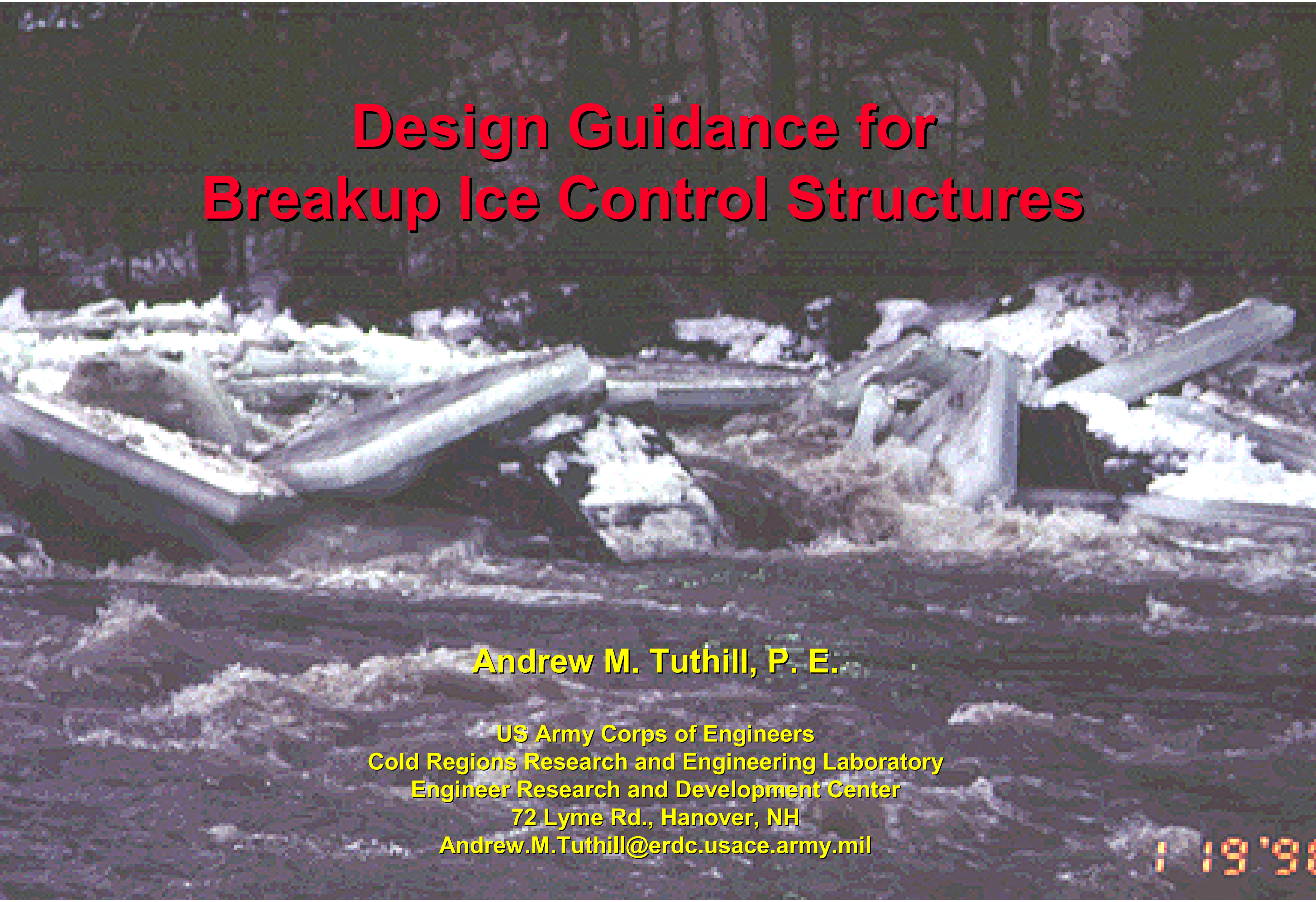

Design Guidance for Breakup Ice Control Structures

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Objectives

- Overview breakup ice jam processes and related problems of ice jam flooding and under ice scour.
- Describe the evolution in breakup ice control structure (ICS) design, focusing on recent advances and ongoing research. Illustrate with examples of existing and soon-to-be-built structures.
- Highlight important aspects of ICS design and describe some of the available design tools.
- Describe limitations of current pier ICS designs current research to address deficiencies.
- Explain rationale and objectives for ICS Design EM Chapter currently in preparation.

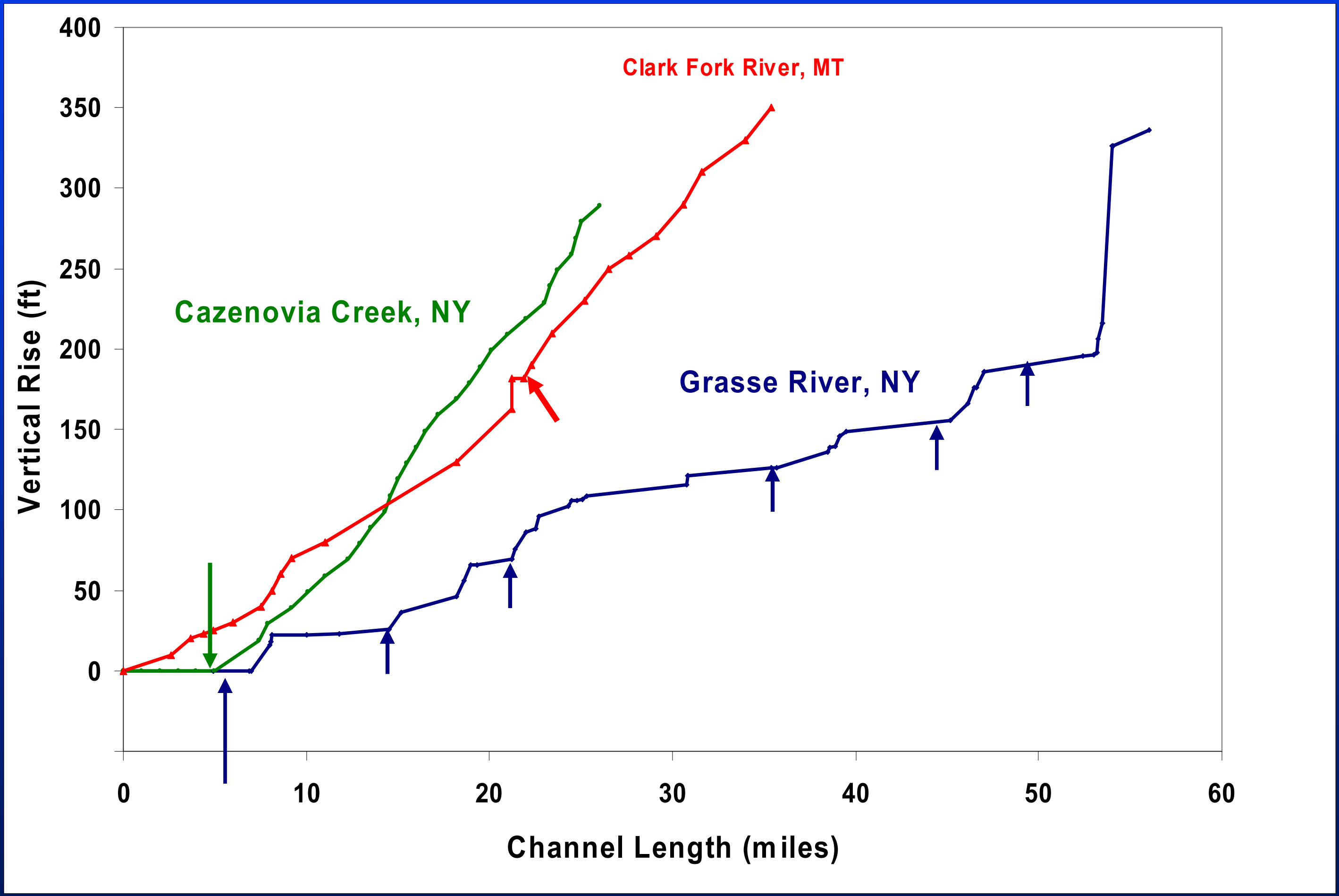
Breakup Ice Jam Processes and Related Problems

- Ice-out on rivers can range for gradual melt-out to dynamic, downstream-progressing breakup events. The latter type can result in ice jams, ice jam flooding and scour of river bed sediments.
- Ice jam flooding often occurs in small remote communities, causing localized damages that require low cost solutions.
- Because ice jams often occur on pristine rivers, solutions must have low environmental impact and not interfere with fish or sediment passage, or recreational uses of the river.
- Recently, the role of breakup ice control has has expanded from flood mitigation to to remediation of contaminated sediment.

Characterizing the Ice Jam Problem

- Research frequency and severity of past ice jam events
  - CRREL Ice Jam Database, newspapers, interviews, etc.
  - River inspection for ice tree scars, damage to banks, structures, etc.
  - Hindcasting analysis based on historic hydro-meteorological data
- Investigate the nature of ice breakup and identify a reasonable worst case scenario for ICS design.
  - Assess likelihood of dynamic breakup vs. thermal meltout.
  - Determine if ice-out typically occurs as a single downstream-progressing breakup front, or series of simultaneous jams.
  - Identify source reach supplying ice to the problem jam.
  - Determine a maximum probable ice volume, based on historic jams or probable ice source reach.

River Gradient, Breakup Progression, Ice Jam Location and Ice Jam Source Reach



- Continuously steep river grading into backwater reach: Single breakup event forming a large jam near mouth.

- Stepped river profile: Ice breaks up in sections or in a downstream progressing sequence.

Typical Ice Jam Locations

Transitions from steep to mild slope

Ice jam on the Connecticut River at Windsor, VT above the head of the Bellows Falls Dam impoundment.

Channel constrictions, bends and meanders

Ice jam in constricted bend in the Androscoggin River downstream of Canton, ME.

Also: bars, islands, dams & bridge openings

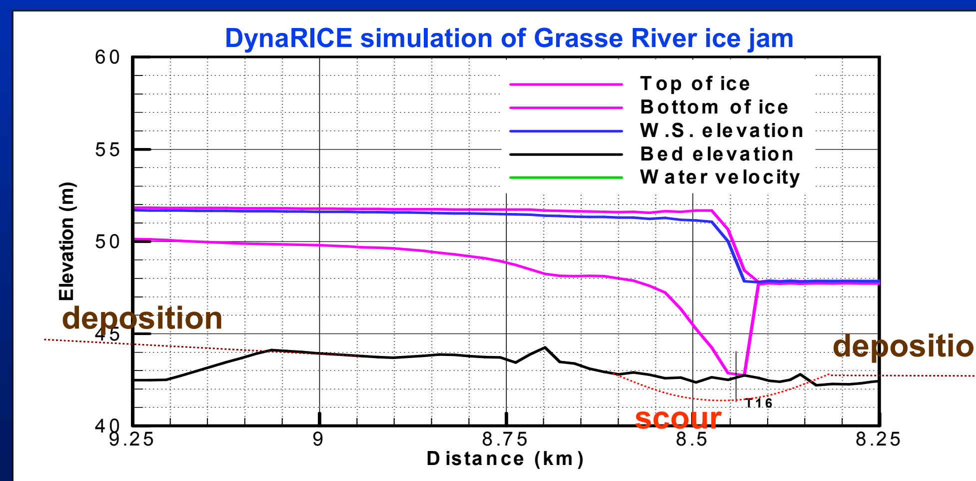
Both these events caused significant residential flooding

Common sediment deposition areas frequently coincide with ice jamming locations, resulting in a recurring deposition-ice jam scour cycle.

Examples of Ice Jam Scour and Transport of Contaminated Sediment

Milltown Dam, Clark Fork River, MT

Grasse River, Massena, NY



Both EPA Superfund Sites. CRREL participating in ice evaluations and mitigation.

Evolution in Breakup Ice Control Structure Design

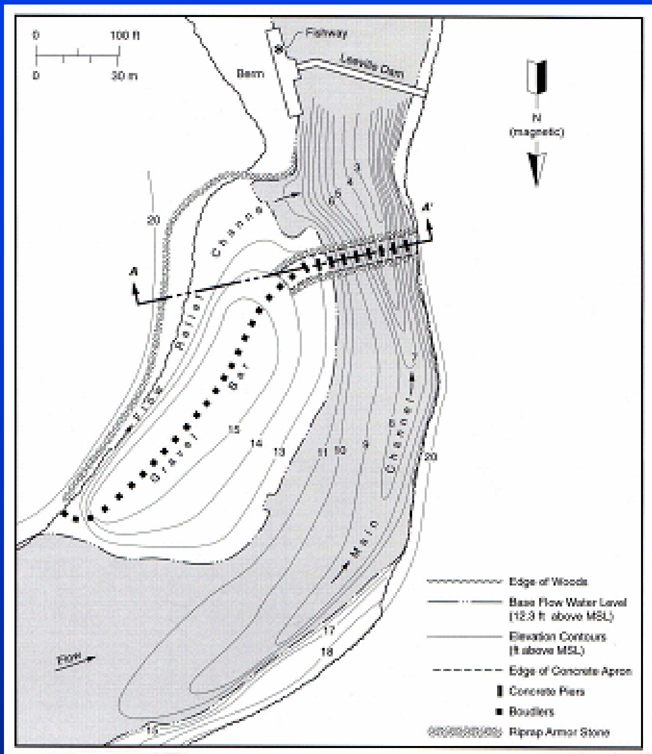
1960's 40-ft-high dam, Chaudiere River, St. Georges, QUE

1970's Riviere Ste. Anne, St Raymond, Quebec, 15-ft-high weir with piers 20-ft-apart, all flow over weir.

1986 Credit R., Mississagua, ONT., Piers 6-ft-apart, grounded jam in channel, bypass flow via floodplain.

1994 Lamoille R., Hardwick, VT., Grounded jam behind boulders, 14-ft gaps, bypass flow via tree covered floodplain (CRREL design). Monitored by CRREL as field site. No ice jam flooding since construction.

Scheduled for this summer-fall: Salmon River ISC, East Haddam, CT



Leesville Dam lowered 10 ft in 1979 for safety and construction of fish ladder.

Ice now passes crest to jam in tidal reach downstream, flooding houses.

Much sediment has eroded from former impoundment to deposit lower river decreasing recreational value.

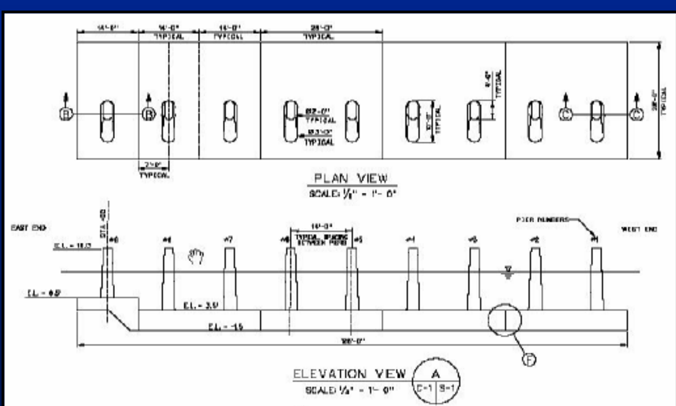
ICS design by CRREL and NAE consists of piers across channel with adjacent gravel bar to bypass water flow around jam.

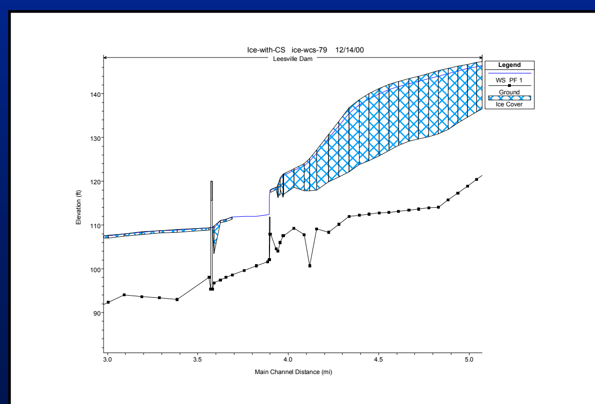
Design relied on HEC-2 and HEC-RAS simulations using ice jam routines.

Design includes a sedimentation basin upstream of the piers.

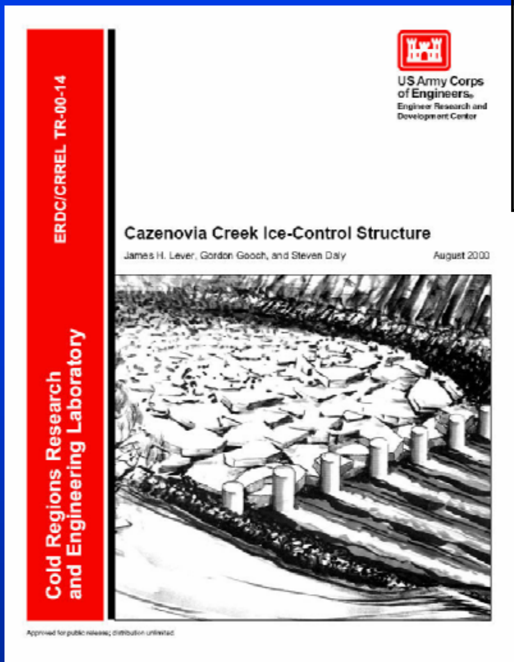
Upstream reach uninhabited state park ideal for ice storage.

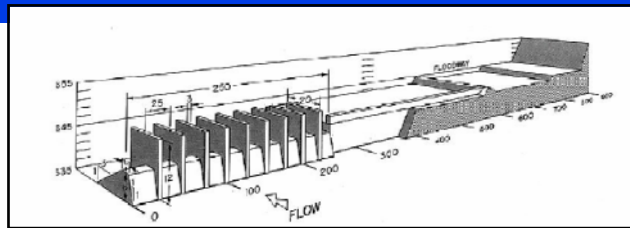
Strong support from the State of Connecticut DEP and local residents.

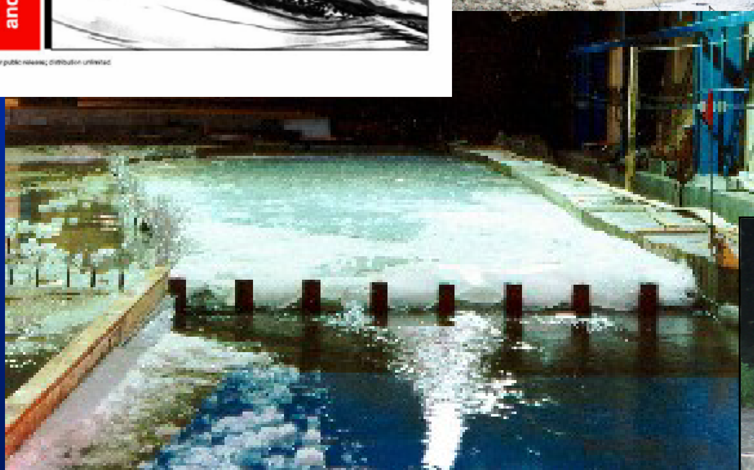




Currently Under Construction: Cazenovia Creek ISC, West Seneca, NY







Site of frequent severe ice jams and ice jam floods with high damages.

ICS design by CRREL and LRE consists of piers across channel with adjacent floodplain to bypass water flow around jam.

Design based on Hardwick ICS, CRREL physical model study, HEC-RAS and CRREL DEM simulations.

Although floodplain uninhabited, the high number of affected parcels complicated the land easement process and raised project costs.

Due the long history of flooding in West Seneca, strong local support for the project.

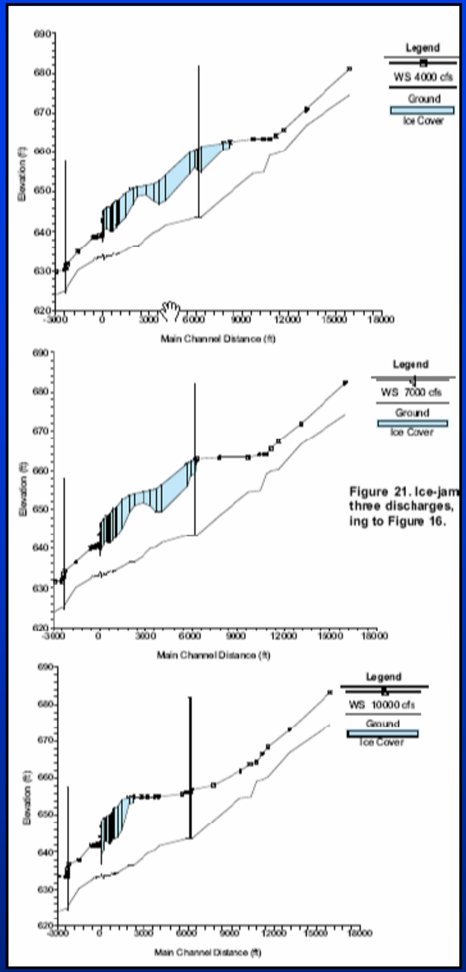
Lever (2000) documents the design process. *Excellent* ICS design reference.

Important Hydraulic Aspects of ICS Design

- Select design event based on historical info, analysis of historical breakup discharge, air temperature and precip. data.
- Model existing conditions ice jam in historic problem area. Validate model against observed data. Estimate ice jam volume.
- Evaluate upstream ICS sites and select preferred site.
- Based on pre-breakup ice conditions near ICS, predict how run will impact structure.
- Model ice accumulations at structure and historic jam site for range of breakup scenarios and ice parameters such as ice roughness, under ice water velocity and ice jam volume.
- Evaluate stability of retained ice accumulation based on under-ice water velocity and ice jam thickness profile.
- Evaluate relief flow channel capacity, (Manning Eq., HEC-RAS) and how flow escapes and re-enters the main channel.

Hydraulic Aspects of ICS Design

- Estimate/calculate ice forces on structure: Lever (2000), AASHTO code.
- Evaluate ice storage capacity of upstream channel and floodplains.
- Analyze upstream water level rise resulting from ICS, considering potential ice release at structure and progressive melting.
- Estimate shear forces on bed and banks in vicinity of structure to be used in design of bed protection.
- Estimate ice retention capacity of ICS and possible failure modes (compare to similar structures or physical model).



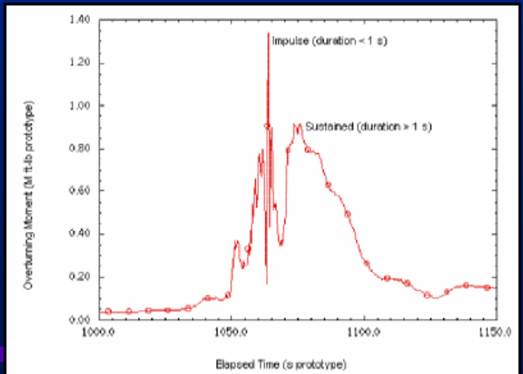
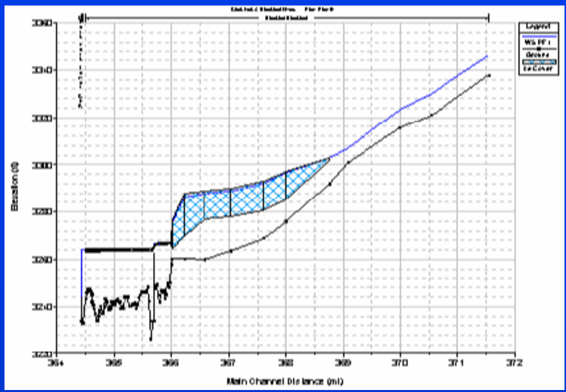
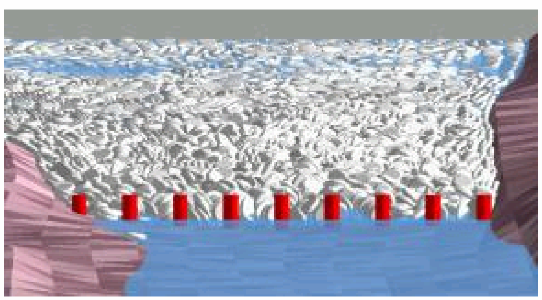


Figure 9. Measured downstream overturning moment (test 5
M1), showing peak impulsive and sustained moments.

ICS Design Tools





- **Classic 1-D hydraulic methods such as Manning equation and equilibrium ice jam theory (EM 1110-2-1612 "Ice Engineering" Chapter 4)**
- **HEC-RAS with ice jam option bracketing accepted range of ice parameter values, such as ice roughness and under ice water velocity for ice jam erosion.**
- **State of the art ice-hydraulic models such as DynaRICE and the CRREL DEM**
- **Ice-hydraulic physical models with plastic or natural ice.**

Increasing

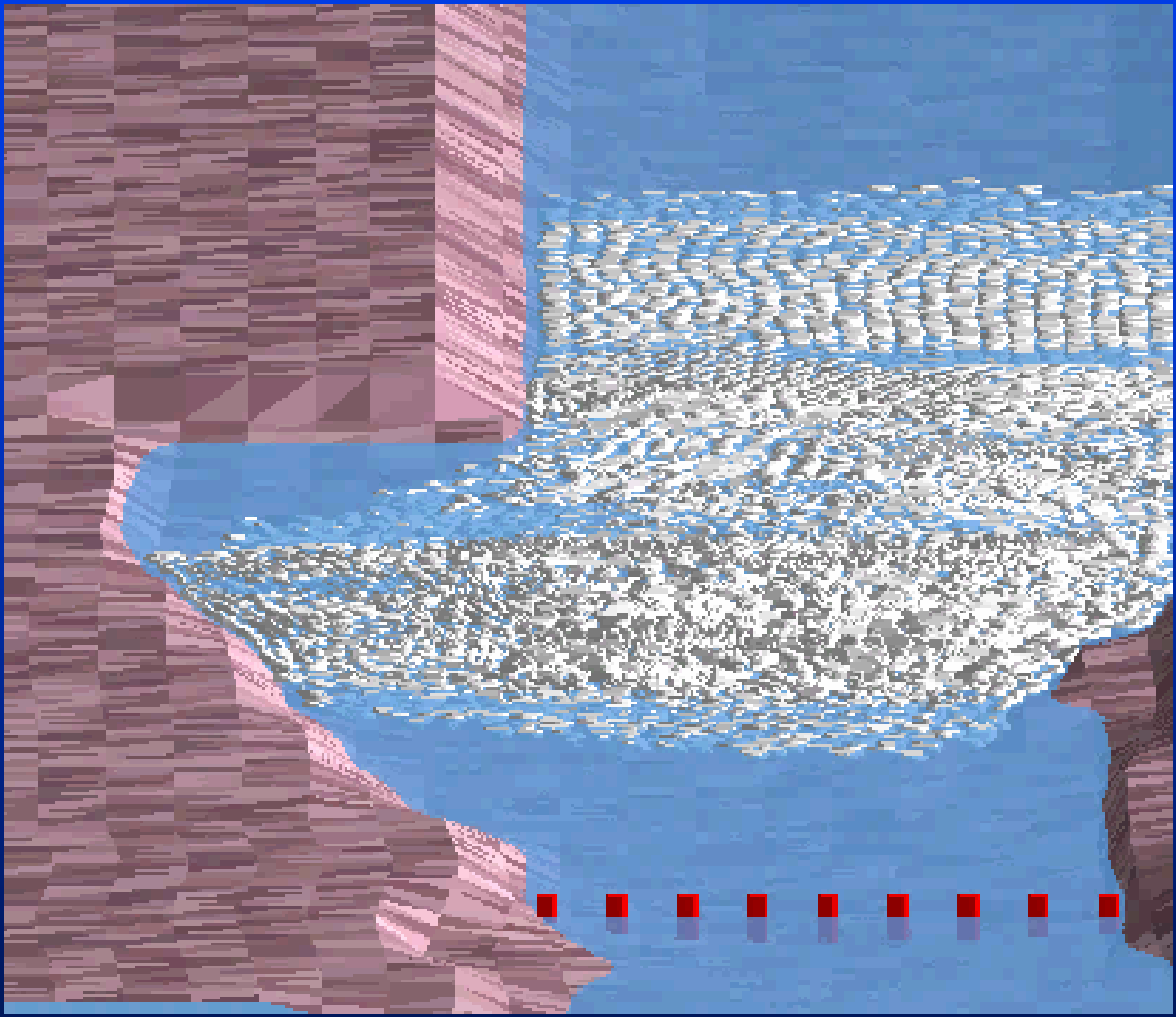
Time

Cost

Confidence

& Reliability

CRREL DEM Simulation of Ice Run Impacting Cazenovia Creek ICS



http://www.crrel.usace.army.mil/sid/hopkins_files/Riverice/Caz.htm

Limitations of Pier ICS Designs and Current Research

- Many ice jam problem locations lack upstream ice retention sites with floodplains for relief flow.
  - Existing sites with overbank relief flow may be too far upstream to retain sufficient ice to solve problem.
  - Land issues may prevent use of sites with floodplains for ICS.
  - Concept of in-channel flow relief under development (CRREL & Grasse R. project).
- Pier structures not 100% reliable. Conditions for under-ice erosion, piping, and release poorly understood.
  - At some elevated discharge the ice may pass the structure, usually as a release between two or more piers.
  - This de-phasing of the hydrograph and the breakup ice run may alleviate the downstream ice jam problem but the process is difficult to quantify and design for.
  - Research needed to quantify parameters for ice release at pier structures.
  - Canadians working on pier-net ICS designs (Morse et al, Laval, U.)
- Concrete piers considered by some as unaesthetic.
  - Hardwick granite blocks represent a more natural looking alternative
  - CRREL model tests of man-made island arrays as alternative to piers.

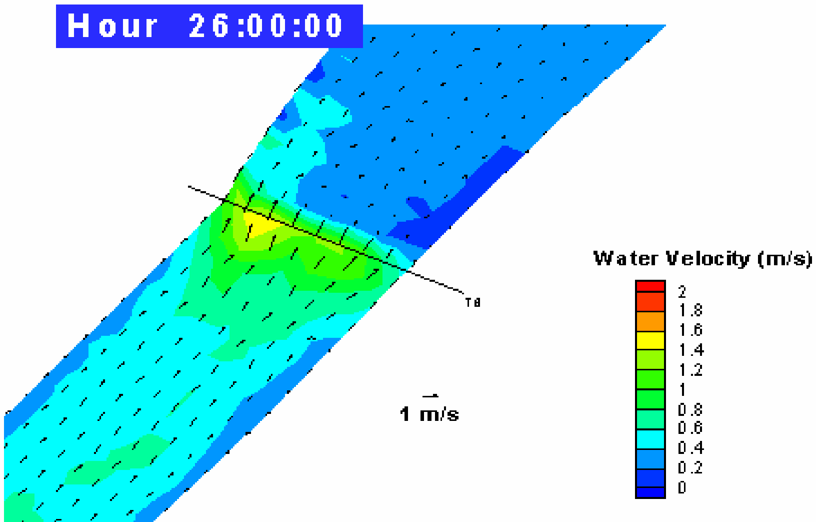
CRREL Physical Model Tests of Pier ICS Without Flow Relief

Cazenovia Creek ICS model with floodplain walled off.

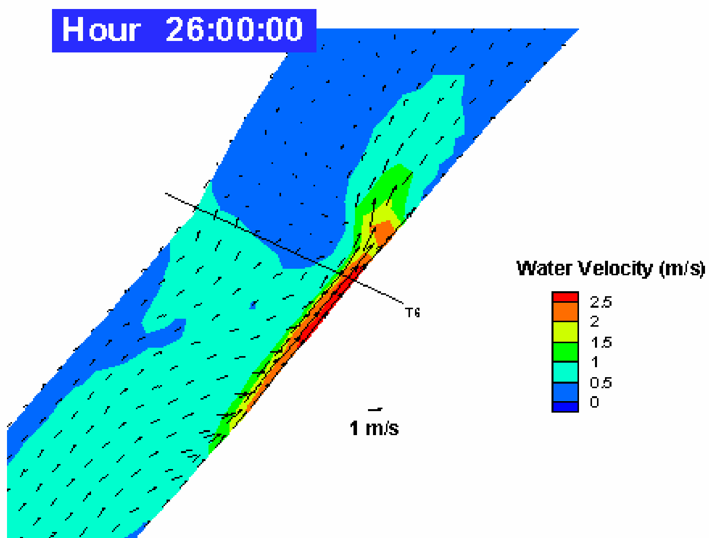
Array of artificial islands as a more aesthetic alternative to concrete piers. Performance similar to piers.

Ice blowout typically occurred at about half the discharge of the overbank relief flow cases. Morse et al. found similar.

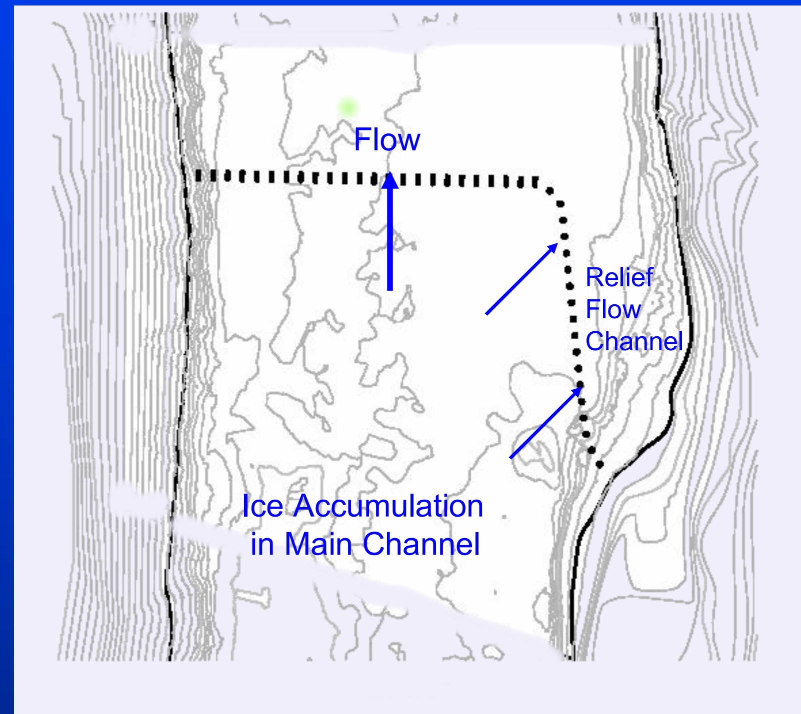
In-Channel Flow Relief Concept



DynaRICE simulation of pier ICS with no flow relief (above) compared to in ICS with in-channel flow relief (below).



Simulations by L. Liu and H. T. Shen, Clarkson U.



Longitudinal row of piers allow water flow to to bypass jam in main channel reducing under-ice water velocity and the potential for ice erosion and jam failure.

Physical model tests will improve confidence in concept.

EM Chapter on ICS Design

- Distill existing breakup design guidance into a single concise document.
- Offer logical step-by step approach to ICS design.
- Where possible, avoid dependence on time-consuming and costly numerical and physical modeling.
- Provide guidance on which situations require a more sophisticated design approach, provide direction and references.

Acknowledgements

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