Impacts to Ice Regime Resulting from Removal of Milltown Dam, Clark Fork River, Montana

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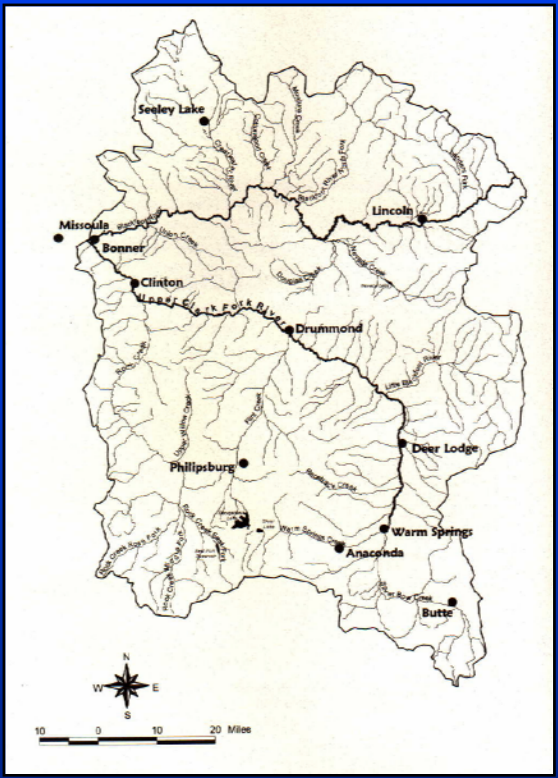
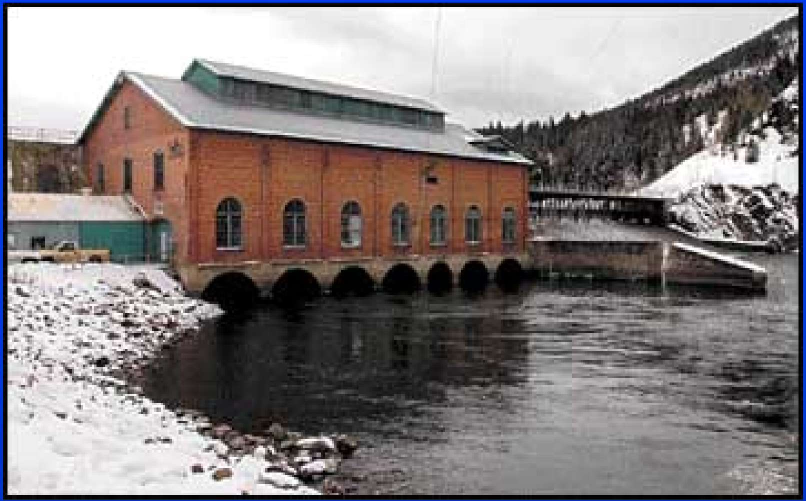
Introduction



Dam located 120 miles downstream of Butte and Anaconda historic copper mining district.

7 MCY sediment behind Milltown Dam containing As, Cd, Cu, Pb and Zn. 2.4 MCY to be removed.

During floods and ice events, metal-contaminated sediment are scoured from impoundment and deposited downstream.



Milltown Dam on Clark Fork River, built 1907
Now part of nations largest Superfund site.
Remedial action plan calls for phased removal of dam and contaminated sediments.

Stimson Dam 1 mi. upstream on Blackfoot R. to be removed as well.

1996 Ice Event

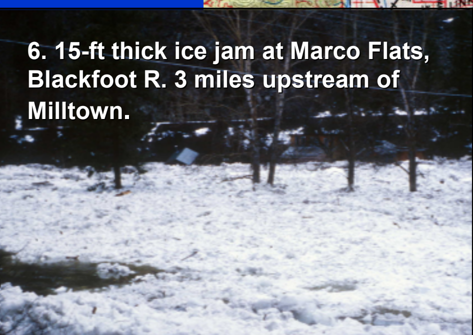
1. Three weeks of extreme cold produced extensive thick ice covers on Clark Fork and Blackfoot.

2. Sudden thaw with rain on 2/9/96 triggered dynamic downstream-progressing breakups on both rivers.

3. Early evening of 2/9/05, ice run tracked moving along HY 200, estimated speed over 10 mph.

4. Milltown pool lowered 10 ft. to stall ice run. All stop logs removed down to dam sill.

5. Ice run stopped 0.5 mi. upstream of Stimson Dam, 9:30 PM 2/9/96.



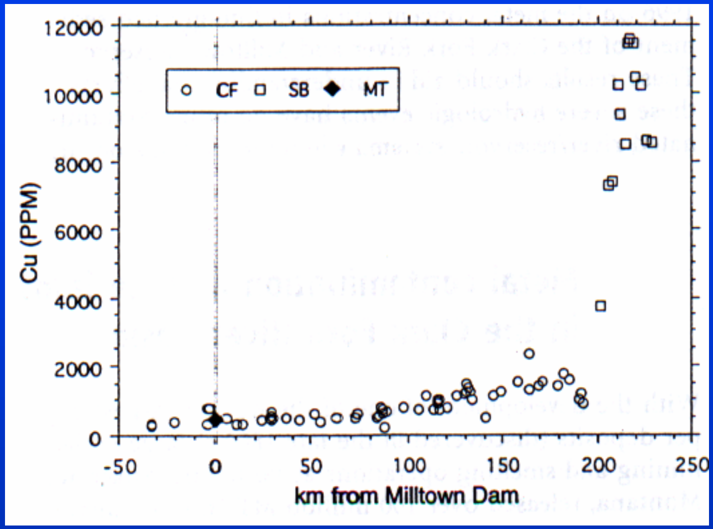
6. 15-ft thick ice jam at Marco Flats, Blackfoot R. 3 miles upstream of Milltown.

Ice damaged trees and destroyed bridge on upper Blackfoot 40 mi u/s of Milltown.

7. Ice on Blackfoot portion of Milltown Pool remained intact throughout the event.

8. Upper Clark Fork ice jammed at Turah Bridge and at head of Milltown Dam impoundment. Clark Fork channel through impoundment broke up on 2/10/96. Much ice passed dam.

Migration of Contaminated Sediments on the Clark Fork River



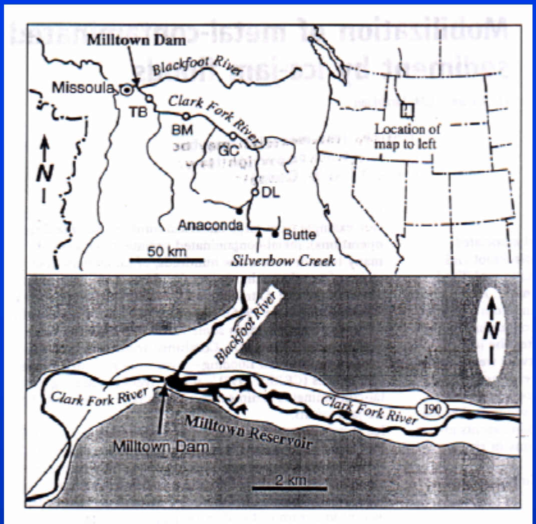
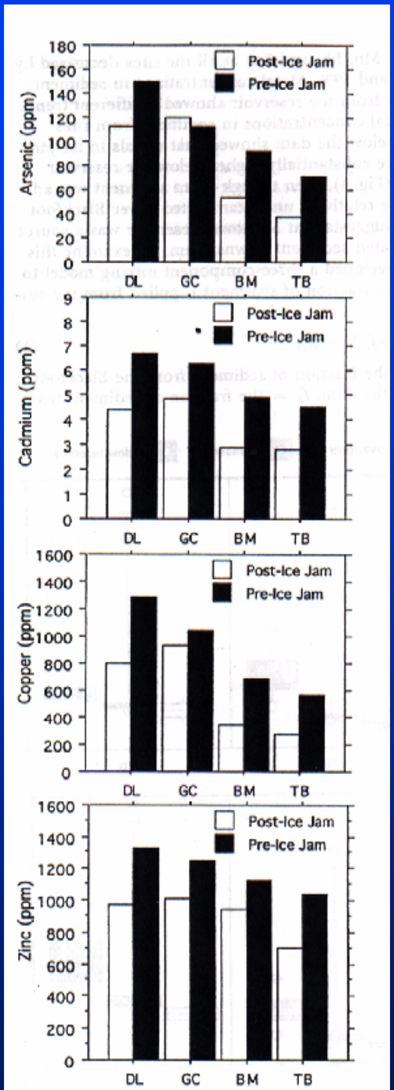


Table 1
Average metal concentrations in fine-grained sediment [* data from sediment collected from the tops of ice blocks (Landrigan 1997); † data from shallow cores taken from within Milltown Reservoir (Woessner and others 1984)]

Site	As (ppm)	Cd (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)
Blackfoot R. above reservoir*	8	0.3	20	16	43
Clark Fork R. above reservoir*	43	2.9	300	60	800
Within reservoir†	372	16.3	2506	289	4283
Below reservoir	100	4.5	700	90	1300



-Milltown Reservoir traps metal contaminated sediments from upstream mining activities.

-Ice events scour contaminated sediment from upstream channel and reservoir, enriching downstream sediments with metals.

-Significant fish kill downstream.

Figures from Moore and Landrigan (1999) "Mobilization of metal contaminated sediment by ice jam floods" Environmental Geology 37 (1-2)

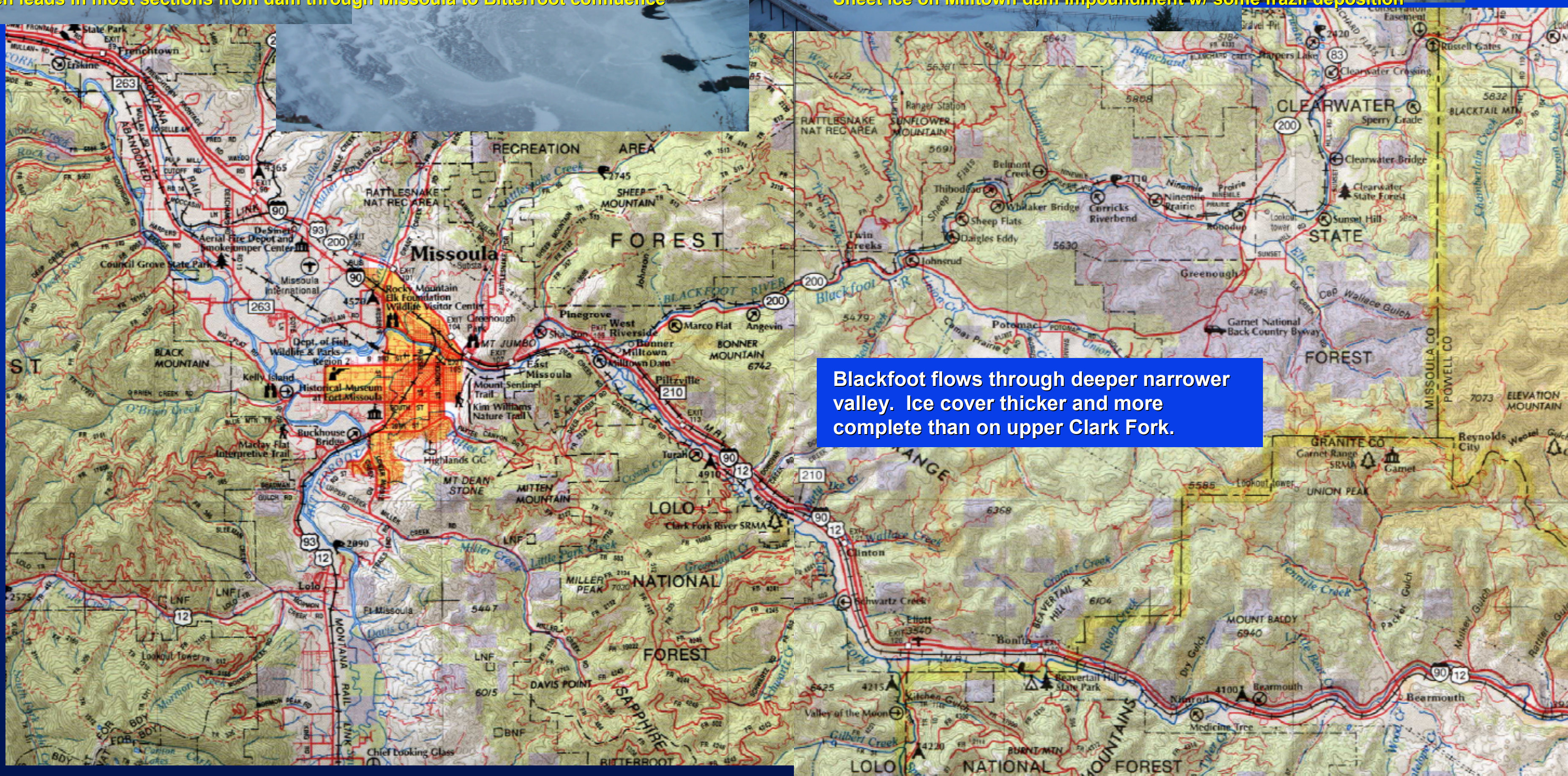
Study Objectives

- Characterize the existing ice regime through historical review and field observation
- Model ice cover formation and breakup for the pre- and post-dam removal cases
- Evaluate the potential for post-dam removal ice jam scour around the bridge piers on the lower Blackfoot
- Identify and outline ice mitigation measures that may be needed

Characterization of Existing Ice Regime

Open leads in most sections from dam through Missoula to Bitterroot confluence

Sheet ice on Milltown dam Impoundment w/ some frazil deposition



Blackfoot flows through deeper narrower valley. Ice cover thicker and more complete than on upper Clark Fork.

Winter 2004-2005 Ice Observation Program

- Ice conditions documented 10-14 Jan. 2005 representing maximum ice extent for winter.
- Ice covers composed primarily of frazil, up to 4-ft-thick. Complete covers on pool sections. Open leads up to ½ the channel width on faster sections of river, compared to near complete ice cover that preceded 1996 ice event.
- 12-inch-thick sheet ice on Milltown and Stimson Dam impoundments. Some frazil deposition beneath, particularly u/s of Stimson Dam.

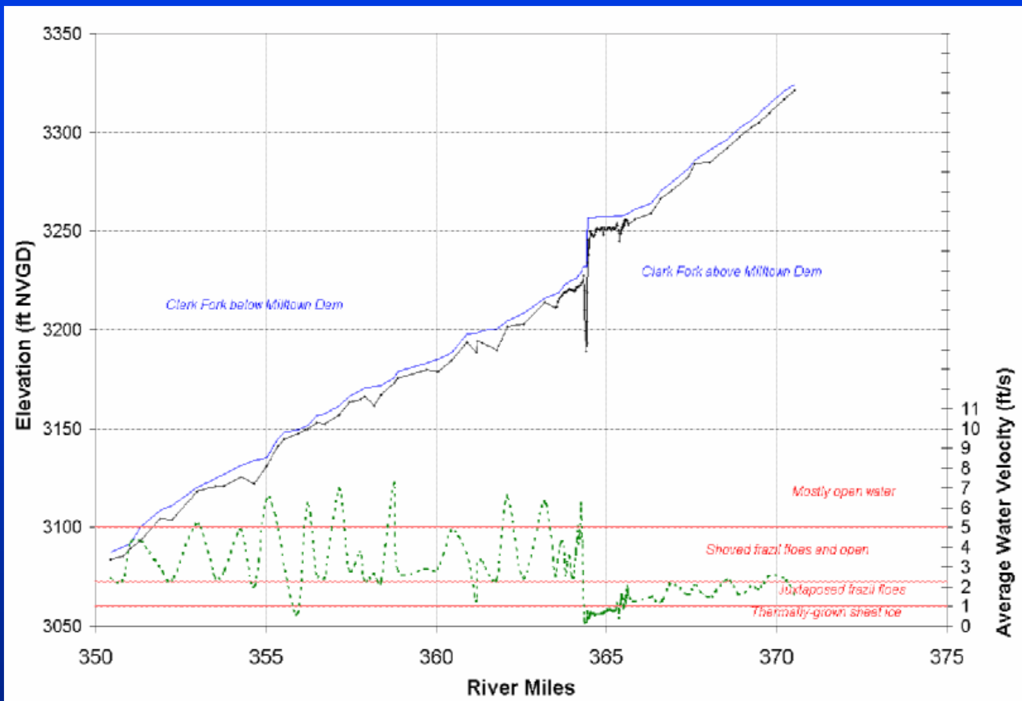
Open channel on upper Clark Fork below Turah Bridge

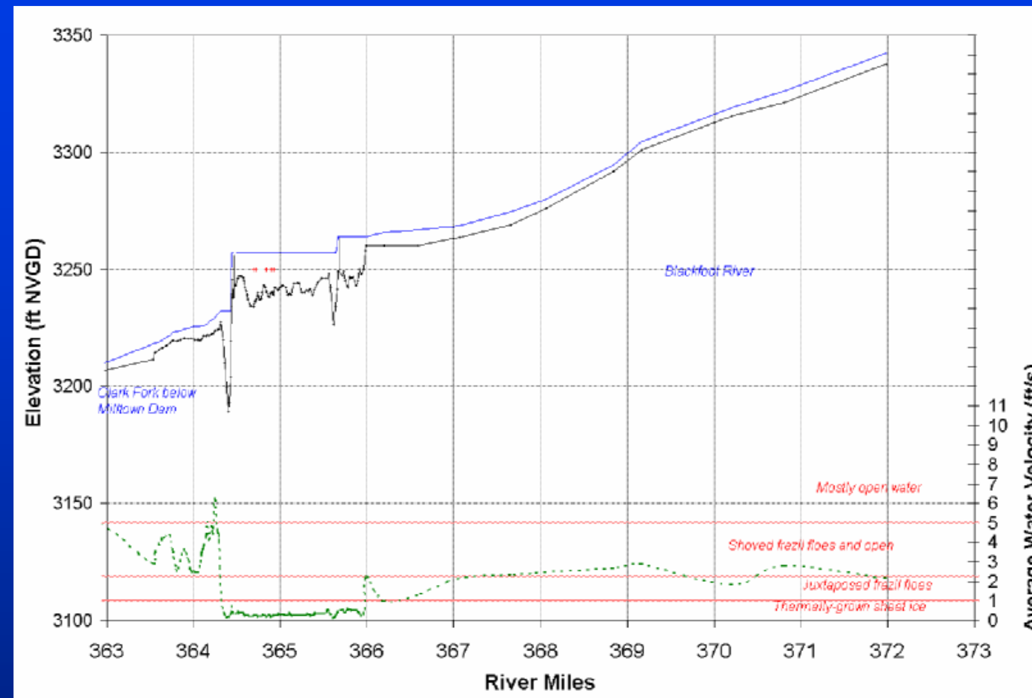
Frazil ice cover and anchor ice on upper Blackfoot River

Frazil ice accumulation on pool section, Clark Fork River, Missoula

Open channel with border ice on Clark Fork through Missoula

Winter Base Flow Velocity Profiles

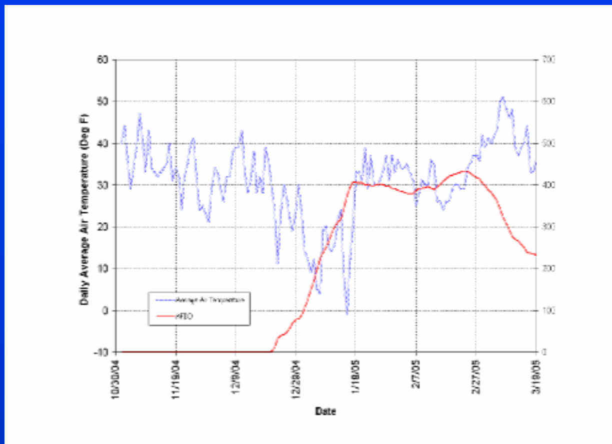




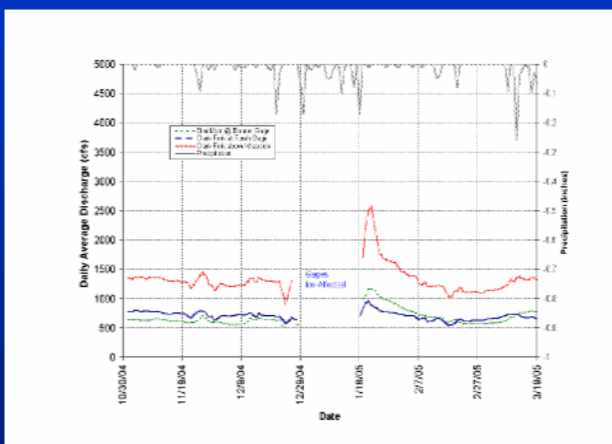
Average water velocity as a predictor of ice cover type:
<= 1.0 ft/s   sheet ice
1.0 – 2.3 ft/s juxtaposed frazil floes
2.3 – 5 ft/s shoved frazil floes
> 5 ft/s channel stays open all winter

With the exception of the Milltown and Stimson Dam Impoundments, few pool sections of any great length.

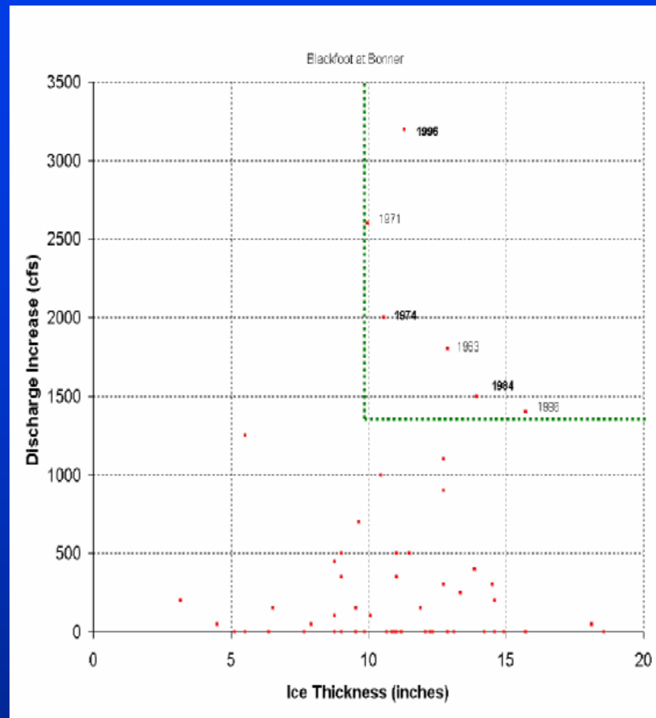
Frequency and Magnitude of Ice Events



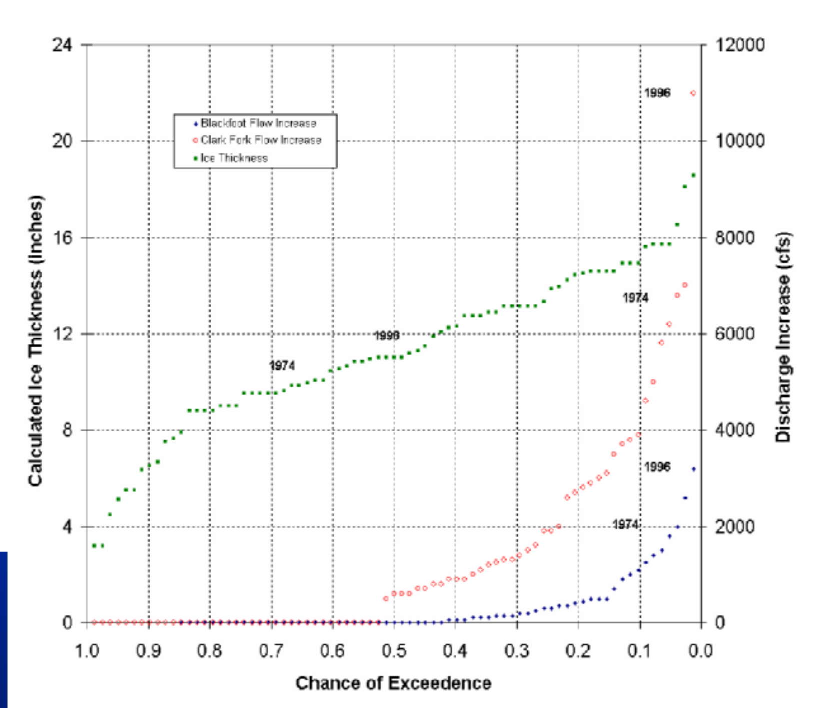
Historic ice thickness calculated from maximum AFDD



Occurrence of ice events influenced by breakup hydrograph.



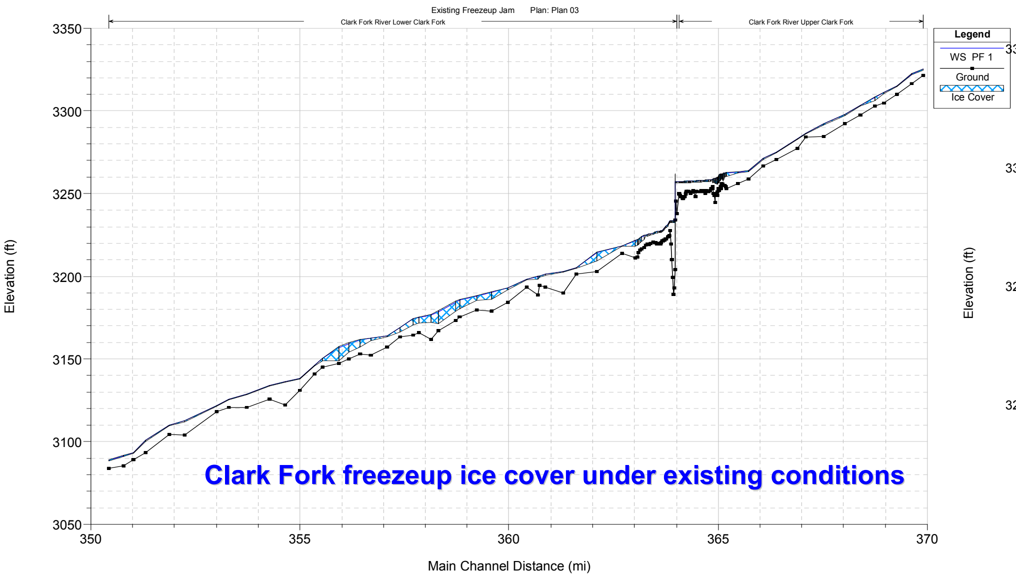
For all known historic ice events,
ice thickness >= 10 in and
Blackfoot discharge increase >= 1400 cfs

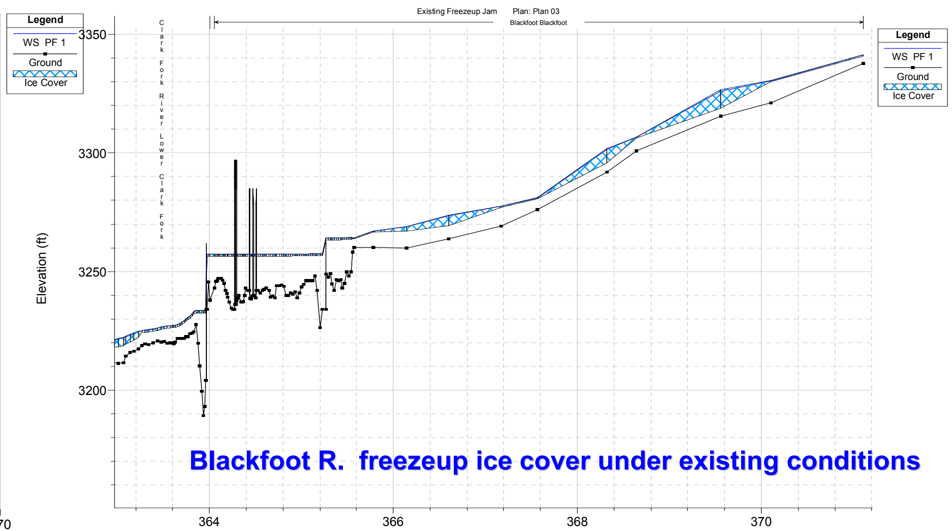


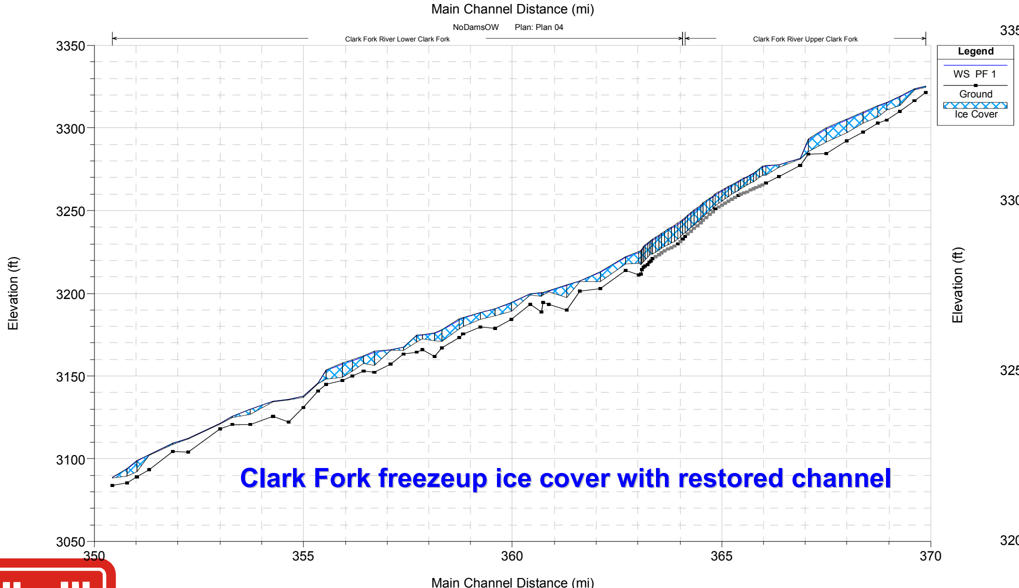
Ice thickness and discharge increases ranked and assigned probabilities.

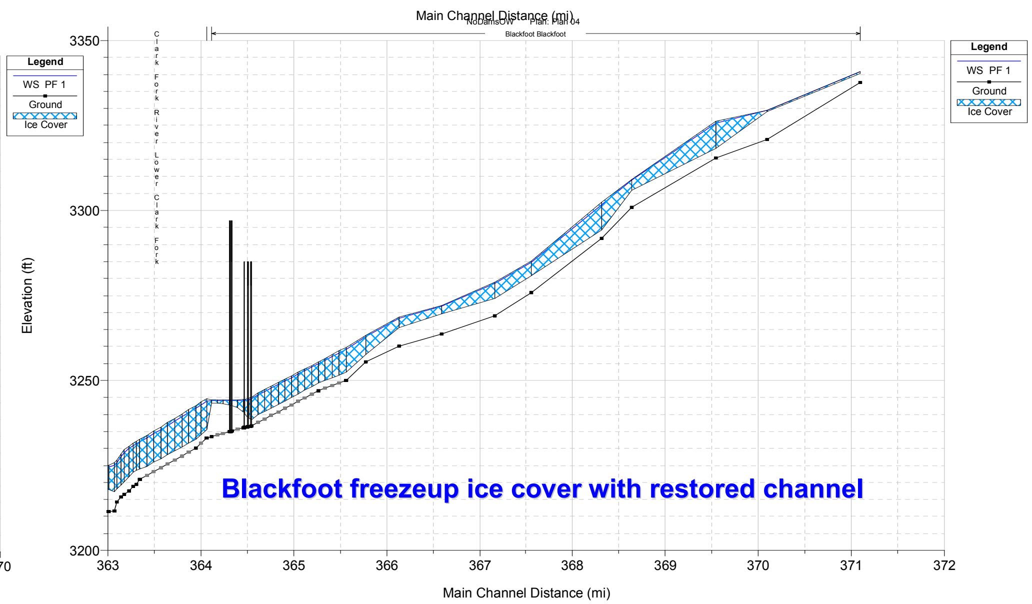
- Historical review found event similar but less severe than 1996 occurred Jan. 1974.
- Ice jam near Bitterroot Confluence in Jan. 1984
- No known jams from Milltown Dam through Missoula
- By “hindcasting” analysis, chance of recurrence of a 1996-like event extremely small.

HEC-RAS Modeling of Ice Cover Formation Pre and Post Project



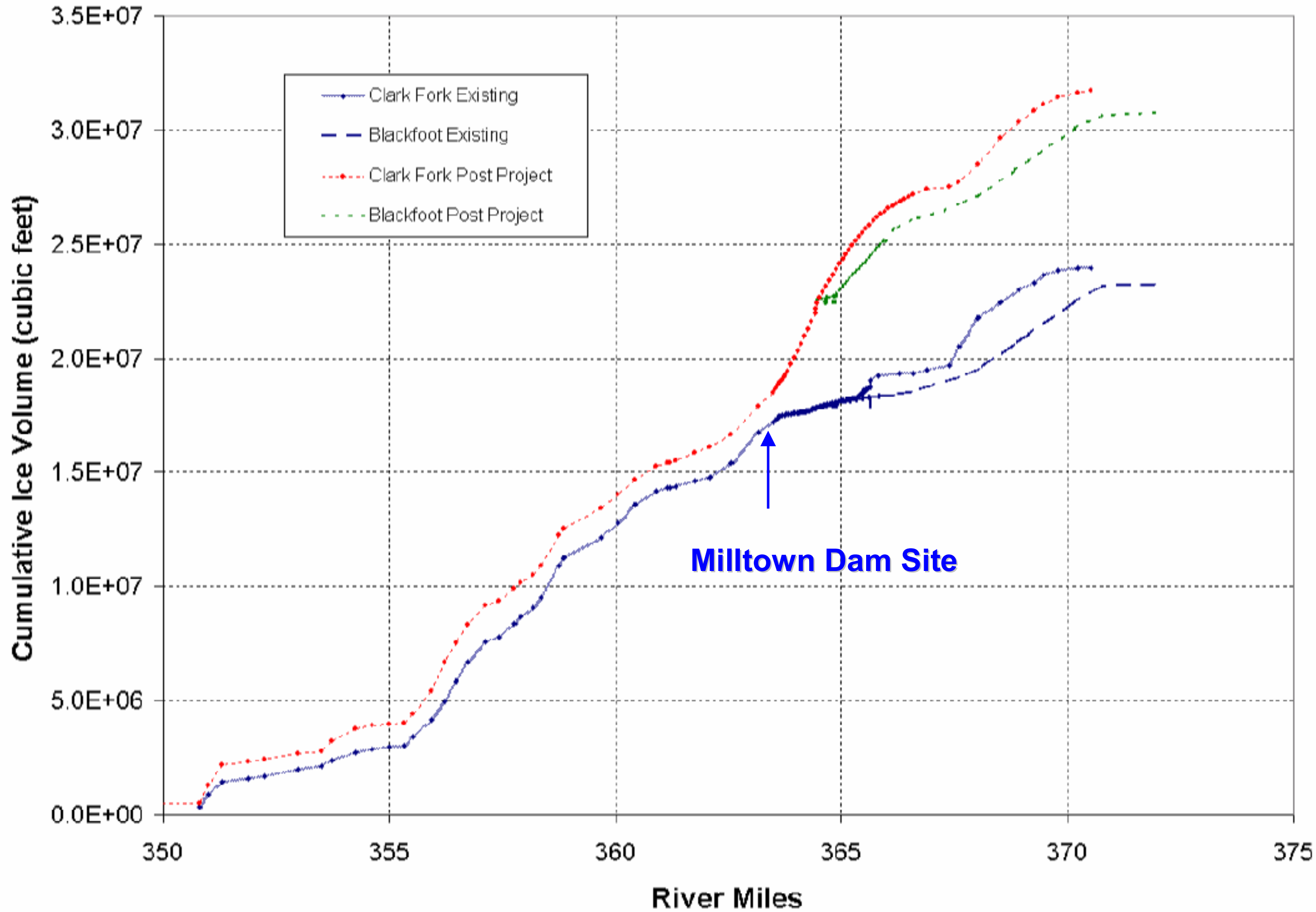






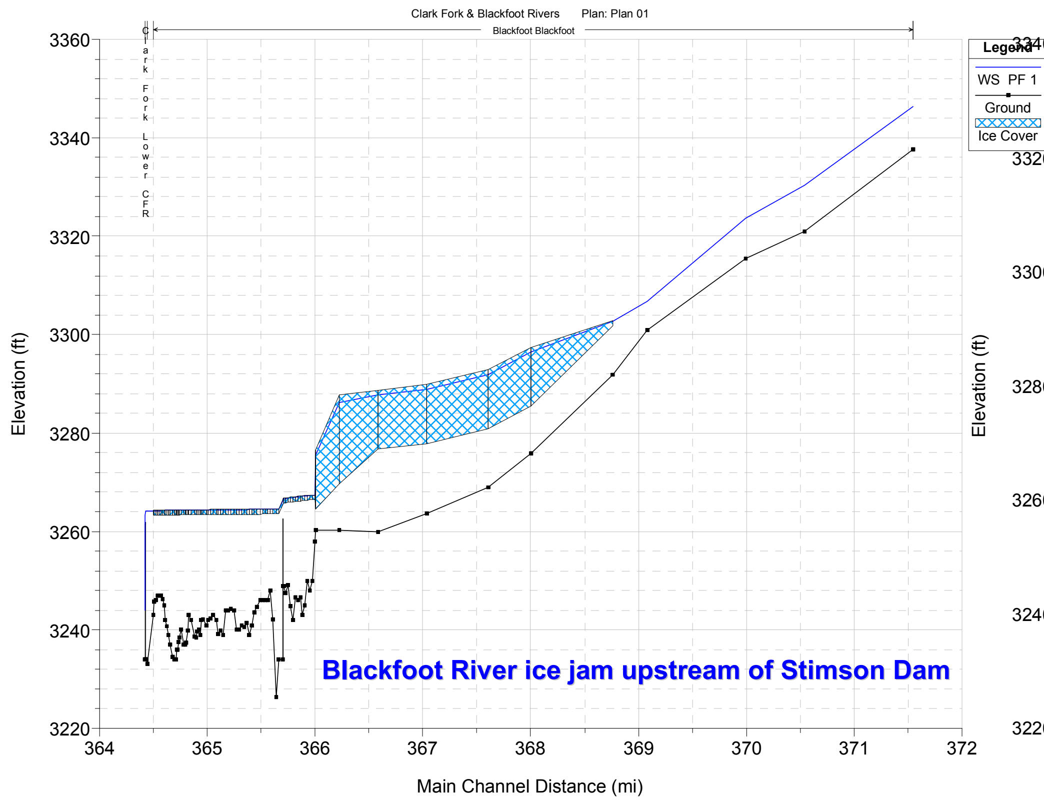
Simulations based on long-term January discharges of 899 cfs at Turah and 1711 cfs on the Clark Fork below the Blackfoot confluence.
These profiles represent worst case scenarios. A prolonged period of extreme cold and a large upstream area for frazil ice generation area assumed.

Cumulative Freezeup Ice Volumes Pre and Post Project

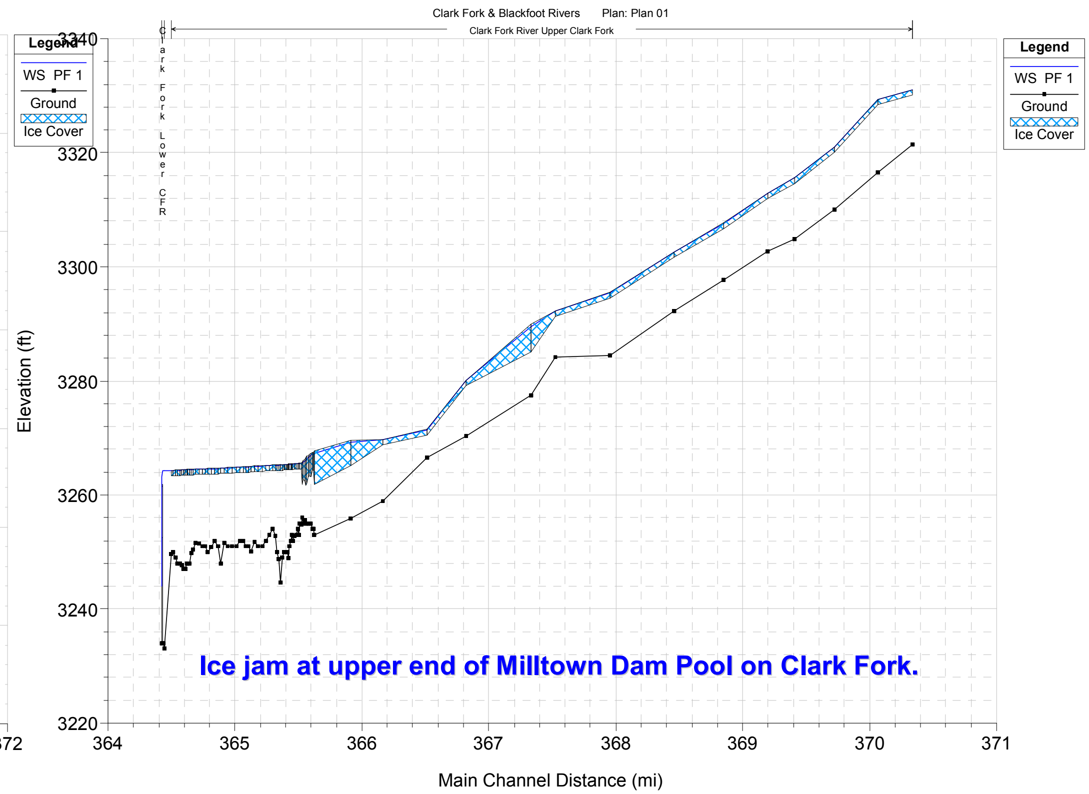


Freezeup ice volumes expected to increase post-project as a result of frazil accumulations upstream of Milltown dam site.

HEC-RAS Modeling of Existing Conditions Breakup Ice Jams



Blackfoot River ice jam upstream of Stimson Dam



Ice jam at upper end of Milltown Dam Pool on Clark Fork.

Worst case scenario based on the February 1996 ice event.

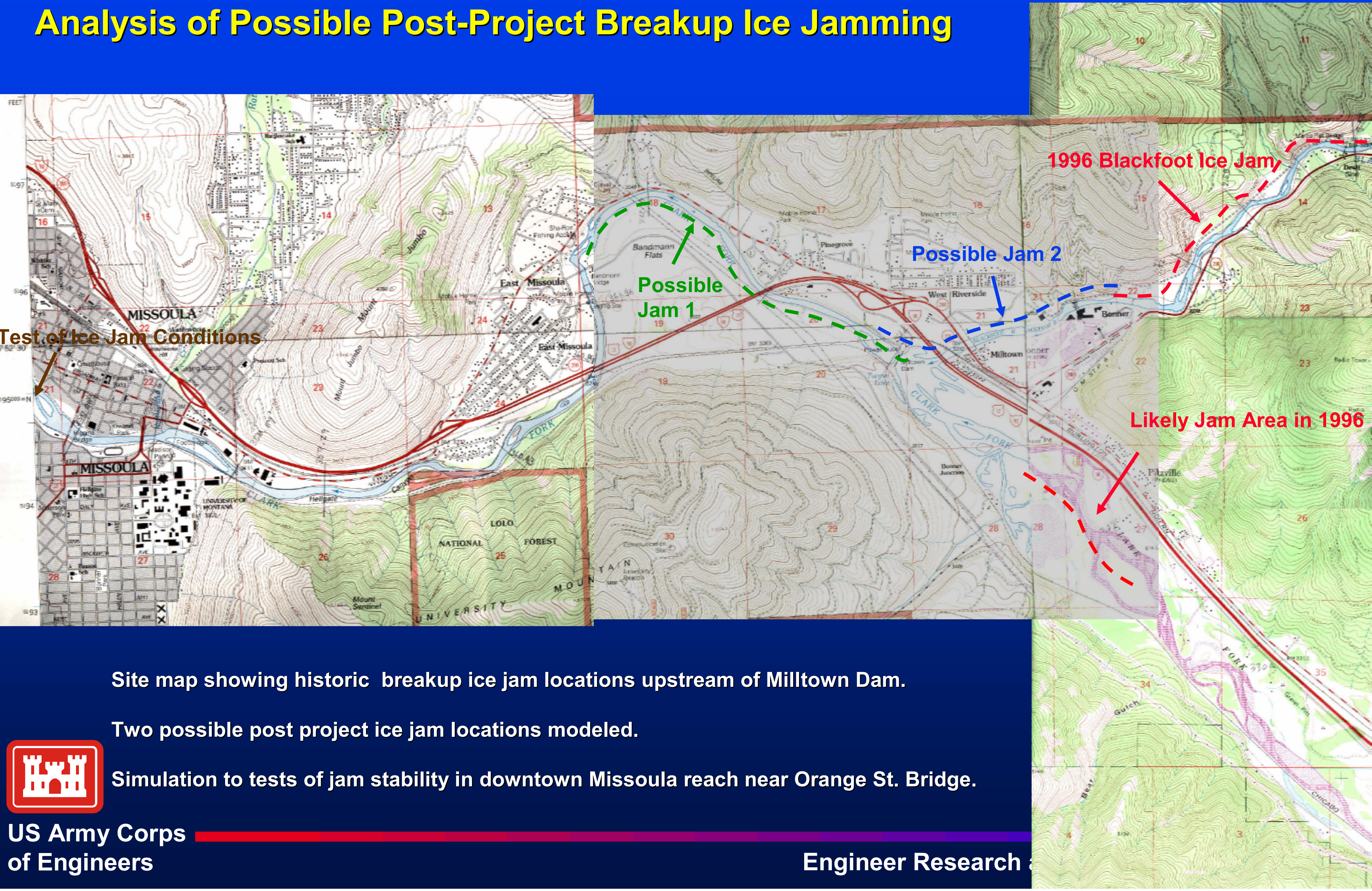
Blackfoot ice jam calibrated to observed high stages and ice thickness from the 1996 ice jam.

Location of Clark Fork Ice jam assumed.

Breakup Ice Jam Parameters

Blackfoot discharge at Bonner Gage	4000 cfs
Clark Fork discharge at Turah Gage	6000 cfs
Clark Fork discharge above Missoula	11,000 cfs
Under-ice roughness	0.06
Ice erosion velocity	4 ft/s
Ice jam porosity	0.5
Internal angle of friction for ice material	45º

Analysis of Possible Post-Project Breakup Ice Jamming

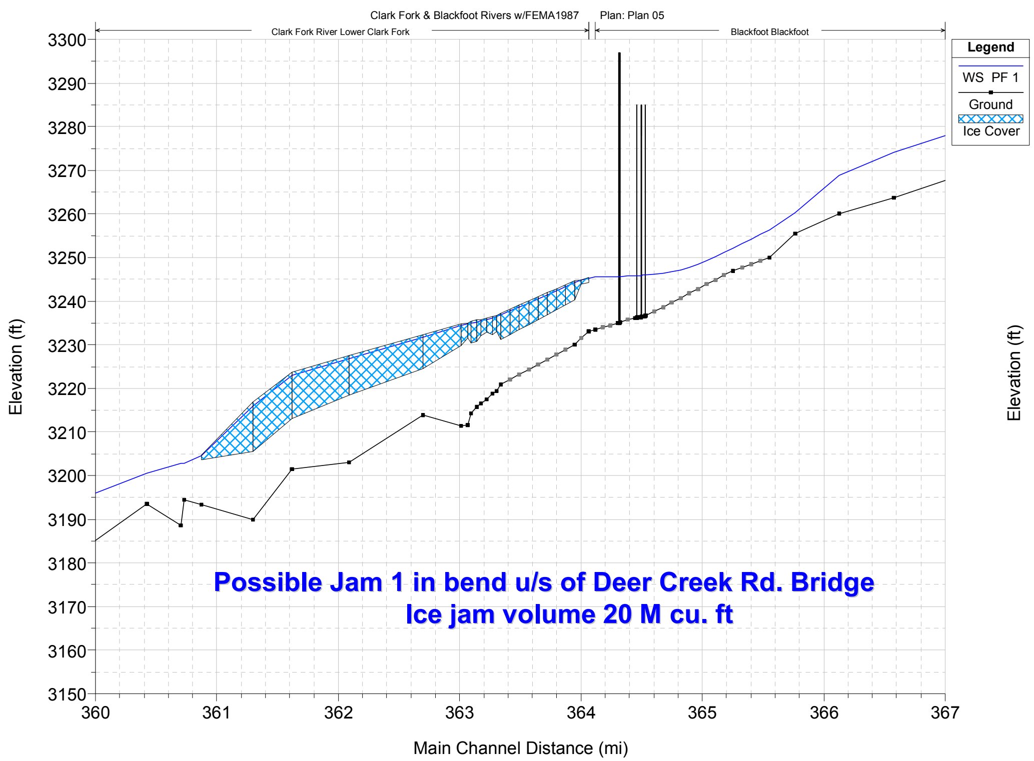


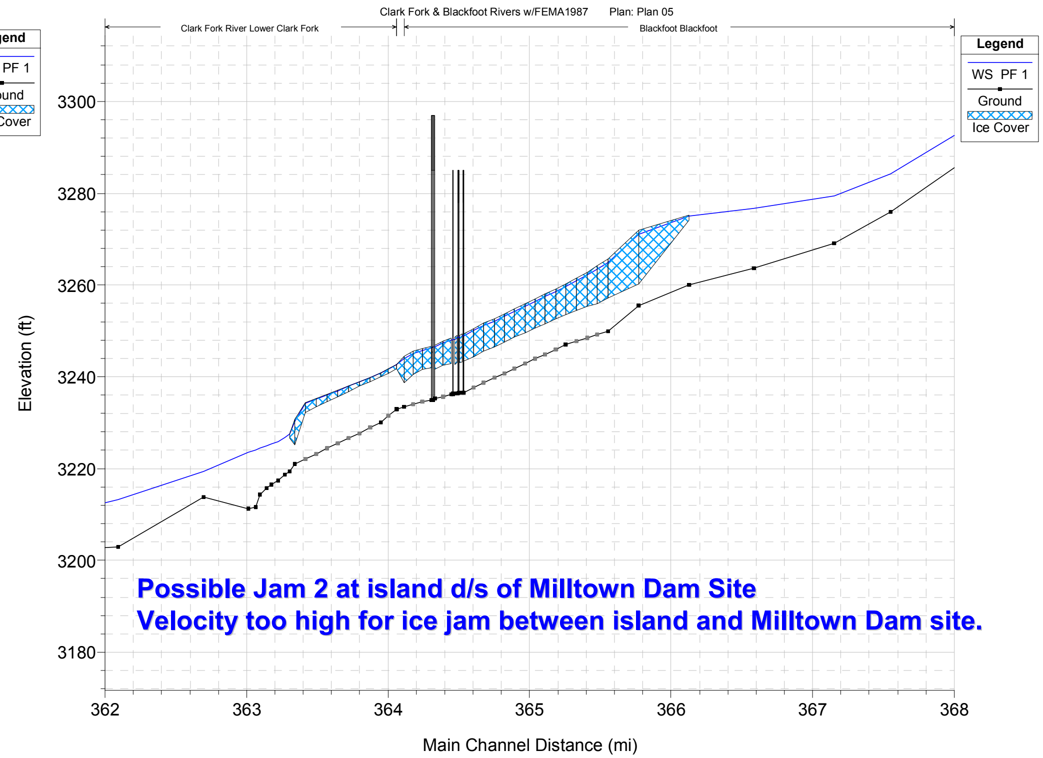
Site map showing historic breakup ice jam locations upstream of Milltown Dam.

Two possible post project ice jam locations modeled.

Simulation to tests of jam stability in downtown Missoula reach near Orange St. Bridge.

HEC-RAS Modeling of Possible Post-Project ice Jamming





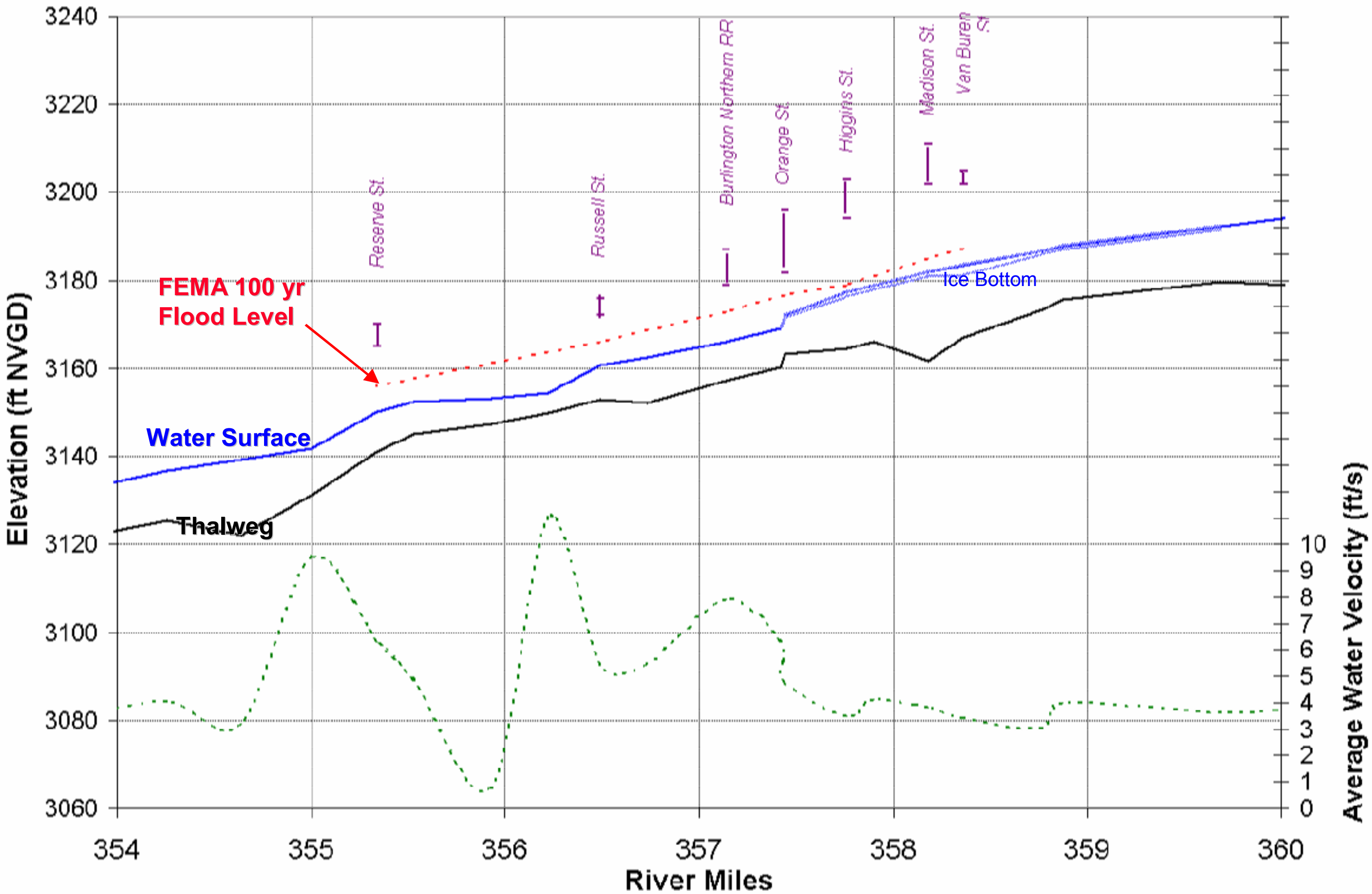
Total ice jam Volume based on the February 1996 ice event.

Same breakup ice jam parameters as in simulation of 1996 Blackfoot ice jam.

Breakup Ice Jam Parameters

Blackfoot discharge at Bonner Gage	4000 cfs
Clark Fork discharge at Turah Gage	6000 cfs
Clark Fork discharge above Missoula	11,000 cfs
Under-ice roughness	0.05
Ice erosion velocity	4 ft/s
Ice jam porosity	0.5
Internal angle of friction for ice material	45º

HEC-RAS Test of Ice Jam Stability in Downtown Missoula Reach

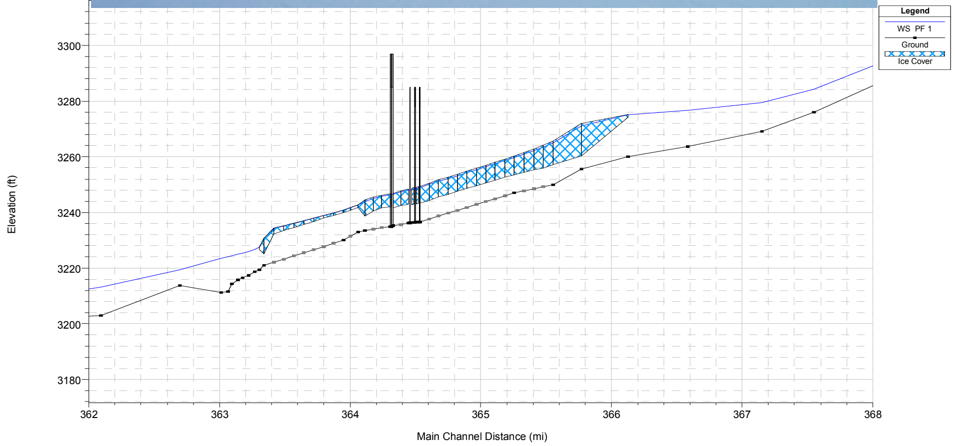


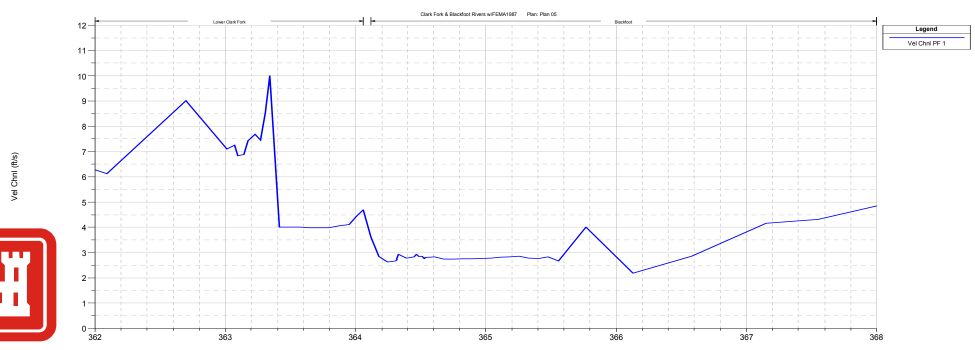
Simulation motivated by concern for post-project ice jam impacts to downtown bridges.

At breakup discharge of 11,000 cfs, water velocity too high for stable ice jam to exist in the downtown area.

Lack of observed ice jams in this section of river support simulation results.

Bridge deck elevations and 100 year flood profile shown for comparison.





Ice-Related Bridge Scour Analysis

Ice-hydraulic parameters were taken from HEC-RAS simulation of possible Jam 1 in the confluence area.

Q_{BF} = 4000 cfs, Q_{UCF} = 6000cfs, t_j = 6 ft, y_{ui} = 6 ft
S = 0.00250, n_i = 0.06, v_{eros} = 4 ft/s, R_i = 2.86 ft

Mean bed shear of 0.45 psf, calculated by depth-slope product

$$\tau_b = \gamma R_i S$$

For the open water 100 year flood: Q = 24,000 cfs, y = 20 ft, S = 0.00256 , mean bed shear by depth slope product was 2.8 psf

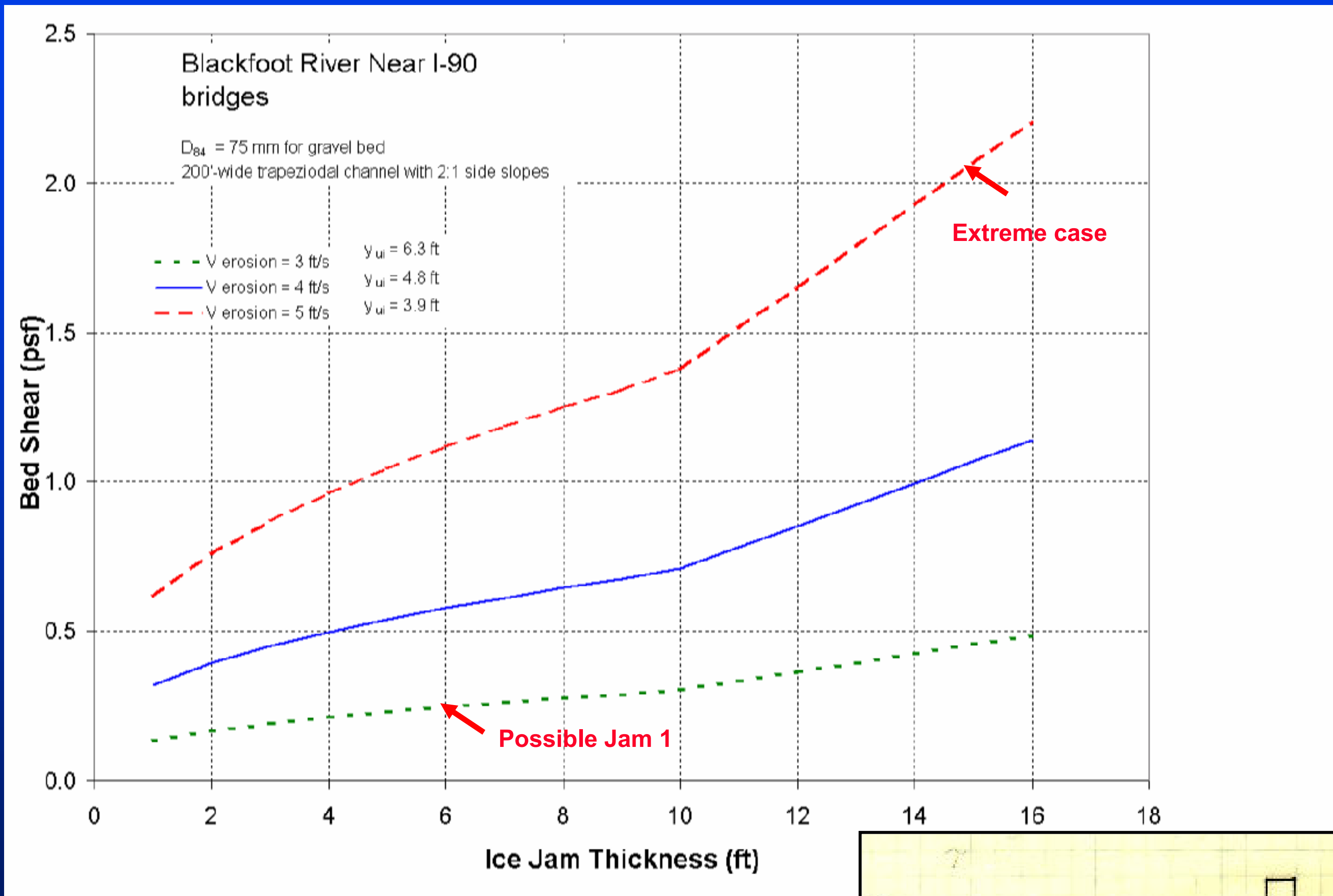
The Beltaos (2001)* approach which better accounts for the effect of ice jam roughness on bed shear was also used. With D_{84} for coarse gravel = 75 mm, an ice-influenced friction factor f_b was calculated for the bed as function of ice and bed roughness, and bed shear calculated using the Darcy-Weisbach equation:

$$\tau_b = \frac{1}{8} f_b \rho_w U^2$$

For an average under-ice water velocity of 3 ft/s, the Beltaos method gave an ice-affected bed shear of 0.25 psf, which is about half the shear calculated by the depth-slope product, and an order of magnitude less than the calculated mean bed shear for the open water 100-year discharge.

***Beltaos, S (2001) "Hydraulic Roughness of Breakup Ice Jams", Journal of Hydraulic Engineering, Vol. 127, No. 8, August, 2001.**

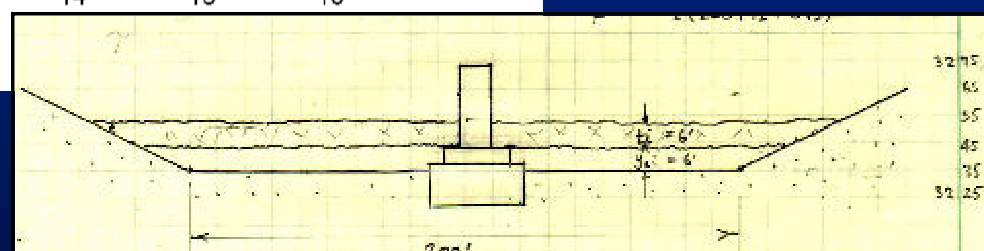
Sensitivity of Bed Shear with respect to Ice Jam Thickness and Under Ice Water Velocity



In the HEC-RAS ice option, under ice flow depth governed by user-input ice erosion velocity.

Higher erosion velocity results in thicker jam and greater calculated bed shear.

In terms of calculated bed shear, a 15-ft-thick ice jam with an under ice velocity of 5 ft/s would be comparable to the 100-yr open discharge water case.



Conclusions

- Juxtaposed and shoved frazil with semi-continuous open leads characterize the ice cover in the study reach. The pools upstream of dams where sheet ice exists are an exception.

- Severe ice jams have occurred at the upstream end of the Milltown and Stimson Dam impoundments, but historical research and hindcasting analysis found this type of event very infrequent.

- Based on HEC-RAS modeling, severe ice jams on the lower Clark Fork are not anticipated following dam removal and channel restoration. At the expected breakup discharges, average water velocity should be sufficient to convey the breakup ice run through this section of river without significant jamming.

- In the event of an ice jam forming near the Clark Fork-Blackfoot confluence, HEC-RAS predicts that a stable, floating ice accumulation could exist on the Blackfoot in the vicinity of the I-90 bridge piers. Calculated ice-affected bed shear is less than the mean bed shear for the 100-year open water discharge, however.

- The Blackfoot ice run may continue to jam in its traditional location upstream of the Stimson Dam Site. Grade control and possibly ice retention piers would insure that this occurred, but it is not clear at this point that such structural measures will be needed.

Acknowledgements

The U. S. Environmental Protection Agency funded this study in support of the Clark Fork River Superfund Project. The Seattle District of the U. S. Army Corps of Engineers managed the study and participated in the program of winter field observations.