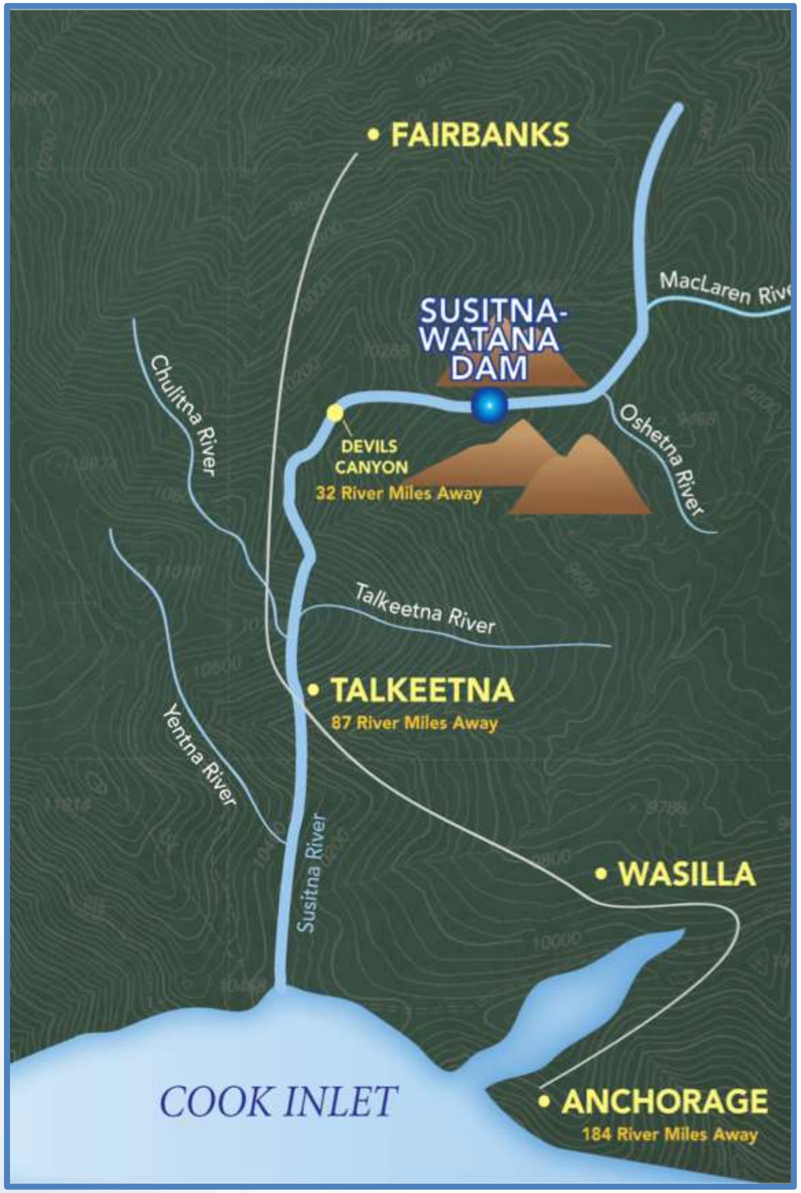

Ice Processes Modeling

Technical Team Meeting –

Riverine Modeling

November 13 - 15, 2013

Prepared by: HDR, Inc.

Prepared for: Alaska Energy Authority

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Ice Processes Modeling and Analysis

- <u>Key Ice Questions:</u>
  - How does ice cover formation, growth, jamming affect main channel and lateral habitats?
  - Will operational scenarios significantly change the ice impacts on main channel and lateral habitats?
    - Freeze-up processes
    - Mid-winter conditions
    - Breakup jamming

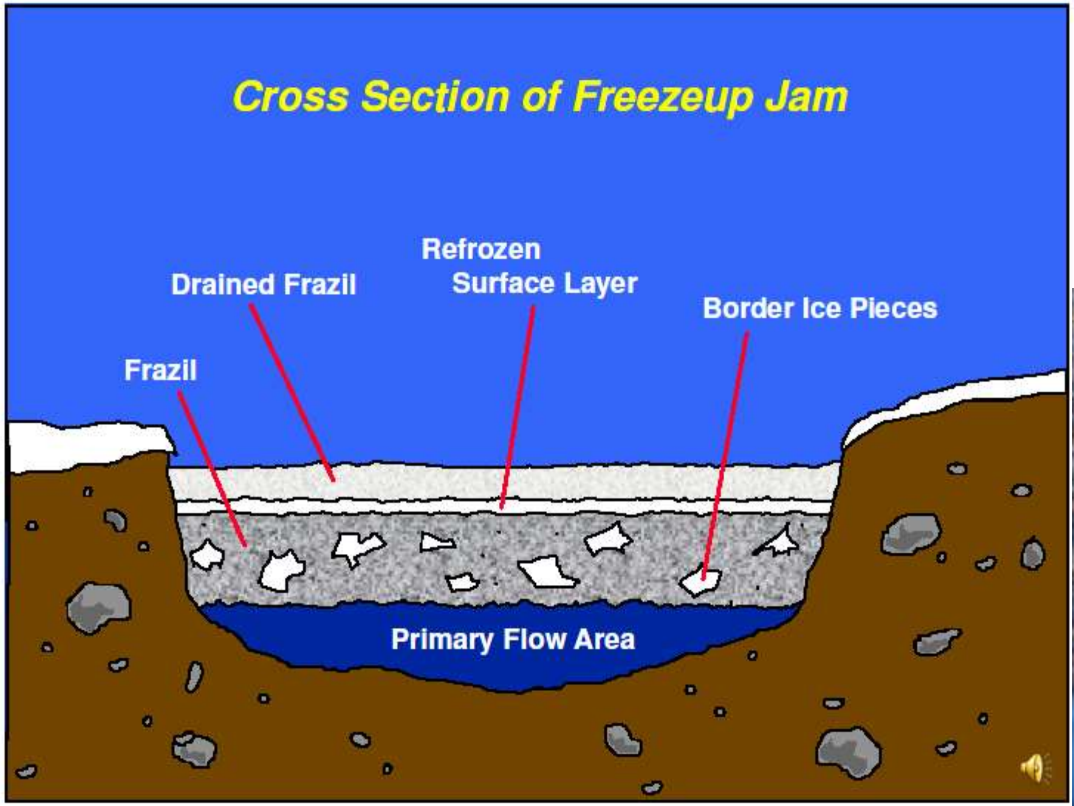
River Ice Basics

- Generally divide the winter (Oct- May) into 3 periods
  - Freeze-up: frazil production, border ice growth, bridging, ice cover and freeze-up jam formation
    - Characterized by cold air temps, relatively steady discharge (falling), cover progression upstream
  - Mid-winter: thermal ice growth, continued frazil production in open areas
    - discharge generally recedes throughout winter

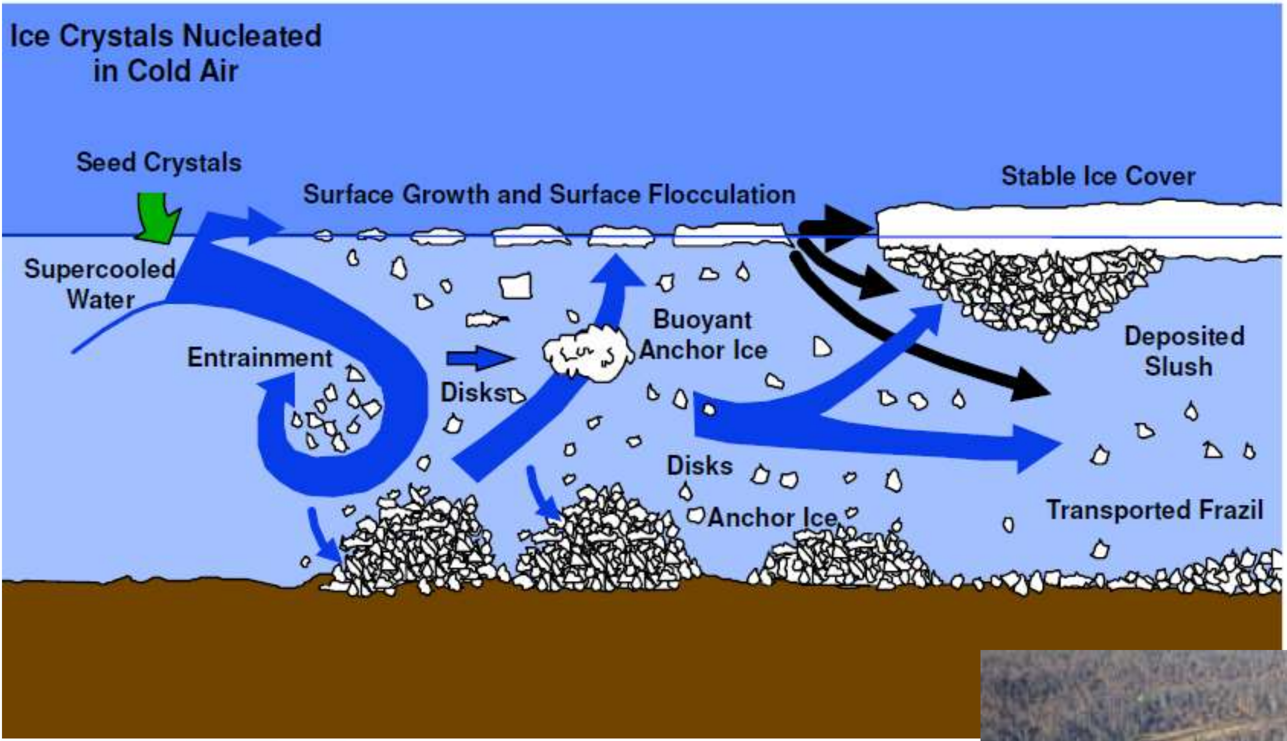
River Ice Basics (cont)

- Breakup: ice melting, open areas growing
  - Characterized by warming air temps, increasing discharge, increased solar incidence, snowmelt runoff, cover thermal and mechanical disintegration
  - Breakup ice jams and ice runs can result in highly unsteady discharge and stage
  - Greatest likelihood of overbank flows
  - Jamming is a function of snowpack, rate of warming, date, freeze-up conditions, etc.

Freeze-up

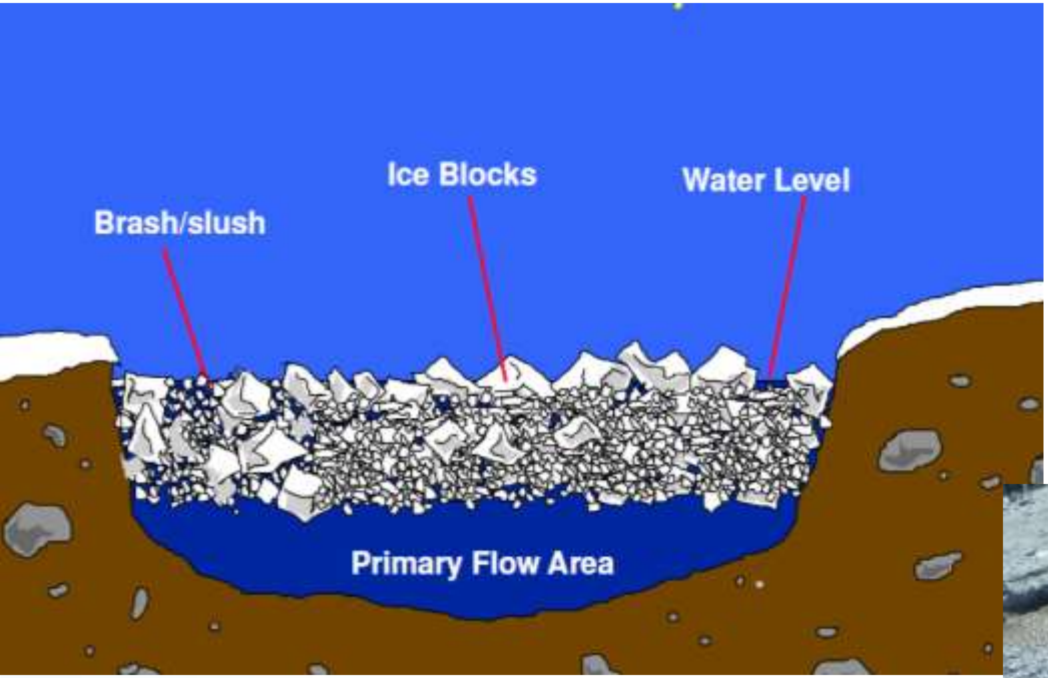


- Cold air temperatures
- Frazil generation
- Border ice growth
- Steady discharge (falling)
- Increase in stage with passage of ice front



Frazil transport stages

Breakup



Highly variable discharge
Thermal degradation
Increasing flows
Surges in stage
Overbank flooding
Ice runs
Shear walls

Stage and Discharge Dynamics

- Moving vs stopped ice
  - Moving (floating) ice travels at nearly the velocity of the underlying water (low resistance)
  - Stopped ice becomes a shear surface nearly doubling resistance to flow
- Jams vs covers
  - Covers are relatively thinner and smoother than jams (often single layer)

Stage and Discharge Dynamics

- Roughness and resistance
  - Interaction can lead to cover and jam consolidation and thickening
  - Side channel typically freezes before main channel, increasing resistance and discharge in side channel
  - May increase discharge in main channel, leading to thicker cover/jam (higher water levels)

Stage during Freeze-up

- Freeze-up at FA-104 (Whiskers Slough)
  - Whiskers Slough time lapse
  - ESS40 time lapse
- Freeze-up at FA-128 (Slough 8a)
  - Slough 8a time lapse

FA-104 (Whiskers Slough)
PRM 104.9 Freeze-up 2012

FA-104 (Whiskers Slough) PRM 104.9 Freeze-up 2012

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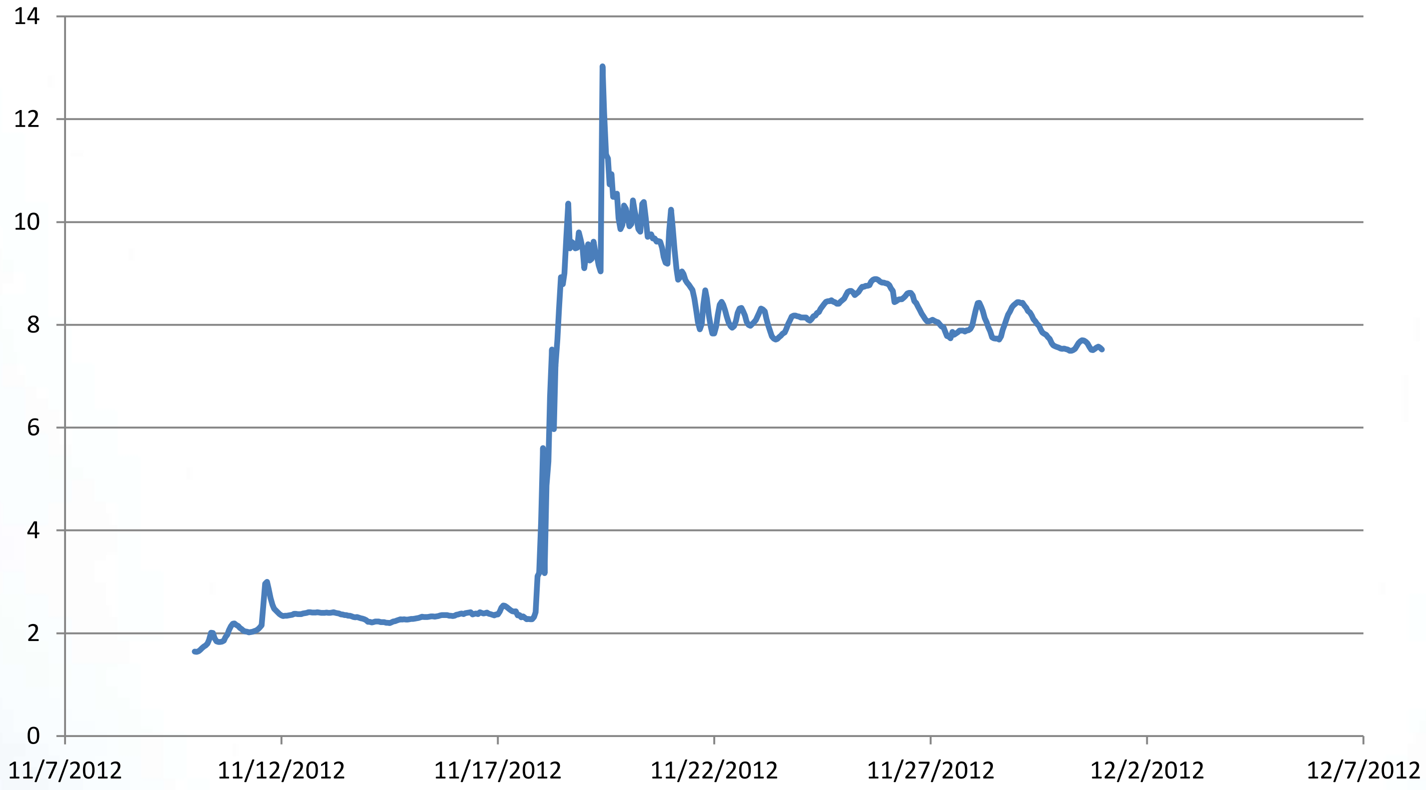
ESS40, PRM 106.8
Freeze-up 2012

ESS40, PRM 106.8
Freeze-up 2012

SUSITNA-WATAN

ESS40, PRM 106.8
Freeze-up 2012



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FA-128 (Slough 8A)
PRM 127.9 Freeze-up 2012

FA-128 (Slough 8A)
PRM 127.9   Freeze-up 2012

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Stage during Breakup

- Initial breakup followed by several ice runs/re-jamming events
- Breakup at FA-128 (Slough 8a)
  - Slough 8a timelapse
  - Impacts showing shear walls
  - Evidence of very high stages, ice runs

FA-128 (Slough 8A)
PRM 127.9 Breakup 2013

SUSITNA-WAT

FA-128 (Slough 8A)
PRM 127.9 Breakup 2013

SUSITNA-WAT

General Modeling Approach

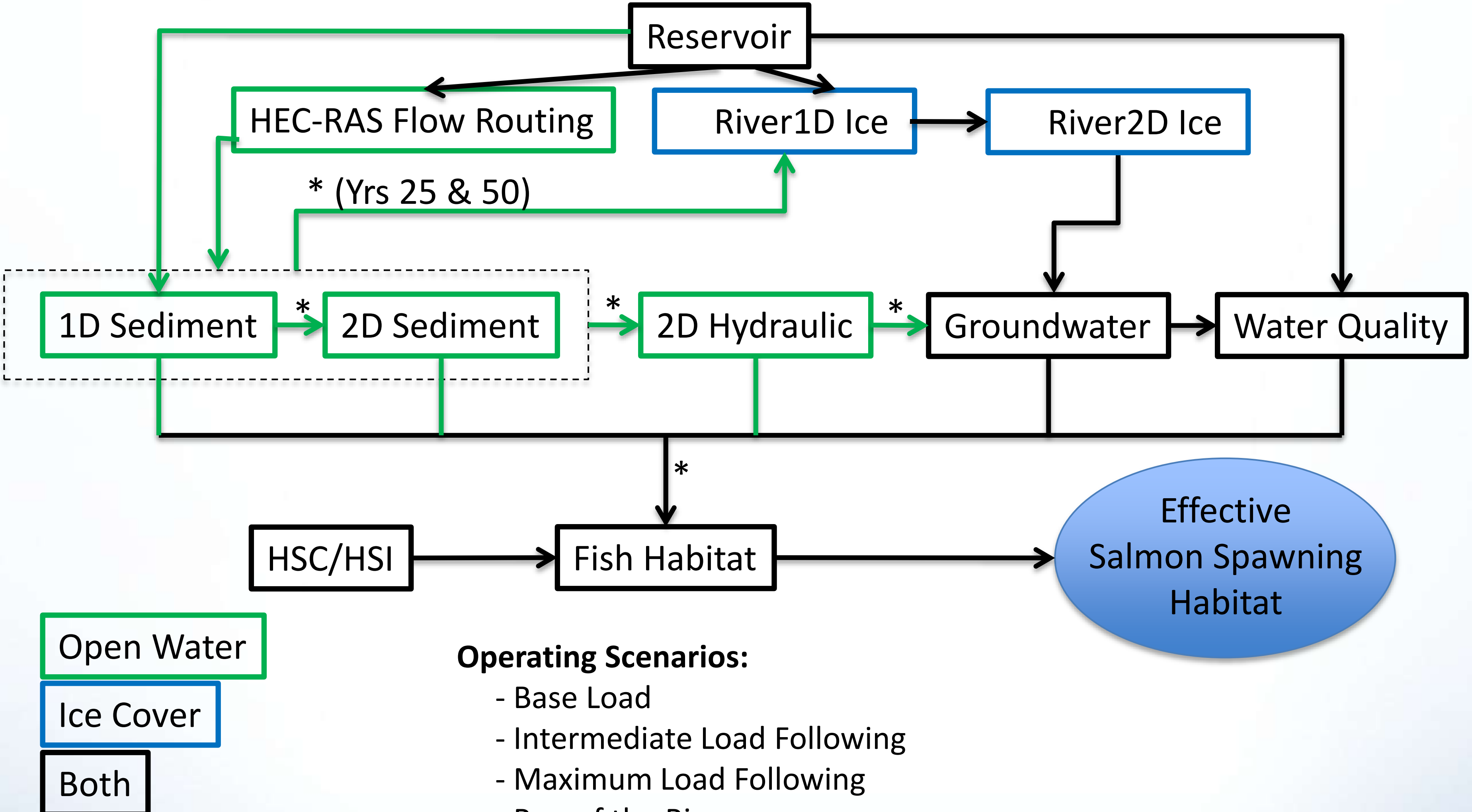
River1D → River2D

Dynamic ice modeling
Temperature modeling
Ice generation/growth
Discharge
Stage/under-ice depth
Velocity
Ice thickness

Static ice cover (specified)
Temperature modeling
Discharge
Stage/under-ice depth
Velocity (2D)

Ice Processes Modeling Team
Study Lead: Jon Zufelt
Lead Modeler: Steve Ertman
U of Alberta: Faye Hicks, Julia Blackburn

Model dependencies flow chart



Operating Scenarios:

- Base Load
- Intermediate Load Following
- Maximum Load Following
- Run of the River

River1D Hydraulic Overview

- *One-dimensional hydraulic flood-routing model*
- *Detailed compound channels*
  - *Main channel*
  - *Right and left overbanks*
- *Channel resistance (calibration parameter)*
  - *Manning's n*
  - *Roughness height*
- *Simulates steady or unsteady flows*

River1D Hydraulics-- Continued

- *Boundary Conditions*
  - *Upstream Inflow discharge hydrograph*
  - *Lateral inflow discharge hydrographs*
  - *Downstream stage hydrograph or normal depth*

- *Initial Conditions*
  - *Base flow*
  - *Initial water-surface elevation*

River1D Ice-Processes Modeling

- *Conservation of thermal energy*
  - *Heat exchange between water and atmosphere*
  - *Heat exchange between ice and atmosphere*
  - *Heat exchange between ice and water*
- *Frazil ice forms when water drops below 0 ℃*
  - *Frazil slush collects below ice cover*
  - *Frazil ice rises as floes and aggregates as new cover*
- *Pore water also freezes to form new ice cover*

River1D Ice-Processes -- Continued

- *Heat transferred to ice cover or frazil slush from atmosphere or water results in melting*

- *Ice front progresses upstream from ice bridges*
  - *Juxtaposition of ice floes traveling downstream*
  - *Bridge locations must be specified ****

- *Channel cross sections occluded by ice and additional hydraulic resistance of ice cover can result in dramatic changes to river stage.*

River1D Ice-Processes Modeling

- *Additional data requirements:*
  - *Air temperature*
  - *Inflow water temperature at upstream boundary*
  - *Inflow ice conditions at upstream boundary*
    - *Suspended frazil concentration*
    - *Surface ice concentration*
    - *Frazil floe thickness*
    - *Solid ice thickness*
  - *Locations and timing of ice bridges*

River1D Ice-Processes Modeling

- *Calibration data requirements:*
  - *Water temperature*
  - *Ice front position with time*
  - *Solid and frazil ice concentrations*
  - *Ice thickness*

- *Output of River Ice-Processes Model*
  - *Water temperature*
  - *River stage*
  - *Ice profile (both position and thickness)*

Ice-Processes Modeling

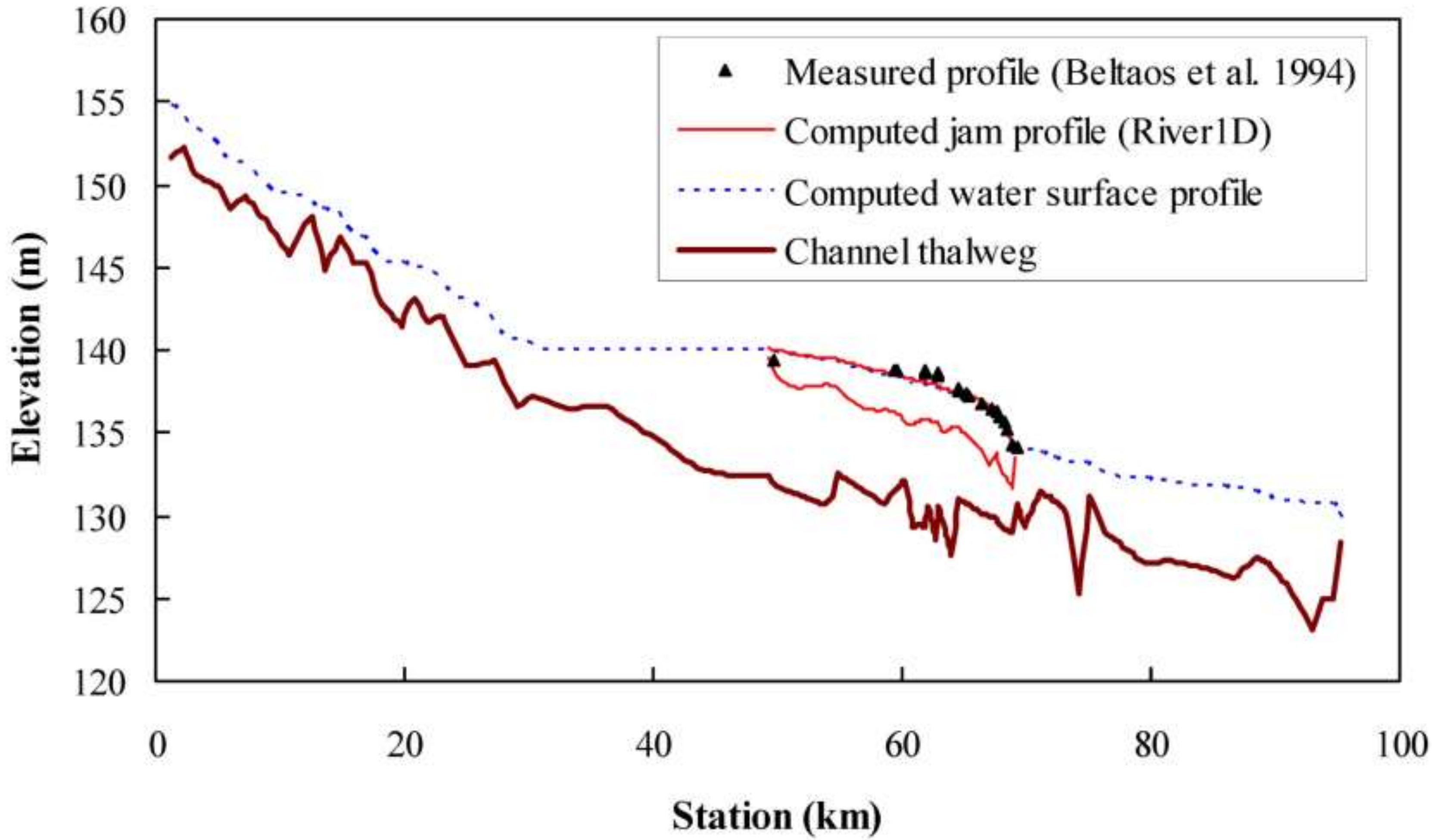
- ***Capabilities Enhancements for River1D Model***
  - Effort led by Dr. Faye Hicks, River Ice Research Group, University of Alberta (UA)
  - HEC-RAS to River1D geometry file converter
  - Ability to model compound channels (i.e., main channel and left/right overbanks)
  - Ability to model natural cross-section geometry
  - Ability to work directly with Imperial or SI units
  - Updating User Manual to reflect new capabilities.

River1D Model Middle River

- Surveyed geometry at 88 cross sections
  - Main channel only. Awaiting overbank geometry to be developed by others (e.g., LiDAR).
  - Interpolated cross sections at 0.2-mile spacing.
- Main-channel Manning's *n* from R2's HEC-RAS open-water model. Need overbank roughness.
- Upstream inflow hydrograph from USGS 15291700 (Susitna River above Tsusena Creek).
  - Calibration interval: August 11-17, 2012

River1D Model Middle River – cont'd

- Validating lateral inflows
- Steady-flow test run conducted with successful convergence.
- Unsteady, open-water calibration (calibration interval: August 11-17, 2012) matched open-water flow routing results.
- Additional in-channel open water calibration runs to be conducted.
- Collect and compile winter data to support ice-processes modeling.
- Input data needs for River2D open water modeling identified



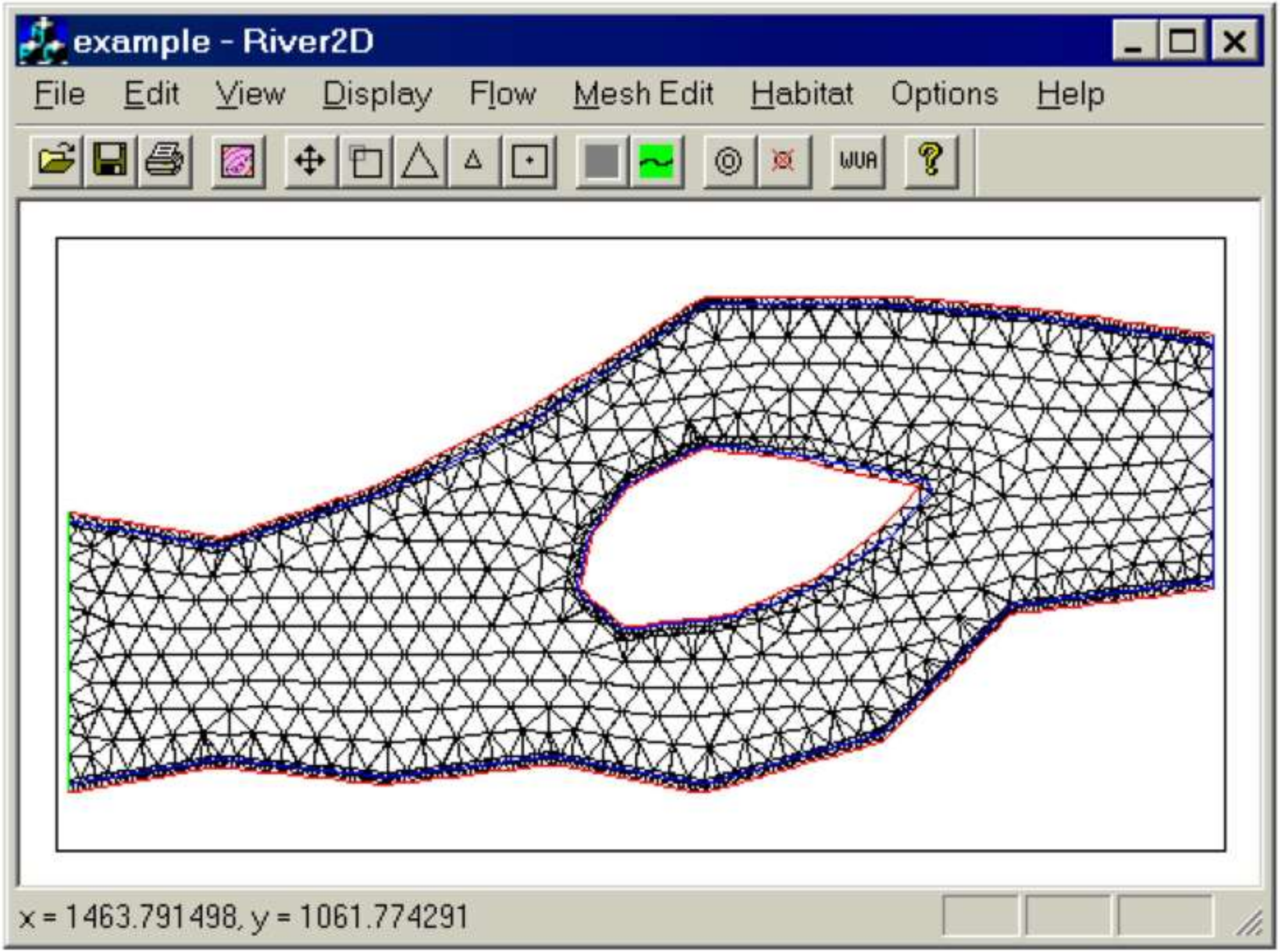
Measured profile (Beltaos et al. 1994)
Computed jam profile (River1D)
Computed water surface profile
Channel thalweg
Elevation (m)
160
155
150
145
140
135
130
125
120
0
20
40
60
80
100
Station (km)

River1D

- Animations of output

River2D Ice-Cover Model Overview

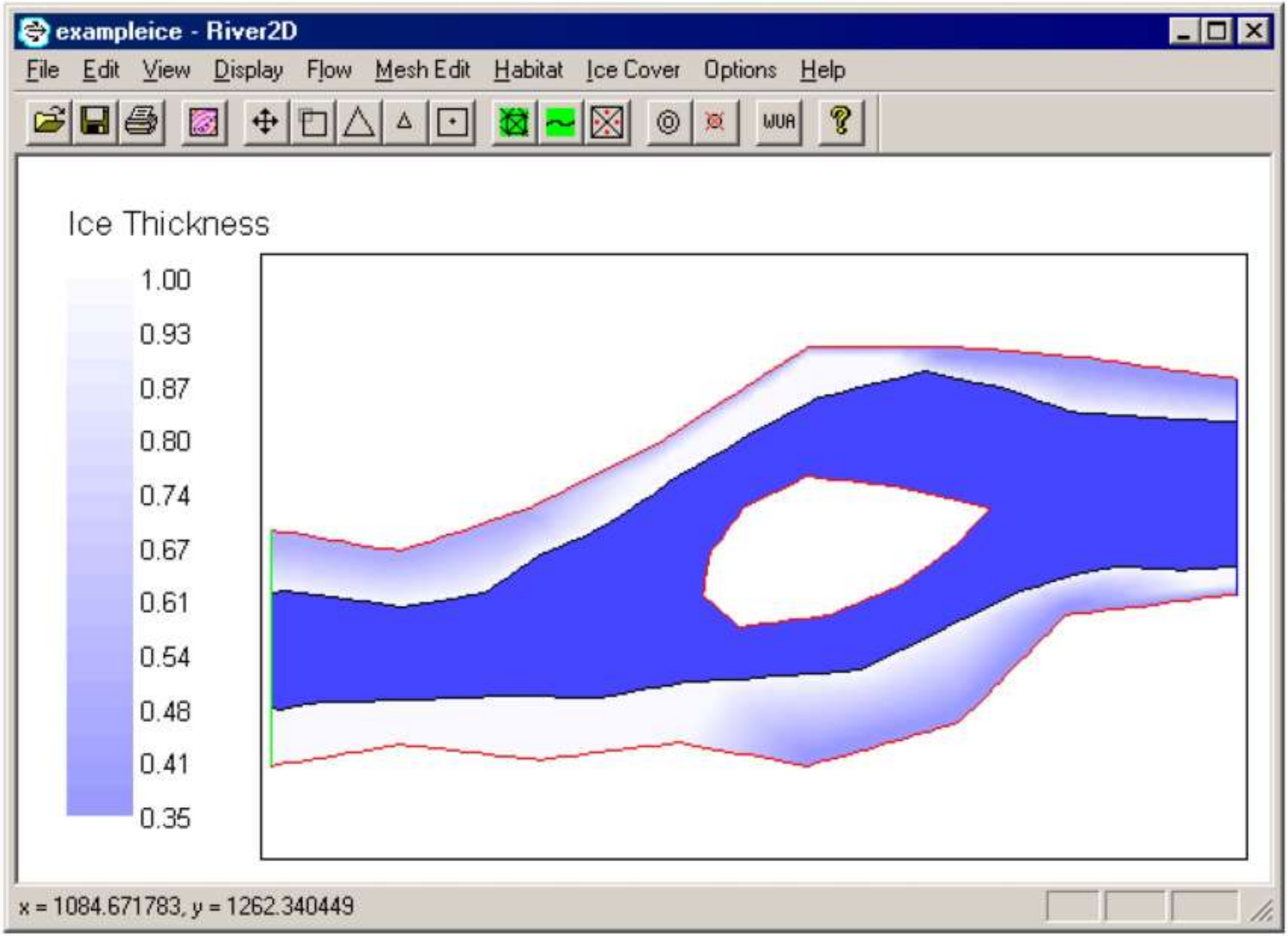
- *Two-dimensional depth-averaged model*
- *Spatially variable, triangular, finite-element grid*
  - *Fine spatial resolution*
  - *Detailed bathymetry*
- *Channel resistance*
  - *Manning's n*
  - *Roughness height*
- *Simulates steady or unsteady flows*
- *Wetting and drying (floodplain inundation)*



example - River2D
File Edit View Display Flow Mesh Edit Habitat Options Help
WUA
x = 1463.791498, y = 1061.774291

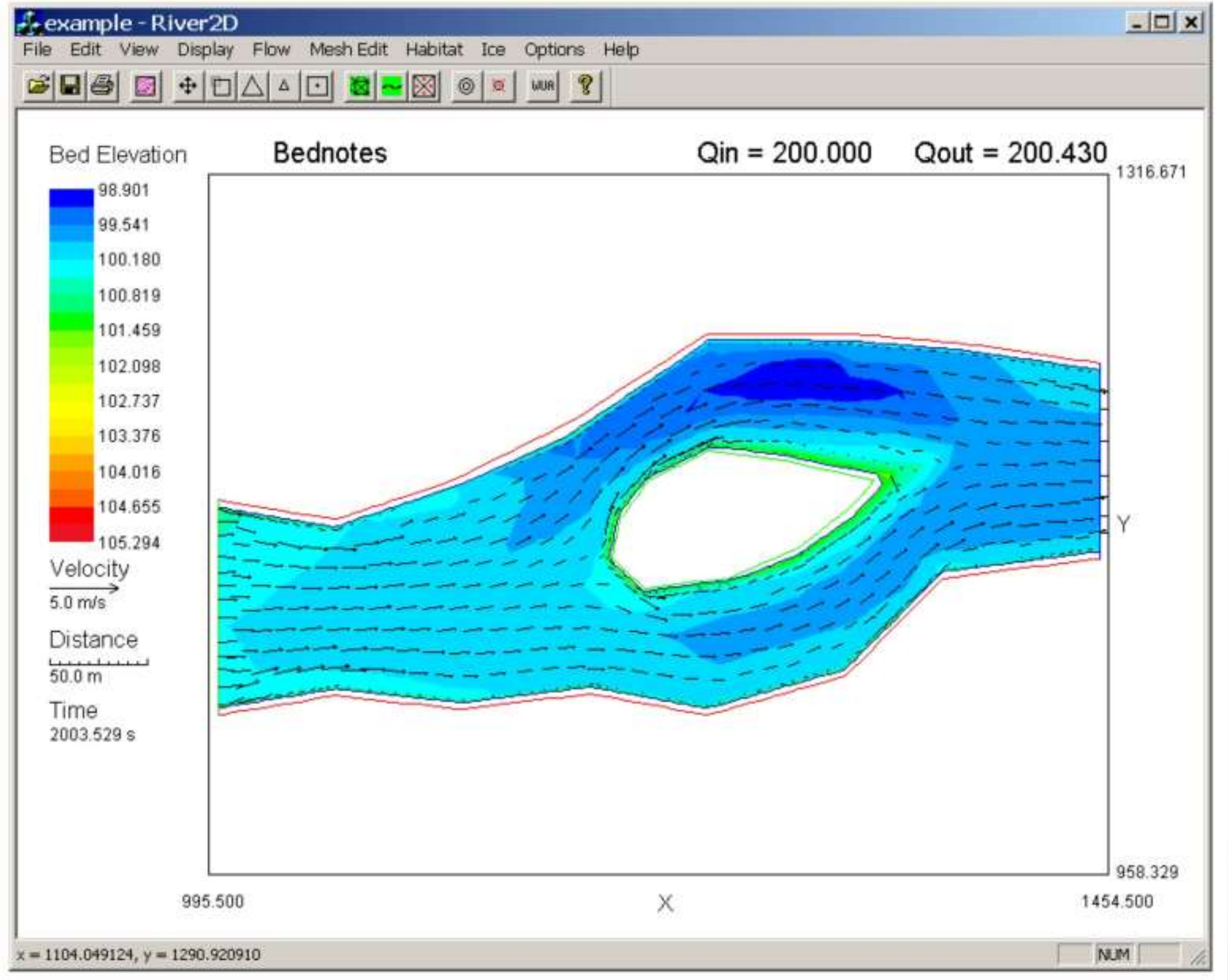
River2D Overview -- Continued

- *Ice cover is specified ****
  - *Spatially variable ice thickness*
  - *Thickness does not vary with time*
    - *Evolution of an ice cover can be approximated by separate model runs at different stages of ice development.*
  - *Fixed in space horizontally*
  - *Cover is in isostatic balance with water column*
    - *Computation elements seeks isostatic balance independently*
  - *Ice roughness contributes to channel resistance*


exampleice - River2D
File Edit View Display Flow Mesh Edit Habitat Ice Cover Options Help
WUA
Ice Thickness
1.00
0.93
0.87
0.80
0.74
0.67
0.61
0.54
0.48
0.41
0.35
x = 1084.671783, y = 1262.340449

River2D Overview -- Continued

- *Boundary Conditions*
  - *Inflow hydrograph*
  - *Outflow Stage or Stage-Discharge Rating Curve*
- *Model Output*
  - *Channel discharge*
  - *2D water-surface elevation*
  - *Vertically averaged current velocity*



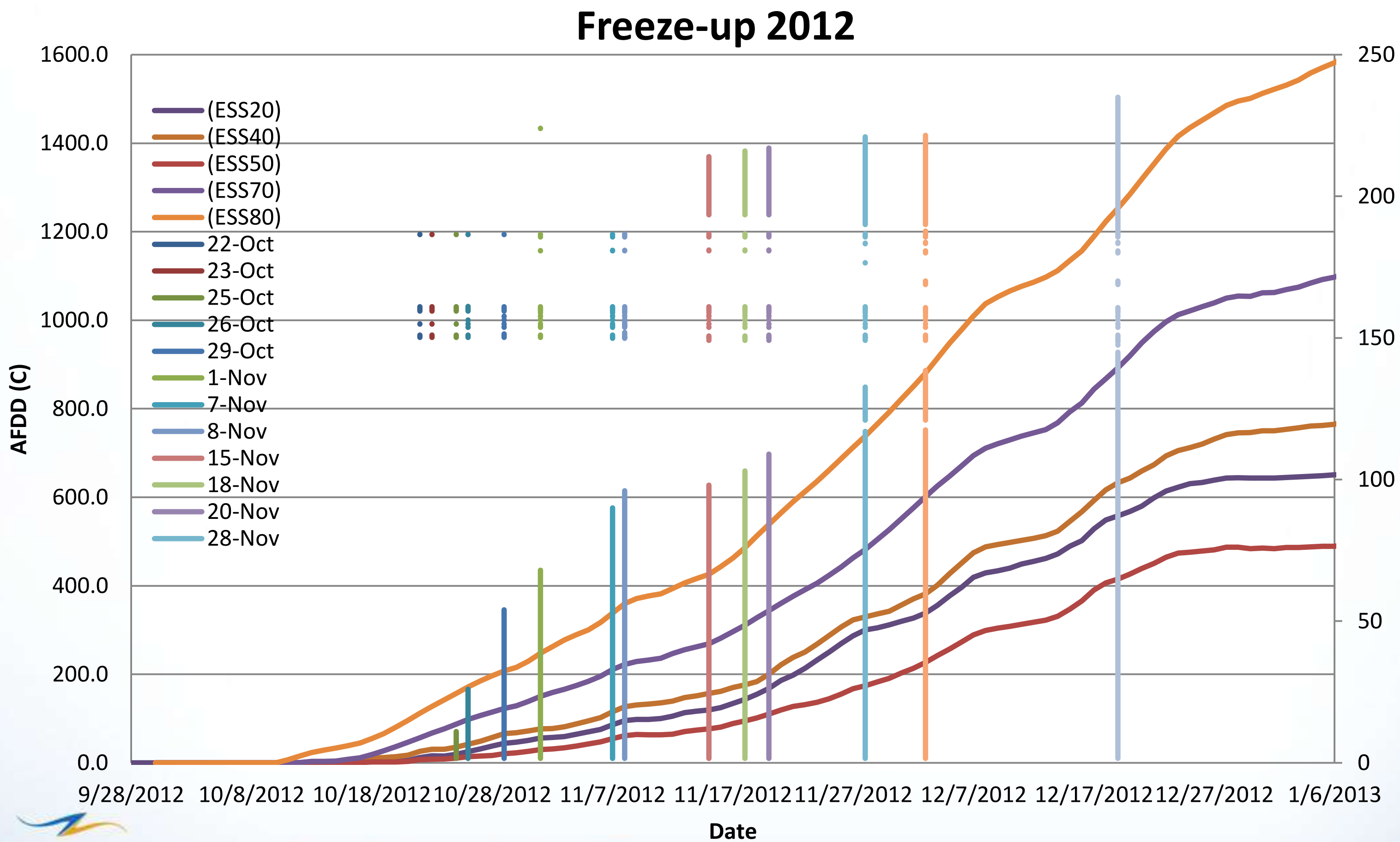
example - River2D
File Edit View Display Flow Mesh Edit Habitat Ice Options Help
Bed Elevation
Bednotes
Qin = 200.000
Qout = 200.430
1316.671
98.901
99.541
100.180
100.819
101.459
102.098
102.737
103.376
104.016
104.655
105.294
Velocity
5.0 m/s
Distance
50.0 m
Time
2003.529 s
Y
958.329
995.500
X
1454.500
x = 1104.049124, y = 1290.920910
NUM

Ice Processes – Next Steps

- Continued River1D modeling (open and ice)
- Begin River2D modeling
- 2013 Freeze-up observation program begun
    - Previous efforts and data required for River1D model guide program planning and efficiency
    - Time Lapse Camera maintenance October
    - 12 freeze-up flights beginning Nov 6, 2013

Freeze-up Forecasting

- Freeze-up progression from 1980s and 2012



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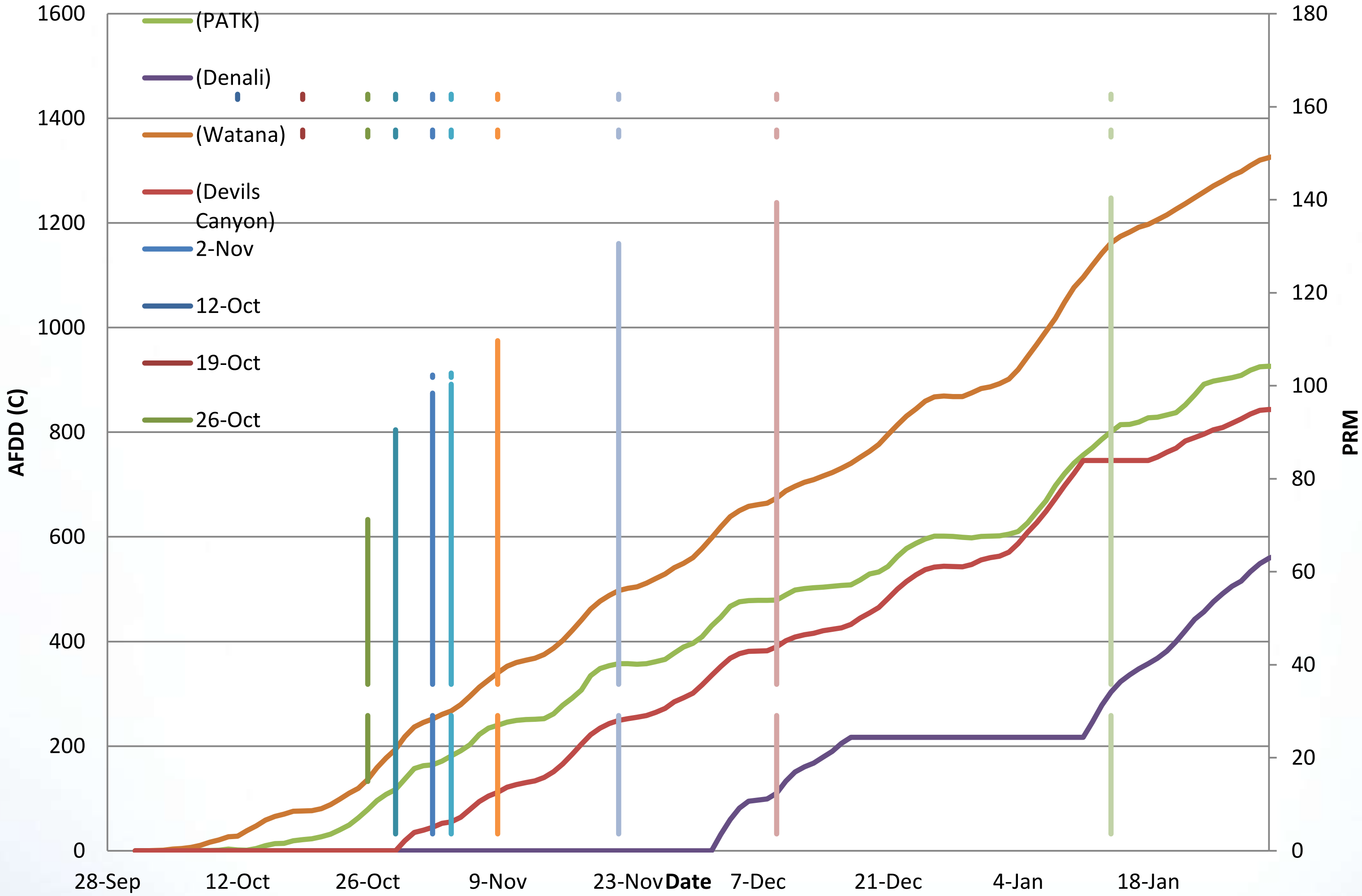
Freeze-up 1982



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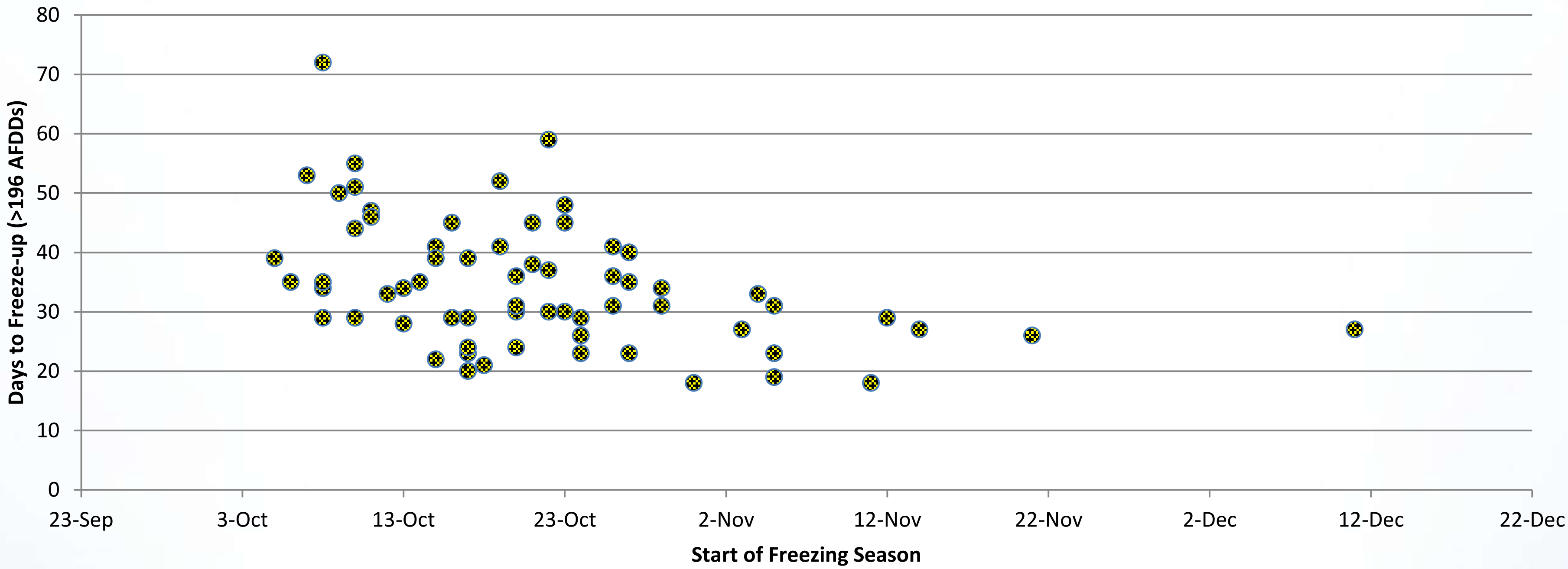
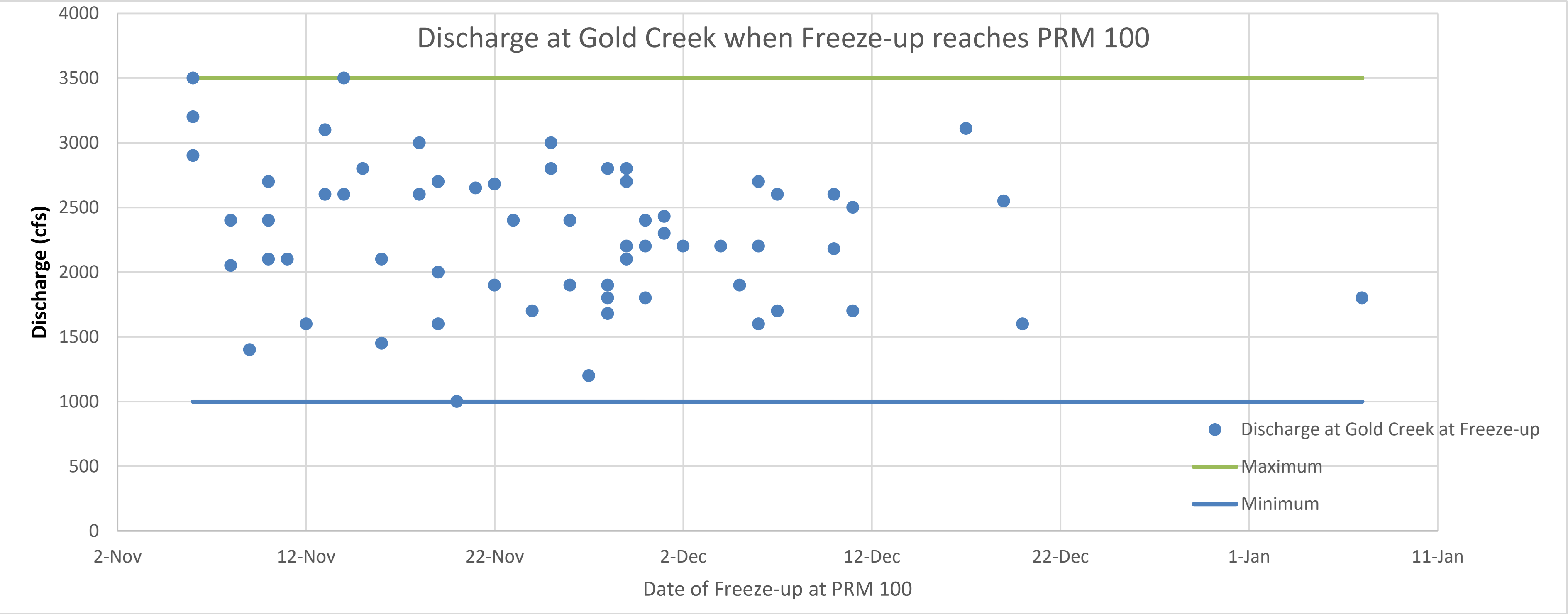
Number of Days to Freeze vs. Freezing Start Date



Number of days for cover to progress to PRM 100 based on Talkeetna temperatures. Start of Freezing this year is Nov 6, 2013.



Discharge at Gold Creek when the ice cover reached PRM 100