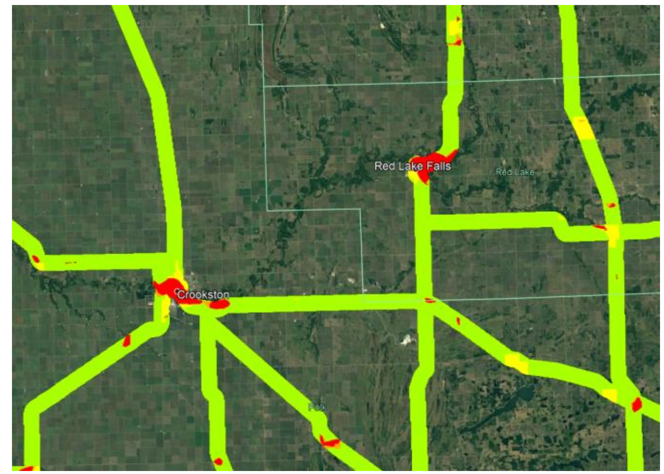
DEPARTMENT OF TRANSPORTATION



A Geomorphology-based Model for Vulnerability Assessment of Slopes in MnDOT

Landslide Capacity Building Seminars

September 11, 2020

Acknowledgements

GIS Model Developing Team:

Nick Bradley, Nick Rodgers, and Jen Holmstadt

Technical Advisory Panel (TAP) Members:

Nathan Bausman, Jim Bittmann, Christine Dulian, Katie Fleming (PC), Shannon Foss, Sara Johnson, Blake Nelson, Amy Thorson, Raul Velasquez (TL)

(MnDOT)

Andrew Shinnefield

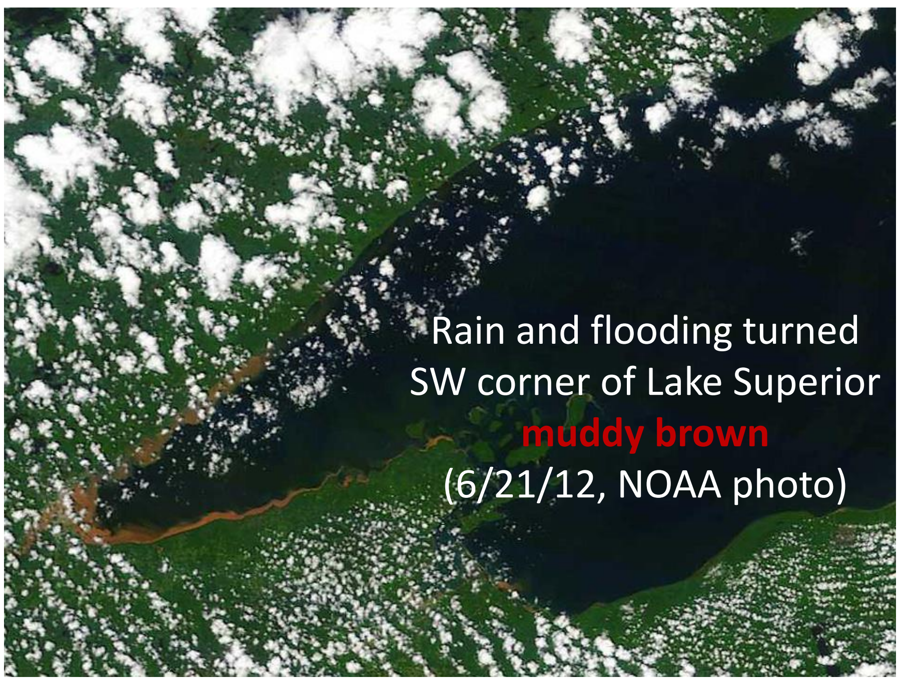
(Terracon)

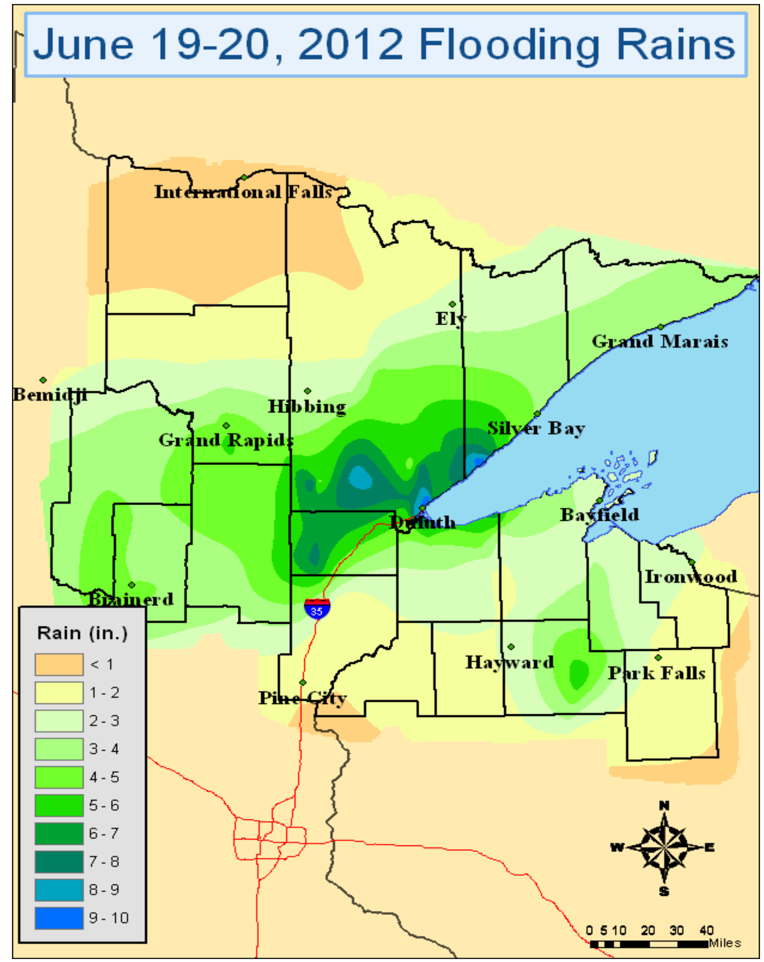
Tony Runkel

(UMN)

Why Slope Vulnerability Assessment?

- Rainy season in June 2012 in Minnesota caused slope failures and major damage in MN Trunk Highway (~ $50 million dollars in damage)





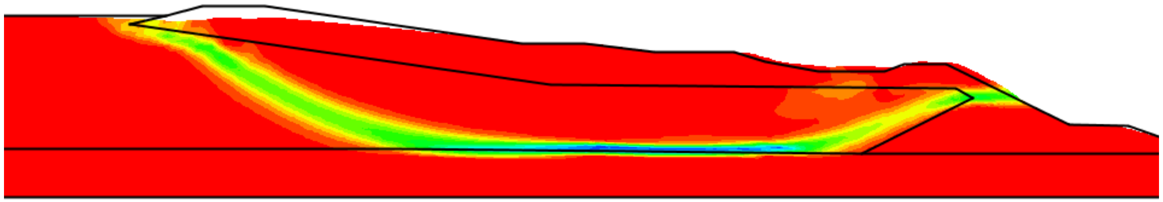
Why Slope Vulnerability Assessment?

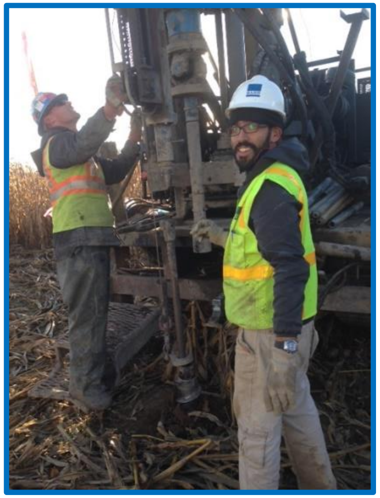
- **26** Road Closures on Trunk Highway System
- Major team effort to bring system back:
  - MnDOT, DNR, DPS, Local Law Enforcement, FHWA, Consultants, Contractors.
- MnDOT Main Damage Areas:
  - TH-210 in Jay Cooke
  - TH-210 in Thomson
  - TH-23 in Fond du Lac
  - TH-2 from Proctor to I-35

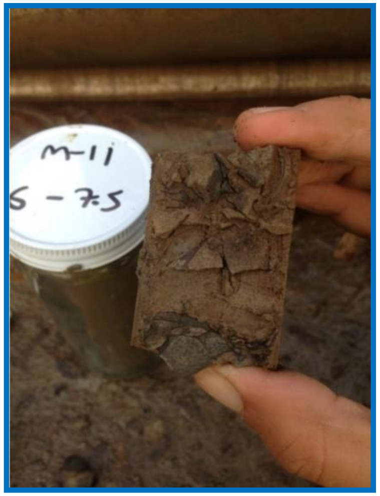
Geotechnical Approach for Slope Assessment

Geotechnical Approach for Slope Assessment

1. Site characterization (in-situ and lab testing)
2. Instrumentation (piezometers, inclinometers, etc.)
3. Estimation of lithology, soil strength, and pore water pressure distribution
4. Development of digital twin of site/slope
5. Estimation of Factor of Safety (FoS) via analytical or numerical methods
6. Repair/improvement options (e.g., drains, cut/fill, structural elements, etc.)
7. Reinforced/Improved slope FoS estimation

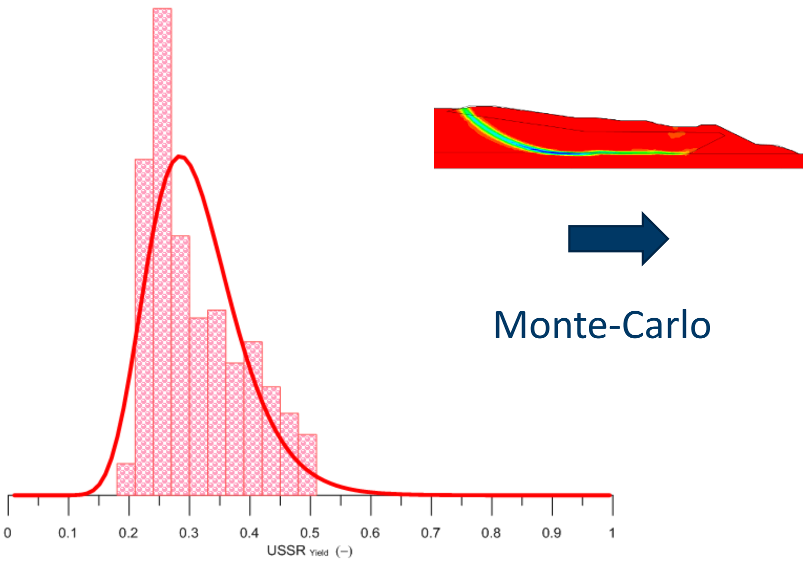


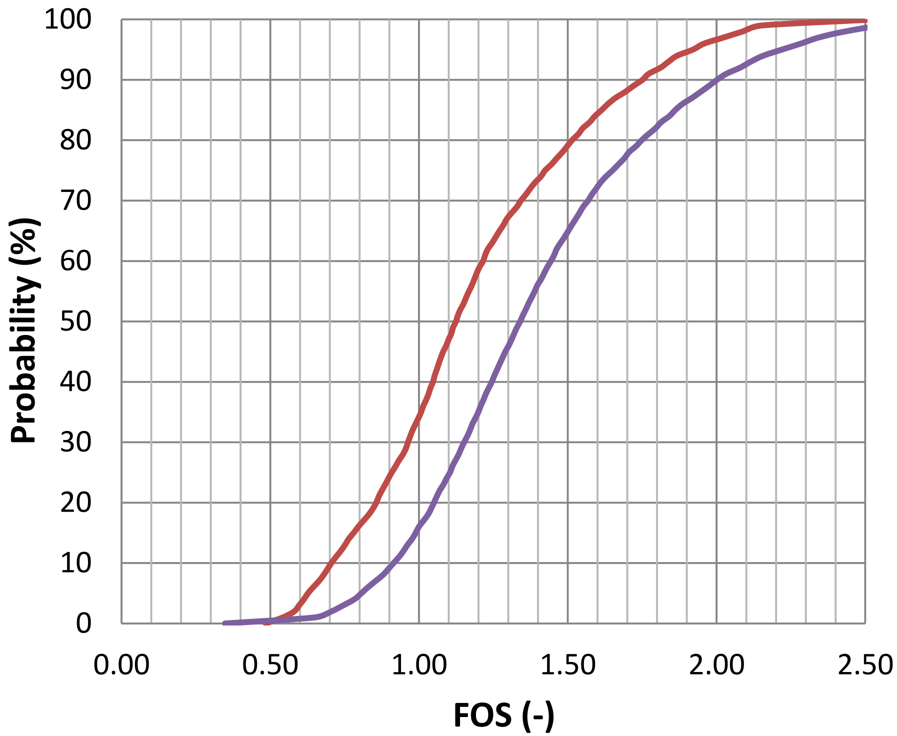




Geotechnical Approach for Slope Assessment

<u>Risk Assessment</u> can be added via powerful numerical methods commonly available:



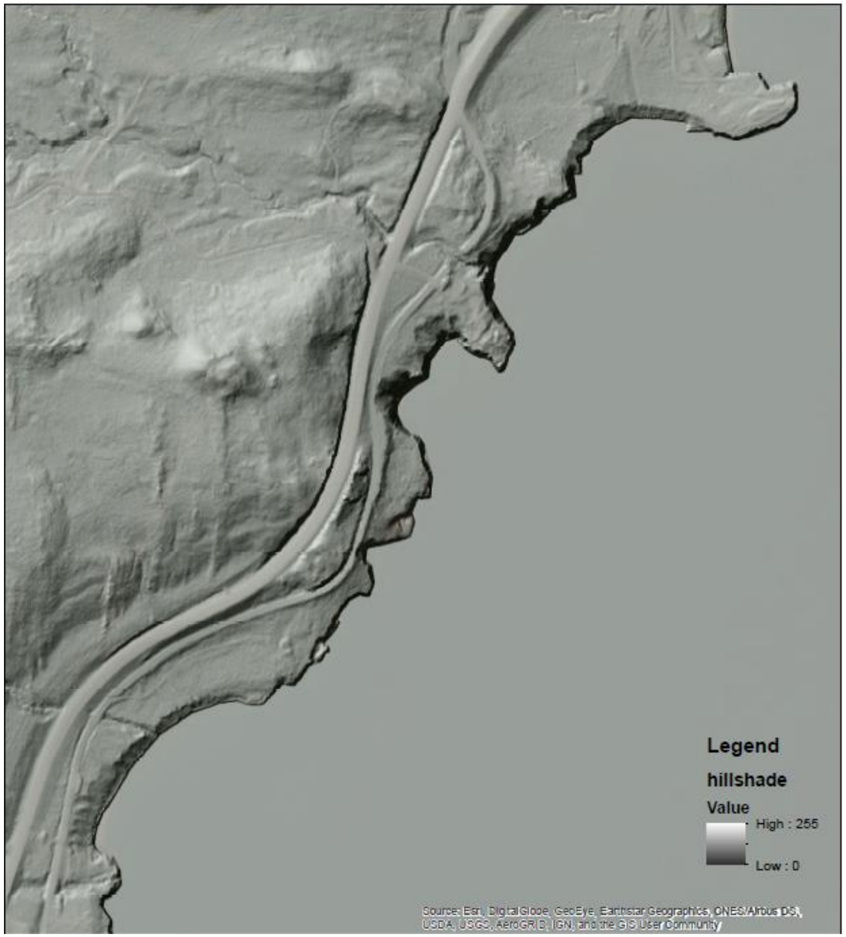


Goals of Slope Vulnerability Model

- *Assist engineers to proactively identify and mitigate slope risk along interstate highways*
    - Help during **project scoping** to **long range planning**
    - Enhance risk-based **asset management** decision making

Model assist in proactive identification of slope failures like deep-seated slide in TH-67

Slope Vulnerability Model



Geographic Information Systems (GIS) model that uses:

- **Geomorphology** of site among other key parameters to provide a *vulnerability rating score*
- **Geographic Weighted Regression (GWR)** to account for local variation of key parameters and minimized bias and subjectivity

Slope Vulnerability Model

Vulnerability Rating Score is computed with:

$$p = \frac{e^z}{1 + e^z}$$

$$z = \beta_o + \beta_1 X_1 + \cdots + \beta_n X_n$$

p= probability of slope failure (0 < p <1)

X_n=input parameters (independent variables)

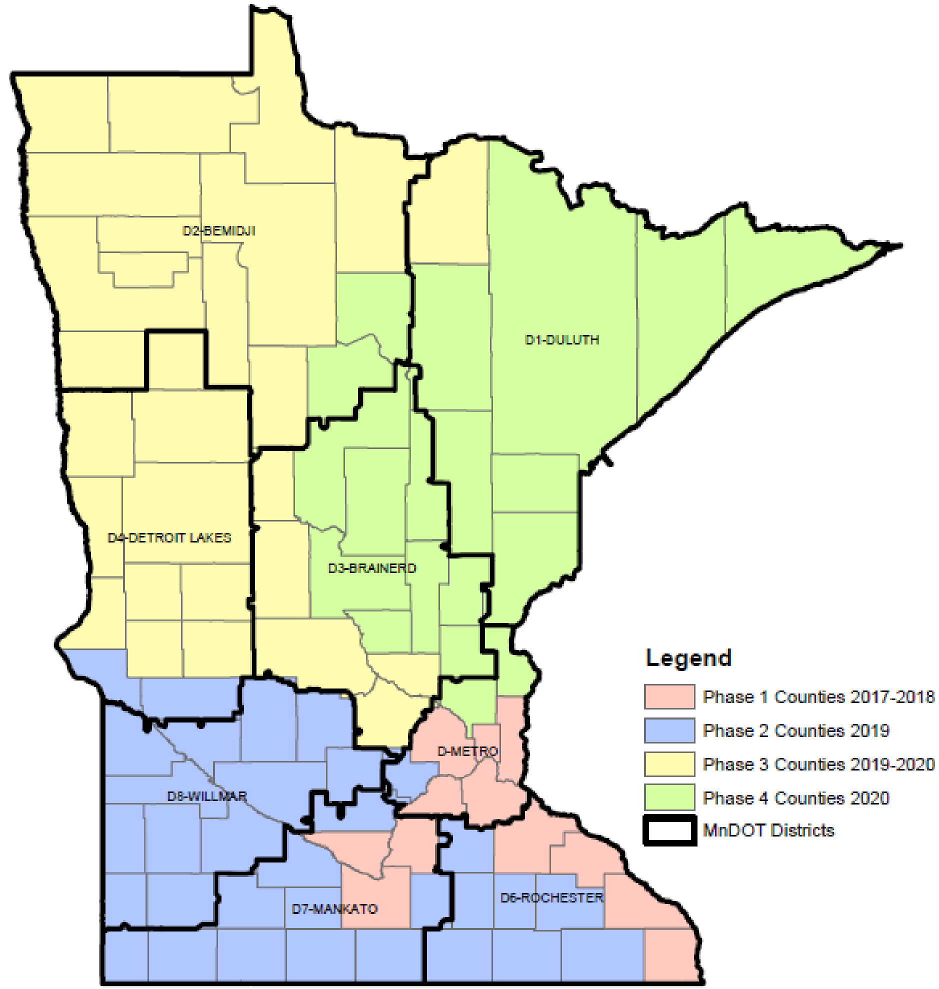
β_n=regression coefficients from GWR

Model Development

1. Selection of preliminary input parameters (vulnerability factors) and interaction terms based on geomorphology and geology of region
2. Checking vulnerability rating using preliminary input parameters and historical slope failures (sensitivity analysis)
3. Selecting final input parameters (statistically significant)
4. Field verification of model
5. Further adjustment (if required)

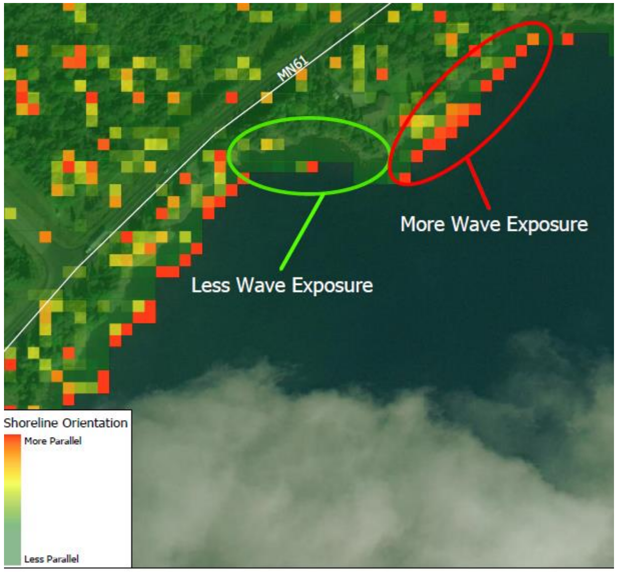
Model Development

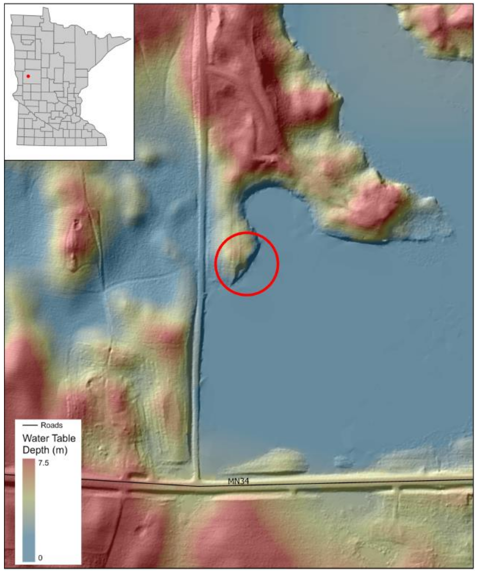
- **Phase 1** - includes steep terrain and bedrock exposures
- **Phase 2** - contains steep slopes along river tributaries formed by catastrophic drainage of Glacial Lake Minnesota
- **Phase 3** - low relief and gradual slopes formed in bed of Glacial Lake Agassiz and glacially eroded and deposited landforms
- **Phase 4** - small mountain ranges with steep slopes and exposed bedrock and glacial till deposits that form gently rolling terrain



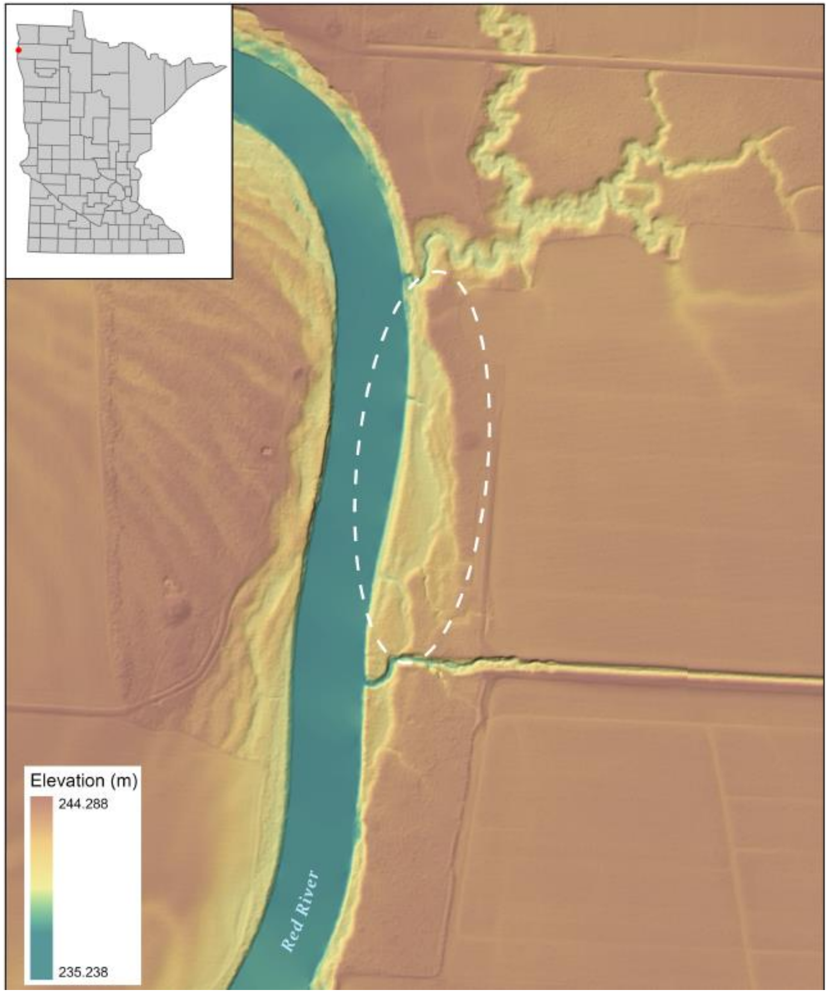
Model Development- Final Input Parameters

- **Phase 1**
  - Slope angle
  - Terrain curvature
  - Distance to streams
  - Distance to bedrock outcrops
- **Phase 2**
  - Slope angle
  - Terrain curvature
  - Incision potential
  - Local relief
- **Phase 3**
  - Slope angle
  - Terrain curvature
  - Water table depth
- **Phase 4**
  - Slope angle
  - Slope orientation
  - Local relief
  - Bedrock proximity
  - Elevation

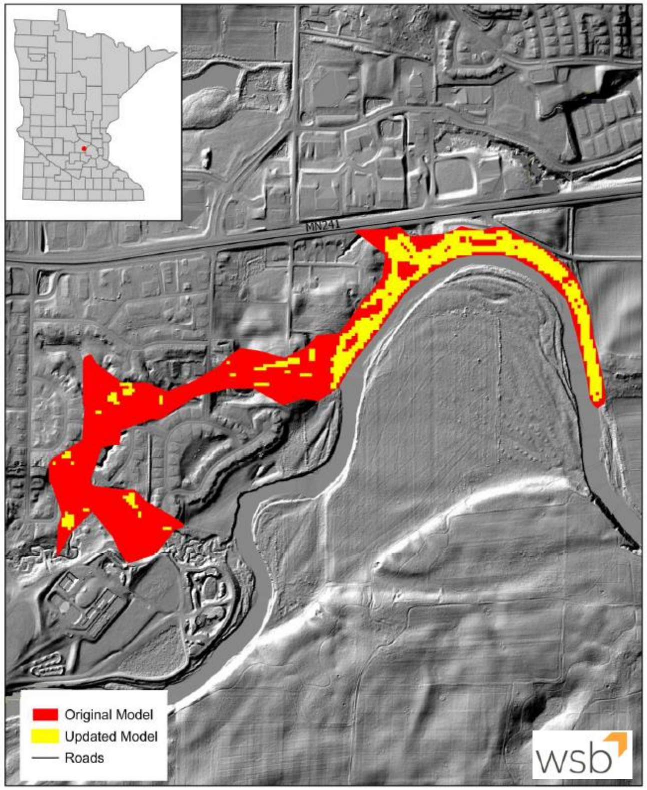




Deep-Seated Slide

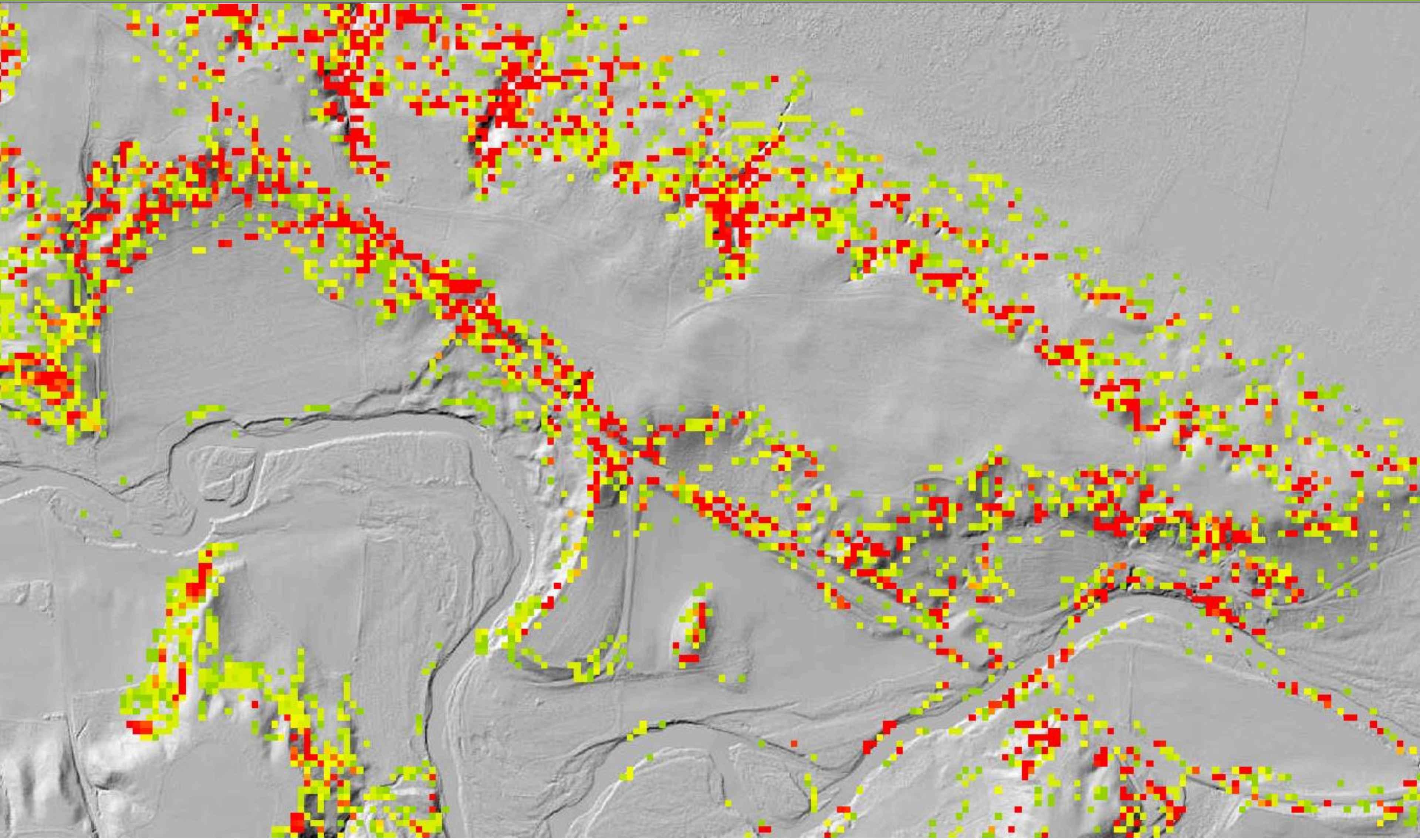


Field Verification



- Validation of final input parameters and vulnerability rating score
- Selection of sites with different geomorphology, geology, and hydrology

Example

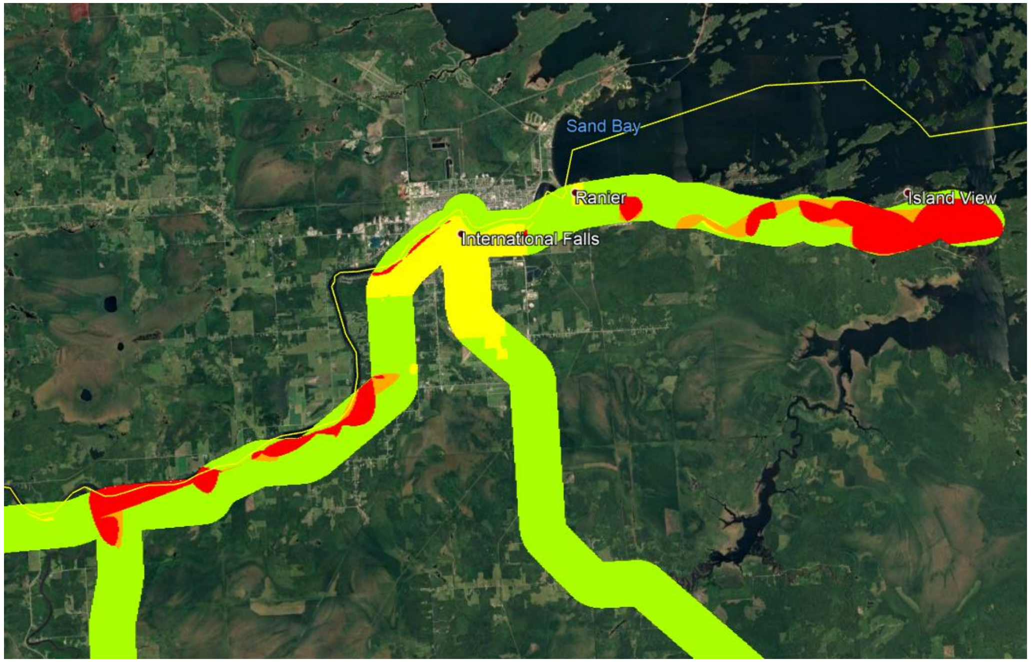


Preliminary Risk Ranking

				Consequence		
				Intersects Trunk Highways	Within 500 feet of Trunk Highways	More than 500 feet of Trunk Highways
				Within Metro or Incorporated Town	Rural	
	Slope Stability	Rational		Critical (5)	Serious (3)	Marginal (2)
LIKELIHOOD	Low	Slope is likely already experiencing mass failure or has the highest risk of failure.	Likely (4)	20 Site Visit / Action Recommended	12 Further Evaluation	8 Monitoring
	Medium	Surface erosion and other pre-cursors for catastrophic failure.	Possible (3)	15 Further Evaluation	9 Monitoring	6 No Action Recommended
	High	Slope has been repaired, recovered, or shows no signs of imminent future.	Unlikely (2)	10 Monitoring	6 No Action Recommended	4 No Action Recommended

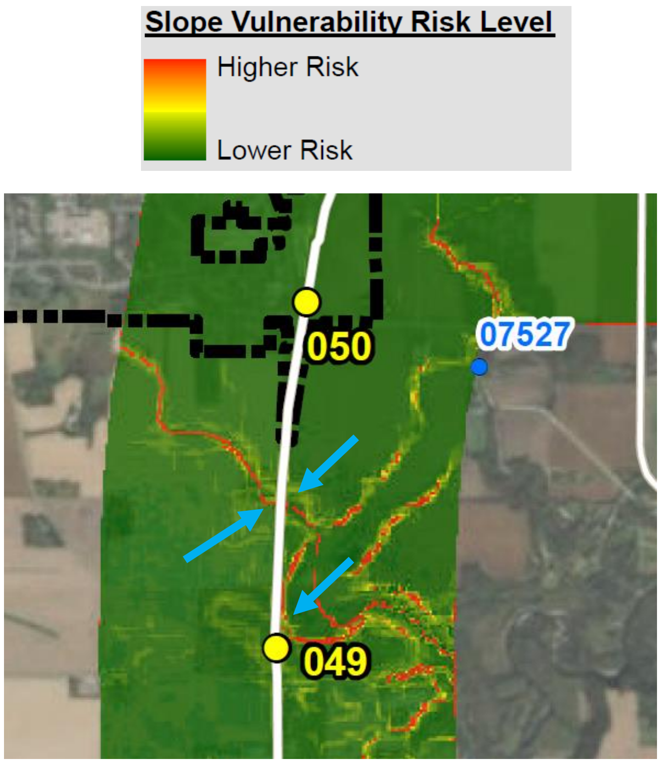
Risk = Likelihood (model output) × Consequence (effect on infrastructure)

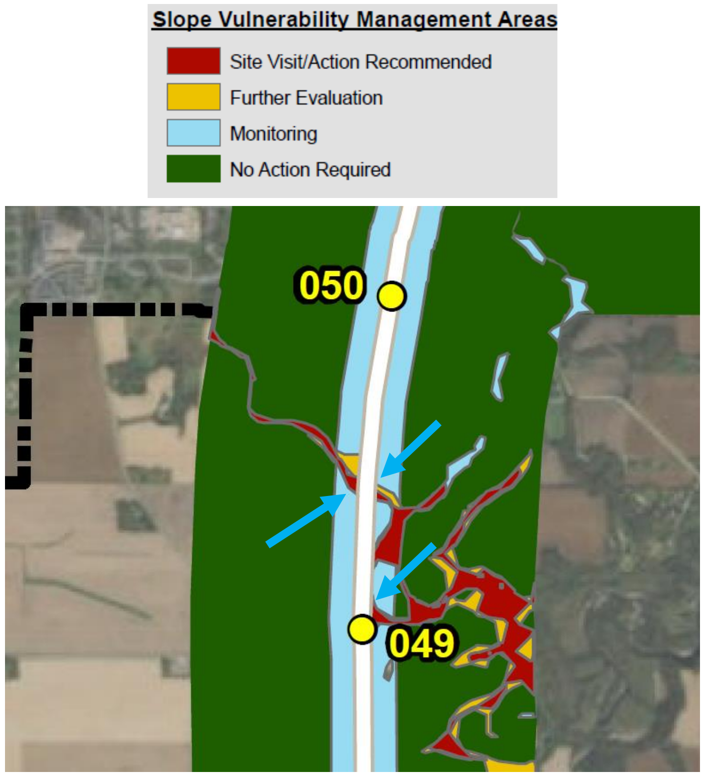
Preliminary Risk Ranking



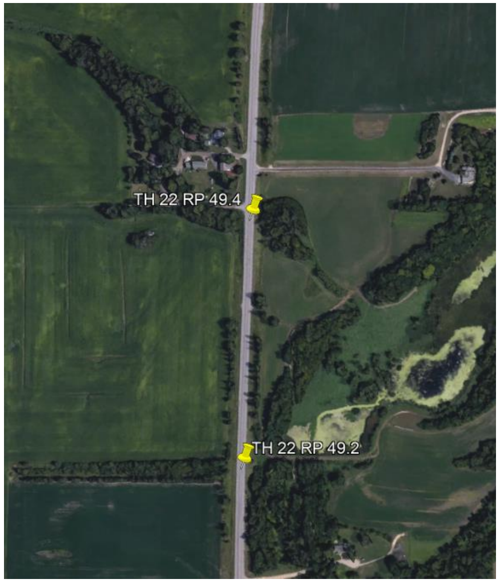
- Risk matrix used to create **Preliminary Management Areas**
- Preliminary Management Areas => *<u>delineated areas in GIS with similar risk ranking</u>*

Recent Verification of Model





Location of TH-22 Slides, July 2020



Closing Remarks

- GIS model helps identify, map and categorize slopes vulnerable to failure with potential to affect MnDOT highways
- Assist in risk evaluation during project development
- Model is data-driven (minimizes bias)
- Time efficient approach that can cover large geographic areas
- Can be used in Transportation Asset Management Plan (TAMP)

Resources

- NASA Landslide Viewer:
  - https://maps.nccs.nasa.gov/arcgis/apps/webappviewer/index.html?id=824ea5864ec8423fb985b33ee6bc05b7
- MnDOT Slope Vulnerability Phase I:
  - https://researchprojects.dot.state.mn.us/projectpages/pages/projectDetails.jsf?id=18450&type=CONTRACT
- MnDOT Slope Vulnerability Phase II:
  - https://researchprojects.dot.state.mn.us/projectpages/pages/projectDetails.jsf?id=22079&type=CONTRACT
- MnDOT Slope Vulnerability Phase III:
  - https://researchprojects.dot.state.mn.us/projectpages/pages/projectDetails.jsf?id=23499&type=CONTRACT

Thank you!

Raul Velasquez

raul.velasquez@state.mn.us

651-366-5533