Design and Operation of Ice Roads

Amit Armstrong, Ph.D., P.E., Project Manager
Billy Connor, P.E., Principal Investigator

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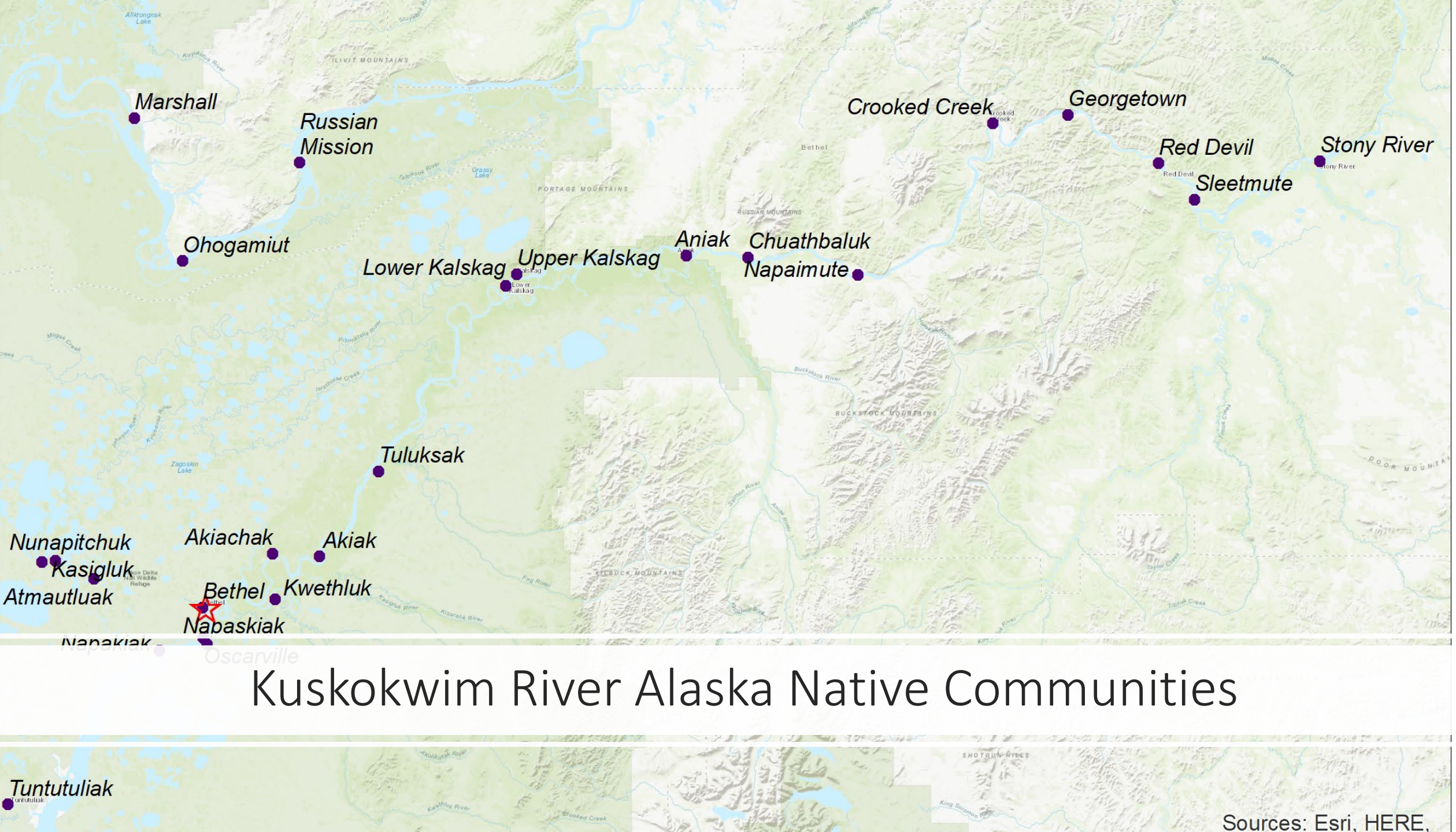
Office of Federal Lands Highway

- Funding provided by Office of Federal Lands Highway research program
- Sponsored by Tribal Transportation Program
- The project is nearing completion
  - Final Report
  - Field Guide Application

Ice Roads

- Provide vital links to Alaska Native Communities during arctic winters
- Support resource extraction activities
- Mostly located in Alaska, Yukon, and Northwest Territories
- Planned, designed, and constructed for every winter season



Kuskokwim River Alaska Native Communities

The Team

Billy Connor

Steven Daly

Kevin Bjella

Sveta Stuefer

Nathan Belz

Vicky Wolf

Introduction
&
Ice Road Framework

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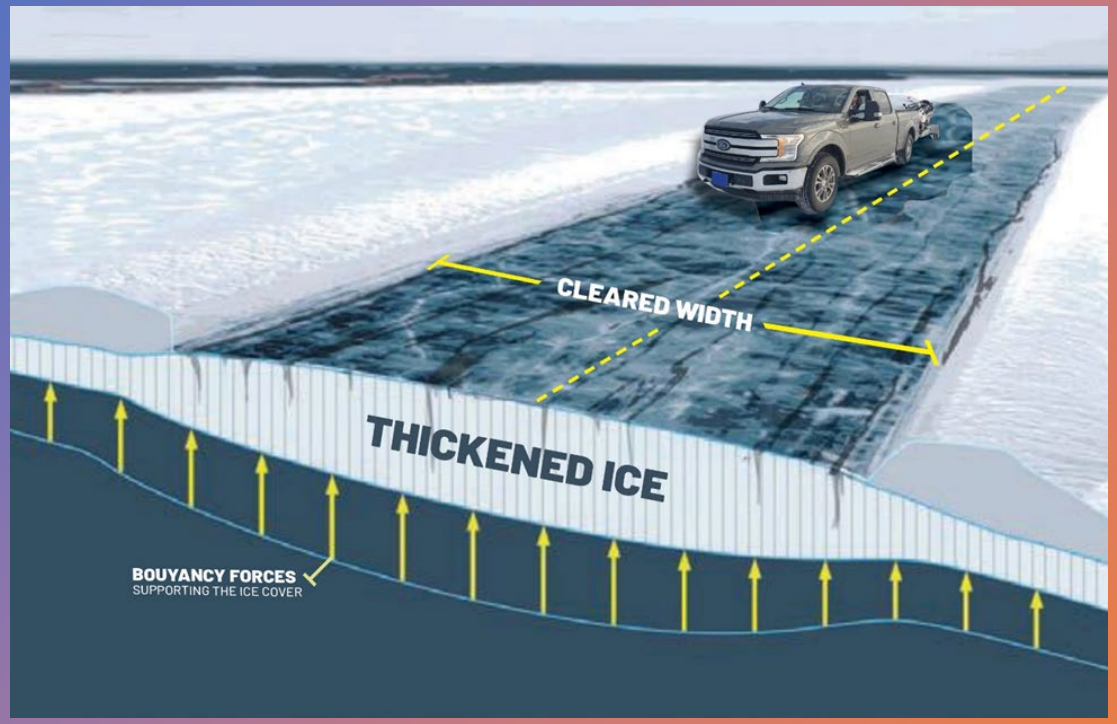
Disclaimers

While the manual provides an overview of the principles of ice mechanics and operations requirements, it is not nor is it intended to be an in-depth discussion of these principles. Rather, it is intended to provide an overview of those principles so that the practitioner has a basic understanding of the principles of the performance of an ice sheet under traffic loadings.



Purpose

- Provide guidelines for ensuring safe operation of ice roads
  - Route selection
  - Minimum ice thicknesses
  - Geometry
  - Monitoring
  - Maintenance and repair strategies
  - Vehicle weight and speed
  - Signage
  - New Technologies

Phase	Main Activities	Tasks
Pre-Season	Planning	Route Planning
		Select Operations Level
		Determine Signage Requirements
		Determine Equipment Requirements
Pre-Construction	Surveying	Manual Surveying
		GPR Surveying
	Route Selection	Route Selection
		Access Points
Construction	Ice Road Establishment	Preparing Travel Lanes
		Snow Clearing
		Ice Strengthening
		Surveying
	Signage	Construction Signs
		Entry Signs
		Regulatory and Advisory Signs
Ice Road Operation	Monitoring	Visual Inspection
		Surveying
	Maintenance	Repairing Cracks
		Traffic Control
		Updating Signage
	Administration	Controlling Loads and Speeds
		Safety
		Training
End of Season	Shutdown	Close Ice Road to Public Use

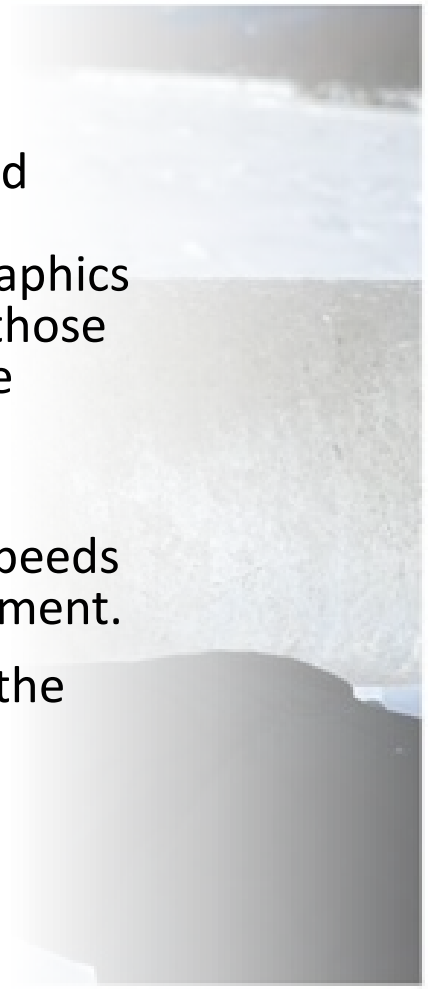
Organization

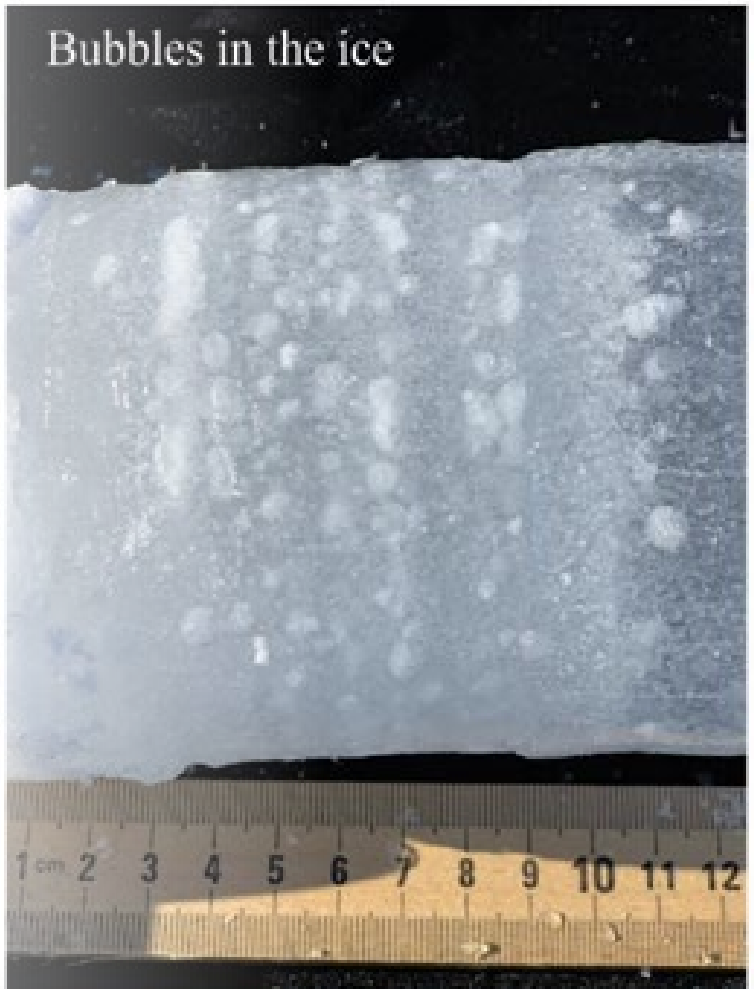
- The manual is organized around the phases of the ice road framework along with the associated activities and tasks.

- Phases are arranged in a logical order which guides the user through the design, construction and operation of the ice road while providing ready access to information during each phase.

Ice Road Philosophy

- Safety above all.
- The manual seeks to blend science, experience and judgement into tables, graphics and standards to ensure those responsible provide a safe transportation facility.
- Determination of safe ice thicknesses and vehicle speeds are bases on risk management.
- As risk increases so does the need for monitoring.





Safety Considerations

We must consider the ice over which the public travels as material subject to the imperfections created by the environment. It is the responsibility of all who are responsible for the design, construction and operations of the ice roads to ensure the safety of those who use the ice road.

Users also have the responsibility to adhere to all safety provisions as required by the those who manage and operate the ice roads.

BACKGROUND ON ICE ROADS

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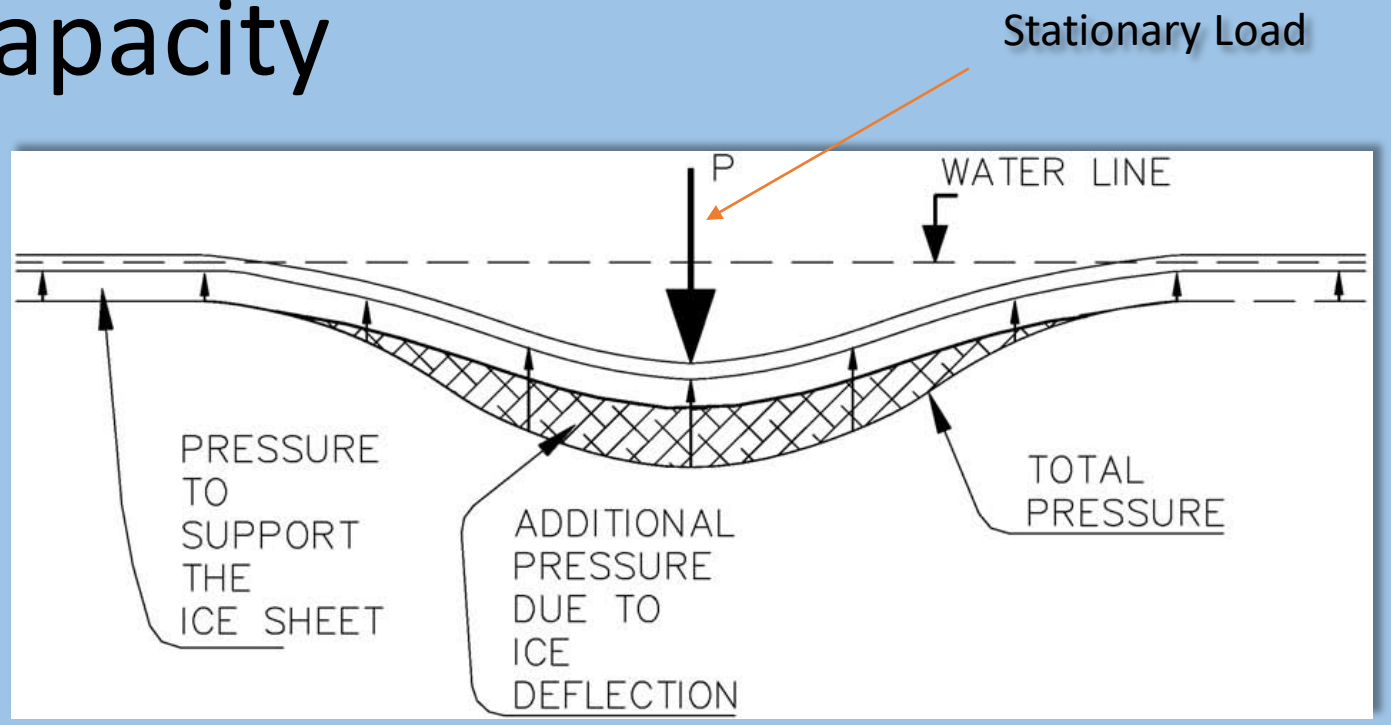
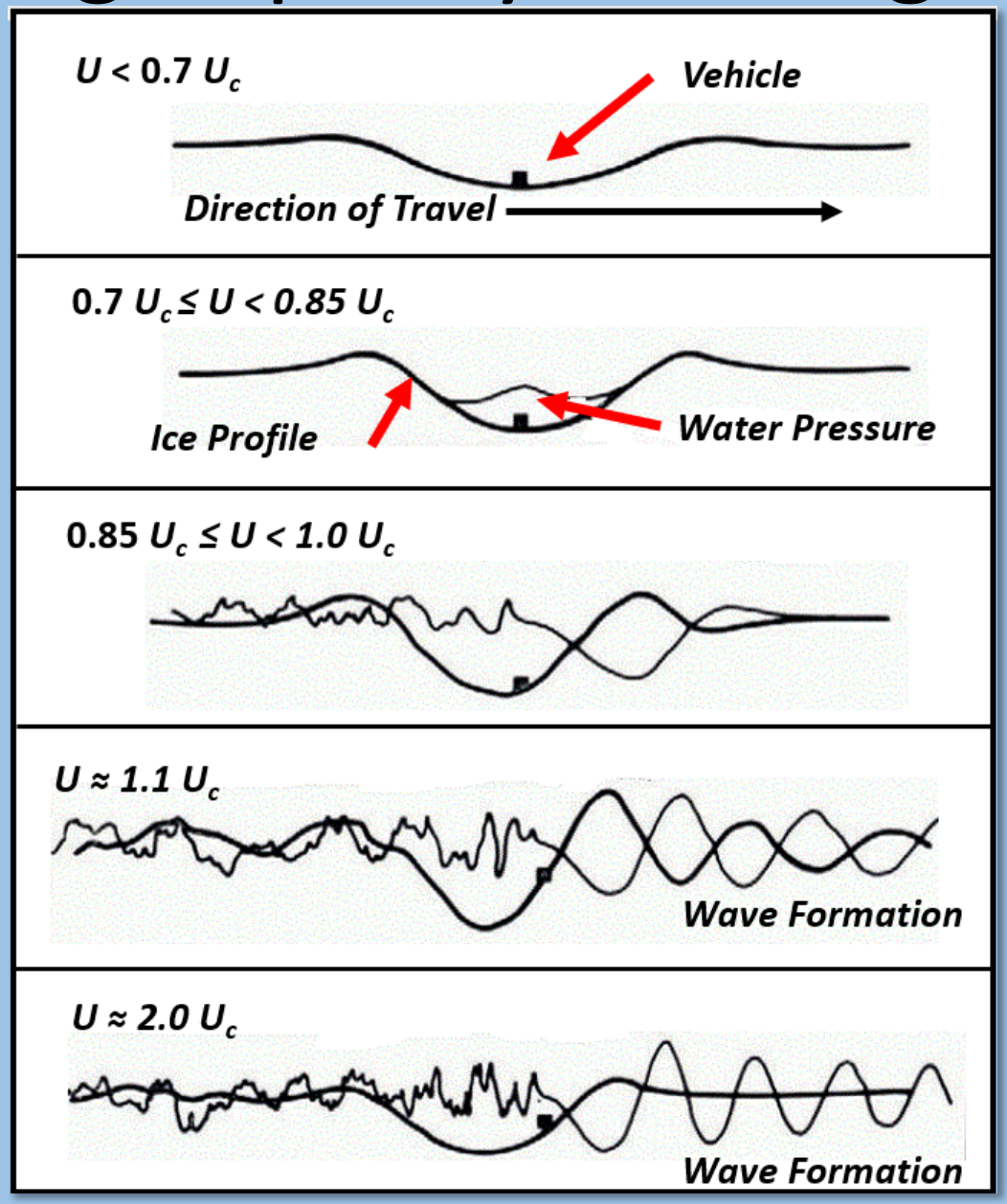
Bearing Capacity



The ability of the ice cover to support a load is the *bearing capacity* of the ice cover.

The water pressure at the bottom of the ice cover is the source of bearing capacity. Think of the ice sheet as a raft.

Bearing Capacity: Moving Loads



The *critical speed* is where the deflection is a maximum

Water pressure waves form at speeds above the critical speed

The greatest risks occur when moving loads transit from deep water to shallow water over a short distance.

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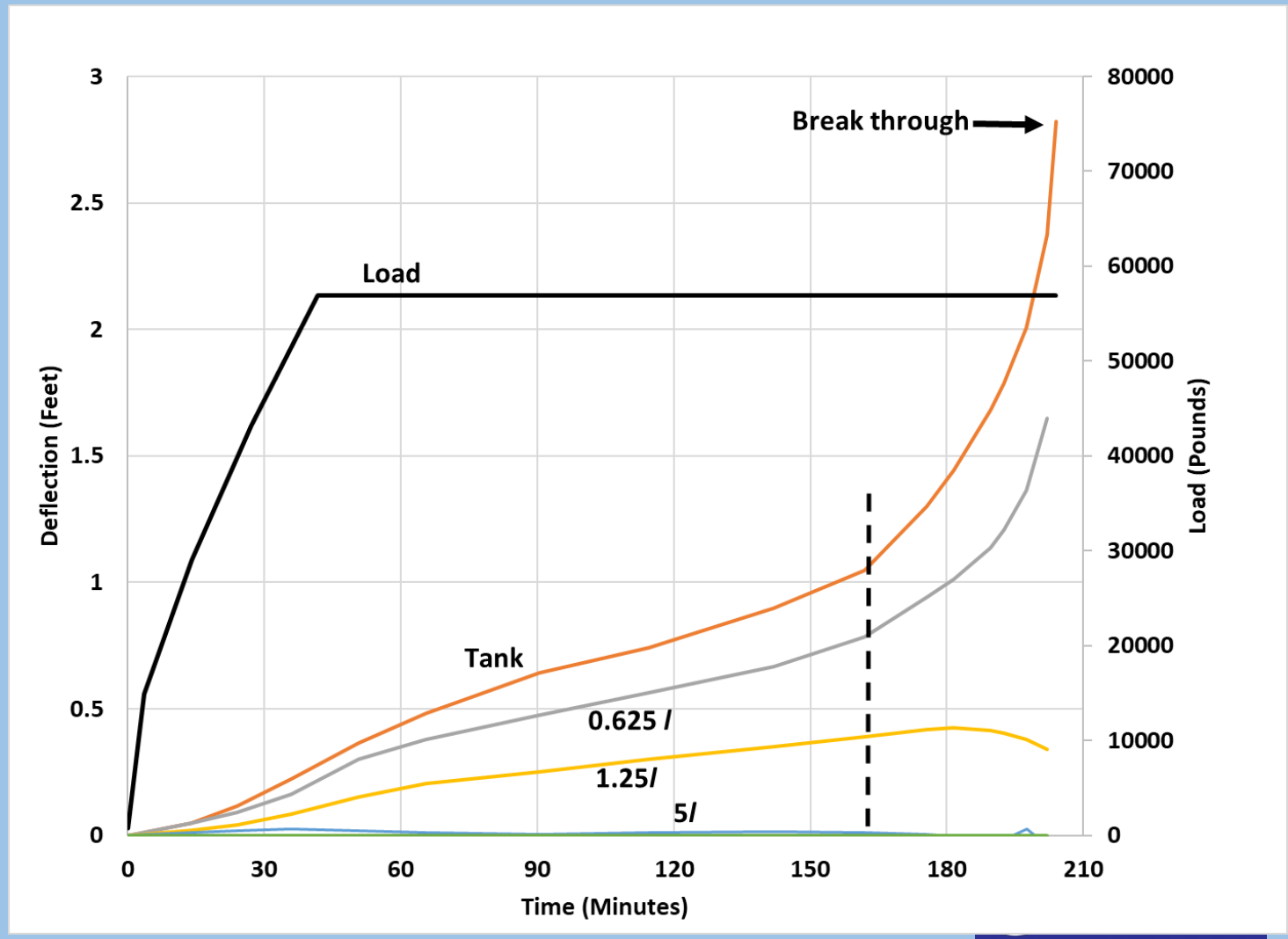
Bearing Capacity: Ice Creep

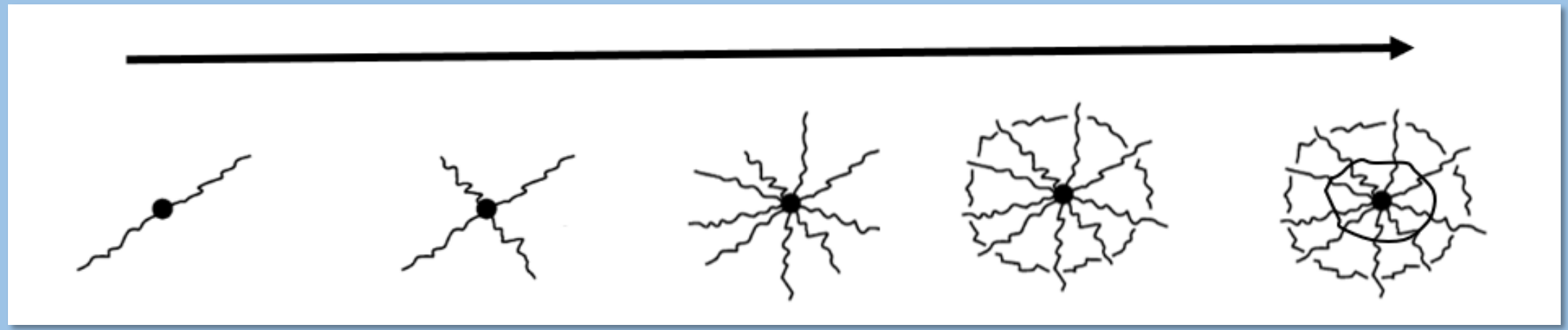
Creep: the gradual increase in deflection of the ice cover over time with a constant load

Creep can lead to ice cover failure.

Creep begins within minutes



Progressive Ice Cover Failure



First Crack Criterion: Ice loads are managed so that no cracks form.

Maximum flexural stress << Ice bending strength

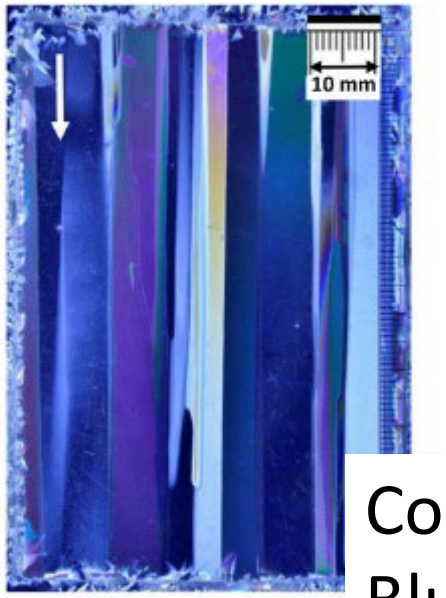
Slow moving loads; no creep

Ice Types

Fine grain Ice
Frazil Ice

White Ice
Snow Ice

Controversial
-only include ½ thickness
-include entire thickness



Columnar Ice
Blue or Black Ice

Excluded Ice Types

- visible water lenses
- incompletely frozen frazil (slush) ice.
- Ice layer that is not completely frozen to the adjoining layer.
- Ice that has wet cracks.

HAZARDS & DESIGN

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Hazards

A primary hazard to the ice cover integrity is the formation of cracks.

dry and re-frozen wet cracks

Crack Types

Dry Cracks: Do not penetrate through the ice cover.

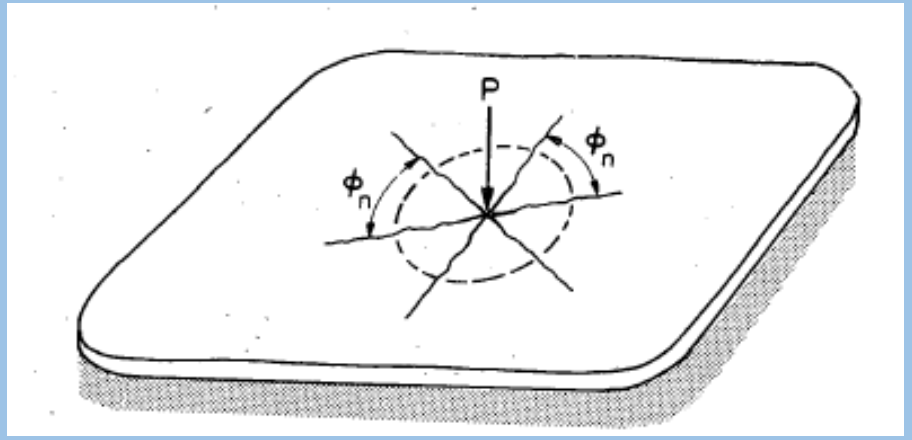
Wet Cracks: Penetrate the ice cover. May indicate the freeboard has been exceeded.

Re-frozen wet crack

Crack Formation

Excessive Loads

Loads that exceed the first crack criterium



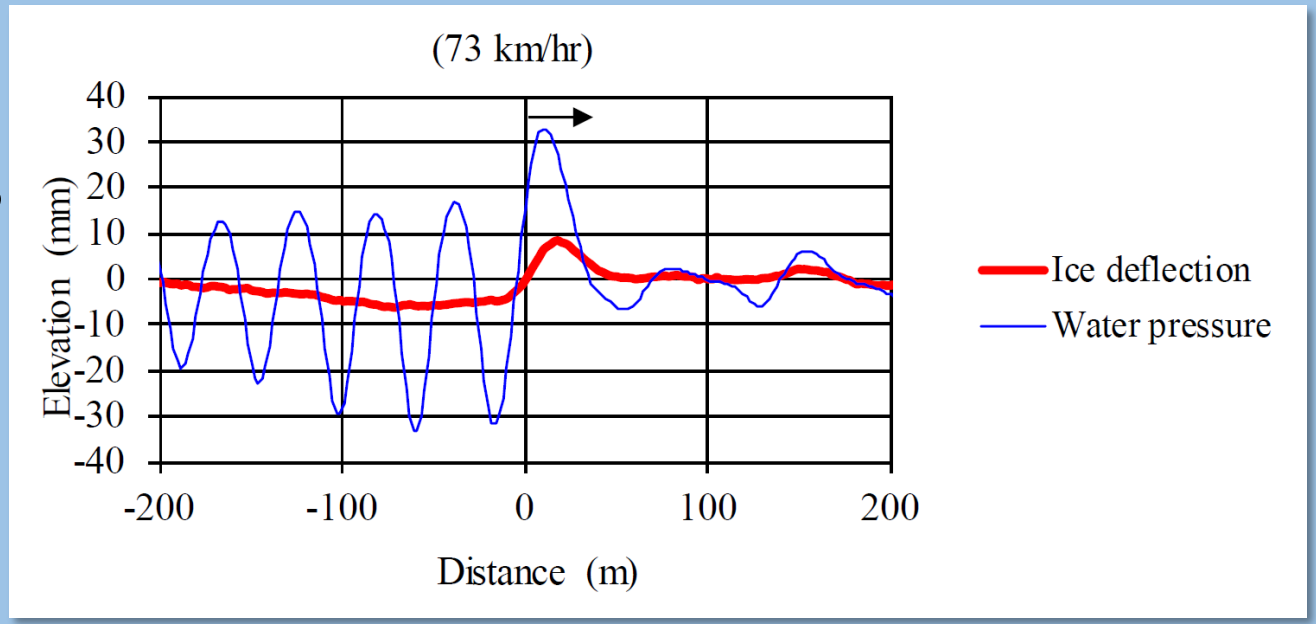
1. Radial Cracks – warning, load should be removed immediately
2. Circumferential Cracks – evacuate the area
3. Pie-shaped Wedges – ice cover failure. Breakthrough can occur at any moment

Required ice thickness is presented in Chapter 5, Design.

Crack Formation

Moving Loads

Moving loads at excessive speeds that are transiting between deep water and shallow water



Shoals

Ice frozen to bottom

Shoreline

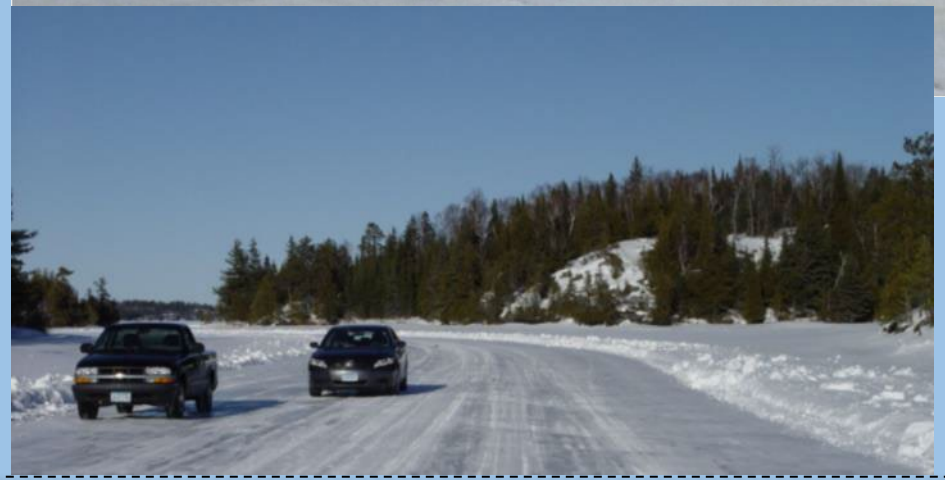
Maximum speed limits are presented in Chapter 8, Ice Road Vehicle Control.

Crack Formation

Multiple Loads

the overall deflection bowl is the sum of the deflection bowl created by each vehicle (superposition).

Minimum distances between vehicles and equipment are required to prevent large stresses in the ice cover.



Minimum vehicle spacings are presented in Chapter 8, Ice Road Vehicle Control.

Crack Formation

Frequent Loads

Gold (1971) reported that the “quality of the ice cover can … deteriorate because of fatigue.”

Frequently repeated loadings will cause damage such as rutting, potholes, and cracking (SASK, NWT). “Any ice cover can develop cracks by … frequent loading on the ice cover” (AB, ONT).

There are no quantitative observations relating frequency of loading to ice cover deterioration.

Crack Formation: Environmental

<u>Thermally induced</u> Abrupt drops in air temperature can cause cracks to form.

- The top portion of the ice contracts in response to the change in temperature.
- Cracks form where the bending stress exceeds the flexure strength of the ice.

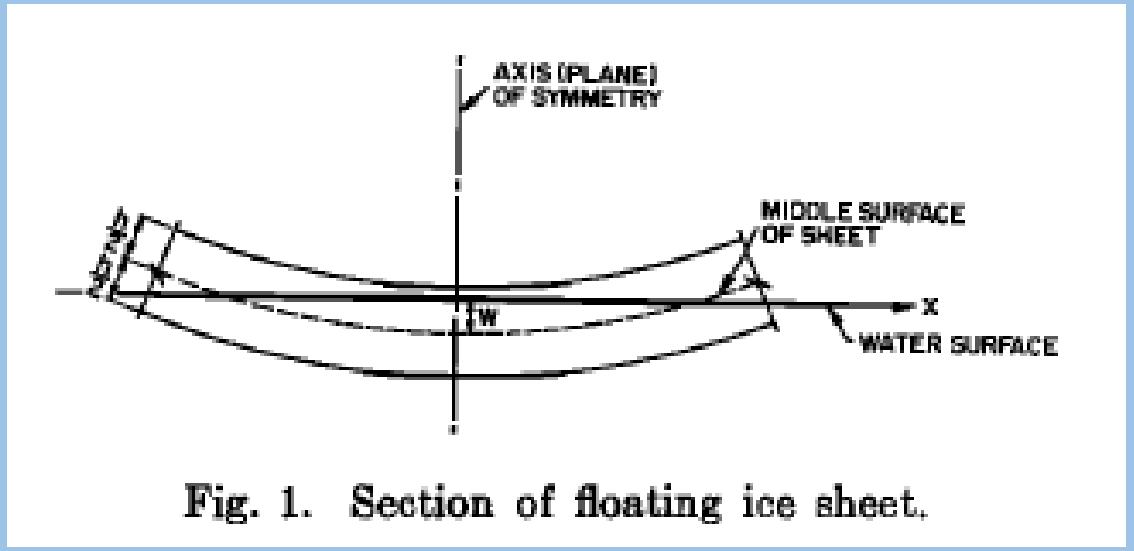


Fig. 1. Section of floating ice sheet.

This is similar to warping in concrete

Causes of Crack Formation: Environmental

Pressure Ridges

- Form in larger lakes where the thermal expansion effect and the wind stress can accumulate over large distances (several miles or more).

Causes of Crack Formation: Environmental

Water Level Changes

- Cracks are almost always wet
- tend to follow the shoreline and grounded ice features.

Drifting Snow

- Adds weight to the ice
- Reduces ice thickness due to insulation.
- Increases potential for additional drifting.

Thin Ice and Open Water

- The most dangerous hazard
- Continuously monitor for thin ice and open water especially after extended warm periods
- Rivers tend to freeze late in areas where water is moving rapidly due to shallow water or narrow channel
- Often occur in the same areas each year

Design

- Route Selection
- Required Ice Thickness

Route Selection

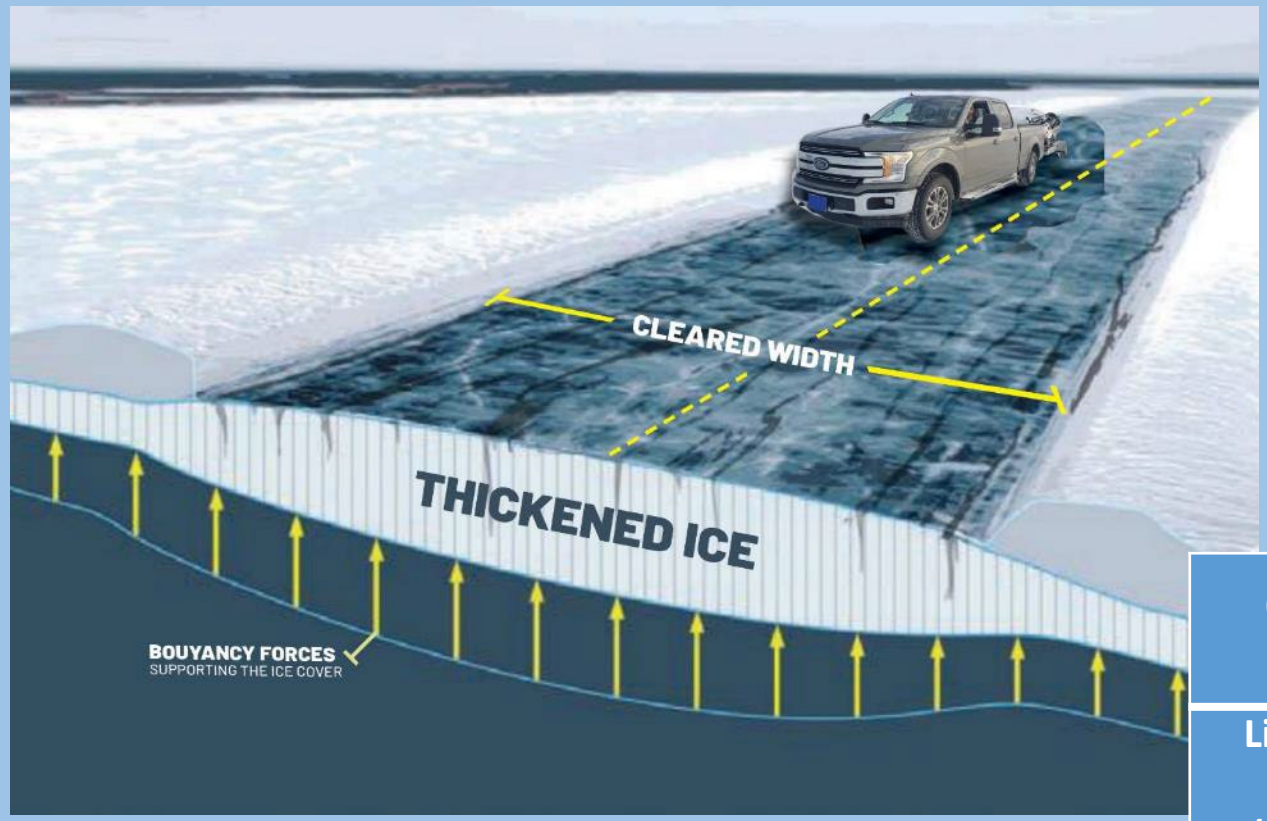
Previous experience

- Build on previous experience by thoroughly evaluating the previous use. Keep good records.
- Water levels, channel locations, weather and ice conditions vary from year to year

Local Climate

- Local climatic variations and year to year variability may need to be considered if data from local weather stations are used in route selection.

Ice Road Widths and channel Bank Offsets.



Operating Vehicles	Cleared width - Between snowbanks	Driving lanes - Total width	Channel Bank Offsets on each side
Light vehicle traffic (11,000 lbs)	65 ft	32 ft	32 ft
Construction (50,000 lbs)	82 ft	50 ft	50 ft
Super B Train (140,000 lbs)	100 ft	65 ft	65 ft

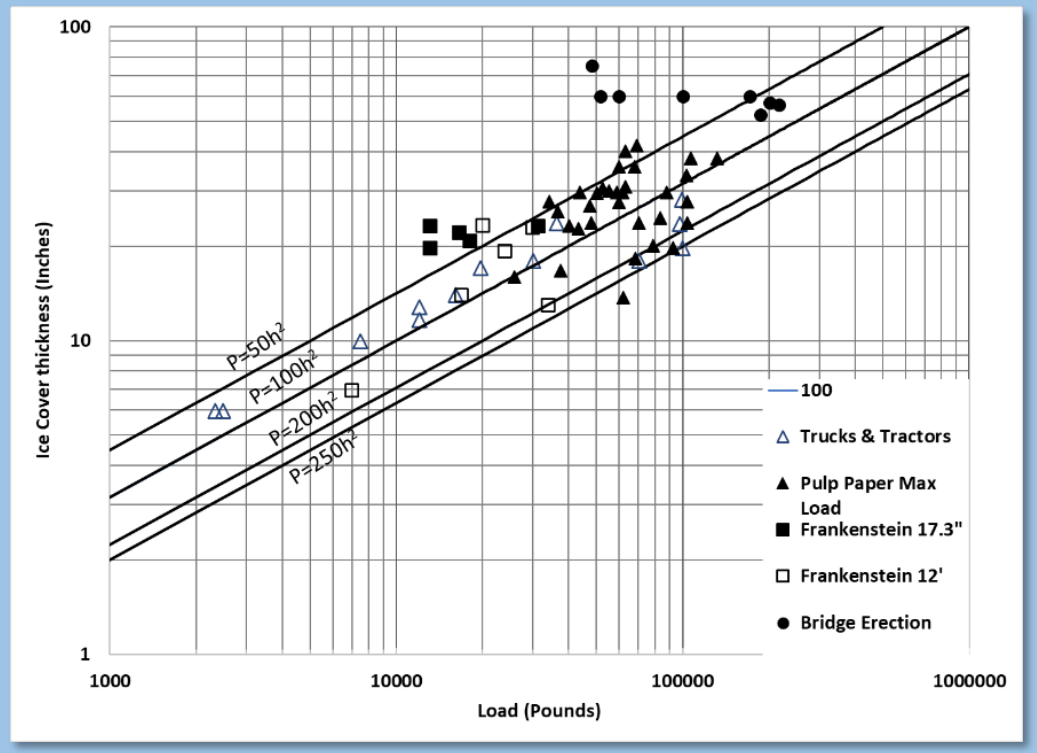
Route Selection for Ice Roads following Rivers

Difficulties

- Variable channel geometry
- Complex ice cover formation process
- Wintertime Decline in River Discharge

Key Factors

- Access points
- Minimum depths
- Observations



A	Risk Level
50	Low
57	Tolerable
71	Moderate
85	Substantial

Northwest Territories, Saskatchewan, Alberta, Ontario

Gold's Formula to determine ice thickness

$$P = Ah^2$$

P = load (lbs),

A= risk factor,

h=ice thickness (inches)

Load	Weight	A	Risk Level	Ice Thickness
Ford F-450 Chevy Silverado 4500 Ram 4500	17,000	50	Low	18.5
		57	Tolerable	17.5
		71	Moderate	15.5
		85	Substantial	14

Gold's Formula

$$P = Ah^2$$

$$h = \sqrt{\frac{P}{A}}$$

P = load (lbs),

A= risk factor,

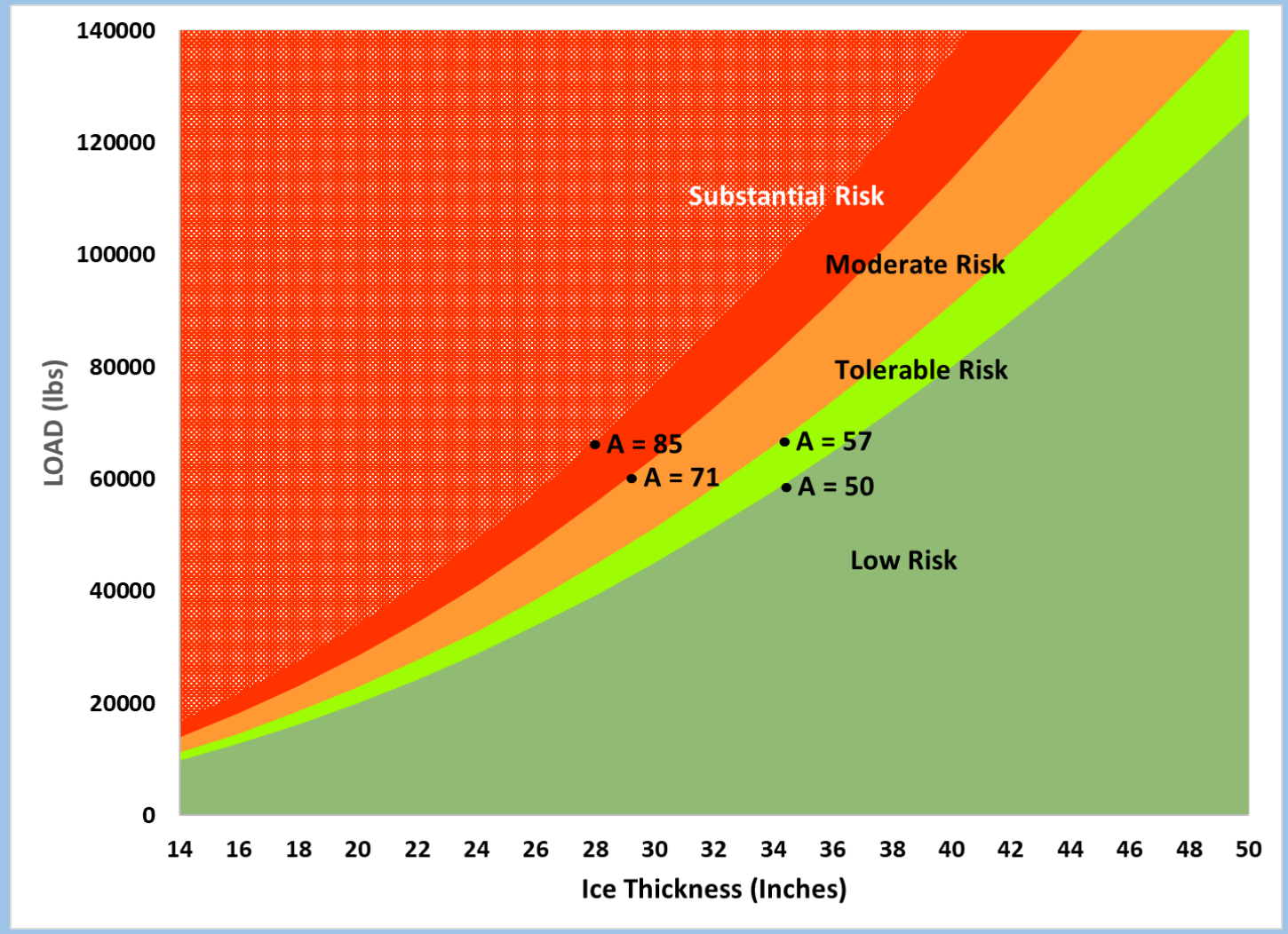
h=ice thickness (inches)

- Lighter Loads
  - loads of less than 11,000 lbf
  - Minimum effective ice thickness

Load/Situation	Estimated Weight (lbf)	Minimum Ice Thickness (Inches)	A value
Person walking	260	4	10
Snowmobiles (machine + rider)	< 1,100	7	22
3/4-ton 4x4 vehicles	GVW < 11,000	15	49

Traffic Loads

- Moving loads on ice
- Creep is not an issue
- Vehicle speed is not an issue – low speed
- Traffic Loads range from 11,000 lbs to 142,000 lbs.
- >142,000 lbs. requires professional engineer



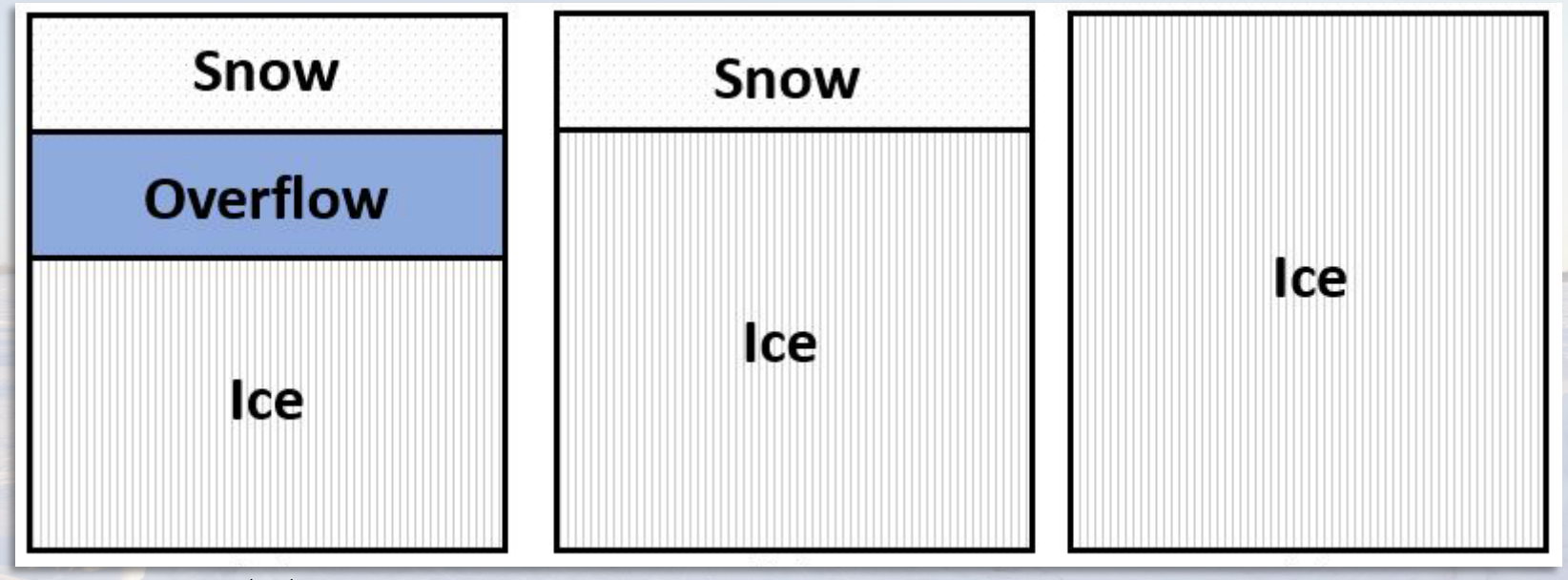
Ice Thickness Critical

- Systematically measure ice thickness along the route to ensure it can support construction equipment. Include access points
- Know the weight of each piece of construction equipment including fuel and cargo.
- Continuously monitor ice thickness ahead of construction activities.
- Brief all personnel on safety protocols and inspect safety equipment. Review emergency protocols should equipment break through the ice.
- Get off the ice if there is any doubt whether the ice can support the equipment.

Measuring Ice Thickness

- **Hand, battery and gas-powered augers**
  - Quick and cheap
- **Cores**
  - Requires more time and more expertise
- **Ground Penetrating Radar**
  - Provides continuous data
  - Requires more expertise
  - Equipment expensive
  - Requires ground truthing

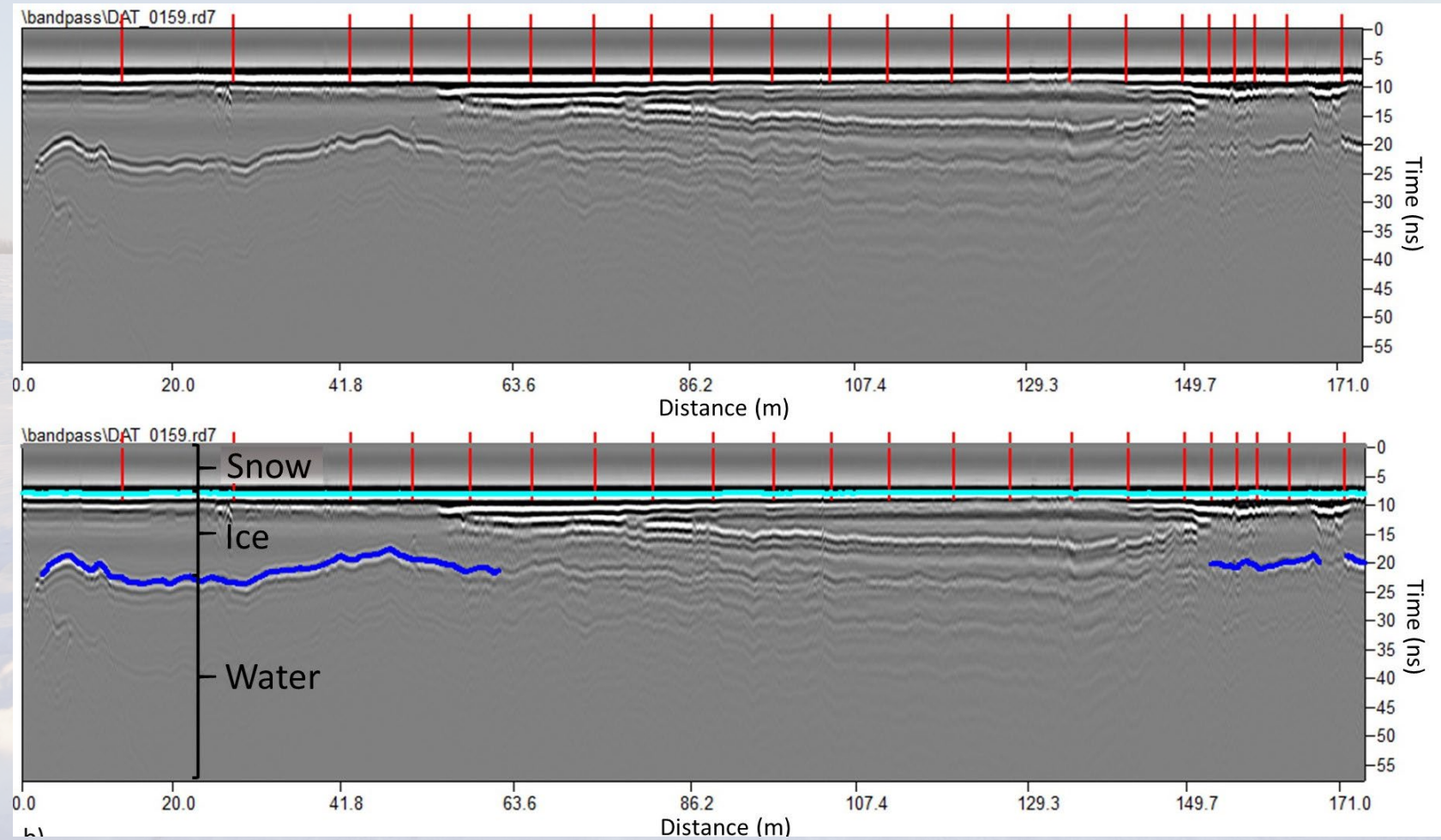
Ground Penetrating Radar

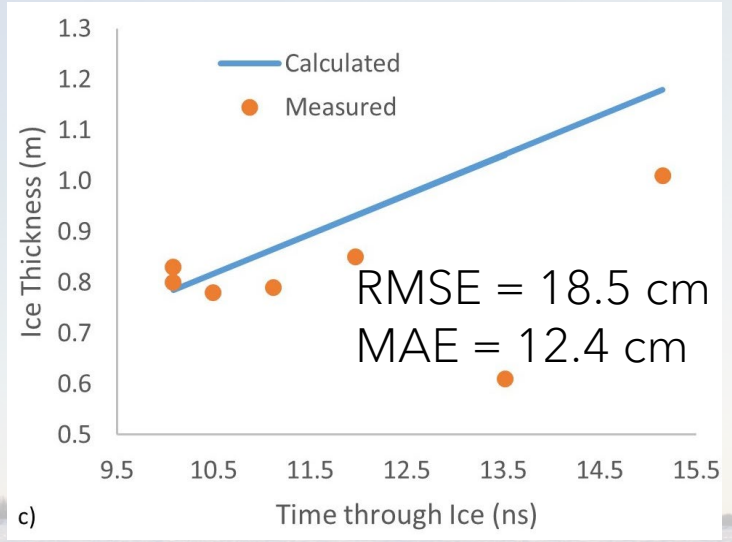


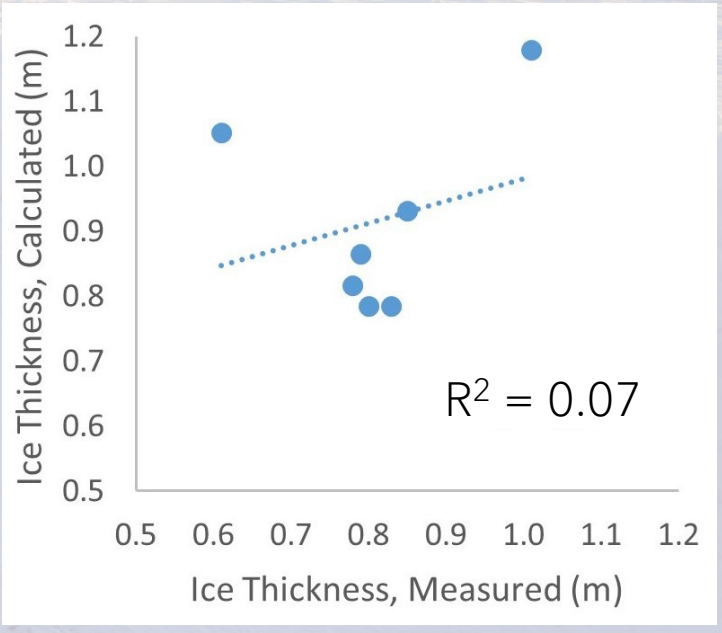
Three conditions from the two locations:

- Condition 1: Snow cover and overflow (Tanana 2019)
- Condition 2: Snow cover (Tanana 2020)
- Condition 3: Bare ice cover (Trench Road)

RESULTS – Condition 1







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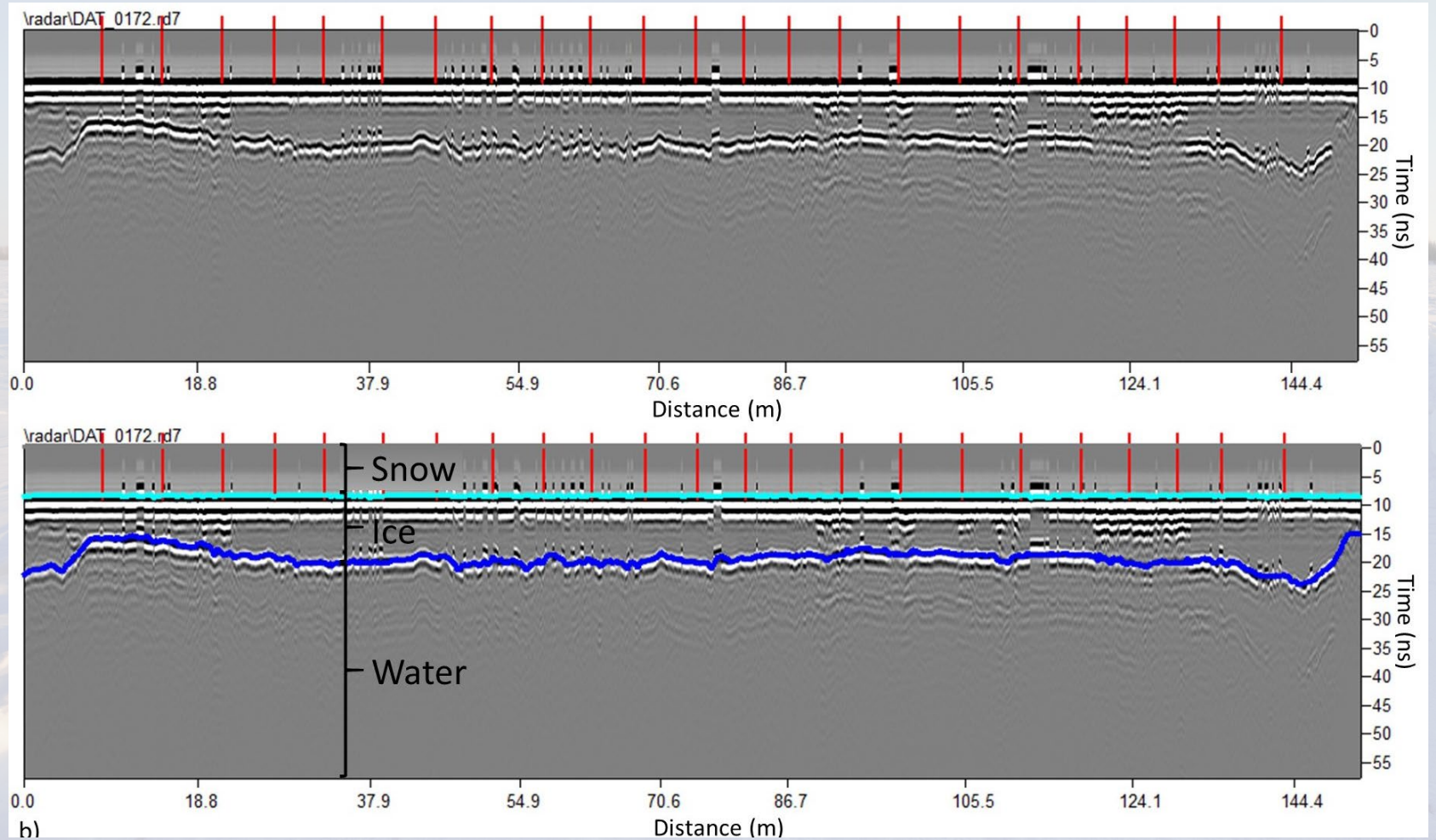
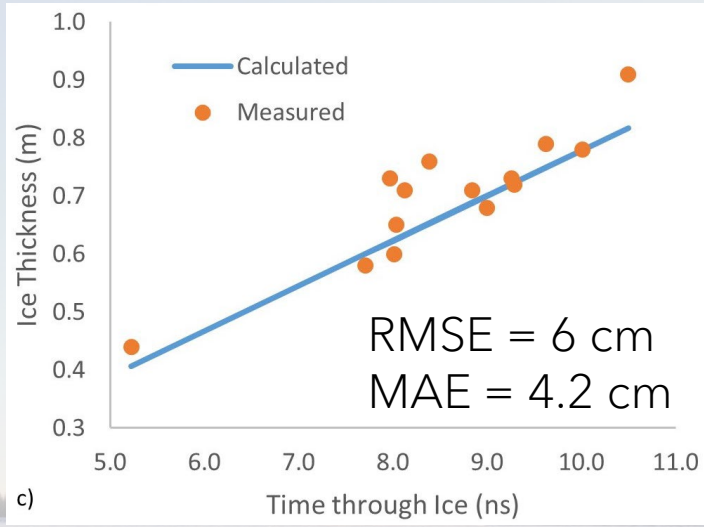
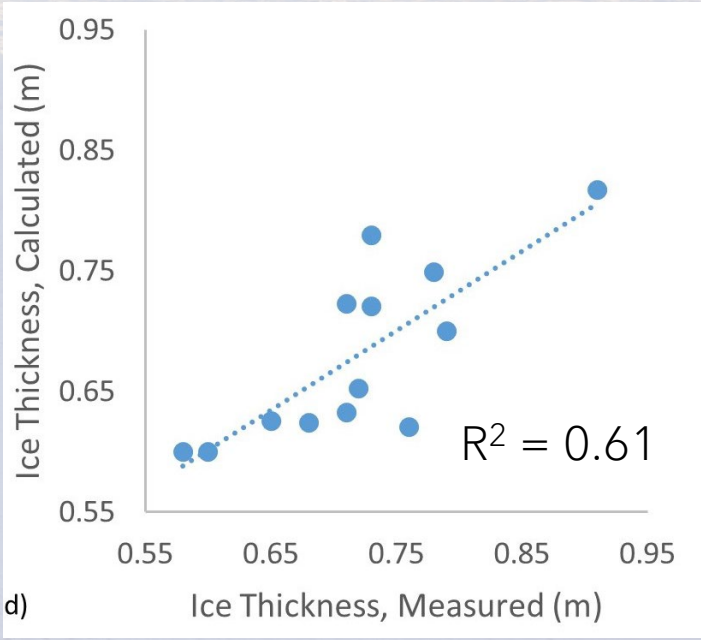
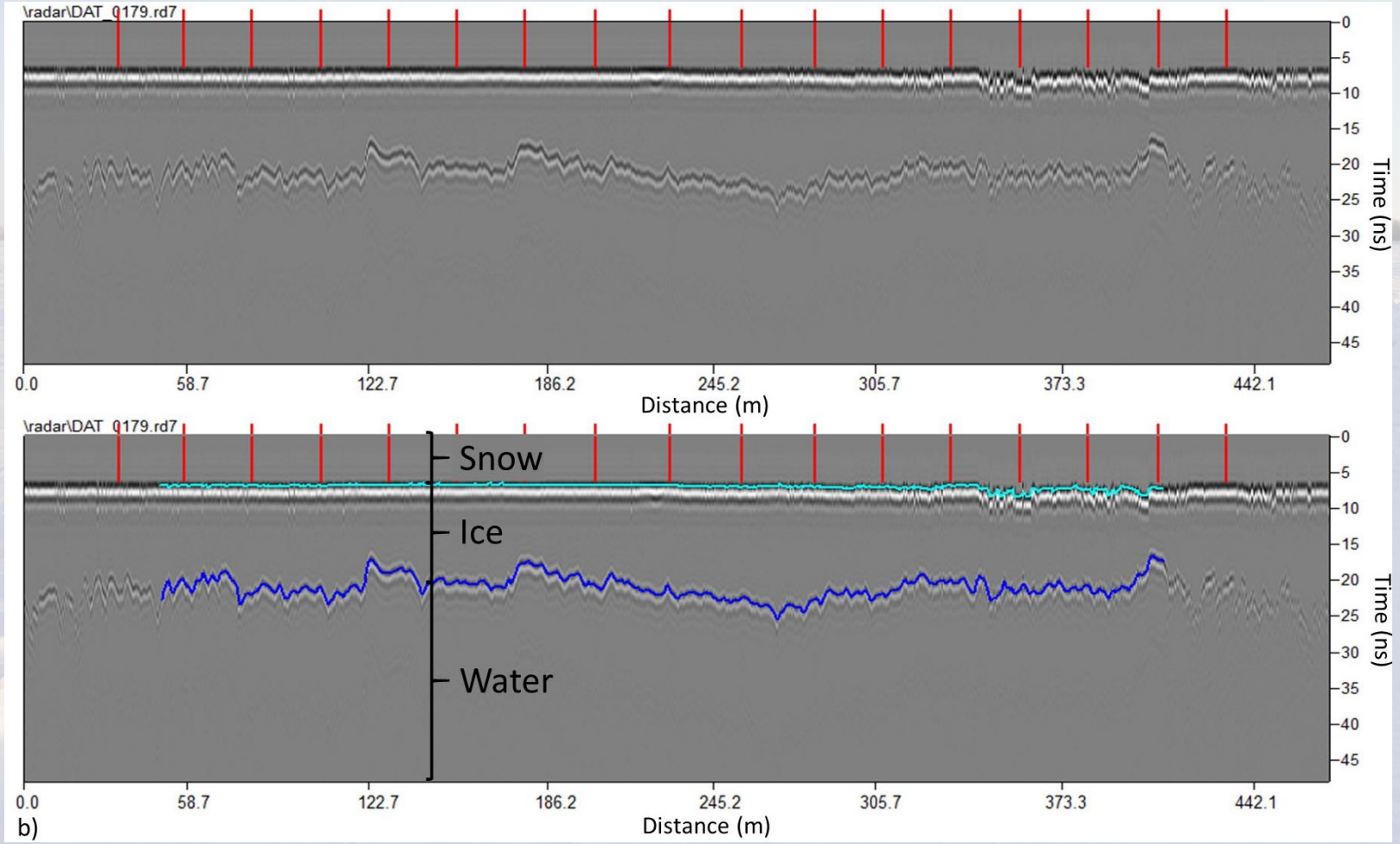
RESULTS – Condition 2

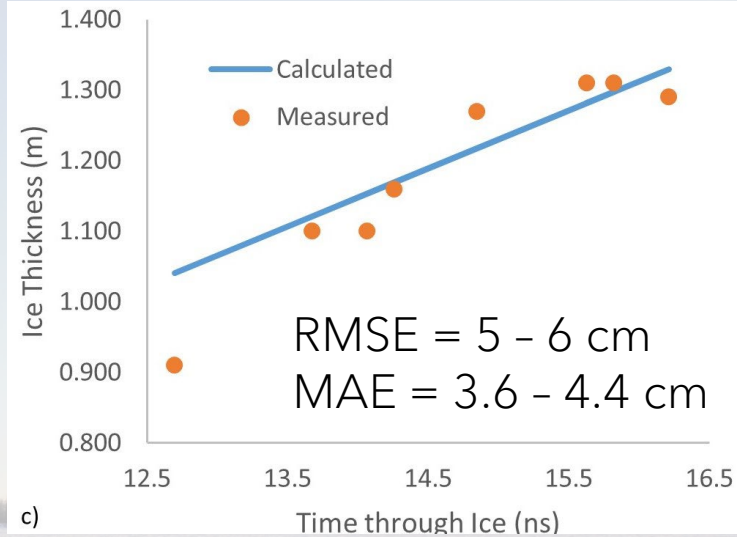


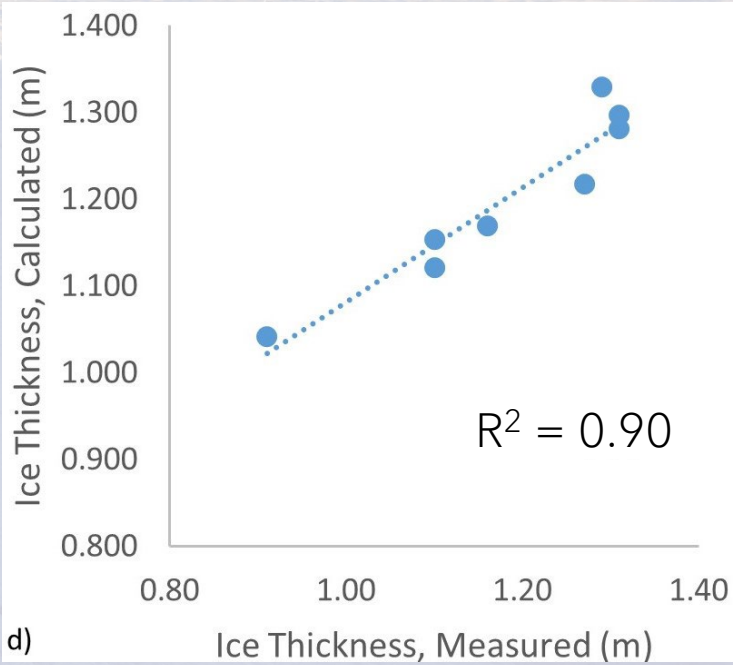




RESULTS – Condition 3







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Snow Clearing Procedure

- Minimize thickness
- Keep out of clear zone

Increasing Ice Thickness

- Snow Removal
- Flooding
  - Use head, high volume pump
  - Do not dike.
    - The created transition reduces cracking
  - Can be done on either ice or compacted snow

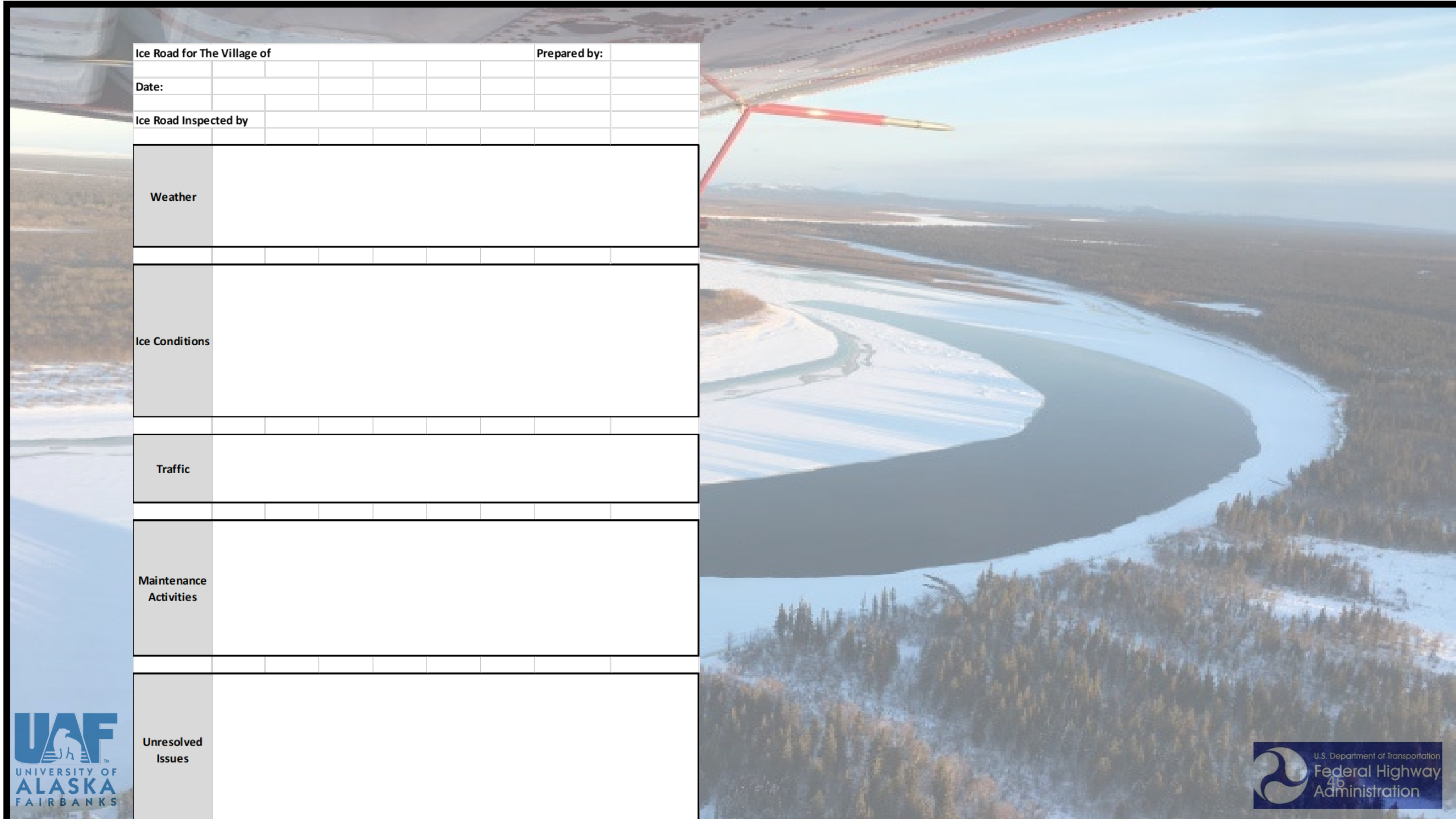
Heavy Equipment Daily Inspection Checklist Prior To Use On Site

Inspection Date:_____ Time: _____

Equipment Type: _____ Unit #: _____

Vendor: _____

What to Inspect and Look for:	Good/ Present	Needs Repair/ Not Present	N/A
Backup lights and alarm			
Blade/Boom/Ripper condition			
Brake condition (dynamic service, park, etc.)			
Brake fluid			
Cab, mirrors, seat belt and glass			
Cooling system fluid			
Coupling devices and connectors			
Engine oil			
Exhaust system			
Fall protection (lanyards/harnesses)			
Fire extinguisher condition			
Frame, ladder(s) and walkway			
Guardrails/ Outriggers/Brakes			
Ground engaging attachments			
Hand grabs and steps			
Horn and gauges			
Hose condition			
Hydraulic oil			
Lights			
Oil leak/lube			
OTHER			
Personal Protective Equipment			
Power cable and/or hoist cable (s)			
ROPS			
Safety Decals			
Seatbelts			
Steering (standard and emergency)			
Tires or tracks			
Transmission fluid			
Turn signals			
Wheels/ Tires			
Windshield wipers and fluid			



Ice Road for The Village of	Prepared by:
Date:	
Ice Road Inspected by	

Weather	
Ice Conditions	
Traffic	
Maintenance Activities	
Unresolved Issues	

Signage

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SIGNAGE GOALS //

- Establish guidelines for the use of signage when establishing constructing, or maintaining ice roads
- Establish safe standards that provide users with enough information for safe transport
- Consider cost and maintenance requirements
- Follow existing FHWA/USDOT guidelines where applicable

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DESIGN //

- Effectively treat ice roads as “low-volume roads” (Part 5 MUTCD)
- Follow the “Standard, Guidance, Option” model of the MUTCD for consistency
- Sizes of signs and plaques according to Table 5A-1 MUTCD

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Ice Road Vehicle Control

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Vehicle Control

- Speed
- Distance between vehicles
- Maximum vehicle weight
- Stationary Loads

Maximum Vehicle Loading

Traffic should be restricted to vehicles with a Gross Vehicle Weight that meets the requirements for bearing capacity of the current ice conditions as discussed in Chapter 4.

Post maximum GVW and speed limits at every access point.

Make sure everyone knows that GVW is the weight of the vehicle including the vehicle, people, cargo and fuel.

Table·8.1·Maximum·Speed·Limits¶

Vehicle·Situation¤	Maximum·Speed·Limit¤	¤
Vehicle·operating·at·the·minimum·ice·thickness·for·its·weight¤	15·mph·(25km/h)¤	¤
Vehicle·operating·at·2·x·minimum·ice·thickness·for·its·weight¤	25·mph·(35km/h)¤	¤
Approaching·or·leaving·shore·access·points¤	5·mph·(10km/h)¤	¤
Meeting·oncoming·vehicles¤	5·mph·(10km/h)¤	¤
Passing·work·crews¤	5·mph·(10km/h)¤	¤
GPR·Profiling¤	5·mph·(10km/h)¤	¤

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Table·8.2·Minimum·Distances·Between·Vehicles¶

Vehicle·Weight¤	Minimum·Distances·¤	Time·Spacing·at·25·mph¤
Vehicles·<·11,000·lbs¤	660·ft·(200m)¤	18·seconds¤
Vehicles·>·11,000·lbs¤	1,640·ft·(500m)¤	45·seconds¤

Monitoring and Maintenance

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Monitoring done through visual inspection

- Requires travelling the entire route
- Look for
  - Wet and dry cracks
  - Water on ice
  - Snow drifts
  - Other problems
- Frequency depends on risk. The higher the risk the more frequent the inspection.
- Measure ice thickness
- Document the inspection

Monitoring Program

A Value	Level of Risk	Visual Inspection	Surveying
50	Low	-At least once every three days -checking of ice quality	-Manual measurements every 10-14 days
57	Tolerable	-Regular Ice quality monitoring program	-Program of regular manual ice measurements
71	Moderate	-Daily Ice quality monitoring program	-Daily program of regular ice measurements or program for regular GPR ice profiling plus manual ice measurements
85	Substantial – Special Procedures	-Daily Ice quality monitoring program	-Daily program of regular ice measurements or program for regular GPR ice profiling plus manual ice measurements

Visual Inspection Checklist

Date: _____	**Time:** _____	**Location:**	
Cracking Extent and Geometry			
Dry Cracks	Number:	Max Penetration: _____%	
Wet Cracks	Number:	Max Width: _____In.	
Comments:			
Ice and Surface Characterization			
Ice Color	Clear/Blue/Black	Thickness: _____In.	
	White	Thickness: _____In.	
	Other_____	Thickness: _____In.	
Snow Cover	Depth: _____In.		
Surface Roughness			
Water on Ice			

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Maintenance Program

A Value	Level of Risk	Maintenance
50	Low	- Repairs and maintenance as needed
57	Tolerable	- Repairs and maintenance as needed
71	Moderate	- Regular program of repairs and maintenance
85	Substantial –Special Procedures	-Daily program of repairs and maintenance

Snow Removal

- Minimize height and weight of windrows.
- Use equipment that can cast snow away from ice road
- Don’t allow snow to build up and remain on the ice road.

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Planning for Closure

- All the information in this manual applies.
- Have closing procedures in place well before anticipated closure.
  - The ice will melt from both top and bottom
  - Keep the public informed.
    - Where will updates be posted?
    - Who to call?
    - Anticipated timeframe.
    - Will the entire ice road be closed at once or in segments?
  - How will access be closed and marked?
  - Removal of signage.
  - Putting emergency procedures in place.
  - How will ice road be monitored.

Using Drones

UAF UNIVERSITY OF ALASKA FAIRBANKS

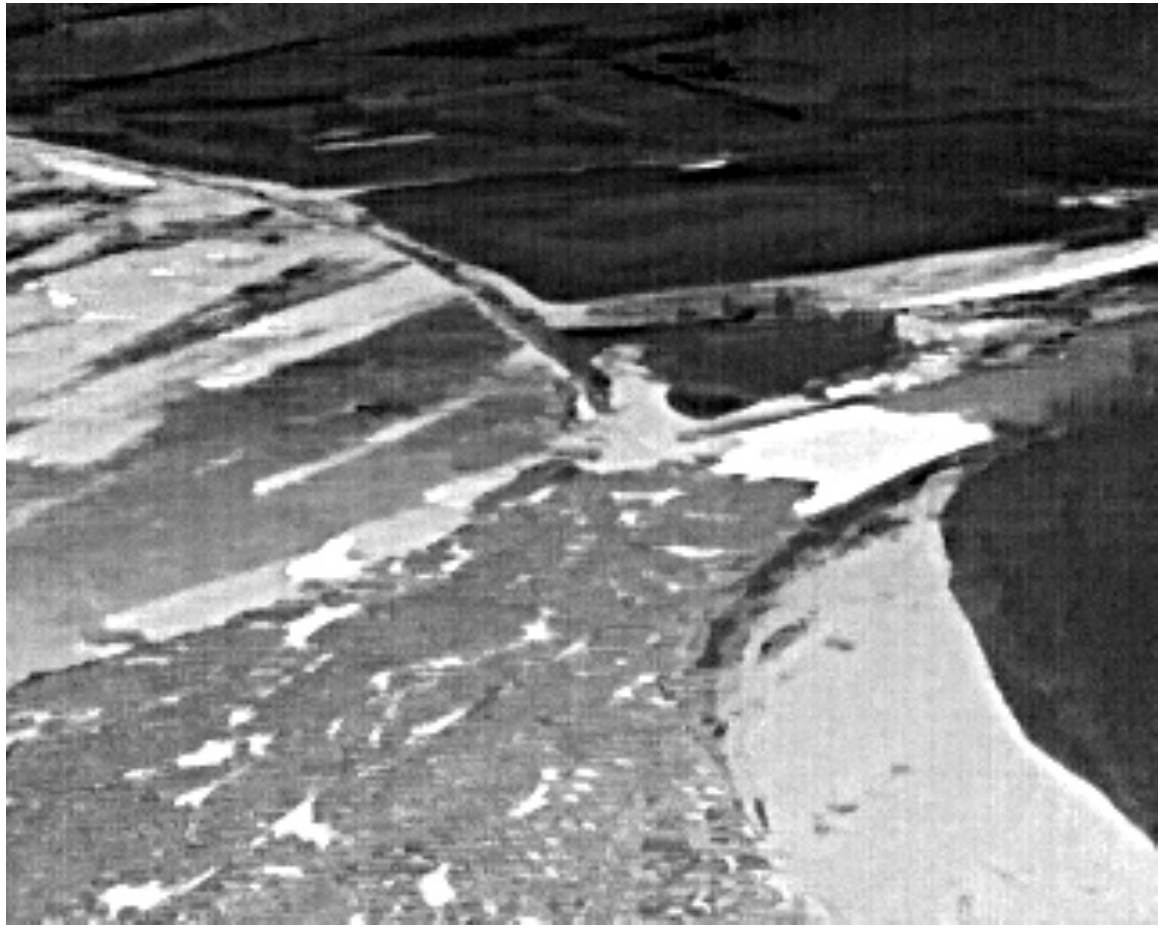
U.S. Department of Transportation
Federal Highway Administration

Use of Drones for Ice Road Support *Risk Reduction*

- Route Selection, Establishment and Monitoring
- Post-storm Inspections
- Seasonal Deterioration
- Search and Rescue
- Other uses……

Road grader on Kuskokwim ice road. c/o KYUK.org

Drones for Ice Road Support: **Synoptic View**



Airborne GPR

Questions/Comments

Amit.Armstrong@dot.gov
Bgconnor@alaska.edu