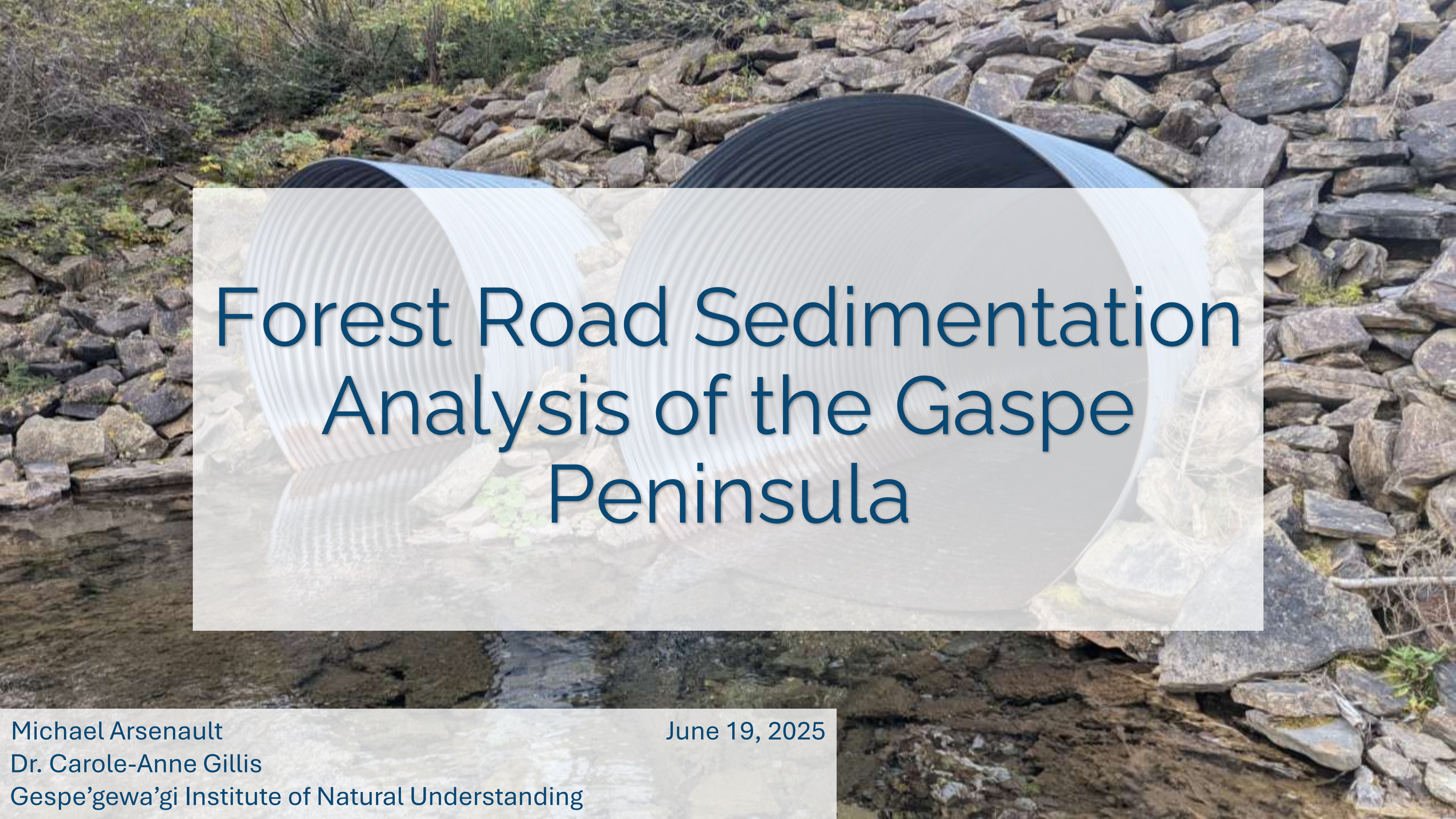


Forest Road Sedimentation Analysis of the Gaspe Peninsula

Michael Arsenault
Dr. Carole-Anne Gillis
Gespe’gewa’gi Institute of Natural Understanding

June 19, 2025

Forest Road Sedimentation

How do roads affect sedimentation?

- Impervious surfaces will create more runoff volume and at a faster delivery rate to watercourse.

- Non-impervious surfaces (forest roads) still facilitate the delivery and volume due to low absorption/percolation of the forest road.

- Non-maintained, poorly designed, or abandoned forest roads not only facilitate the above problems, the rate of erosion and sediment input into the watercourse drastically increases.

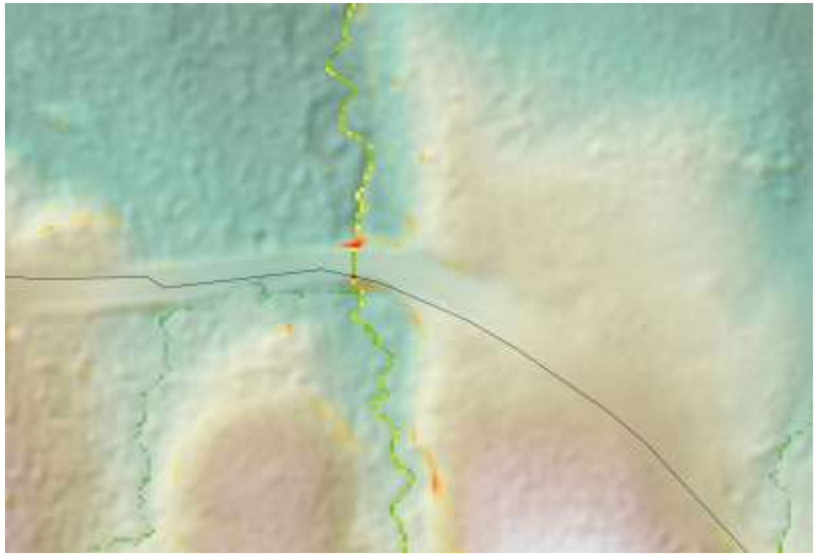
(Poesen et al., 2003; Cocker, 2007; Ferencevic & Ashmore, 2012; Katz et al., 2014)

Study Area: Cascapedia

3 step methodology for identifying sedimentation at a watershed scale

Step 1: Use the Revised Universal Soil Loss Equation (RULSE) to identify areas that have are most vulnerable to erosion relative to the study area (watershed).

Step 2: Use the RULSE output and isolate them to stream-road crossings that have increased erosion chance.



Step 3: Identify the sediment sources (ditch, road/stream embankment, culvert, road, etc....) at each individual stream crossing.

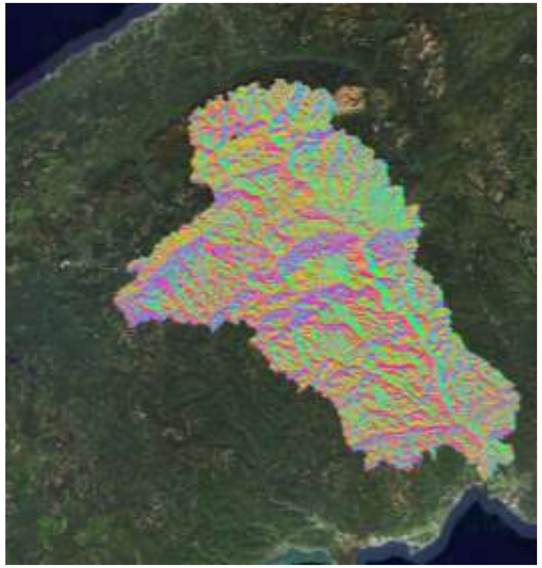
Watershed-scale → All stream crossings → SPI Individual crossing

Methodology: Hydro Condition

Digital Elevation Model

Hydro-condition (Fill Sinks/Breach)

Flow Direction (Inf)



Flow Accumulation (Inf)

The Universal Soil Loss Equation (USLE)

$$A = RKLSCP$$

Where:

A= mean annual soil loss

R= Rainfall Erosivity Factor

K= Soil Erodibility Factor

L= Slope Length Factor

S= Slope Steepness Factor

C= Crop Management Factor

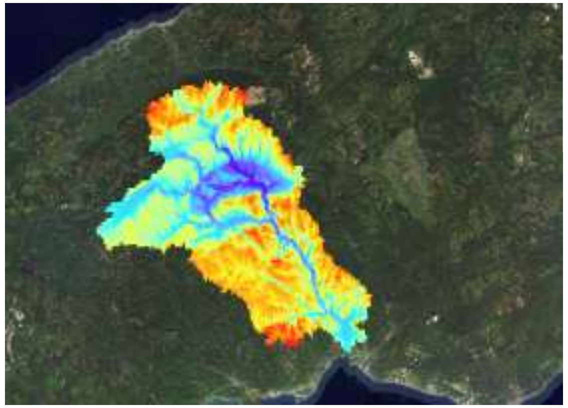
P= Erosion Control Practice Factor

A= RKLSCP

Methodology: RULSE Inputs

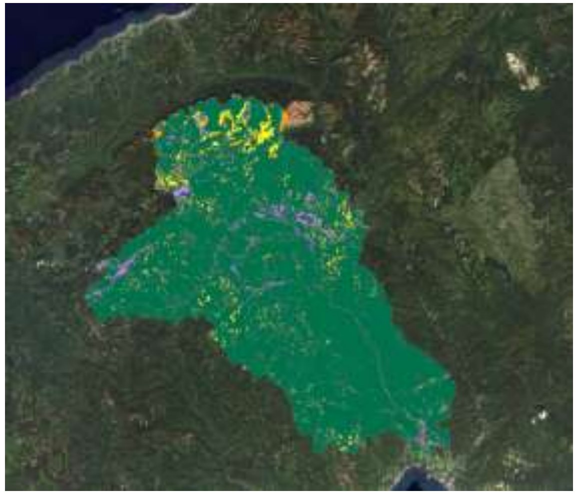
Annual Soil Loss (tons/hectare/year) =

Rainfall Erosivity

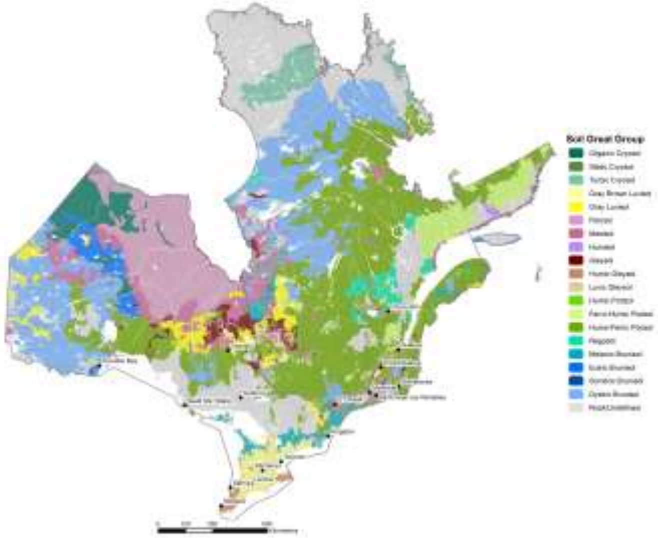


Rain Erosivity (R) = 732 – 1066 MJ mm ha^{-1} h^{-1} yr^{-1}

Land Use



Soil Erodibility Factor



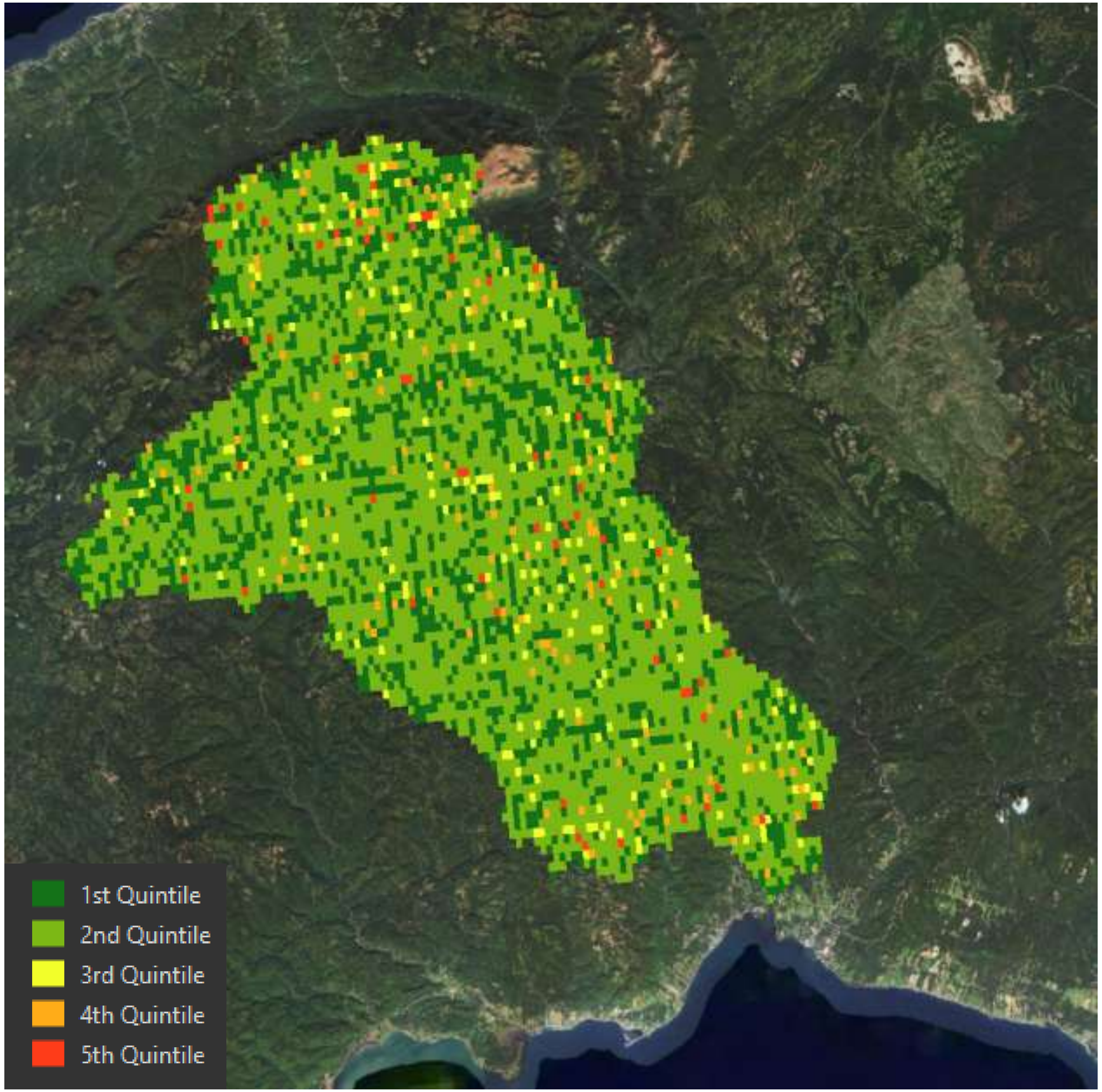
Length and steepness of slope factor

$$LS = \left(flow\ accumulation \times \frac{Cell\ Size}{22.13}\right)^{0.5} \times \frac{Sin\ (Slope)^{1.3}}{0.0896}$$

Methodology: Sources

Symbol	Description	Data Source	Spatial Resolution	Source
R	Rainfall Erosivity	GloReda (Panagos et al., 2017-2023)	-	https://www.sciencedirect.com/science/article/pii/S2352340923005826
K	Soil Erodibility	Donnees Quebec	100 meter	https://www.donneesquebec.ca/recherche/dataset/siigsol-100m-carte-des-proprietes-du-sol
L	Slope Length	User Generated	1 meter	-
S	Slope Steepness	User Generated	1 meter	-
C	Vegetation Cover	Donnees Quebec	30 meters	https://www.donneesquebec.ca/recherche/dataset/carte-ecoforestiere-avec-perturbations
P	Support Practice	Donnees Quebec	30 meters	https://www.donneesquebec.ca/recherche/fr/dataset/utilisation-du-territoire

The Universal Soil Loss Equation (USLE)



A= mean annual soil loss

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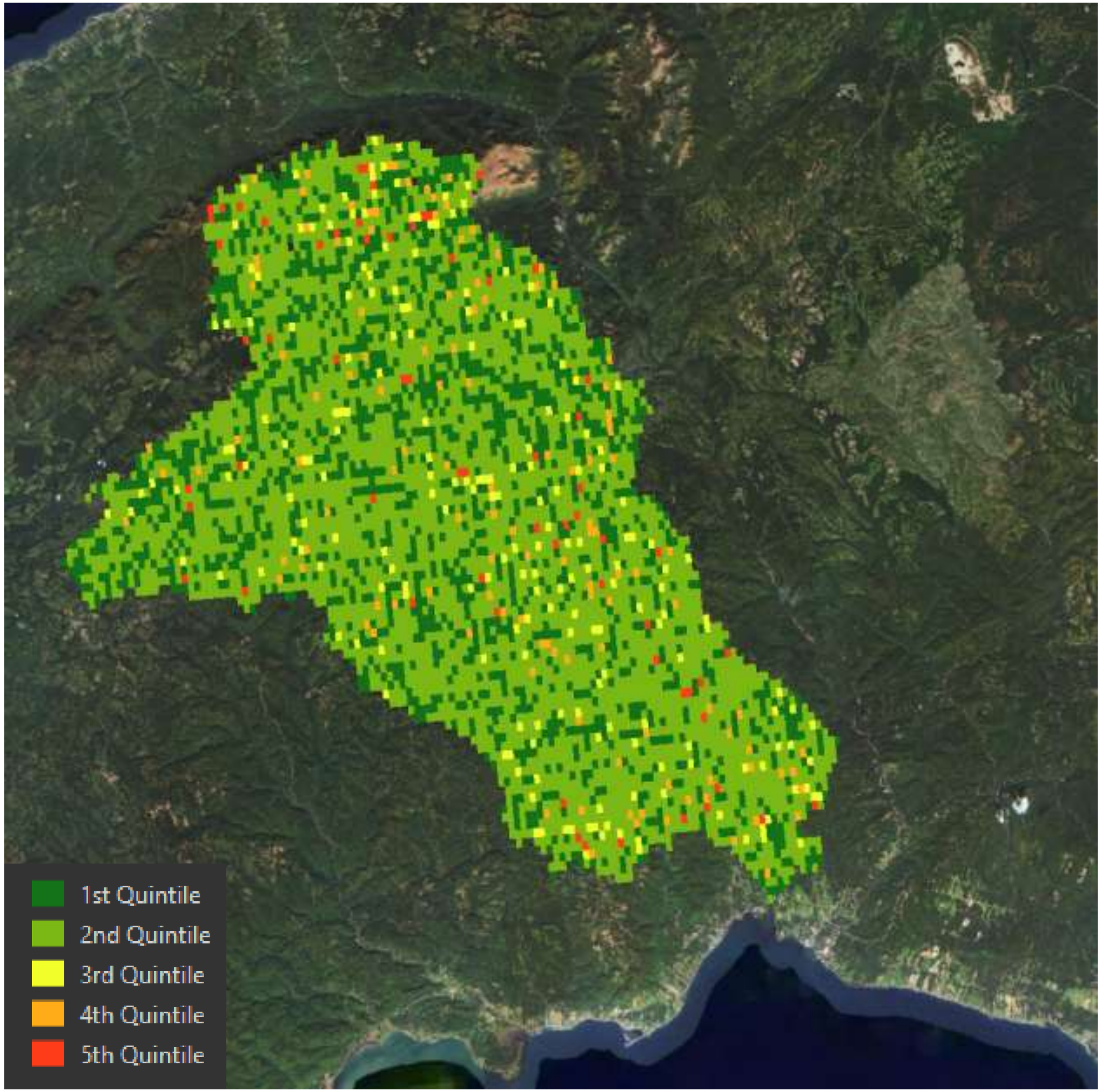
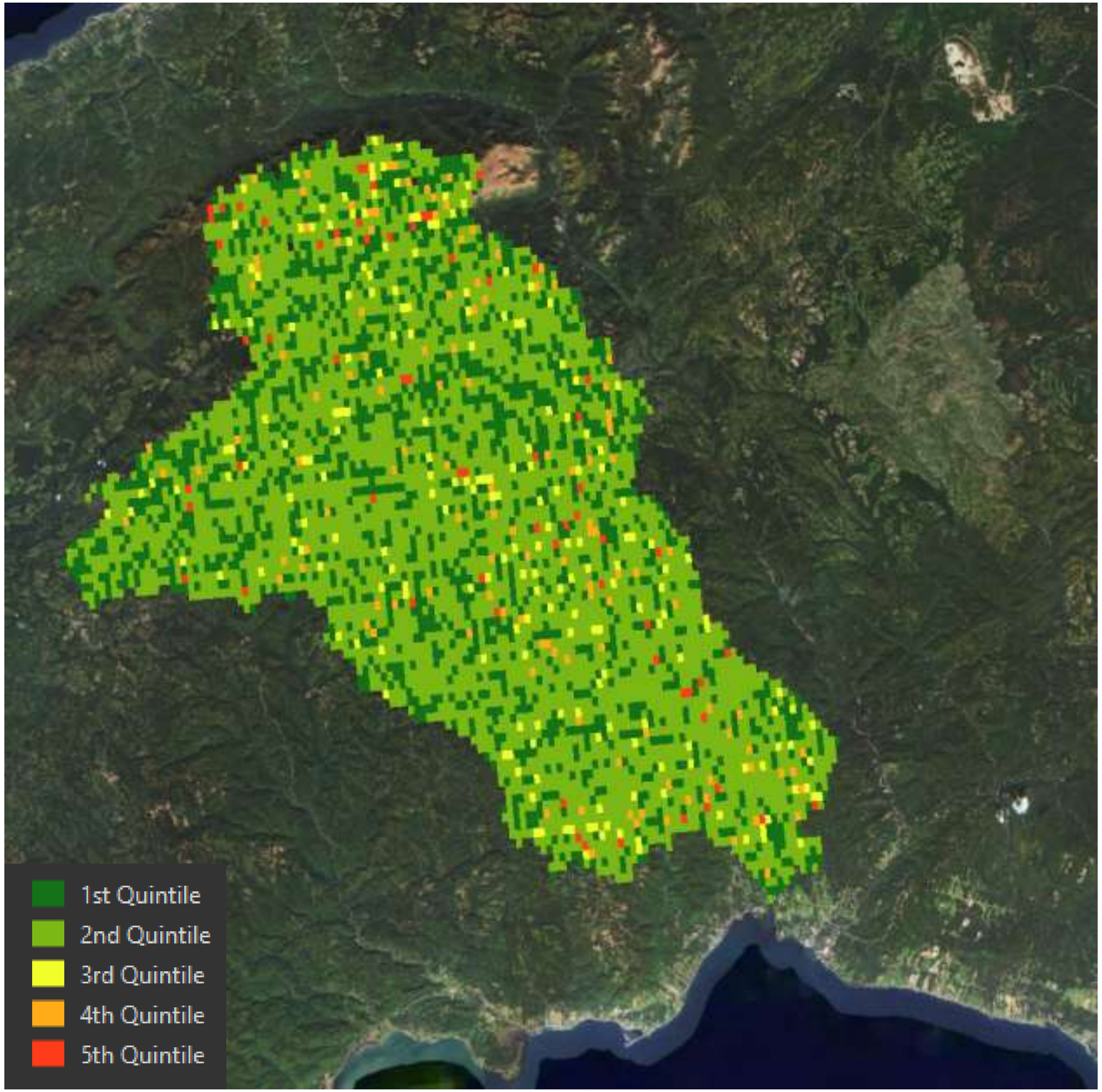


The Government of Canada (GoC) in their "RUSLECAF: Revised Universal Soil Loss Equation for Application in Canada (2015)"

Soil Erosion Class	Potential Soil Loss tonnes/hectare/year
Very Low	< 6
Low	6-11
Moderate	11-22
High	22-33
Severe	> 33

The GoC created these categories by separating the results by soil loss tolerance. The underlying research the GoC used was conducted by Shelton et al., 1985. The study sites were located in Ontario.

The Universal Soil Loss Equation (USLE)



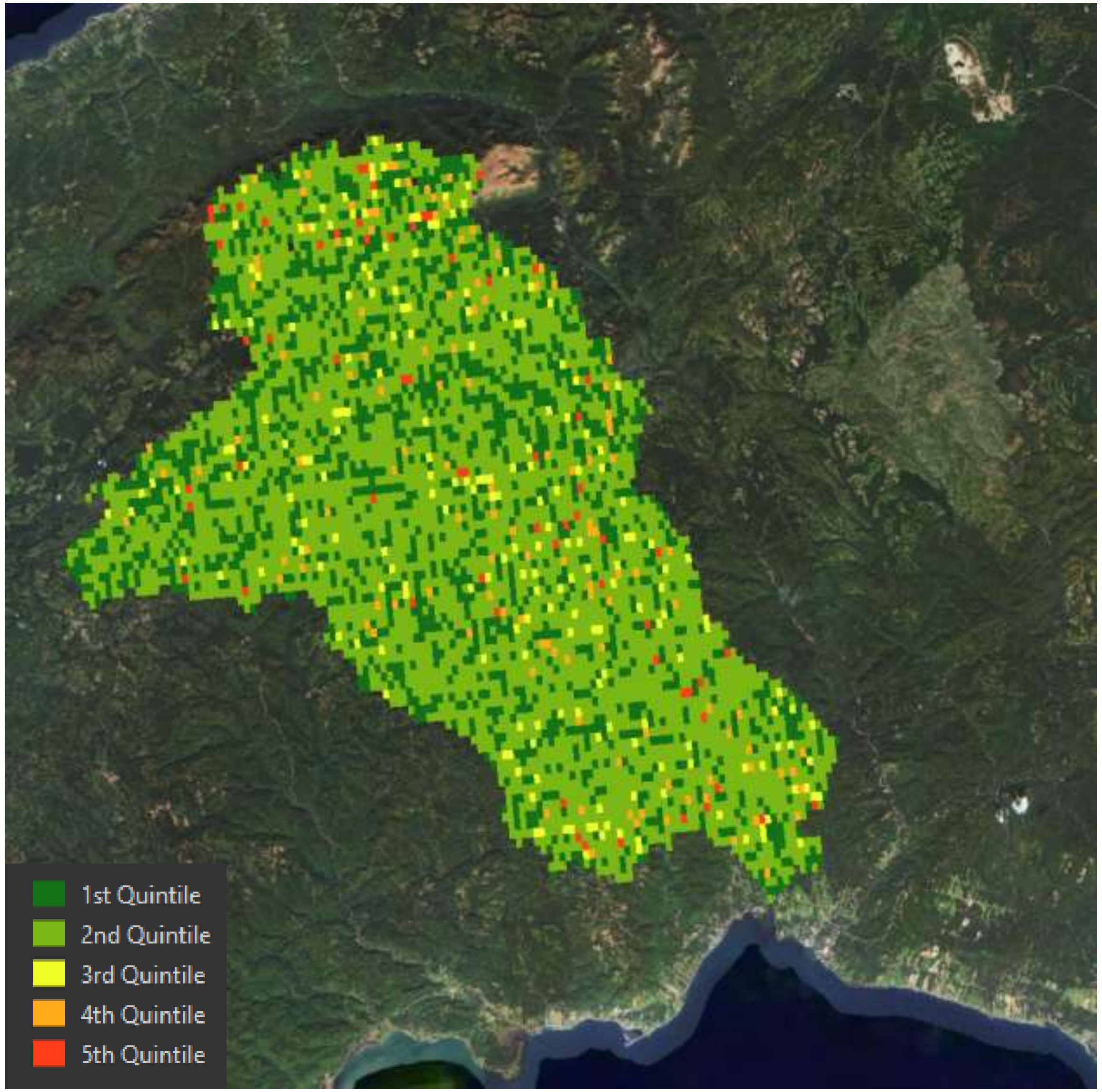
Drawbacks of using GoC categorization in Gaspésie:

Different landscape characteristics, topsoil depths, soil group type, annual rainfall, organic matter composition.

Using “local” measurements to extrapolate national guidelines.

Quantifying erosion potential through indices. Shelton et al., (1985) and the GoC Erosion handbook warned against taking the RULSE results as fact/

The Universal Soil Loss Equation (USLE)
A= RKLSCP



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Very Low	< 6
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Relative percentile classification

Soil Erosion Class	Quintile Ranges
Very Low	0 - 19.99%
Low	20 - 39.99%
Moderate	40 – 59.99%
High	60 – 79.99%
Severe	80 – 100%

3 step methodology for identifying sedimentation at a watershed scale

Step 1: Use the Revised Universal Soil Loss Equation (RULSE) to identify areas that have are most vulnerable to erosion relative to the study area (watershed).

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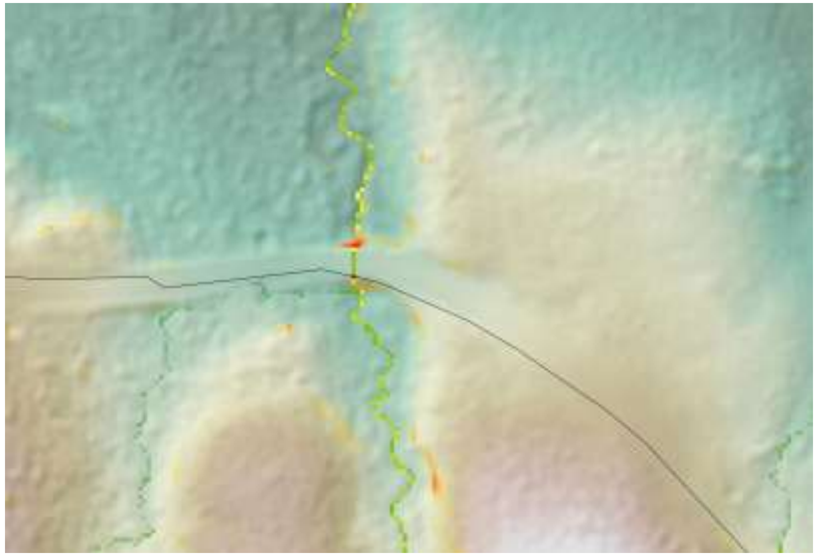
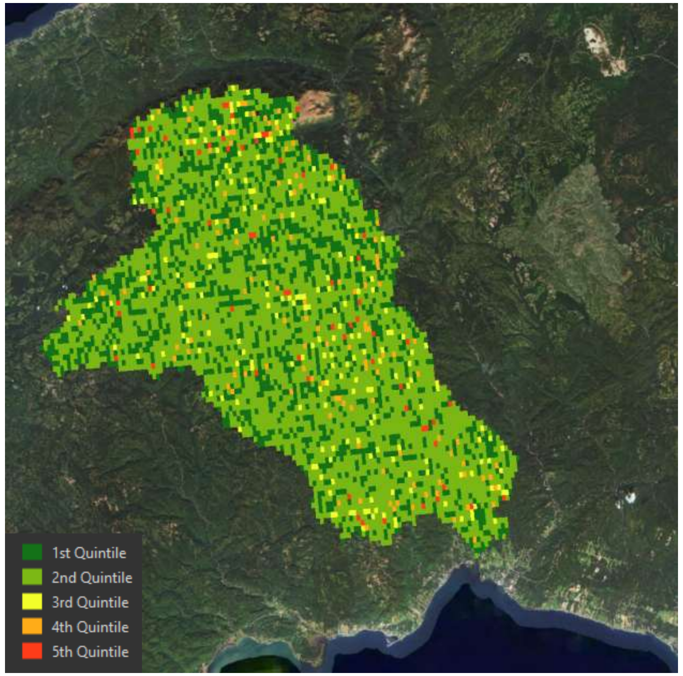


Step 3: Identify the sediment sources (ditch, road/stream embankment, culvert, road, etc....) at each individual stream crossing.

Watershed-scale → All stream crossings → SPI Individual crossing

Stream crossings with high relative erosion



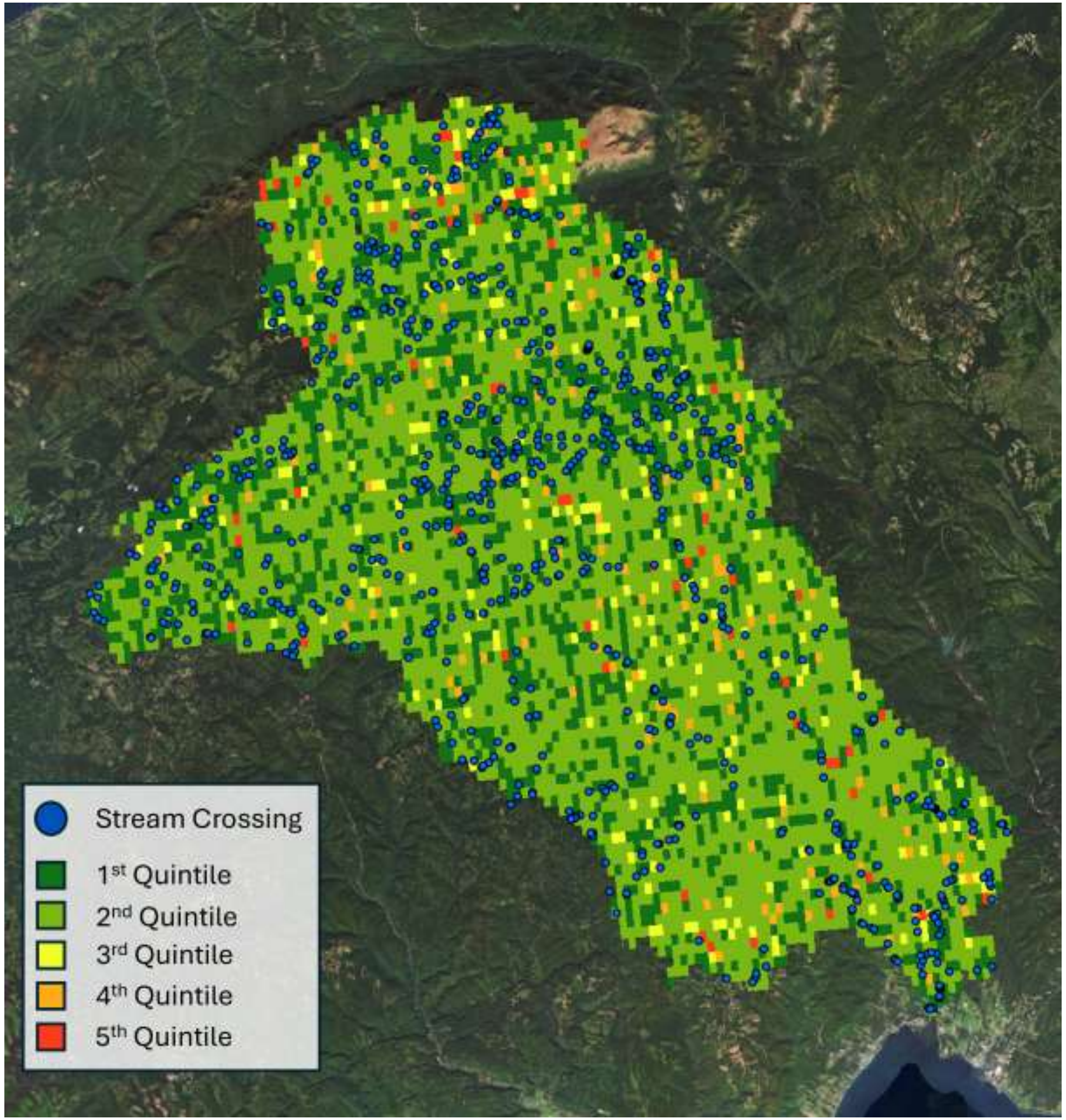
100-meter buffer →

- Stream buffer is based on how far sediment can travel through forested landscapes.
- Sediment being transported through a vegetated landscape can be transported between 80-100 meters (Cooper et al., 1987; Lowrance et al., 1988).
- Other studies (Richardson et al., 2012; Sweeney & Newbold, 2014) have recommended site specific or variable buffer zones.
- We will use the 100-meter buffer for our analysis to ensure that we capture as many legitimate erosion sites as possible, recognizing that it could increase our false detection rate.

Sediment Transport Index

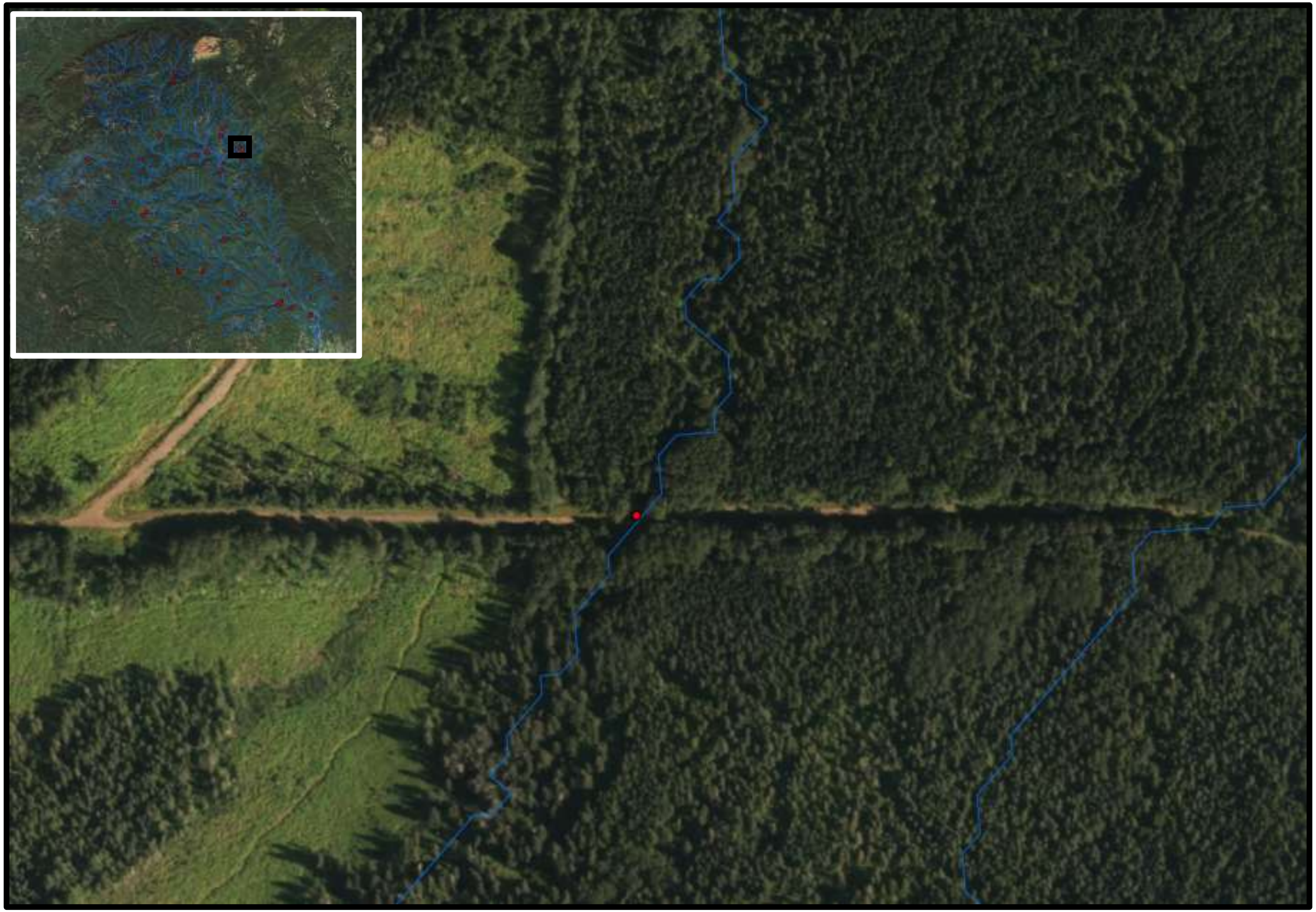
$$Power\ (\text{“,}SCA\text{”}/22.13\ \ 0.16)\ *\ Power\ (Sin(\text{“}Slope.tif\text{”})\ /\ 0.0896,1.3)$$

Sediment Transport Index



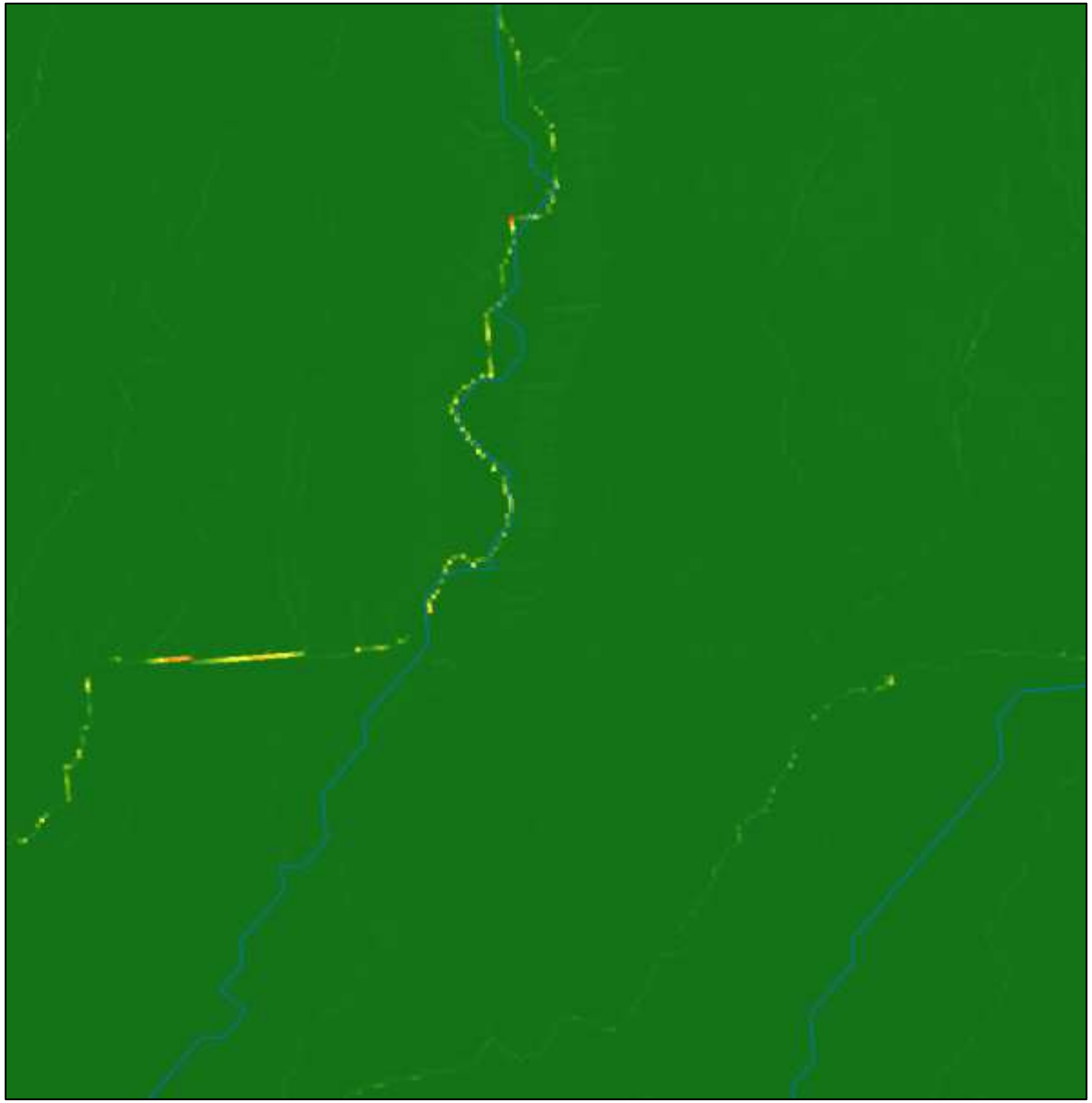
- Input road and stream shapefile into the “Intersect” tool to determinene potential stream road crossings.
- Extract all stream crossings that are within the 3rd Quintile and above using the “Extract Values to Points” tool.
- Manually review each crossing to identify sediment sources.

Sediment Transport Index



Sediment Transport Index

Whitebox ArcGIS Toolbox



$STI = (m + 1)(A_s / 22.13)^m*(\sin(\beta) / 0.0896)^m$

Sediment Transport Index

Variable	Qualitative or Quantitative?	Measurement
Stream crossing type	Qualitative	Culvert, bridge, ford, impoundment
Crossing characteristics	-	Condition of the stream crossing structure (failure, blockage, hanging)
Road surface material	Qualitative	Paved or Dirt
Road shape	Qualitative	Shape of road (crown, inslope, outslope)
Up/downstream road embankment erosion	Qualitative	Percentage of the road embankment that shows evidence of erosion
Sediment source	Qualitative	Rill/rut from road surface, gully, hanging culvert, undercut culvert, road embankment, stream embankment
Channel constriction	-	Percentage the stream narrows at the stream crossing structure
Road slopes	Quantitative	% slope rises from the stream crossing to the crest of the road

Sediment Transport Index

Crossing Type	N	Crossings vulnerable to erosion
Culvert	183	22
Bridge	68	4
Ford	78	9
Impoundment	19	2

Field Verification

Crossing #	GIS					Field				
	Gully	Rill/Rut	Culvert	Road embankment	Stream embankment	Gully	Rill/Rut	Culvert	Road embankment	Stream embankment
1	1	1	0	0	0	1	1	0	0	0
2	1	1	1	0	1	1	1	0	0	1
3	1	0	0	1	2	1	0	0	1	2
4	1	1	0	0	0	0	1	1	0	0
5	1	1	1	1	0	0	1	1	1	0
6	0	1	0	0	0	0	1	0	0	0
7	2	1	0	1	0	1	1	0	1	0
8	1	1	1	0	1	0	1	1	0	2

Field Verification

Watershed	# of Sediment Sites	# of sediment sources from field (% Accuracy Field vs. GIS)				
		Gully	Rill/Rut	Culvert	Road embankment	Stream embankment
Bonaventure	26	10 (77%)	11 (84%)	9 (89%)	6 (83%)	2 (100%)
Cascapedia	8	4 (50%)	4 (57%)	3 (100%)	3 (100%)	5 (83%)
Little Cascapedia	10	3 (67%)	2 (50%)	4 (75%)	2 (100%)	1 (100%)
Madeleine	2	-	1 (100%)	2 (100%)	1 (100%)	1 (100%)
Nouvelle	23	13 (100%)	26 (90%)	16 (94%)	6 (100%)	5 (100%)
York	4	1 (0%)	4 (100%)	2 (100%)	1 (100%)	1 (100%)

Prioritization

Sediment source type	Quintile (Severity)	# of sediment sources	Index score	Normalized index score
Road embankment	0-5	#	0-25	0-1
Stream embankment	0-5	#	0-25	0-1
Gully	0-5	#	0-25	0-1
Road (Rill/Rut)	0-5	#	0-25	0-1
Culvert	0-5	#	0-25	0-1

- 1. The severity of erosion is at watershed scale and expressed as quintiles, the index will be using the quintile classification to assign index weights.

  2. Index Score is the maximum possible sum of all "Sediment source types", resulting in a scale of 0-25 for an index scale. To normalize this, the index score can be divided by 25 for a normalized index scale of 0-1.

Prioritization

Sediment Source Type	Quintile (Severity)	Source Index Score	Site Index Score (0-40)	Normalized Site Index Score (0-1)
Road embankment	5	5	25	0.625
Stream embankment	4	4		
Gully	3	5		
Gully	2			
Road (Rill/Rut)	1	8		
Road (Rill/Rut)	2			
Road (Rill/Rut)	5			
Culvert	3	3		

- 1. Severity measurement methodology for individual sediment sources can be found on supplemental slides at the end of the powerpoint.

  2. Each site can contain more than one of the same sediment source type, so quantity will influence final index scores. The weights are equalized in terms of sediment source type and can be changed if there is evidence of certain sediment sources having more impact than others.

Prioritization

Relative percentile classification

Soil erosion class	Quintile Ranges	Normalized Index Score
Very Low	0 - 19.99%	0 - 0.1999
Low	20 - 39.99%	0.2 - 0.3999
Moderate	40 – 59.99%	0.4 - 0.5999
High	60 – 79.99%	0.6 - 0.7999
Severe	80 – 100%	0.8 - 1

- Index ranges will follow the quintile method for determining priority. Again, this is watershed specific and should not be used to compare to other crossings outside of the watershed.
- The previous example had an index score of 0.625, which is within the 4th Quintile range, a high relative erosion severity.

Prioritization

- Does using an indices score as an input for another index follow our assumptions?
- The LiDAR is a snap shot in time and could be over 5 years old and sites could be remediated, recovered, or not exist.
- Should the individual variables used in the RULSE equation be weighted individually or keep as the RULSE classification.
- Finish sediment analysis for all of Gaspe Peninsula by end of July. Data formatting and export at the end of August. Geo-node or other online GIS host test run at the end of August/early September. Full data upload by end of September/ early October.

Acknowledgments

Variables collected:

- Stream crossing type
- Stream classification
- Crossing characteristics
- Road surface material
- Road shape
- Up/Downstream road embankment erosion
- Sediment sources
- Channel constriction
- Road slopes

Field Season 2024

Field Season 2024

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Double Steel Corrugated Culvert


Concrete Box Culvert


Double Plastic Culvert


Hanging Culvert

Field Season 2024

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Culvert Scouring & Structural Damage

Culvert Woody Blockage

Road Failure

Culvert Scouring & Undersized Culvert

Field Season 2024

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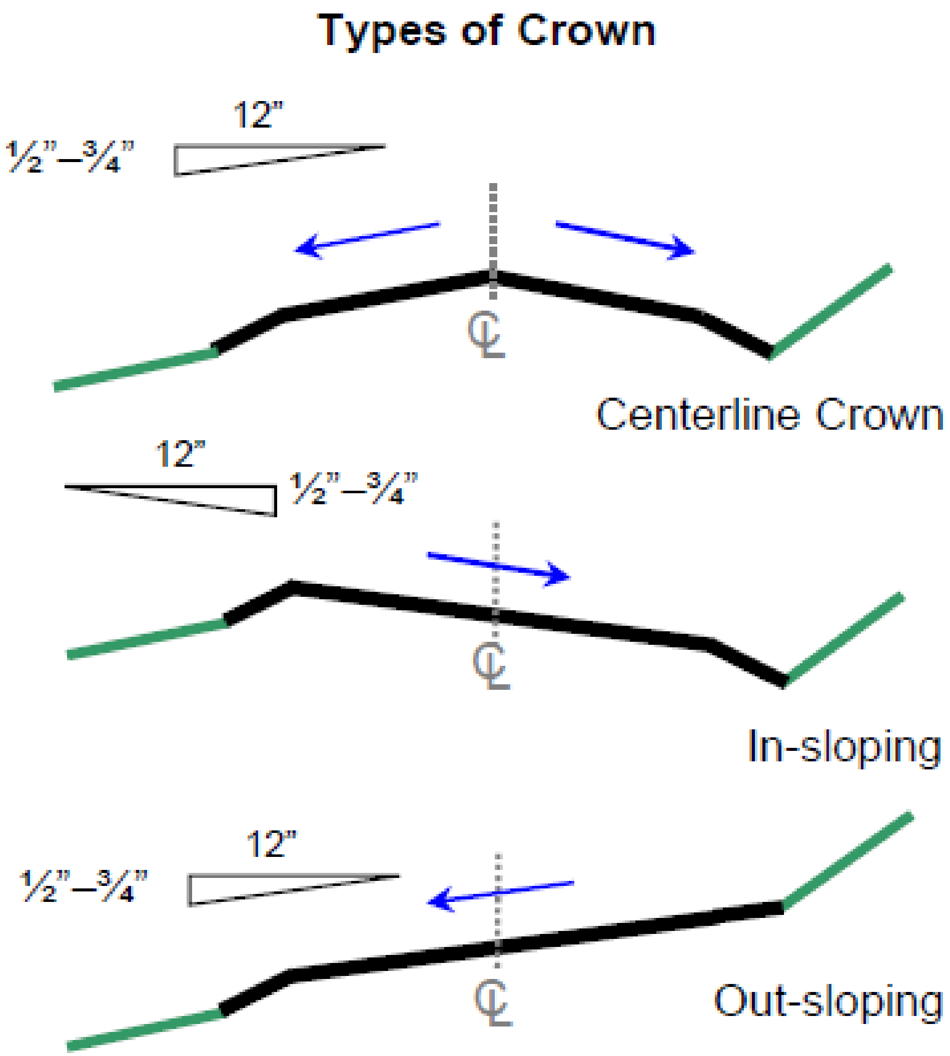

"Crown": Highest elevation point on road is in the center with both sides sloping to the road embankment

"Inslope": Road angle directs flow to a drainage structure/ditch

"Outslope": Road surfaces drain water from the entire width of the road toward the fill-bank or down-slope side

Field Season 2024

Road embankment erosion is measured by how much of the road embankment has evidence of erosion, expressed as a %

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100% Erosion

Field Season 2024

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slope percentage = tan(d) × 100

Field Season 2024

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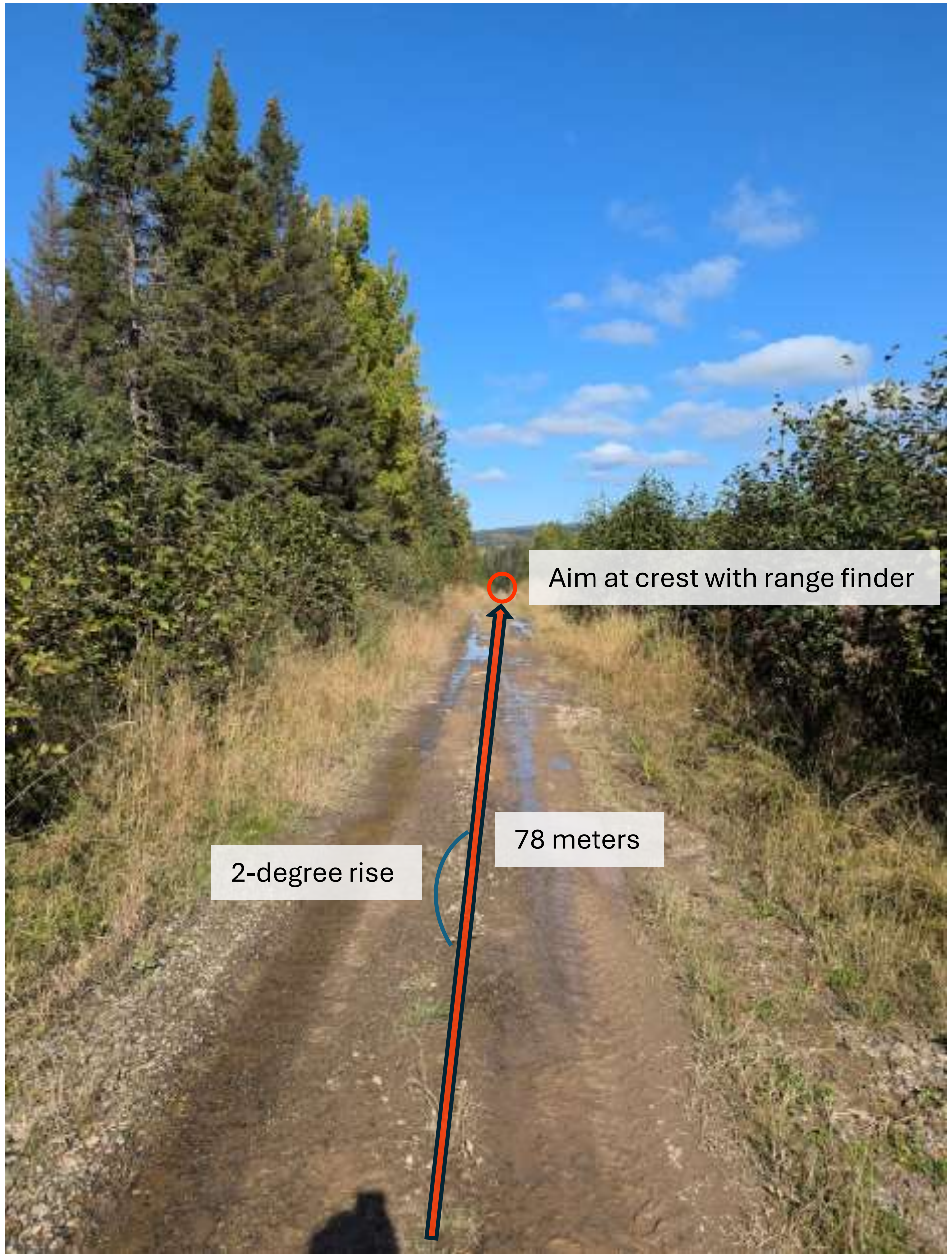
- **Road slopes**



Measure angle from crossing to crest of road, repeat in the other direction

Slope percentage = tan (d) * 100
Where “d” is slope in degrees; not in radian.

Horizontal Distance (Run): 78 meters
Angle: 2 degrees

Slope percentage = tan (2) * 100
Slope percentage = 2.724%