conditions to estimate stages
 - Ice cover
 - Ice jam
 - Numerous conference papers and technical reports available
- Combine frequencies



Recommendations

5. Determine ice impacts expected in channel restoration area (velocity, scour, stage)

ERDC/CHL TR-01-28

Coastal and Hydraulics Laboratory



Hydraulic Design of Stream Restoration Projects

Ronald R. Copland, Dinah N. McComas, Colin R. Thorne, Philip J. Sear, Meg M. Jonas, and Jon B. Fripp
September 2001

Preliminary Watershed Assessment

by Craig Fischerich¹

Complexity			Value as a Planning Tool		
Low	Moderate	High	Low	Moderate	High
Low	Moderate	High	Low	Moderate	High

OVERVIEW
Much has been said about the need to use "holistic" perspectives that consider the entire watershed when contemplating stream restoration options. Unfortunately, political, programmatic, and jurisdictional boundaries seldom correspond with watershed boundaries and restoration projects focus on specific sites. Without a comprehensive reach or watershed assessment, selected restoration measures often ignore underlying problems at a broader scale and are either ineffective or not cost-effective relative to other measures (Figure 1).

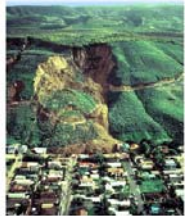


Figure 1. Watershed conditions can dictate restoration potential in reaches far downstream.

¹USACE Research and Development Center, Environmental Laboratory, 3900 Halls Ferry Rd., Vicksburg, MS 39180
Technical Note EMRRP SR-03

ERDC/EL TR-03-4

Environmental Laboratory



Wetlands Regulatory Assistance Program

Effects of Riprap on Riverine and Riparian Ecosystems

J. Craig Fischerich



Approved for public release; distribution is unlimited.

Stability Thresholds for Stream Restoration Materials

by Craig Fischerich¹

Complexity			Value as a Planning Tool			Cost		
Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Low	Moderate	High	Low	Moderate	High	Low	Moderate	High

OVERVIEW

Stream restoration projects usually involve some modification to the channel or the banks. Designers of stabilization or restoration projects must ensure that the materials placed within the channel or on the banks will be stable for the full range of conditions expected during the design life of the project. Unfortunately, techniques to characterize stability thresholds are limited. Theoretical approaches do not exist and empirical data mainly consist of velocity limits, which are of limited value.

Empirical data for shear stress or stream power are generally lacking, but the existing body of information is summarized in this technical note. Whereas shear thresholds for soils found in channel beds and banks are quite low (generally < 0.25 lbf/ft²), those for vegetated soils (0.5–4 lbf/ft²), erosion control materials and bioengineering techniques (0.5–2 lbf/ft²), and hard armoring (> 13 lbf/ft²) offer options to provide stability.

STABILITY CRITERIA

The stability of a stream refers to how it accommodates itself to the inflowing water and sediment load. In general, stable streams may adjust their boundaries but do not exhibit trends in changes to their geometric character. One form of instability occurs when a stream is unable to transport its sediment load (i.e., sediments deposited within the channel), leading to the condition referred to as aggradation.

¹USACE Research and Development Center, Environmental Laboratory, 3900 Halls Ferry Rd., Vicksburg, MS 39180

96-12

REPORT

Ice Action on Riprap Small-Scale Tests

Devinder S. Sodhi, Sharon L. Borland and Jesse M.



ERDC/CRREL TR-02-14



Survey of River Ice Influences on Channel Bathymetry Along the Fort Peck Reach of the Missouri River, Winter 1998–1999

Leonard J. Zabalsky, Robert Etema, James Wuebben, and Norbert Yankielun
September 2000



US Army Corps of Engineers
Engineer Research and Development Center

99-11

CRREL REPORT



US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Hydraulic and Physical Properties Affecting Ice Jams

Kathleen D. White

December 1999



