RIVER ICE MEASUREMENTS FOR TRANSPORTATION SAFETY IN RURAL COMMUNITIES

FINAL PROJECT REPORT

by

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Sponsorship
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16. Abstract

This project is relevant to the cold areas of Federal Region 10, where transportation routes occur on the frozen surfaces of lakes and rivers for three to four months each year Transportation safety on ice roads is a complex problem that involves people, vehicles, river ice, and weather conditions. While all these factors must be considered, this study focused on river ice measurements for ice road construction and transportation safety. Ice thickness measurements are critical in determining the bearing capacity of river ice cover and assessing the risk of breakthrough on ice roads. The project team collaborated with the city of Tanana, a rural Alaska community that builds a winter ice road across the Yukon River to connect to the state road system.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS

ADOT:	Alaska Department of Transportation and Public Facilities
GPR:	Ground penetrating radar
MAE	Mean absolute error
NOAA:	National Oceanic and Atmospheric Administration
NWS:	National Weather Service
PacTrans:	Pacific Northwest Transportation Consortium
RMSE	Root mean square error
SF:	Snowfall
Tair:	Air temperature
TWT	Two-way travel
UAF:	University of Alaska Fairbanks
WERC:	Water and Environmental Research Center
WSDOT:	Washington State Department of Transportation

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EXECUTIVE SUMMARY

This project is relevant to the cold areas of Federal Region 10, where transportation routes occur on the frozen surface of lakes and rivers for three to four months each year. Transportation safety on ice roads is a complex problem that involves people, vehicles, ice cover, snow cover, and weather conditions. While all these factors must be considered for safe construction, operation, and maintenance of ice roads, our project focused on river ice measurements. Ice thickness measurements are critical in determining the bearing capacity of river ice cover and assessing the risk of breakthrough on ice roads.

Traveling on river ice can be dangerous, as ice conditions change in response to weather, river hydraulics, and other factors. River ice conditions, especially ice thickness, strongly depend on air temperature and freezing degree-days. As winters in Alaska become warmer, travel on river ice becomes less predictable. The warming trend in air temperature is strongly pronounced during the fall and winter months, presenting challenges for decision making on when to construct the seasonal ice road and how long people can use the ice road safely.

The project team worked in close collaboration with the city of Tanana, a rural Alaska community that builds an ice road across the Yukon River every winter to connect to the state road system. The project team visited Tanana on October 24–25, 2019, and February 25–28, 2020. Tanana residents expressed an interest in learning about ice measurement techniques and developing consistent procedures for safe ice road construction and operations specific to Tanana's location on the Yukon River.

In winter 2019–2020, the ice road followed the northern bank of the Yukon River for the first 2.5 km; it crossed the river's main channel at Mission Island (0.5 km) and stayed closer to the southern riverbank for another 14 km. Ice measurements at the Yukon River crossing were collected using three techniques: ice augering, ice coring, and ground penetrating radar (GPR).

Ice augering and ice coring provided measurements of total ice cover thickness, as well as columnar ice and snow ice thickness; however, these point measurements were representative of only a small area. Ground penetrating radar was used to estimate ice cover thickness between the points. Collected ice measurements showed that ice thickness varied by a factor of two at the Yukon River ice road crossing. The GPR radargram identified almost a meter (0.98 cm) change in ice thickness over a 350-m-long section of ice road.

While the observed range of variability is less critical in February when river ice is a meter thick at the thinnest areas, early in the season sparsely distributed point measurements might result in missing areas of thinner ice. Therefore, both manual measurements and GPR profiling are needed to provide ice cover thickness surveys and locate dangerous areas of thin ice, particularly during ice road construction operations. Ice coring is important for identifying different ice layers within the ice cover, which assists with determining effective ice thickness and analyzing risk levels.

CHAPTER 1. INTRODUCTION

1.1. Environmental Factors Affecting Transportation on Seasonal Floating Ice Cover

Seasonal ice cover on rivers and lakes is commonly used as a surface for commuting in the vast, remote regions of Alaska (figure 1.1). Traveling on river ice can be dangerous, as ice conditions change in response to weather, river hydraulics, and other factors (Schneider et al., 2013). Seasonal variability in snowfall, snow drifting, winter streamflow regime, air temperature, groundwater, and active layer thickness influences the integrity of river ice cover and can contribute to the formation of ice cracks on these transportation routes (Daly, 2021).

Figure 1.1 Driving on the Yukon River ice road, February 27, 2020

In addition to seasonal variability, river ice conditions, particularly ice thickness, are affected by climate variability associated with warming air temperature and Arctic amplification. As winters in Alaska become warmer, travel on river ice becomes less predictable. The Fourth National Climate Assessment Report (Gray et al., 2018) highlighted the fact that "*the rate at which Alaska's temperature has been warming is twice as fast as the global average since the middle of the 20th century*." This warming trend is strongly pronounced during the fall and winter months, presenting additional challenges for deciding when to construct the seasonal ice road and how long people can use the ice road safely. These decisions are becoming especially challenging for rural communities that rely on traditional practices of determining ice safety (Schneider et al., 2013) that may or may not hold true as winter temperatures grow warmer.

1.2. River Ice Observation Network in Alaska

In Alaska, ice thickness measurements are collected and used by various agencies and organizations. The long-term ice thickness monitoring network is maintained by the NOAA (National Oceanic and Atmospheric Administration) National Weather Service (NWS). River and lake ice measurements are taken by NWS professionals and/or local community members at the beginning of the month from October to June and reported online at the Alaska-Pacific River Forecast Center (APRFC) webpage (NWS, 2021). For example, figure 1.2 indicates that river ice thickness on the Tanana River at Fairbanks was 50 percent and 82 percent of its seasonal normal value in 2019 and 2020, respectively. The maps in figure 1.2 show that only a fraction of Alaska's rural communities is covered by the existing ice-monitoring network.

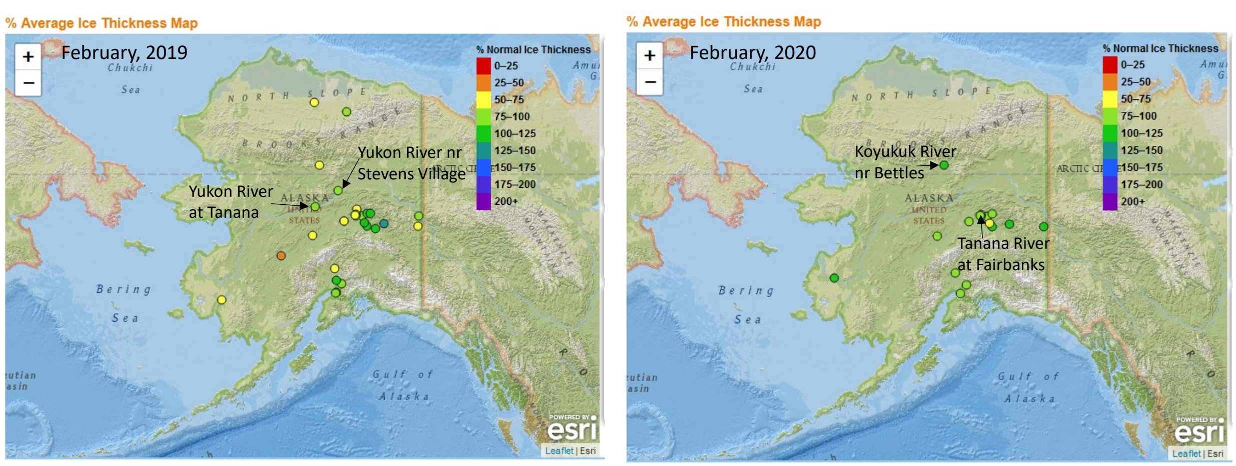

Figure 1.2 February 2019 and 2020 river ice thicknesses
(NWS Alaska-Pacific River Forecast Center)

The NWS ice data set provides valuable metrics for evaluating river ice thickness variability with respect to long-term normal ice thickness values. However, in terms of transportation on seasonal ice cover in rural Alaska, different protocols and guidelines for ice thickness measurements are required. Most rural communities must rely on their own resources to collect ice measurements.

1.3. Project Location

This project was a collaborative effort between the University of Alaska Fairbanks, Water and Environmental Research Center (UAF WERC) and the city of Tanana, a rural Alaska community that maintains a winter ice road across the Yukon River to connect to the state road system (figure 1.3).

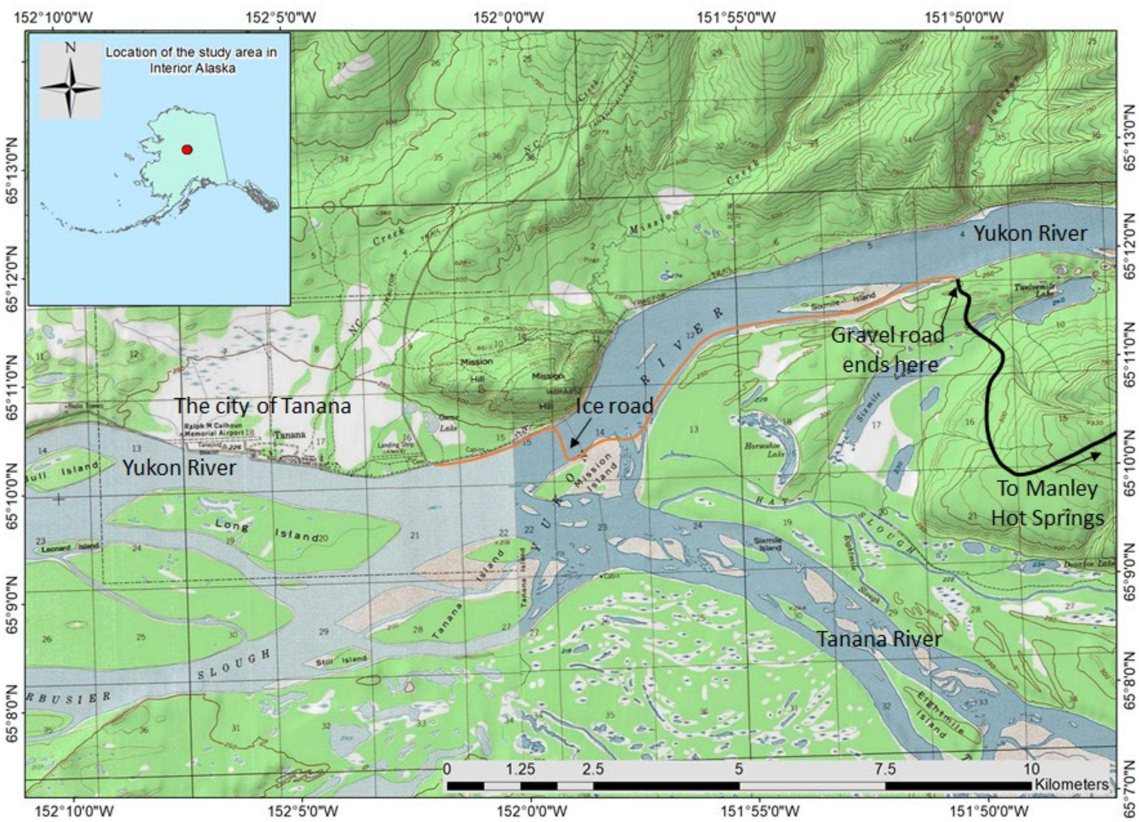

Figure 1.3 Location map showing Tanana and the Yukon River ice road route in winter 2019–2020

Tanana was only accessible by airplane or boat until August 2016, when the Alaska Department of Transportation and Public Facilities (ADOT) opened a one-lane gravel road from Manly Hot Springs to the Yukon River near Tanana (ADOT, 2021). Tanana is located on the north bank of the Yukon River; the state road ends approximately 17 km upstream on the south bank of the Yukon River (figure 1.3). Every winter, the community of Tanana builds, maintains, and operates a seasonal ice road on the Yukon River to connect the state's "Road to Tanana" with the community road system.

1.4. Objectives

Transportation safety on ice roads is a complex problem that involves people, vehicles, river ice, and weather conditions. While all these factors must be considered for safe construction, operation, and maintenance of ice roads, the focus of our report is on river ice measurements. Ice thickness measurements are critical in determining the bearing capacity of river ice cover and assessing the risk of breakthrough on ice roads.

The specific objectives of this project included the following:

(1) a literature review of river ice measurement techniques relevant to ice road operations (Chapter 2);

(2) ice measurements of a rural Alaska river ice road (Chapter 3);

(3) collaboration with an Alaska rural community that uses river ice for transportation (Chapter 4);

(4) preparation of a quarterly and final reports; and

(5) project outreach and support of a graduate student in civil engineering (Chapter 5).

CHAPTER 2. LITERATURE REVIEW

2.1. Safety of Floating Ice Cover for Various Loads

People, animals, and vehicles can break through floating ice if an ice sheet is not safe for a given load. Our literature review showed that Gold's approach is still one of the most commonly used resources for evaluating the safety of ice thickness and the risk of breakthroughs for various short-term moving loads (Gold, 1971; Government of Alberta, 2013; Government of Saskatchewan, 2010; Government of the NWT, 2015; Haynes and Carey, 1999; IHSA, 2014). The minimum ice thickness *h* (m) required to support a given total load *P* (N) can be estimated on the basis of

$$h = \left(P/_{\alpha}\right)^{1/2} \quad (1)$$

Note that *h* is the effective ice thickness. Effective ice thickness refers to the portion of ice cover composed of strong, well-bonded columnar ice. The publication *Best practices for building and working safely on ice covers in Ontario* (2014) cautioned that "*poor quality or poorly bonded ice should not be included in the measurement of ice thickness.*"

Equation (1) can be rearranged to solve for short-term load *P*:

$$P = \alpha h^2 \quad (2)$$

The empirical coefficient α (N/m^2) represents the strength of the ice and specifies a level of risk acceptable for a given ice road. For example, conservative $\alpha=0.35*10^6$ N/m^2 indicates low risk, while $\alpha=7.0*10^6$ N/m^2 indicates substantial risk (Ashton, 1986; Gold, 1971).

Equations (1) and (2) show that field measurements of ice thickness are critical in determining the bearing capacity of river ice cover and in balancing the risk of breakthrough hazards. For transportation safety, it is important to get accurate and detailed ice thickness measurements.

2.2. Ice Thickness Measurement Techniques

Ice thickness measurement techniques have been summarized in informational ice road handbooks used in North America:

- Federal Highway Administration (2020), *Tribal Transportation Program Delivery Guide*.
- Goverment of Alberta (2013), *Best practice for building and working safely on ice covers in Alberta*, Government of Alberta.
- Goverment of Saskatchewan (2010), *Winter roads handbook*, Saskatchewan Ministry of Highways and Infrastructure, Engineering Standards Branch.
- Goverment of the NWT (2015), *Guidelines for safe ice construction 2015*, Department of Transportation, Yellowknife.
- Infrastructure Health and Safety Association (IHSA) (2014), *Best practices for building and working safely on ice covers in Ontario*, Mississauga, Ontario.

The Winter Roads Handbook (Government of Saskatchewan, 2010) and ice road information from a guide for tribes (Federal Highway Administration, 2020) have been used by the city of Tanana as guidance for constructing ice roads.

There are several methods for obtaining river ice thickness along ice roads: ice augering, ice coring, and ground penetrating radar (GPR) profiling.

2.2.1. Ice Augering

The simplest and most common method for measuring ice thickness is to auger holes in the ice, lower a tape or a stick in the hole, and take a reading of ice thickness (Federal Highway Administration, 2020; Government of Alberta, 2013; Government of Saskatchewan, 2010; Government of the NWT, 2015). A measuring tape with a weight attached at the leading edge works well in holes 5-cm in diameter. A graduated rod with a right angle at the bottom works better for holes that are larger in diameter. Sometimes, in the presence of slush or frazil ice under the competent ice cover, it can be challenging to determine the slush ice/columnar ice interface (Hicks, 2016).

2.2.2. Ice Coring

Ice cores are extracted by drilling a rotating core barrel with sharp cutters at the end through the ice sheet. In addition to providing information on total ice thickness, ice coring allows the measurement of the thickness of individual layers within the ice cover (columnar and snow ice). This is an important step, as snow ice has a lower load-bearing capacity than columnar ice (Ashton, 1986). The Saskatchewan winter roads guidelines (2010) recommend modifying Gold's formula to account for the weaker layer of snow ice thickness in the following manner:

$$P = A\left(h + {}^{W}/_{2}\right)^{2} \tag{3}$$

where *h* and *W* represent the thickness of columnar ice and snow ice, respectively. Ice cores can take a longer time to retrieve, but they provide a level of detail that is not available when other measurement techniques are used. Little information on ice coring was found in the ice road handbooks referred to in our literature review, even though ice coring is the only measurement technique that allows visual identification of different ice layers.

2.2.3. Ground Penetrating Radar Profiling

While ice auguring and ice coring indicate ice thickness at a point, GPR provides ice thickness variations between individual points. Ground penetrating radar is "*a geophysical technique that uses radio frequency energy to image the earth's subsurface. It emits microwave electromagnetic radiation and then detects the reflections from land formations or objects it contacts below the surface*" (Government of Alberta, 2013; IHSA, 2014).

During construction and operation of ice roads, GPR is often used for measuring river ice thickness (Government of Alberta, 2013; Government of Saskatchewan, 2010; Government of the NWT, 2015). Common practice includes pulling the GPR system on a sled behind a vehicle. However, the GPR system can also be attached to a snow machine or dragged by a person on foot. Several GPR systems that image river ice and estimate ice thickness are commercially available. A typical ice profiling GPR system includes transmitting and receiving antennae and a digital data logger, a Global Positioning System (GPS), and a battery. The GPR system is connected by cable or wirelessly to a portable control unit with a monitor or laptop computer to display radargrams in real time in the field (Annan et al., 2016). The antenna central frequency of 450 or 500 MHz is commonly used for ice thickness profiling.

Using GPR still requires taking regular manual ice measurements to obtain calibration data (Munk et al., 2013). Equipment must be regularly calibrated during the ice survey because electromagnetic wave velocities in freshwater ice are reported to vary from 0.130 to 0.206 m/ns, depending on ice thickness, type, and age (Annan et al., 2016; Finlay et al., 2008). Winter road guidelines recommend calibrating GPR "*at the start of each day, after four hours of use and whenever erratic or questionable readings are obtained*" (Government of Saskatchewan, 2010). Snow, snowdrifts, overflow, liquid water intrusions in the ice, air bubbles, and other environmental factors affect GPR results (Arcone et al., 1995; Galley et al., 2009; Proskin et al., 2011; Richards, 2021). Note: It is imperative that training be required of persons interpreting collected radargrams.

CHAPTER 3. DATA AND METHODS

3.1. Data Collection

3.1.1. Air Temperature and Snowfall

Tanana has one weather observation station, and it is located at the Ralph M. Calhoun Memorial Airport (65°10'28.477"N; 152°6'22.179"W). This weather station is part of the Automated Surface Observing System (ASOS) network of the United States. Among standard surface weather observations, daily mean air temperature and snowfall have a direct influence on ice growth and decay.

We analyzed average daily mean air temperature (Tair) and daily snowfall (SF) during winter 2019–2020. Both Tair and SF were evaluated against 30-year averaged values called "normal." The normal daily air temperature and snowfall used in this study refer to the climatological average over the 1981–2010 time period. Note that SF refers to the depth of freshly fallen snow accumulated within 24 hours. Snowfall measurement is usually subject to errors associated with wind and drifting and blowing snow.

3.1.2. River Ice Measurements

The river ice data from this study included manual and GPR measurements of ice thickness where the ice road crossed the main channel of the Yukon River. In 2019–2020, the Tanana community constructed two river crossings: a trench road and a packed road (see Section 4.3 for trench road and packed road descriptions). We used a MALÅ Ground Explorer GPR instrument with 450 MHz and 750 MHz central frequency antennae. Distance was measured by both GPS acquisition and an all-terrain wheel attached to the instrument (figure 3.1).

Figure 3.1 GPR measurements by Elizabeth Richards and Stan Zuray, Yukon River, February 27, 2020

Manual ice measurements were collected at 13 points along the trench road and at three points along the packed road (table 3.1). In addition to manual ice thickness measurements, four ice cores were extracted and analyzed. A Kovacs ice coring system with a 7.25-cm inside-diameter barrel was used. Ice cores were used to determine ice layers present in the river ice cover. An avalanche probe with a right angle at one end was used to measure ice thickness by placing the toe at the bottom of the river ice cover. The trench ice road had been plowed, so snow depth and density measurements were not collected.

Table 3.1 Summary of river ice measurements on the Yukon River at Tanana on February 27, 2020

Transect	Frequency (MHz)	Length (M)	Tair (°C)	N[1]
Trench 450	450	461	-28	13
Trench 750	750	520	-28	13
Packed 450	450	494	-28	3
Packed 750	750	527	-28	3

3.2. Methods

3.2.1. Radar Data Processing

Two software packages—RadExplorer (Guideline Geo.) and GPR-SLICE—were used to analyze the GPR radargrams. Most of the data synthesis was completed in RadExplorer. Processing routines were minimized in order to preserve the signal as well as possible. Routines used in RadExplorer include Direct Current (DC) Removal, Trace Edit, and Spatial Interpolation. After signal processing, two-way travel (TWT) time was calculated by picking the time of the first break of the direct arrival signal and picking the time at the bottom of the ice interface. The first break of each signal was determined by hand for each location along the transect associated with a hand measurement (Richards, 2021).

Using the information collected from GPR radargrams, ice thickness was determined by first calculating velocity using Equation (4), and then distance (ice thickness) using Equation (5). These equations use TWT time, the time for the radar to travel from the transmitter to the interface in question and back to the receiver:

$$v = \frac{c}{\sqrt{\epsilon_r}} \tag{4}$$

[1] *N* refers to the number of manual ice thickness measurements taken with an ice auger or ice corer.

$$h = \frac{vt}{2} \tag{5}$$

where v is the wave velocity (m/ns), c is the speed of light (0.3 m/ns), and ϵ_r is the relative permittivity of the material the wave is traveling through. In Equation (2), h is the ice thickness at zero offset (m), and t is the time for the wave signal to reflect to the receiver (ns). The relative dielectric permittivity for river ice is 3 to 4, for fresh water is 80, and for snow is 1.5 to 2. The large difference between the relative dielectric permittivity of water and ice ensures a strong reflection at the ice/water interface and appears in radargrams as a well-defined boundary.

3.2.2. Comparison of GPR and Manual Ice Measurements

Because of the prevalence of GPR systems that automatically output ice thickness measurements by using an average velocity model, the assumption of constant velocity was analyzed by comparing ice thickness measurements from GPR (h) and manual measurements (h_m). By using one-third of manually measured ice thickness and TWT time measured by GPR, the average velocity was calculated for each transect. This average velocity was applied to calculate the GPR ice thickness profile using Equation 5. GPR-calculated ice thickness (h) was then compared with manual ice thickness measurements (h_m) at the remaining two-thirds of hand-measured points. Root mean square error (RMSE) and mean absolute error (MAE) were calculated for each transect to analyze the accuracy of using an average velocity model to calculate ice thickness along a river ice transect (Richards et al., 2021).

CHAPTER 4. RESULTS AND DISCUSSION

4.1. Community Visits in 2019 and 2020

This section is based on our conversations with people who build, use, and maintain the Tanana ice road. A public meeting (kick-off meeting for this project) with Tanana residents (20+ people) was held on October 24, 2019 (figure 4.1). We listened to stories about the ice road and asked questions to better understand community needs and to determine when the ice road is commonly used, as well as which months are perceived to be safe for driving on it. The range of responses was recorded on a white board (figure 4.1, left photograph). The ice road is used from December through March; some drivers traveled on the ice road two to four times per year, while others drove it 25 to 30 times per year. Tanana residents told us about challenges they have faced in building the ice road since the 2016–2017 winter. Interest in learning different ice measurement techniques was expressed. Several people asked if we could provide advice and guidance for safe ice road construction and operation.

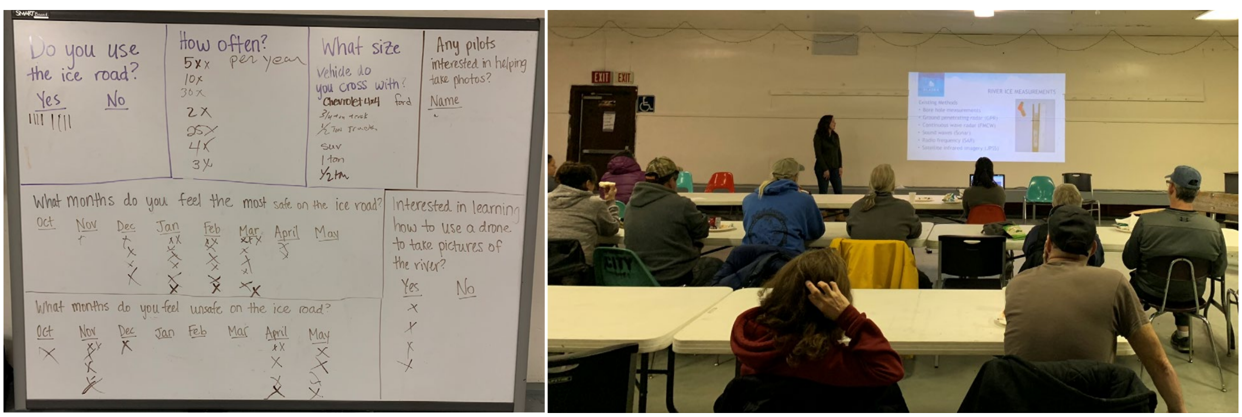

Figure 4.1 Community meeting with Tanana residents, October 24, 2019. Survey responses are summarized on the white board (left photograph). Graduate student Elizabeth Richards talks about river ice measurements.

The next community visit occurred in February 2020, when we had an opportunity to drive the ice road, learn about river ice formation and ice road construction in 2019–2020, and take measurements. This information is presented in the next two sections.

4.2. Air Temperature, Snowfall, and Ice Formation in Winter 2019–2020

Sudden changes in air temperature, as well as snowfall and snow drifting, affect ice properties and ice conditions. If the air temperature drops 20°C in 24 hours or if the air temperature stays above freezing for 48 hours, then re-evaluating the bearing capacity of the ice cover is recommended (Federal Highway Administration, 2020; Government of Alberta, 2013; Haynes and Carey, 1999). Figure 4.2 shows that sudden changes in air temperature and days with above-freezing Tair occur in Tanana throughout the ice road season. This section reports variations in mean daily air temperature and snowfall observed in 2019–2020 as they relate to ice formation processes observed in 2019–2020.

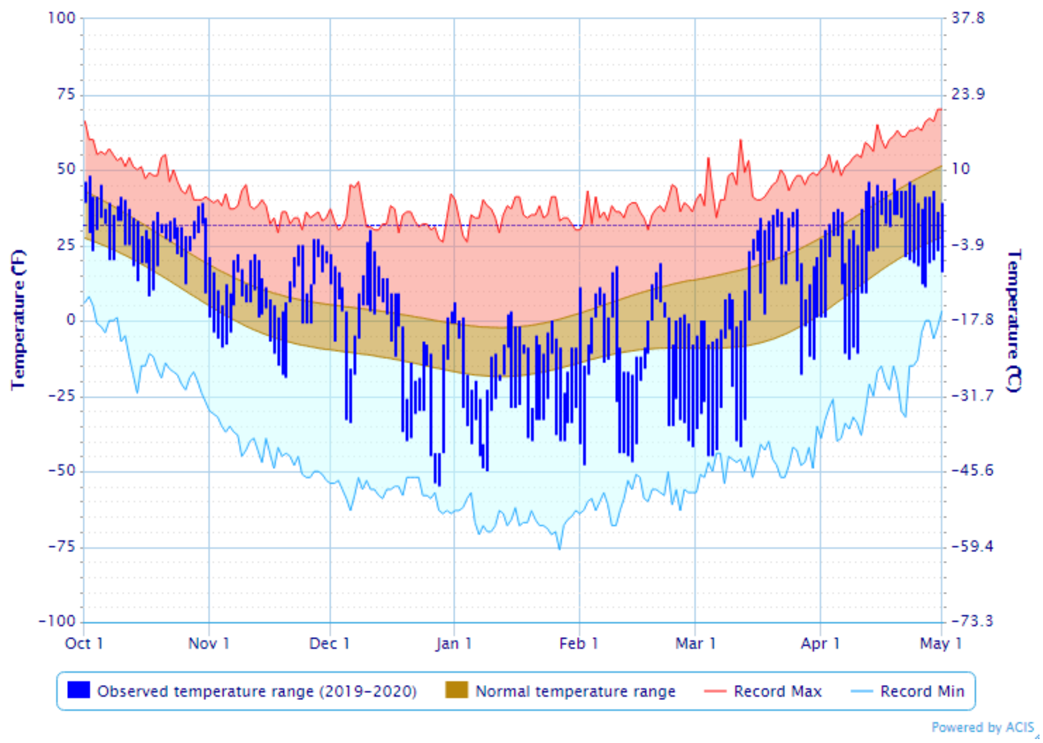

Figure 4.2 Comparison of the daily mean air temperature during winter 2019–2020 (dark blue line) with air temperature range averaged over a normal time period (1981–2010). Record daily minimum and maximum air temperatures are also shown.

The Yukon River freeze-up process starts in October. Figure 4.2 shows that October daily air temperatures were within the normal temperature range during the first few weeks of the month, with an unusual warm snap later in the month. By the end of October, border ice had formed, and frazil ice pans were observed drifting downstream with the flow (figure 4.3).

Air temperatures dropped below freezing in late October and stayed in the normal range for the first week of November 2019 (figure 4.2). During the rest of November, some cooler-than-average and some warmer-than-average conditions were experienced. A similar pattern extended through December. Warmer-than-average days occurred in the second week of December, with Tair reaching -1°C on December 11, 2019. Colder-than-average days occurred later that month, with Tair dropping to -48°C on December 28, 2019.

Figure 4.3 Frazil ice pans observed on the Yukon River near Tanana on October 24, 2019

Tanana residents reported “rough ice,” “cakes of ice,” and some areas of open water in November. In Fall 2019, an unusually large snowfall had an effect on ice conditions that following winter. Figure 4.4 shows that early November brought 0.18 m (7 in) of fresh snow that slowed ice formation. Another sequence of relatively large snowfalls in late November brought seasonal SF to 1.14 m (44.8 in) by December 1, 2019, exceeding the highest SF values reported in the 1930s.

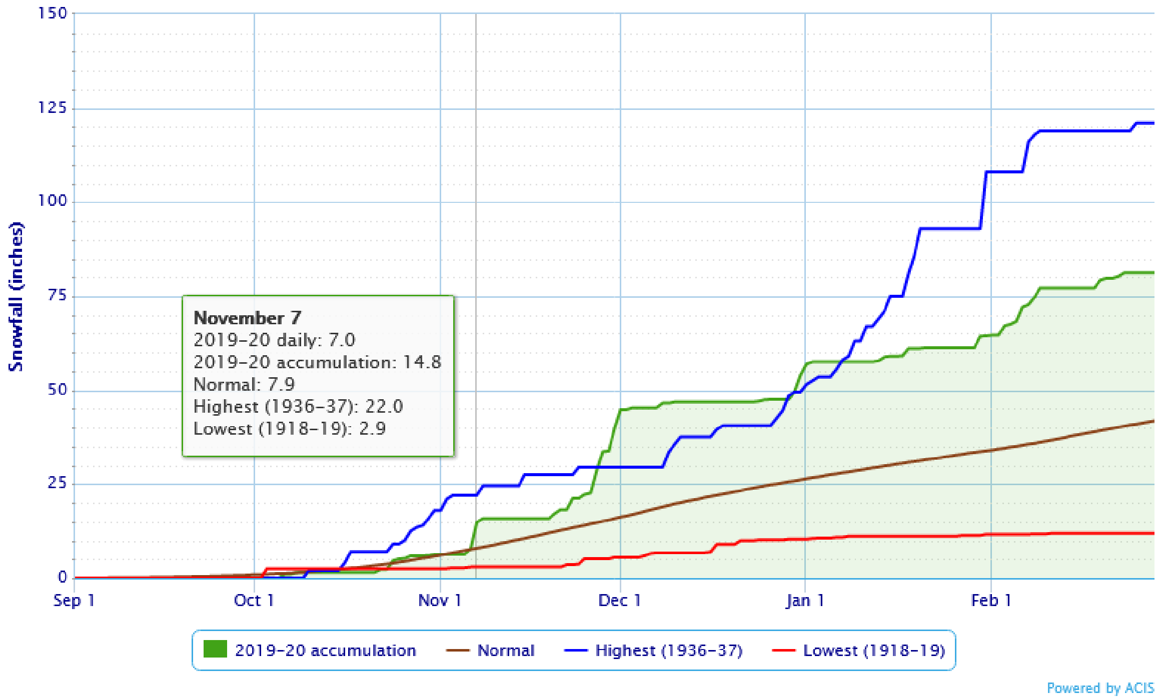

Figure 4.4 Comparison of snowfall accumulation in 2019–2020 with normal snowfall (1981–2010)

Tanana residents observed that late November snowfall "sunk" the ice; i.e., snow accumulation resulted in submergence of the ice cover below the phreatic surface (top of the water in the river), favoring the formation of snow ice. The community reported overflow along the banks as well as submergence of the ice cover. November weather conditions, particularly heavy snowfall, affected the river ice formation process and delayed ice road construction in 2019–2020. The city of Tanana started working on ice road construction in January 2020, after a cold snap that occurred in late December (figure 4.2). At that time, residents felt that the river ice was strong enough to hold the bulldozer used for clearing snow and smoothing the ice surface.

4.3. Ice Road Route

Ice road routes change from year to year as the community attempts to find the best location—one that is both safe for crossing the river and is least prone to formation of snowdrifts. In 2020, the ice road followed grounded overflow ice near the northern riverbank of the Yukon River for the first 2.5 km. The ice road crossed the main channel (0.5 km) at Mission Island and stayed closer to the southern riverbank for another 14 km. The steep drive up the southern bank was one location where snow drifting constituted a significant problem.

The UAF team interviewed Tanana residents on different considerations for choosing ice road routes. Richards (2021) summarized these interviews in her thesis: "*The 2020 location of the ice road was chosen by the city of Tanana because there are high speed winds that remove snow cover and allow river ice to grow faster. Rough (juxtaposed) ice cover is also a characteristic of this location, due to ice jamming that occurs during freeze up. The winter of 2019–2020 is unique because the city maintained two ice roads to determine the best building method for future years. These two roads are referred to as the "Trench Road" and "Packed Road" (Figure 4.6). The Trench Road is formed by consistently clearing snow off the ice and leveling the road so that cold can better penetrate to freeze the ice cover. The Packed Road is built by breaking down all the rough ice at the surface of the ice cover and packing it down by dragging a groomer over the packed snow and ice. The goal of the Packed Road is to minimize snow berms that cause large snow drifts.*"

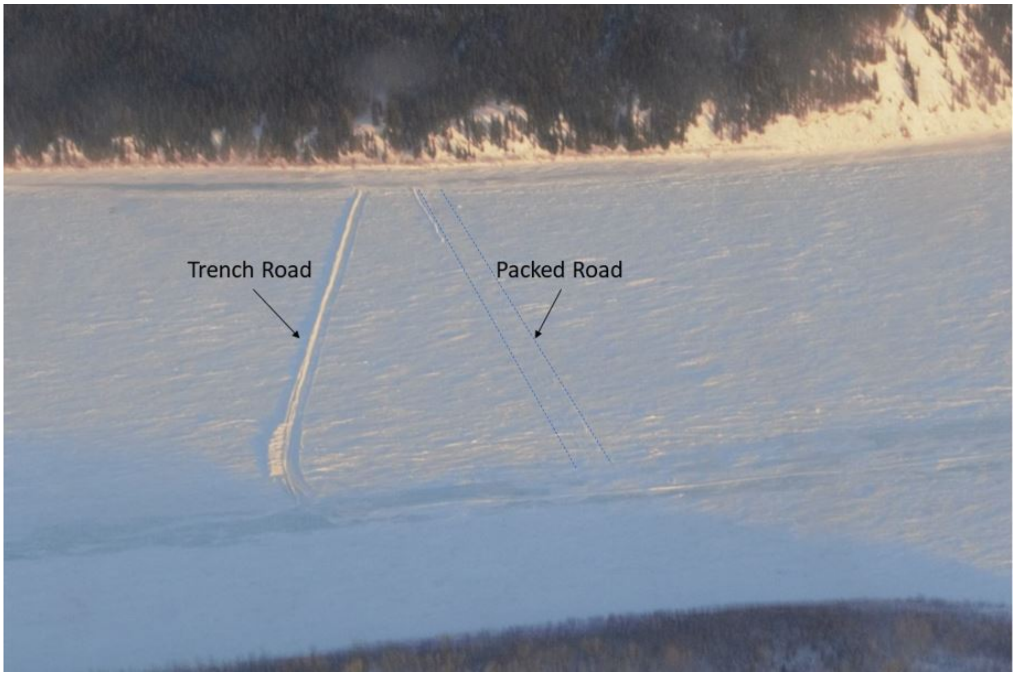

Figure 4.5 Ice roads crossing the main Yukon River channel at Mission Island, February 28, 2021 (Richards, 2021)

4.4. River Ice Measurements

Point measurements indicated an ice thickness range of 0.40 m (from the thinnest ice at 0.91 m to the thickest ice at 1.31 m) over the 350-m section at the trench road (table 4.1). Point ice thickness measurements at the packed road ranged from 1.25 m to 1.57 m. The GPR profile captured a larger range of variability in ice thickness (0.98 m), varying from 0.69 m to 1.67 m at the trench road. Similarly, the range of ice thickness at the packed road was 0.32 m and 0.89 m from point and GPR measurements, respectively.

Table 4.1 Ice Thickness minimum, maximum and range for point measurements and continuous GPR measurements.

Transect	**Length (m)**	**Point Ice Thickness (m)**			**GPR Ice Thickness (m)**		
		Min	**Max**	**Range**	**Min**	**Max**	**Range**
Trench 450	358	0.91	1.31	0.40	0.69	1.67	0.98
Trench 750	350	0.91	1.31	0.40	0.68	1.63	0.95
Packed 450	355	1.25	1.57	0.32	0.74	1.63	0.89
Packed 750	352	1.25	1.57	0.32	0.76	1.64	0.88

The ice measurements shown in table 4.1 highlight the variability in river ice thickness near Tanana, as ice thickness changed by a factor of two over a 350-m road section. According to guidelines for safe ice construction, river ice thickness "*can vary as much as 70% (...) over just a few hundred meters*" (Government of the NWT, 2015). While the observed range of variability is less critical in February when river ice is a meter thick at the thinnest areas, early in the season, sparsely distributed point measurements might result in missing areas of thinner ice and potentially unsafe travel conditions.

Ground penetrating radar was used on both ice roads during the February visit. The GPR radargram obtained with the 450-MHz antenna as well as the locations of hand ice-thickness measurements are shown in figure 4.6.

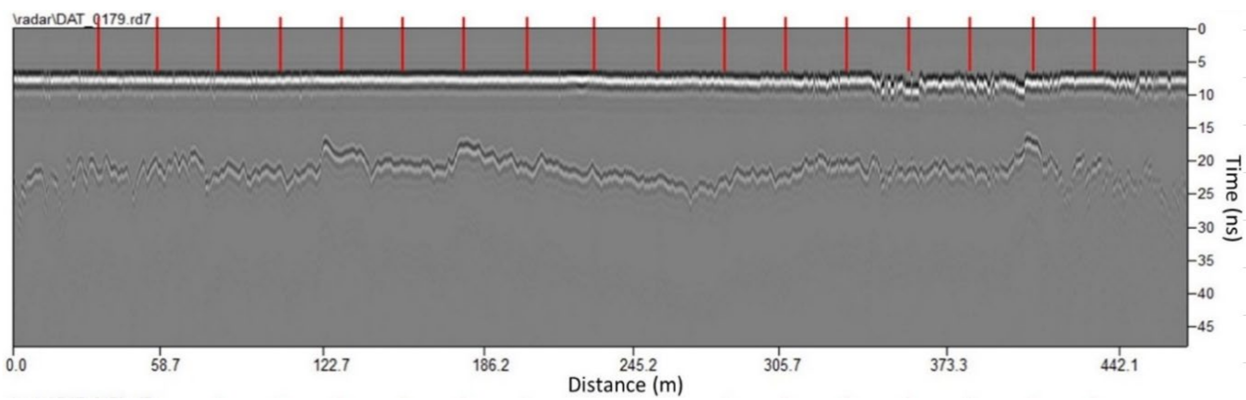

Figure 4.6 GPR radargram along the trench road (adapted from Richards, 2021). Red markers indicate point ice measurement locations.

Electromagnetic wave velocity was calculated at 0.164 m/ns for the trench road and 0.170 m/ns for the packed road. We applied Equation (5), in which hand-measured ice thickness and TWT time recorded by GPR at that location were used to solve for wave velocity. Only three point measurements were used for calibration. Once wave velocity was known, Equation (5) was solved for ice thickness. The resulting ice thickness is indicated in figure 4.7 by the grey line.

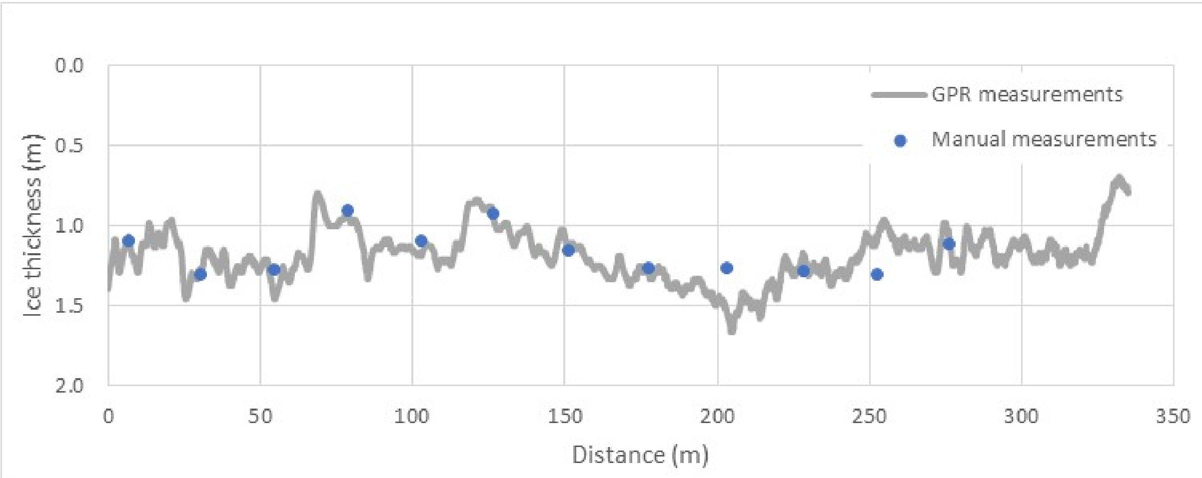

Figure 4.7 Ice thickness along the 350-m long section of the trench road. Blue markers indicate point ice measurements and grey line traces ice thickness from GPR measurements.

The GPR ice thickness was compared with ten manual ice thickness measurements and showed a high level of agreement (R^2= 0.90). The root mean square error (RMSE) for the manually measured ice thickness compared with the calculated ice thickness was 0.06 m, and the mean absolute error (MAE) was 0.044 m for the 750-MHz antenna; the RMSE was 0.05 m and the MAE was 0.036 m for the 450-MHz antenna (Richards et al., 2021). Road conditions were excellent for GPR ice measurements. The surfaces of both the trench road and the packed road were level. Snow had been cleared or well packed a day before the survey. There was no sign of overflow or liquid water inclusions within the ice. Both the 450-MHz and 750-MHz antennae performed well for measuring total ice thickness; however, the chosen frequencies were not able to resolve the different types of ice observed within the ice cover.

Ice coring on the trench road and packed road revealed primarily columnar ice, with some sections of higher gas bubble content, occasional sediment inclusion, and a layer of snow ice. A layer of hard-packed snow was present at the top of cores collected from the packed road (figure 4.8). The effort to identify snow and columnar ice layers with GPR is ongoing.

Figure 4.8 Photograph of a 0.80-m-long ice core collected from the trench road.

CHAPTER 5. PROJECT OUTPUTS AND OUTCOMES

Project outputs include one M.S. thesis, one peer-reviewed paper, one report, four conference abstracts, and five presentations (table 5.1). This PacTrans project supported a female professional pursuing her Master of Science degree in Civil Engineering at the University of Alaska Fairbanks. Project progress and results were transferred to the community and general public during the events summarized in table 5.1.

Table 5.1 Summary of outreach activities and project presentations

N	Date	Event	Location	Audience	UAF participants
1	October 24, 2019	Public meeting	Tanana, AK	Tanana residents (~20 participants)	Richards and Stuefer
2	February 27, 2021	Road committee meeting	Tanana, AK	Tanana residents (~15 participants)	Richards, Stuefer, Belz, Daanen
3	October, 2020	2020 Region 10 Transportation Conference	Virtual, YouTube	PacTrans community	Stuefer and Richards
4	January 29, 2021	Thesis defense, UAF	Virtual, Zoom	Public event (22 participants)	Richards
5	March 17, 2021	Seminar by American Water Resources Association Alaska Section	Virtual, WebEx	Public event (50+ participants)	Richards

Project outputs will be incorporated in new guidelines for ice road establishment and management in Alaska that are currently being developed by UAF's Arctic Infrastructure Development Center (Larsen and Connor, 2021).

CHAPTER 6. CONCLUSIONS

Using appropriate techniques to measure ice road conditions is important to mitigate ice cover breakthrough hazards. The focus of this report is the Yukon River ice road crossing in Interior Alaska near Tanana. The seasonal ice road is built and used by Tanana residents, usually from December to March.

During the study period (2019–2020), heavy snowfall in November 2019 affected the river ice formation process and delayed ice road construction until January 2020. River ice thickness in February 2021 showed high variability at the study location, ranging from 0.69 m to 1.67 m over a 350-m road section.

Frequent and detailed ice thickness measurements using manual and GPR techniques are instrumental in locating dangerous areas of thin and weak ice, especially likely early in the season during ice road construction. Accounting for clear and snow ice layers can be accomplished by evaluating ice cores. Concurrent monitoring of air temperature is also useful, as Interior Alaska is known for extreme temperature changes.

This project contributes to a larger ongoing effort undertaken by FHWA and its partners in providing Alaska-specific protocols and guidelines for seasonal transportation safety on river ice (Larsen and Connor, 2021).

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