NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar:

Engineered Solutions for Low Volume Roads through Graduate Research

April 16, 2026

11:00 AM – 12:30 PM (eastern)

Purpose Statement

This webinar will highlight graduate research focused on engineered and technology-driven solutions for low-volume and rural roads. Presenters will provide findings from a road embankment case study in permafrost areas, discuss the use of digital twins to support safer and smarter low-volume road networks, and share lessons learned from implementing an innovative engineered solution to enhance slope stability.

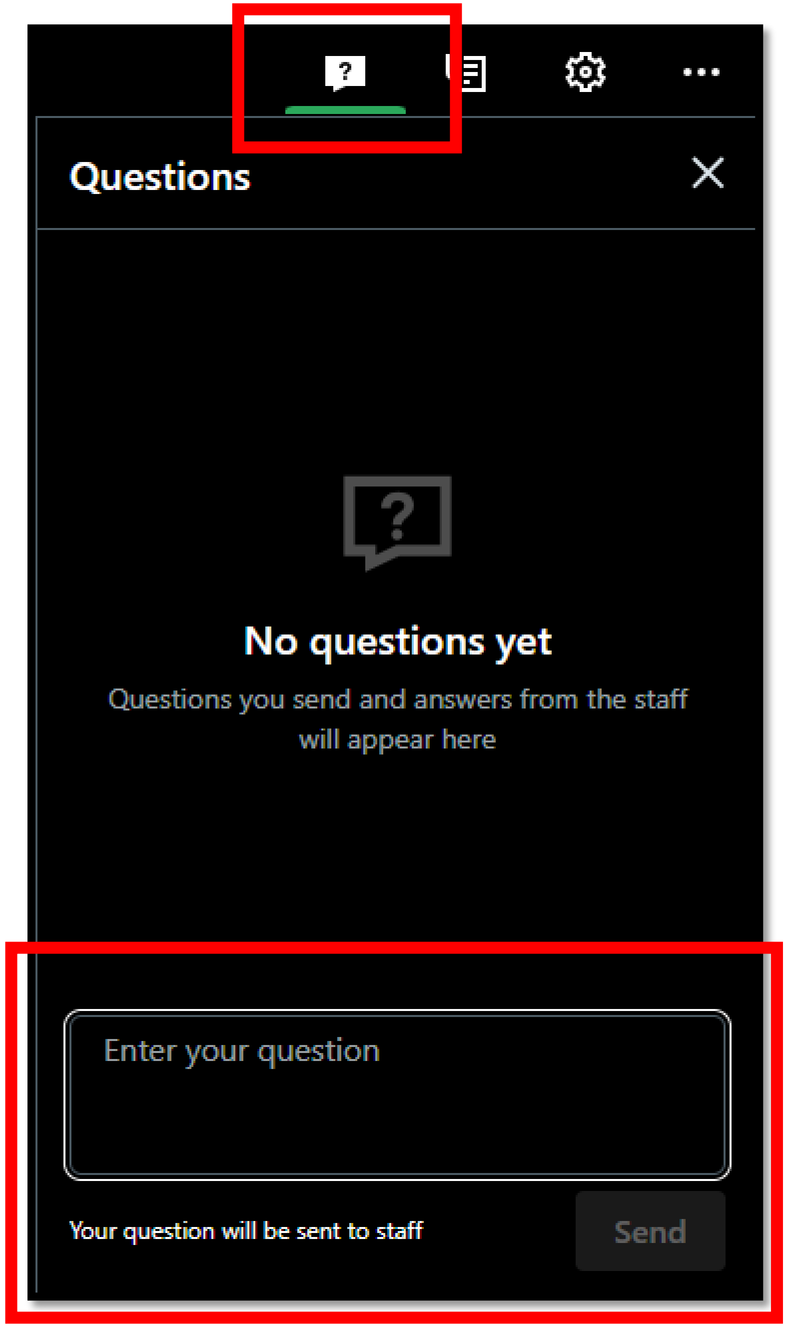
Learning Objectives

At the end of this webinar, participants will be able to:

- Identify key embankment factors that influence low-volume road performance,
- Apply new technology, such as digital twins, to ensure access to safe and smart low volume road networks, and
- Improve the performance of road slopes with nature-based repair techniques.

Questions and Answers

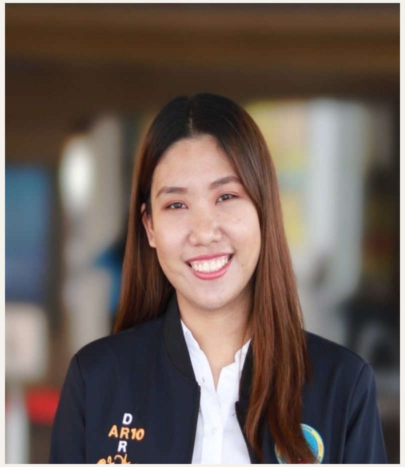
- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today's Presenters

Laura Fay
laura.fay1@montana.edu

Montana State University
Western Transportation Institute



Nutvara Jantarathaneewat
nutvaraj@uw.edu

University of Washington

Farshad Kamran
farshad.kamran.1@ulaval.ca

Université Laval

Fariha Rahman
j00986301@students.jsums.edu

JSU 1877 Jackson State University®

UNIVERSITÉ LAVAL

L. U. C. I. L.

Laboratoire Universitaire sur les Chaussées et les Infrastructures Linéaires

A2R2C

ALLIANCE ACADÉMIQUE EN RECHERCHE ROUTIÈRE DU CANADA

ACADEMIC ALLIANCE FOR ROAD RESEARCH OF CANADA

Assessment of the Mechanical Response of Road Embankments Built on Permafrost located at Inuvik-Tuktoyaktuk Highway

Farshad Kamran, Ph.D., E.I.T.

Background

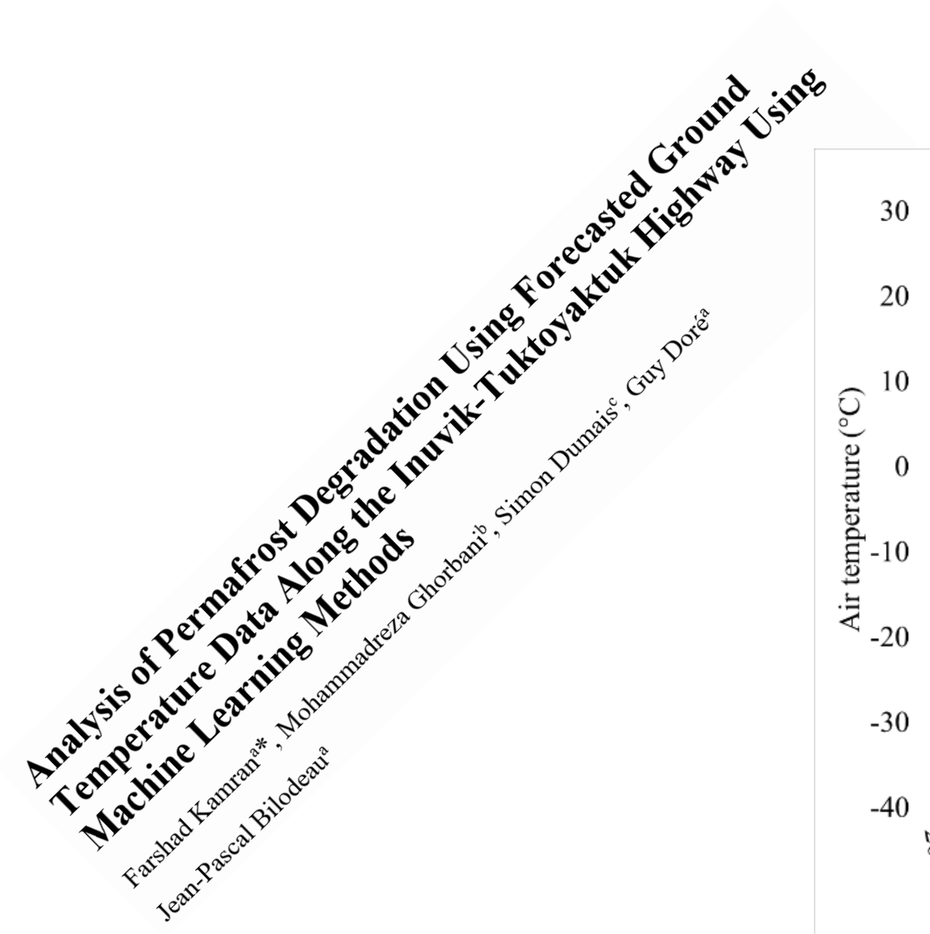
The Canadian Arctic is warming 2–4 times faster than the global average

Permafrost thawing destabilizes soils

The ITH was constructed in 2017, was built on continuous permafrost

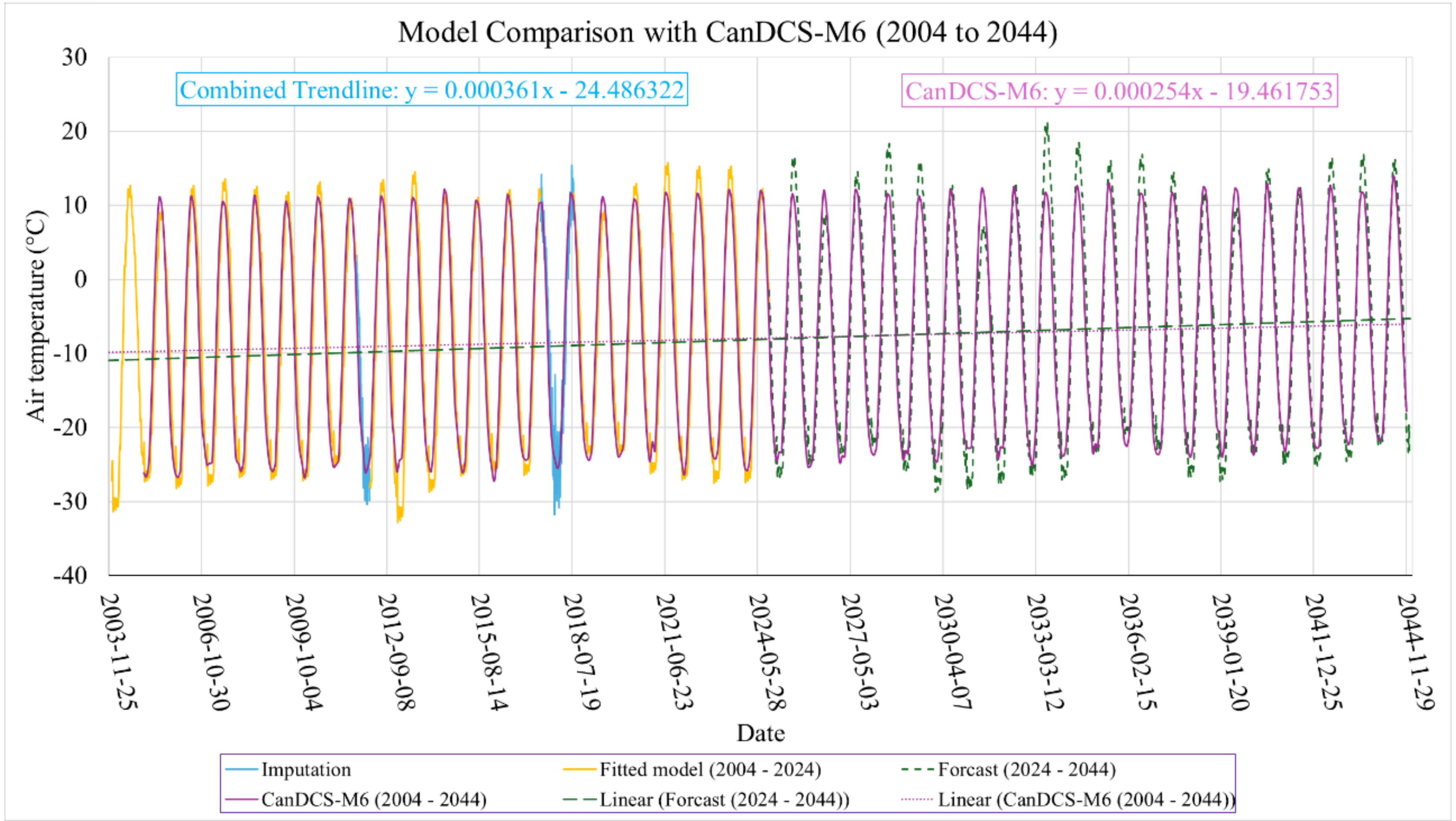
Active layer thickening and saturation over time have compromised the subgrade strength and long-term performance.

Background



Analysis of Permafrost Degradation Using Forecasted Ground Temperature Data Along the Inuvik-Tuktoyaktuk Highway Using Machine Learning Methods

Farshad Kamran[a]*, Mohammadreza Ghorbani[b], Simon Dumais[c], Guy Doré[a], Jean-Pascal Bilodeau[a]



Objective

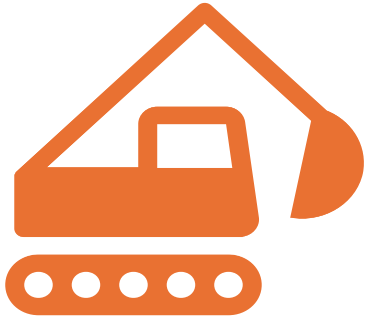
Tracking the seasonal and long-term changes in subgrade behaviour beneath the ITH between 2019-2024

Assessing the influence of soil temperature and moisture on the mechanical response of unbound layers

Analyzing how deformation under traffic varies with speed and season, particularly in relation to thawing permafrost conditions

Supporting climate-resilient pavement design strategies for cold regions by integrating field sensor data with LWD testing results

Objective



Optimized Mechanistic-Empirical Pavement Design based on mechanical analysis

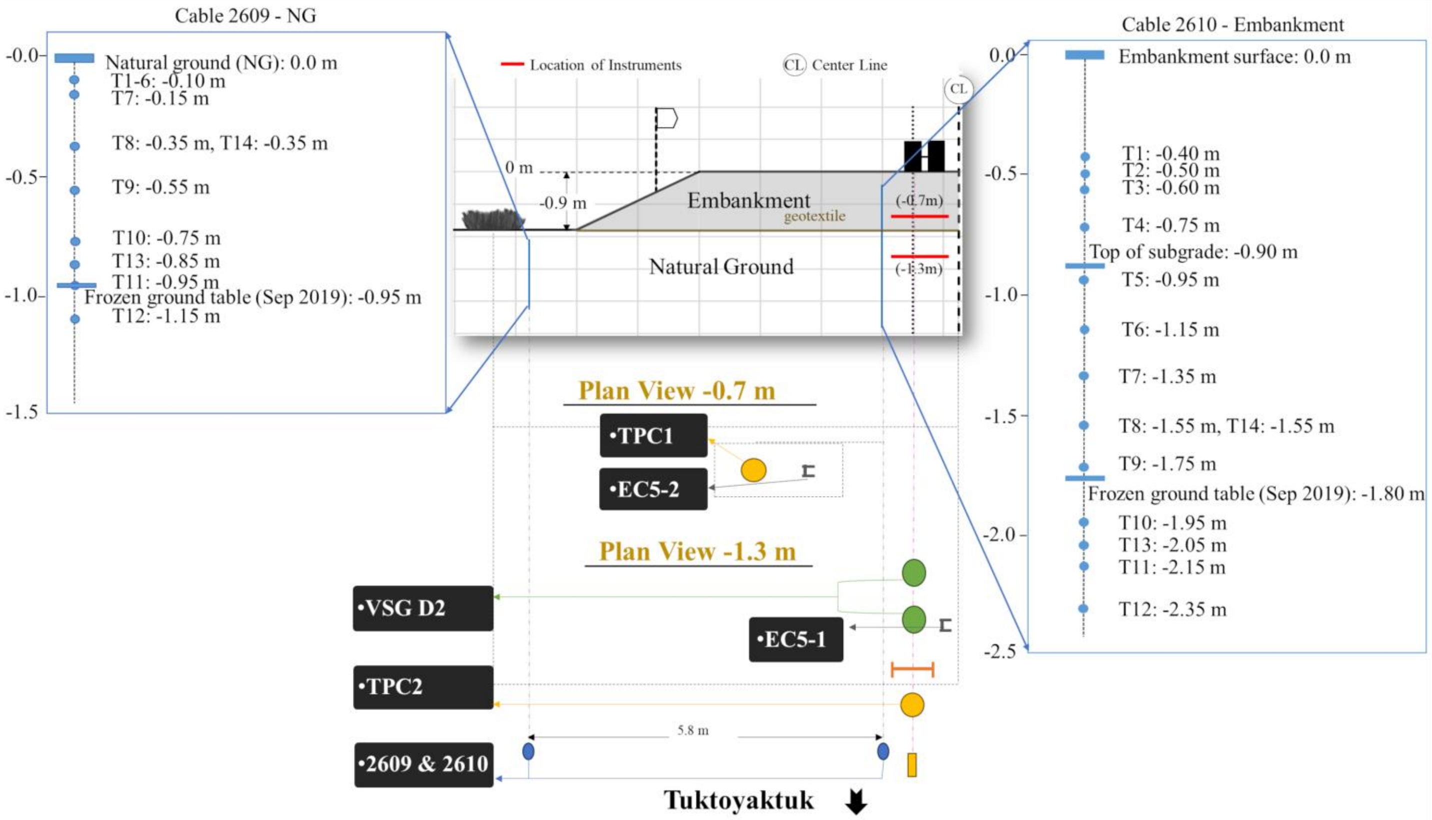
ULaval Test Section: To document the mechanical response of the embankment

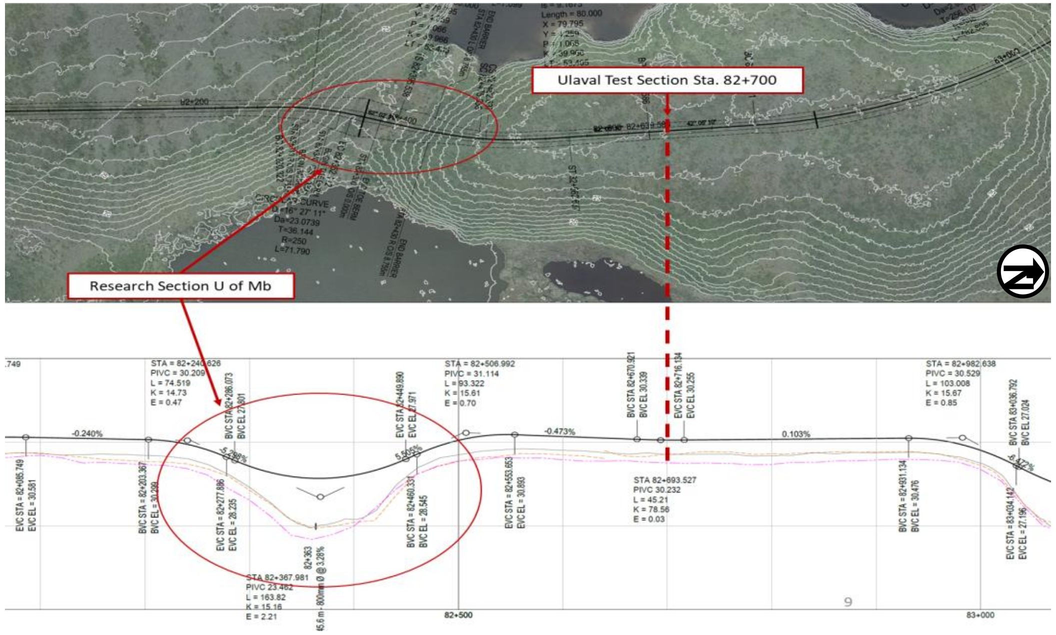
L. U. C. I. L.

Laboratoire Universitaire sur les Chaussées et les Infrastructures Linéaires

Methodology

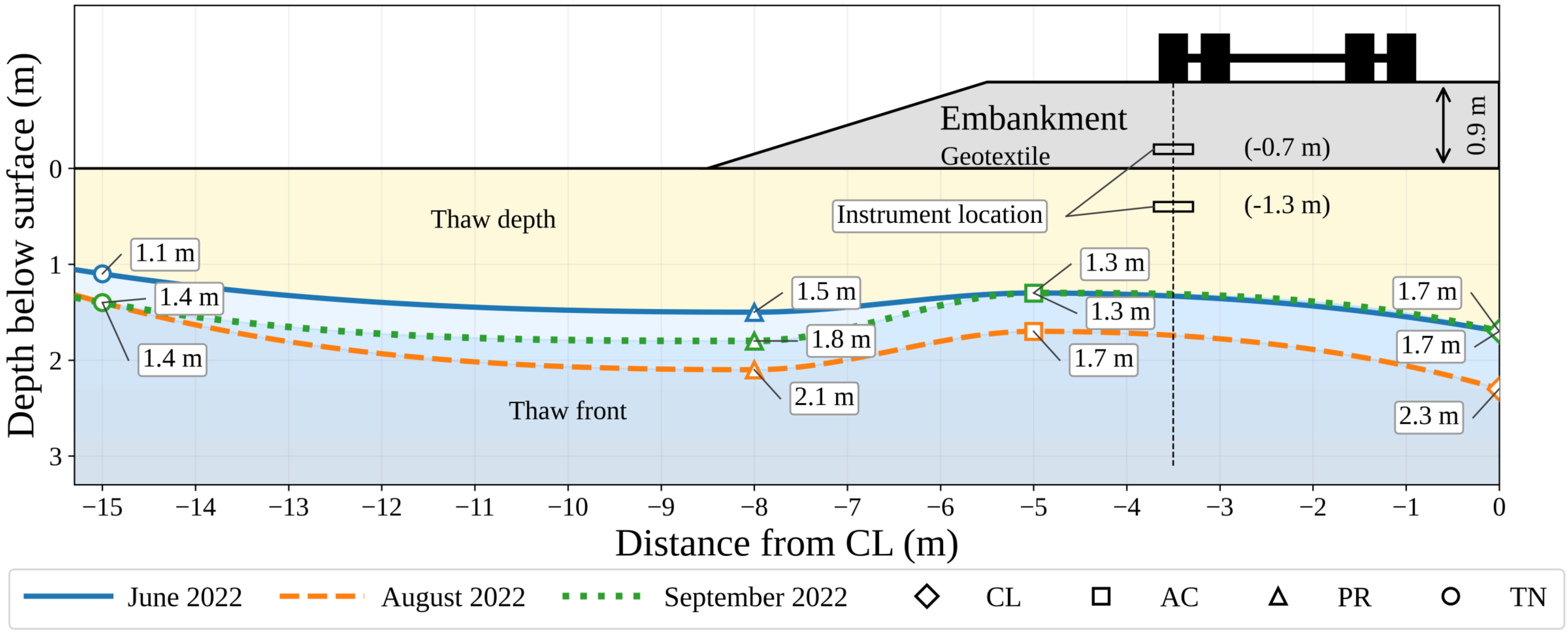
Testing Site and Instrumentation





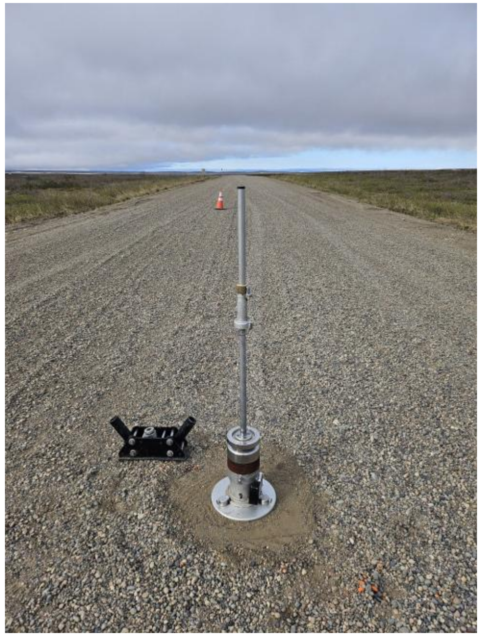
Sensor	ID	Depth (m)
Pressure cell	TPC1900003	0.7
Pressure cell	TPC1800003	1.3
Strain gauge	VSG D101	1.3
Thermistor	2610	0.4 to 2.35
Moisture sensor	EC5-035	0.7
Moisture sensor	EC5-779	1.3

Field conditions during the campaigns



Testing Plan

- Light Weight Deflectometer
  - 19- and 32-inch height
  - 6 drops for each
  - 12 points in and out of embankment
- Dynamic Cone Penetrometer
  - 16 points in and out of embankment
- Mechanical testing on the road
  - Speed: 5 km/hr, 15 km/hr, 25 km/hr
  - Weight: 20 tons, 40 tons



L. U. C. I. L.

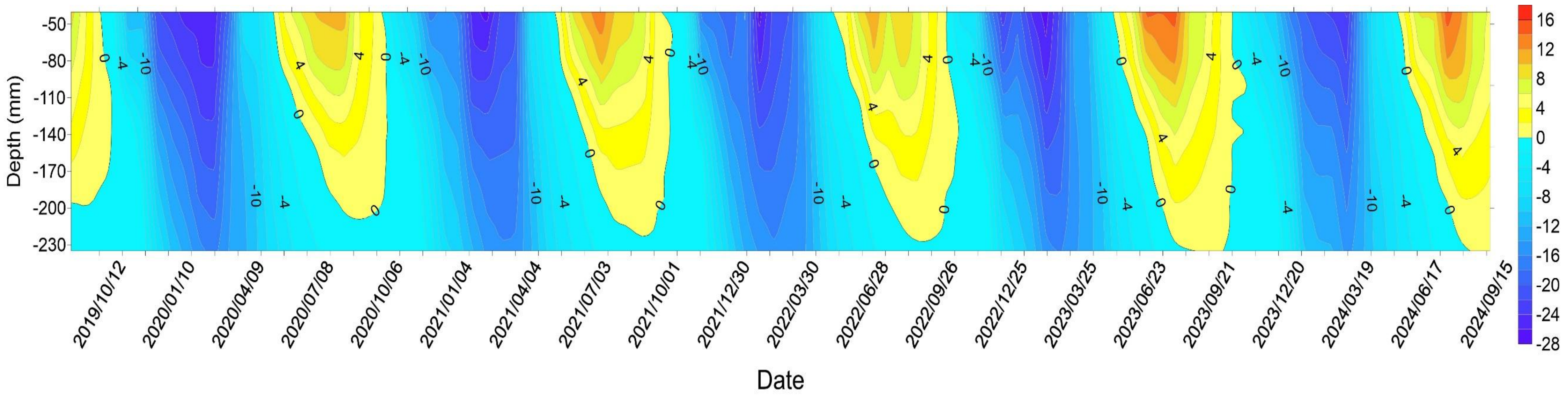
Laboratoire Universitaire sur les Chaussées et les Infrastructures Linéaires

Results

Results (Temp.)

- Temperature is increasing in the embankment

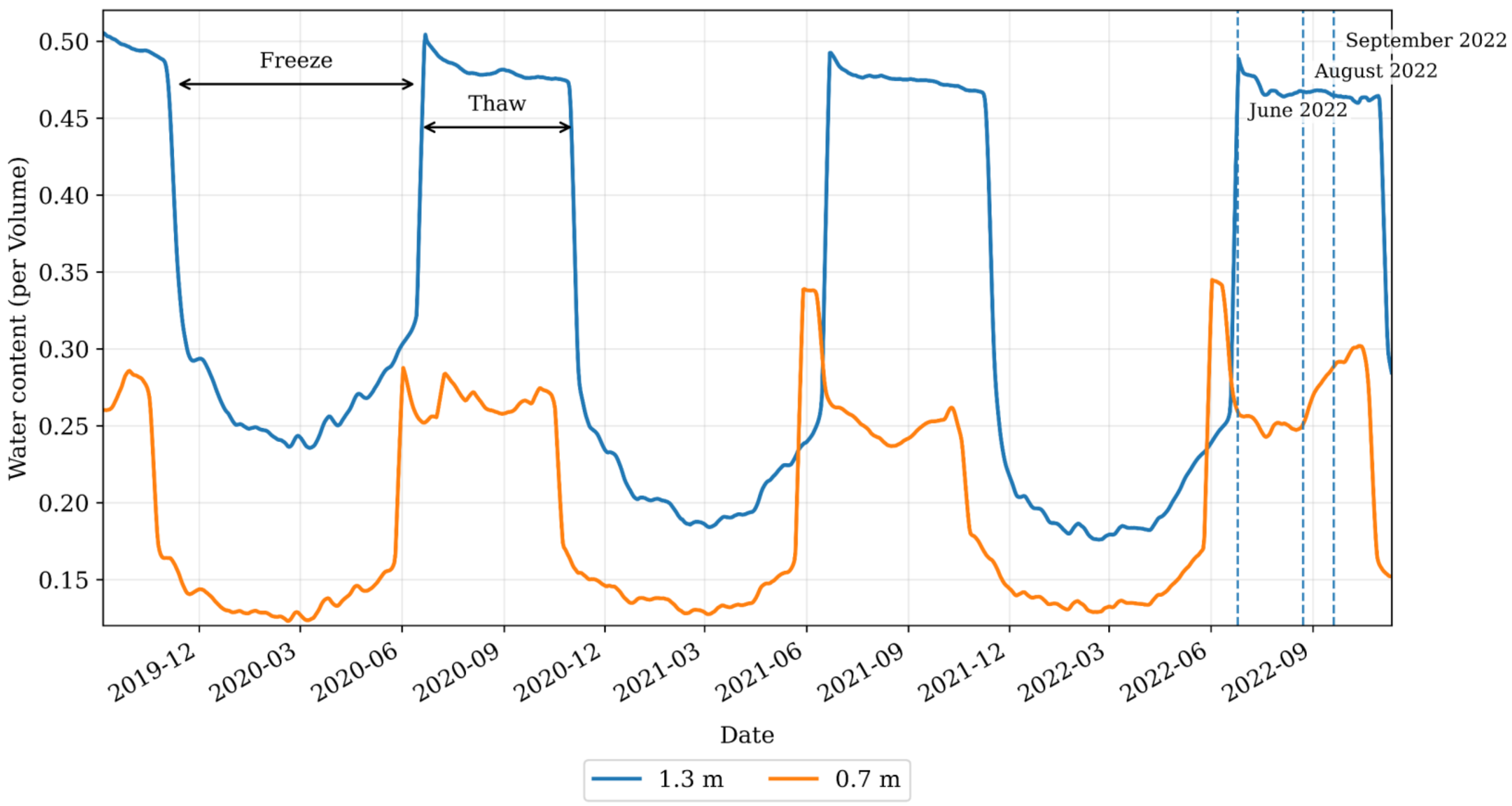
  ❖ Isotherm line is receding



Results (Moist.)

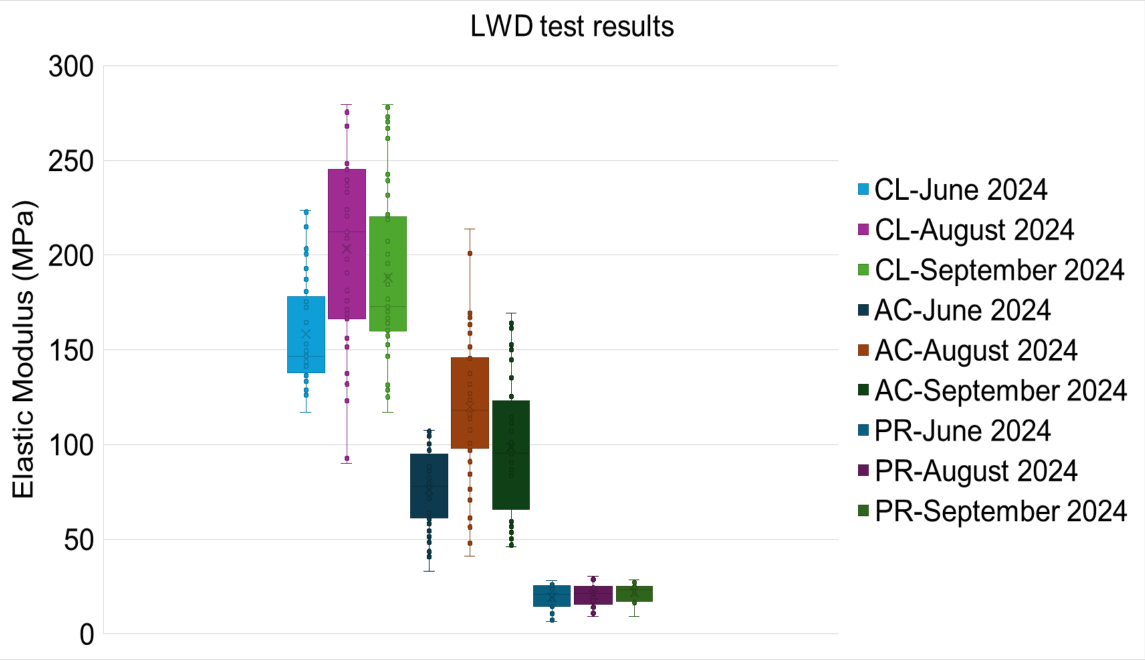
- Ice is melting during thaw season which results in moisture content change

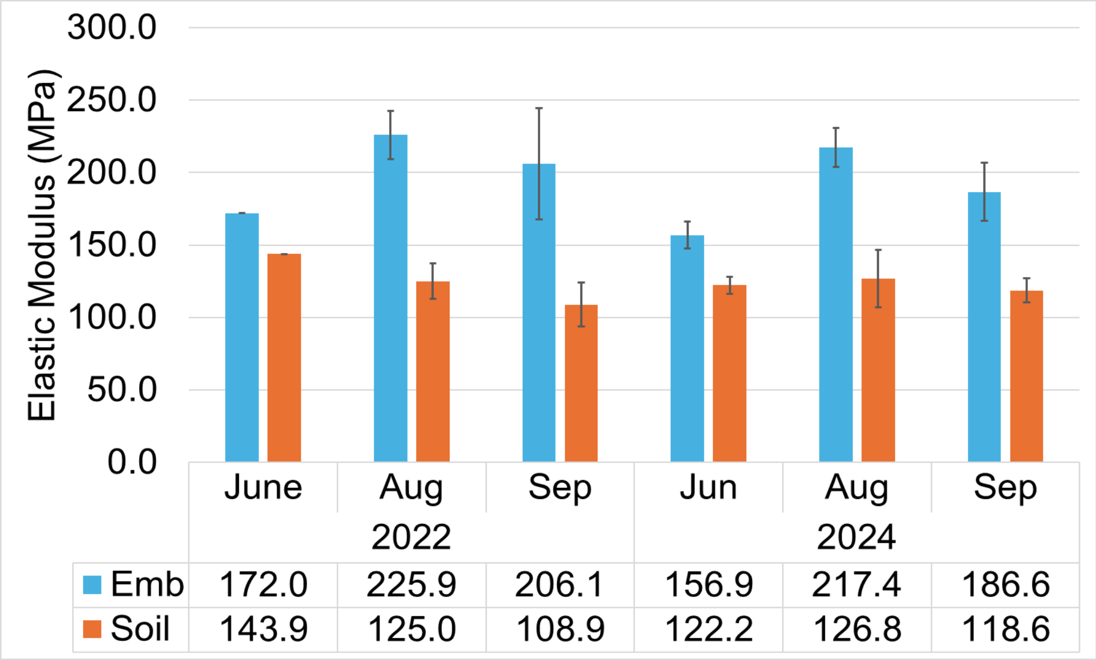
❖Decreasing moisture content



Results (LWD & DCP)

- LWD is increasing from June to August and slightly decreasing in September
- DCP is following similar trend
- Values from both tests are in alignment

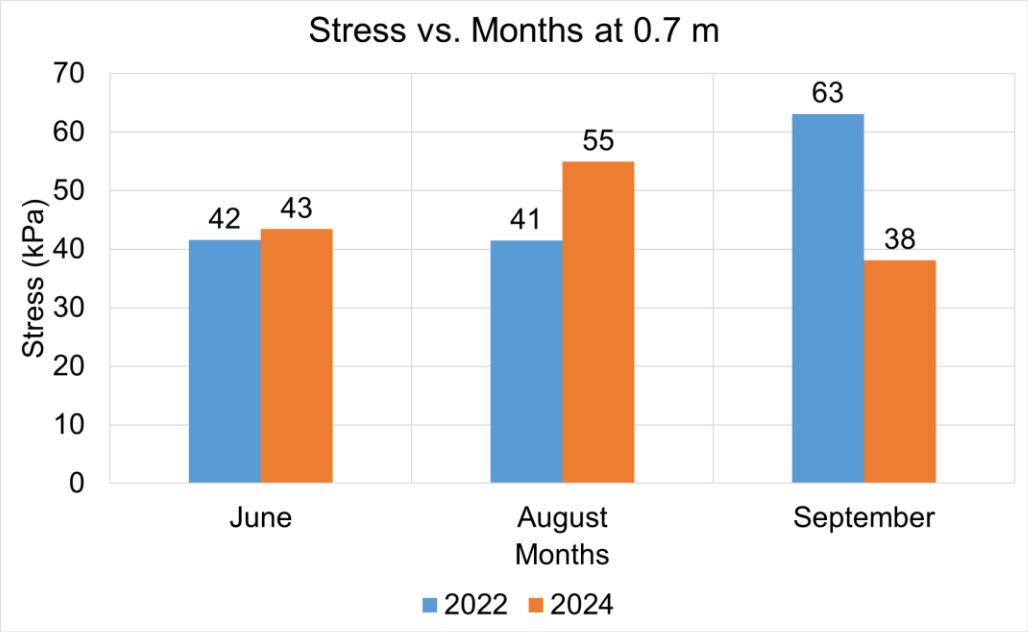


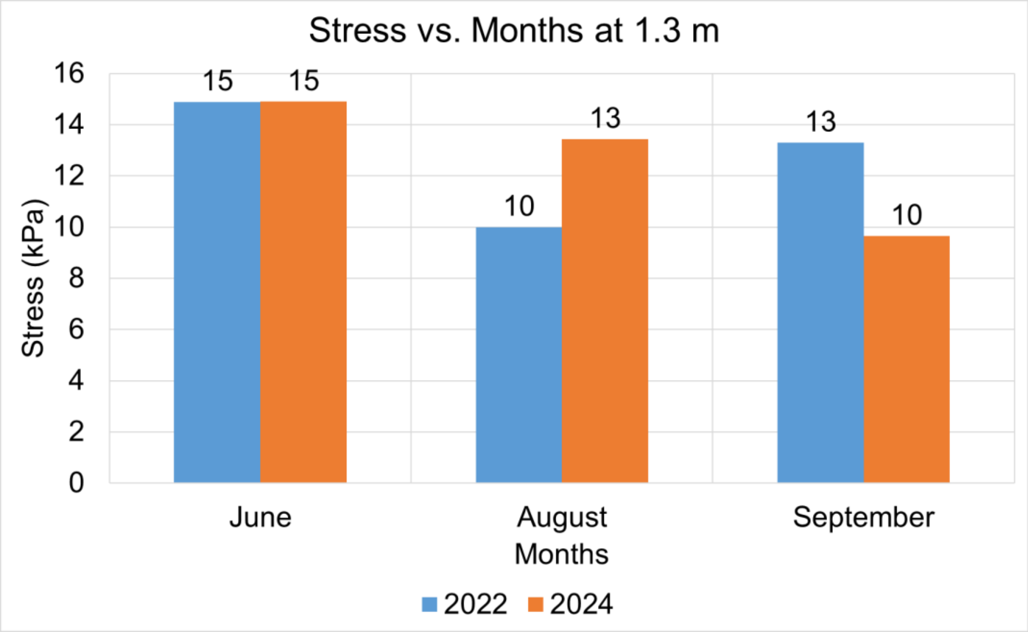


Results (Instrumentation)

- Higher vertical stresses under possible wetter conditions in September 2022 (up to ~65 kPa) compared to June and August (42 and 41 kPa)
- In 2024 at 0.7 m slightly increases for August (55 kPa) and decreases in September (38 kPa)

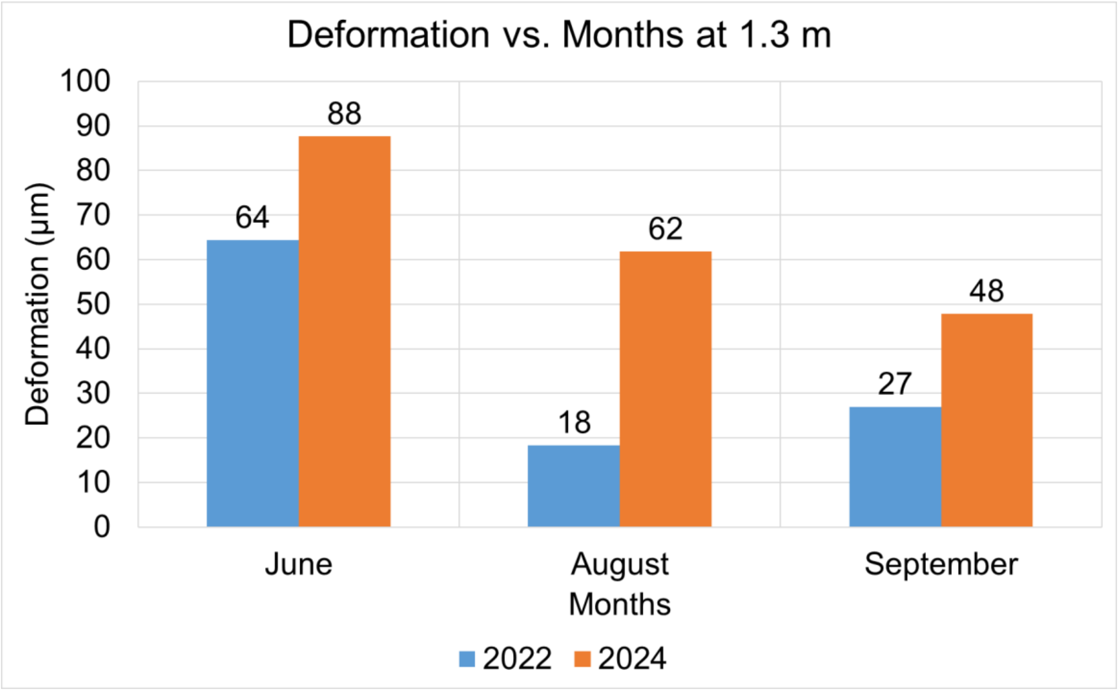
- June: Highest stresses (~15 kPa) → thawing, soft soils, low stiffness
- August: Lower stresses (~10–13 kPa) → drier, stiffer soils, more load transfer
- September: Intermediate to low stresses (~10–13 kPa) → moisture reintroduced, softer active layer





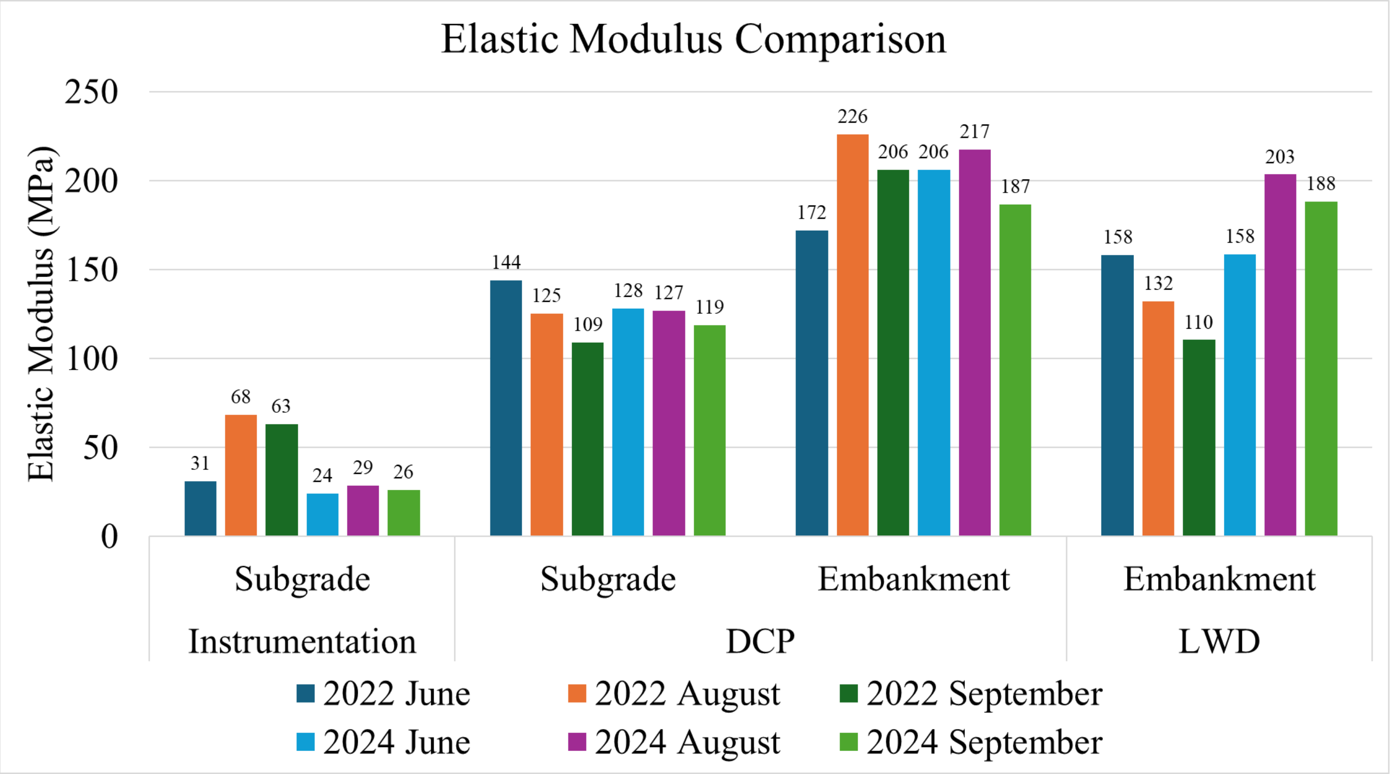
Results (Instrumentation)

- June: Largest deformation (~65–90 µm → thawing soils, significant stress transmission
- August: Reduced deformation (~20–60 µm) → drier, stiff embankment
- September: Moderate deformation (~30–50 µm) → limited deep stress transfer
- Increased deformation from 2022 to 2024 also suggests increasing active layer and softer soil



Results (Instrumentation)

- Subgrade (Active layer): Clear weakening from 2022 to 2024, confirmed by both sensors and DCP → long-term loss of stiffness..
- Embankment at depth (DCP): Remains strong and stable, with some seasonal variation.
- Embankment surface (LWD): Shows strong seasonal variation, influenced by surface drying, temperature, and traffic effects.



L. U. C. I. L.

Laboratoire Universitaire sur les Chaussées et les Infrastructures Linéaires

Conclusions and Future Work

Conclusions

- Stiffness varies seasonally: lowest in early thaw (June), highest in August, intermediate in September due to possible increased weak active layer.
- Moisture and thaw depth strongly control embankment and soil stiffness.
- Progressive weakening observed from 2022 to 2024 due to traffic, moisture, and freeze-thaw cycles.
- LWD and DCP tests align with sensor data → useful for surface and near-surface stiffness assessment.
- Strong link between mechanical behavior, moisture, and temperature → critical for road performance prediction.

Future work:

- Possible back calculation of the modulus for the layers under the embankment including the active layer and frozen layer.

CANADA FIRST
RESEARCH EXCELLENCE FUND

APOGÉE CANADA
FONDS D'EXCELLENCE EN RECHERCHE

UNIVERSITÉ LAVAL

CEN

L. U. C. I. L.
Laboratoire Universitaire sur les Chaussées et les Infrastructures Linéaires

Hydro Québec

Thanks to our sponsors

Northwest Territories

E4M

CRSNG
NSERC

A2R2C
Academic Alliance for Road Research of Canada
Alliance Académique en Recherche Routière du Canada

Ville de Québec

ILLUQ
PERMAFROST
POLLUTION
HEALTH

Transports et Mobilité durable
Québec

wsp

Digital Twins for Safer and Smarter Rural Road Networks

Engineered Solutions for Low Volume Roads through Graduate Research
(AKL17) Standing Technical Committee on Low Volume and Rural Roads

Nutvara Jantarathaneewat, Muhammad Monjurul Karim, Ph.D.,
Yinhai Wang, Ph.D., P.E.

Department of Civil and Environmental Engineering,
University of Washington

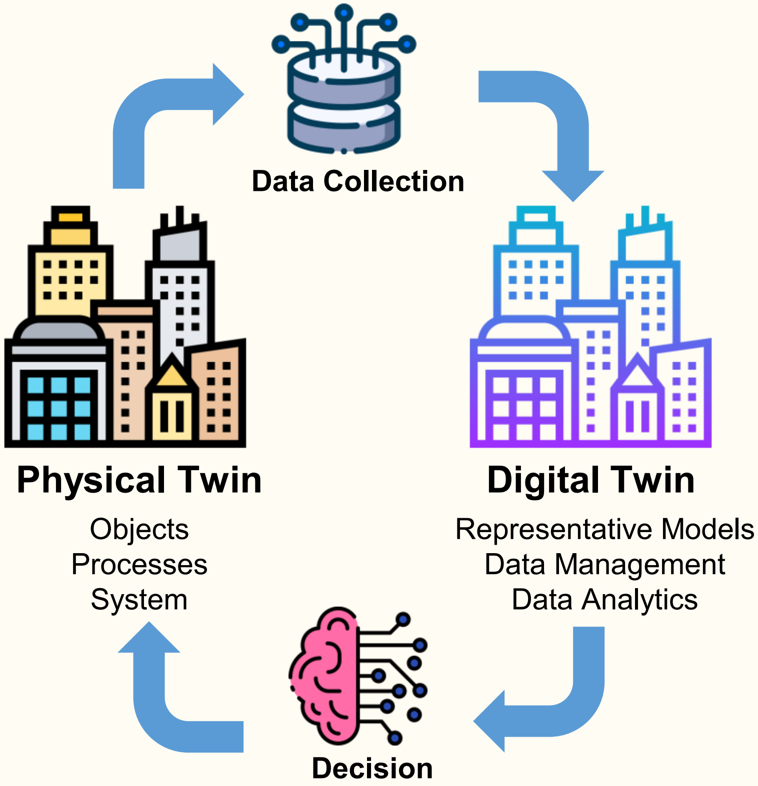
W
UNIVERSITY *of*
WASHINGTON

Outline

- **Introduction**
- **Case Studies Toward Digital Twin**
  - **Digital Representation**
  - **Monitoring Layer**
  - **Integrated Digital Twin System**
- **Future Directions**

What is Digital Twin?

- Virtual copy of an existing physical system
- Bi-directional data connection via real-time data
- Integrates sensors, historical data, and algorithmic models
- Enables monitoring, analysis, simulation, and prediction



Source: Adapted from GAO (2023)

Digital Twin in Transportation Infrastructure

Classified by Function

Monitoring and Control

- Real-time data
- Mange traffic flow and signal timing

Simulation and Analysis

- Models and analyzes transportation scenarios

Predictive and Optimization

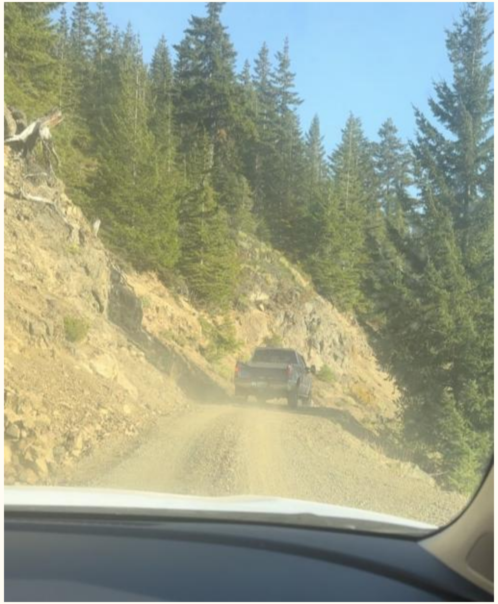
- Real-time data + historical trends
- ML algorithms forecast failures

Digital Twin in Rural Roads

Challenges

- Infrastructure & Data Constraints
- Data Quality & Processing
- Modeling Gap
- System Integration & Visualization

Chiangmai 3052, Thailand (AUG 30, 2024)



Bypass I-90, WA (OCT 10, 2024)

Toward a Digital Twin for Rural Roads

Digital Representation (3D Mapping / Spatial Layer)

Enhancing Deep Learning-Based Segmentation for Obstructive Roadside Element Detection in Point Cloud Data from Mobile Laser Scanning in Rural Road Environments

Nutvara Jantarathaneewat, Chenxi Liu, Ph.D., Shucheng Zhang, and Yinhai Wang, Ph.D., P.E.

Monitoring Layer

Lighting Status Detection on Rural Roads: A Comparative Study of Traditional and Deep Vision Approaches for Edge Deployment

Nutvara Jantarathaneewat, Tanyaluk Ruangket, Pitcha Wachiropathum, and Yinhai Wang, Ph.D., P.E.

Integrated Digital Twin System

Improving Roadway and Intersection Safety for Tribal and Rural Communities Using Cost-effective Sensing and Communication Technologies

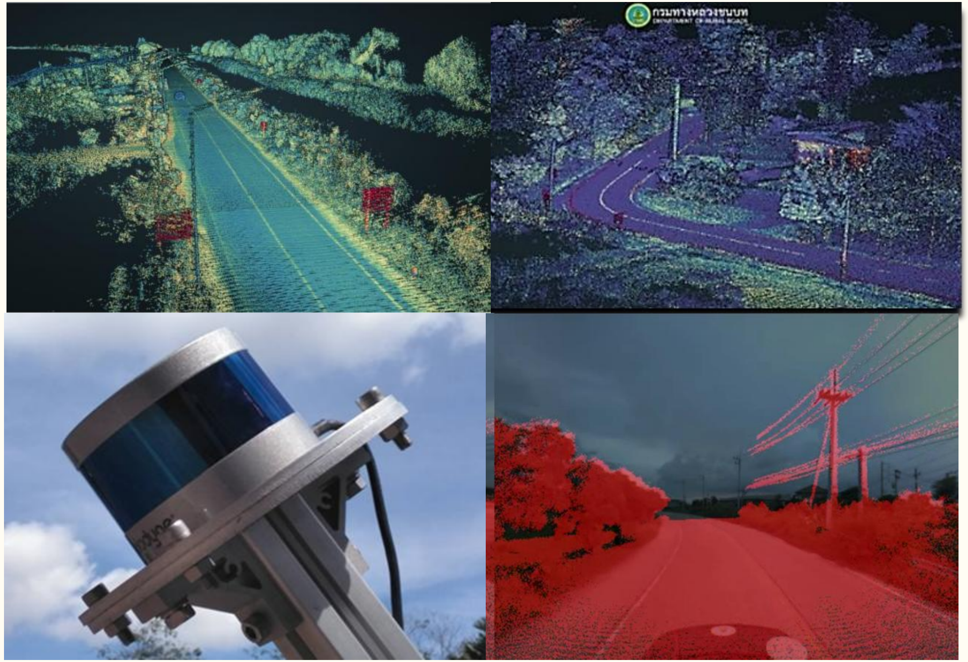
Muhammad Monjurul Karim, Ph.D., Mehrdad Nasri, Yuang Zhang, Nutvara Jantarathaneewat, Ollie Wiesner, and Yinhai Wang, Ph.D., P.E.

Digital Representation

- *Leverage the 3D point cloud data for creating digital replica*
- Deep learning for segmentation

➢ Previous studies* have successfully detected:

  - road surfaces, guardrails, signs, vehicles, ditches, fences, sidewalks, buildings, trees, and streetlights



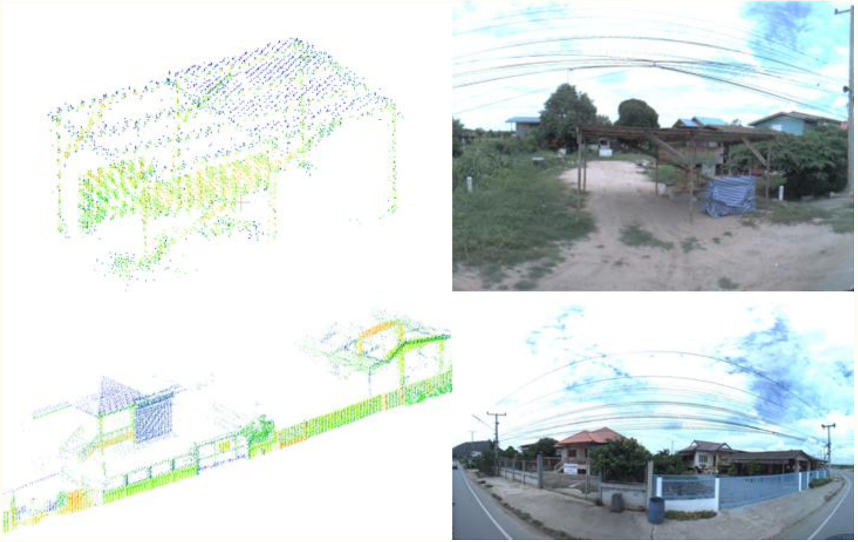
Collecting Point Cloud Data Using Mobile Laser Scanning
Source: Department of Rural Roads, Thailand (2019)

*Balado et al., 2019; Wang et al., 2020; Hou and Ai, 2020

Digital Representation

- Detecting infrastructure is challenging
  - Often constrained by high training costs
  - Generating labeled point cloud data is resource-intensive

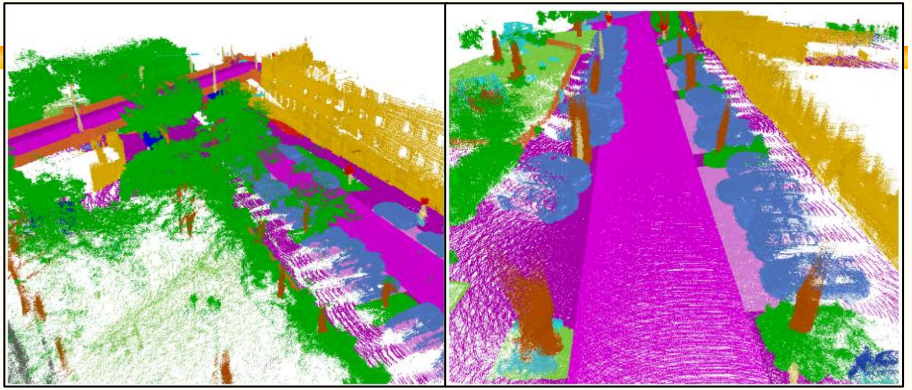
Rural Road Roadside in Thailand (Google Street View, 2024)



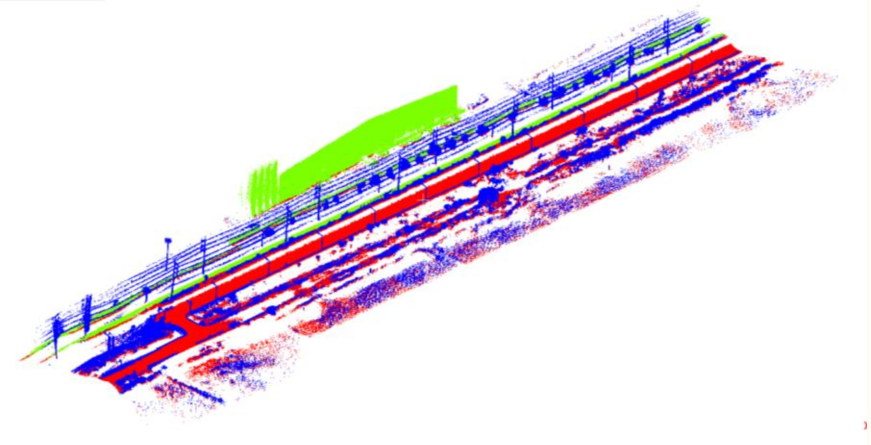
Wall-like object along the CNT1021 rural road in Thailand (2019)

Digital Representation

- Transfer deep learning segmentation model
  1. **Choose a pretrained model:** KPConv[1] on SemanticKITTI Dataset[2]
  2. **Transfer learning:** Modify only the last layer to detect only classes of interest
  3. **Train the model on custom data**: An additional 20 km of point cloud data were manually labeled



Source: SemanticKITTI (Behley et al., 2019)



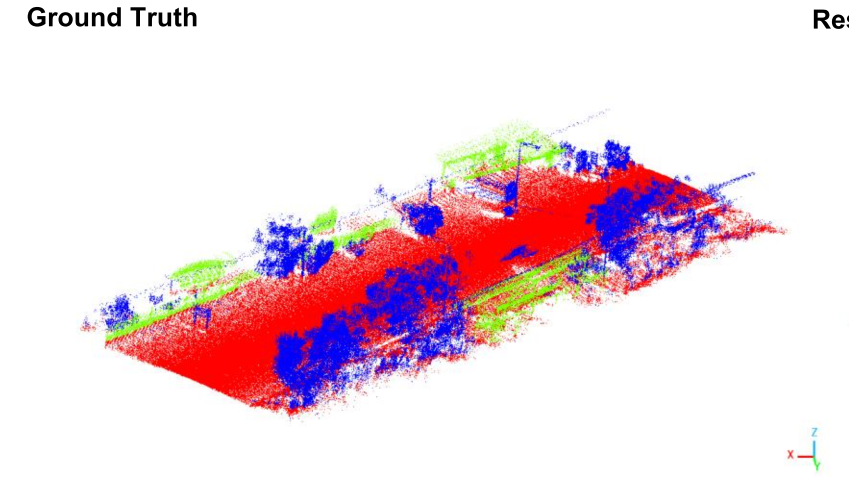
CloudCompare software for labelling

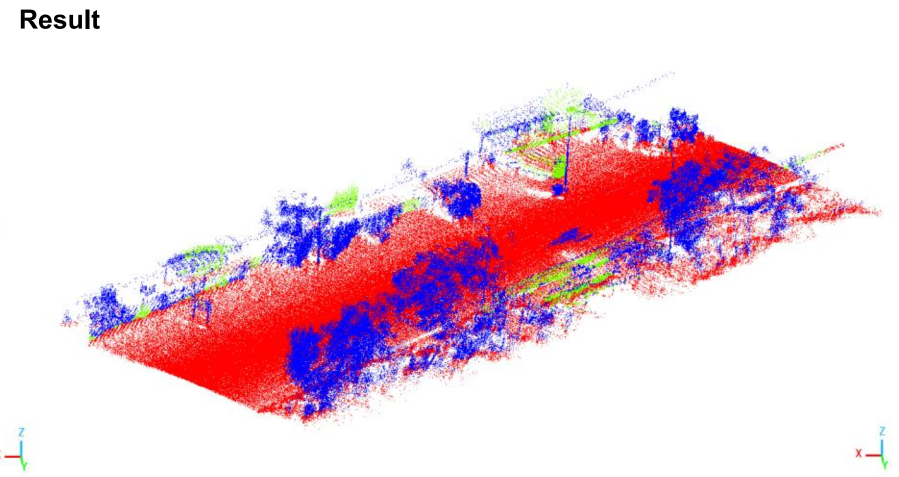
[1] Thomas, H., Qi, C. R., Deschaud, J. E., Marcotegui, B., Goulette, F., & Guibas, L. J. (2019). Kpconv: Flexible and deformable convolution for point clouds. In Proceedings of the IEEE/CVF international conference on computer vision (pp. 6411-6420).
[2] Behley, J., Garbade, M., Milioto, A., Quenzel, J., Behnke, S., Stachniss, C., & Gall, J. (2019). Semantickitti: A dataset for semantic scene understanding of lidar sequences. In Proceedings of the IEEE/CVF international conference on computer vision (pp. 9297-9307).

Digital Representation

- Accuracy = 73.24%
  (Test result on 5 KM)

$$Accuracy_k = \frac{TP_k}{TP_k + FN_k}$$



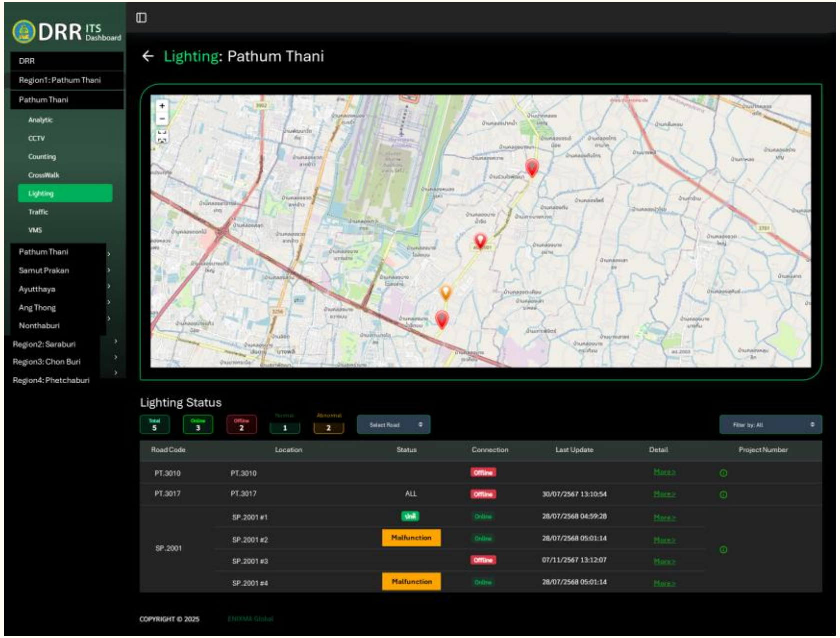


Detection Result on CNT.1021 (Top) Paronamic View of the scene (Bottom Left) Ground Truth Data (Bottom Right) Detection Result from Fine-tuned Model

Monitoring Layer

- ➢Rural lighting is critical for safety
- ➢Current monitoring is inefficient and incomplete

Night Vision on Rural Roads PT.3023 (2025)

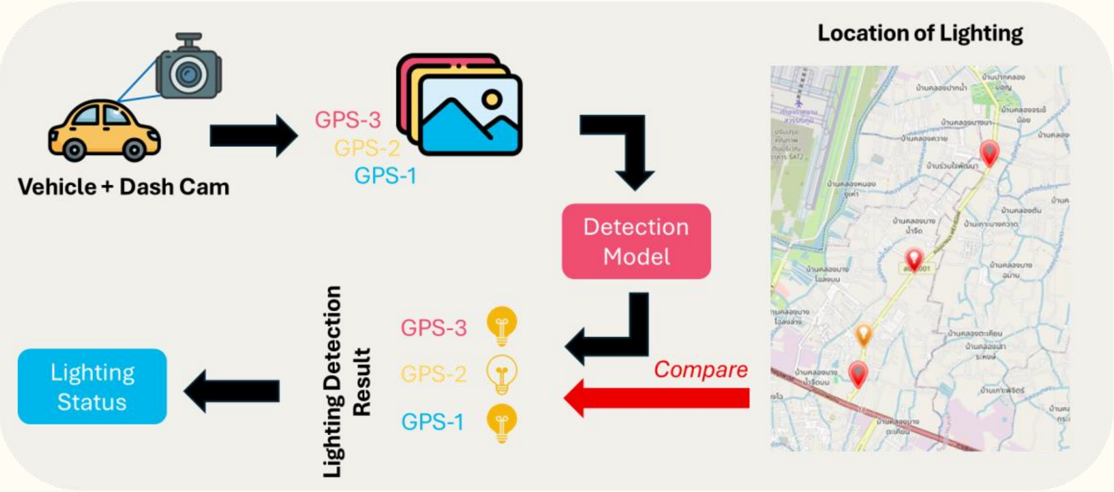


ITS Smartboard interface displaying streetlight status reports
Source: Department of Rural Roads, Thailand (2025)

Monitoring Layer

- ➢Opportunity: Computer vision enables scalable, low-cost monitoring

(Top) Raspberry Pi 4 Model B setup with an attached OLED display showing system status (Bottom) Dash Camera Set Up



Overall pipeline for automated lighting status detection using dashcam images

Monitoring Layer

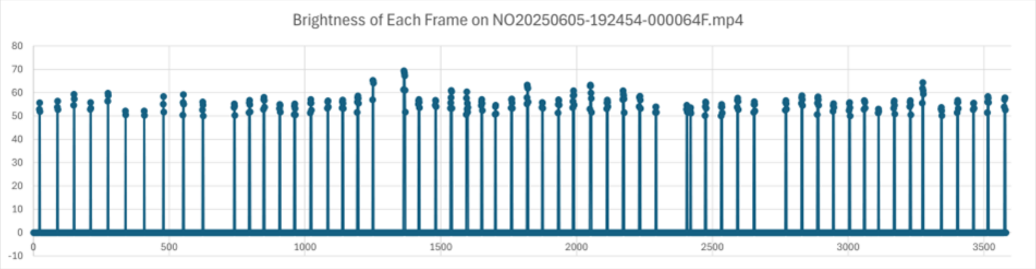
➢Result

- $Precision = \frac{TP}{TP+FP}$, $Recall = \frac{TP}{TP+FN}$
- $F_1 = 2\,x\,\frac{Precision \times Recall}{Precision + Recall}$
- Hardware Efficiency: Throughput (FPS), Memory Usage (MB)
- $FoM = \frac{F1 \times Normalized\ Throughput}{Normalized\ Memory}$

Model	FPS	Time (s)	Memory (MB)
Brightness Threshold	12.25	8.98	2,162
YOLOv5*	4.17	23.98	1,300
YOLOv7-tiny*	3.85	25.97	1,200
YOLOv7*	0.51	196.08	1,250

*Pretrained on COCO models

Detection results produced by the deep learning model



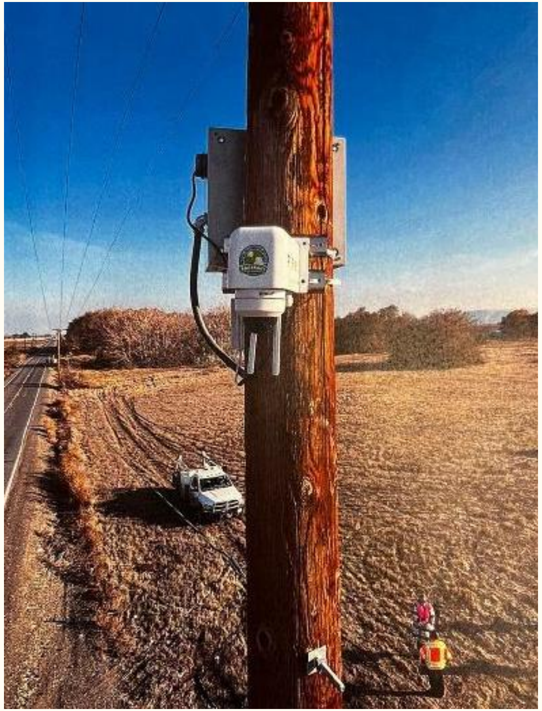
Brightness values for each video frame

Integrated Digital Twin System

[USDOT SMART] **Improving Roadway and Intersection Safety for Tribal and Rural Communities Using Cost-effective Sensing and Communication Technologies**

- **Goal:** Reduce injuries and fatalities on rural/tribal roads through data-driven safety
- **Challenges:** Sparse infrastructure, limited data, and harsh environmental conditions
- **Approach:** Cost-effective sensing & real-time alert system (US-97, Yakama Nation)

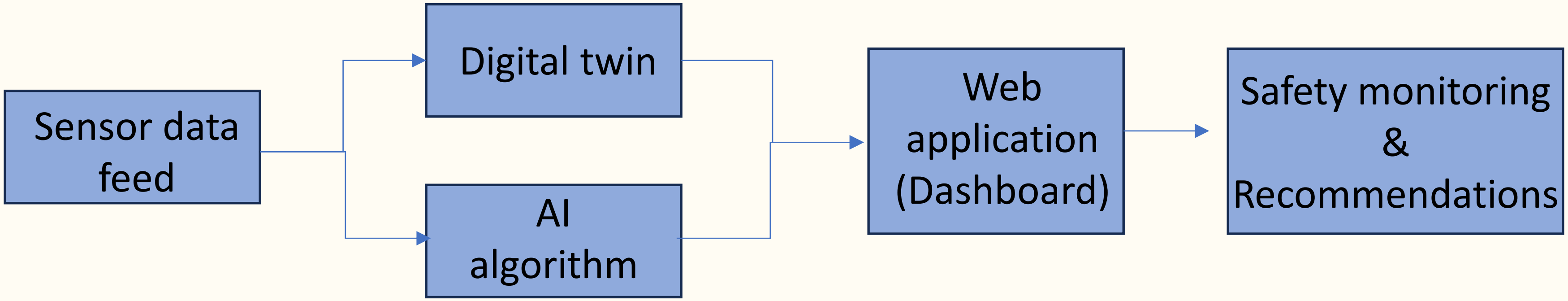
Project Location



Cost-effective sensing

Integrated Digital Twin System

- ➢Implement AI-powered digital twin for real-time crash risk prediction, intervention evaluation, and recommendation.

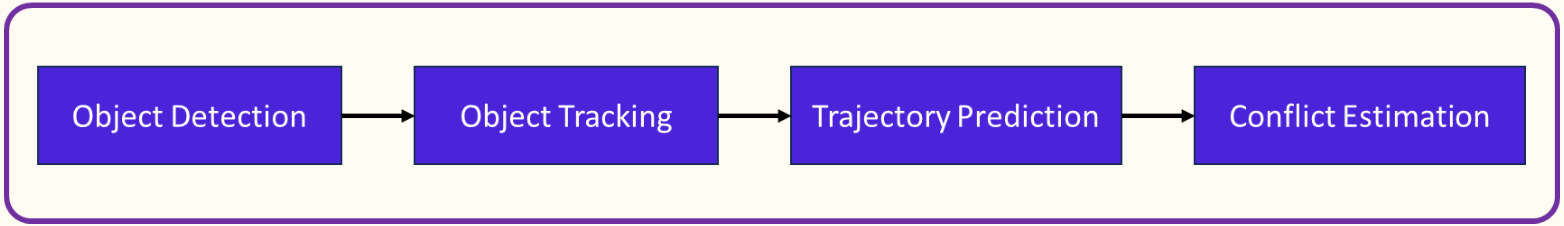


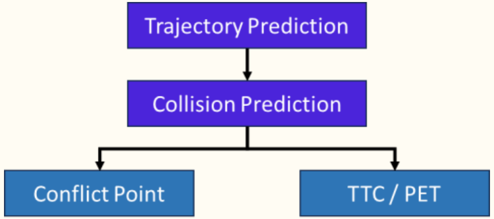
Project Architecture & Workflow

Integrated Digital Twin System

- ➤ Predictive Analytics & Risk Assessment

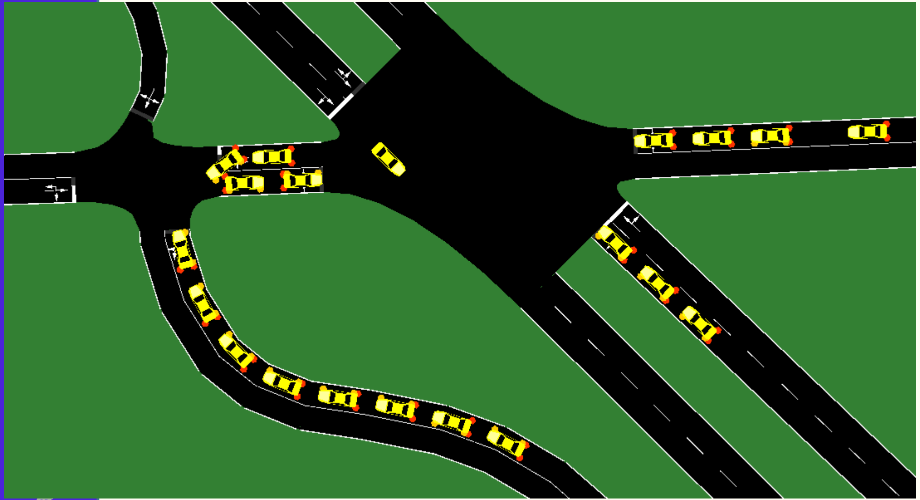
Deployment





Integrated Digital Twin System

- ➢Digital twin integration



2D Microscopic Simulation

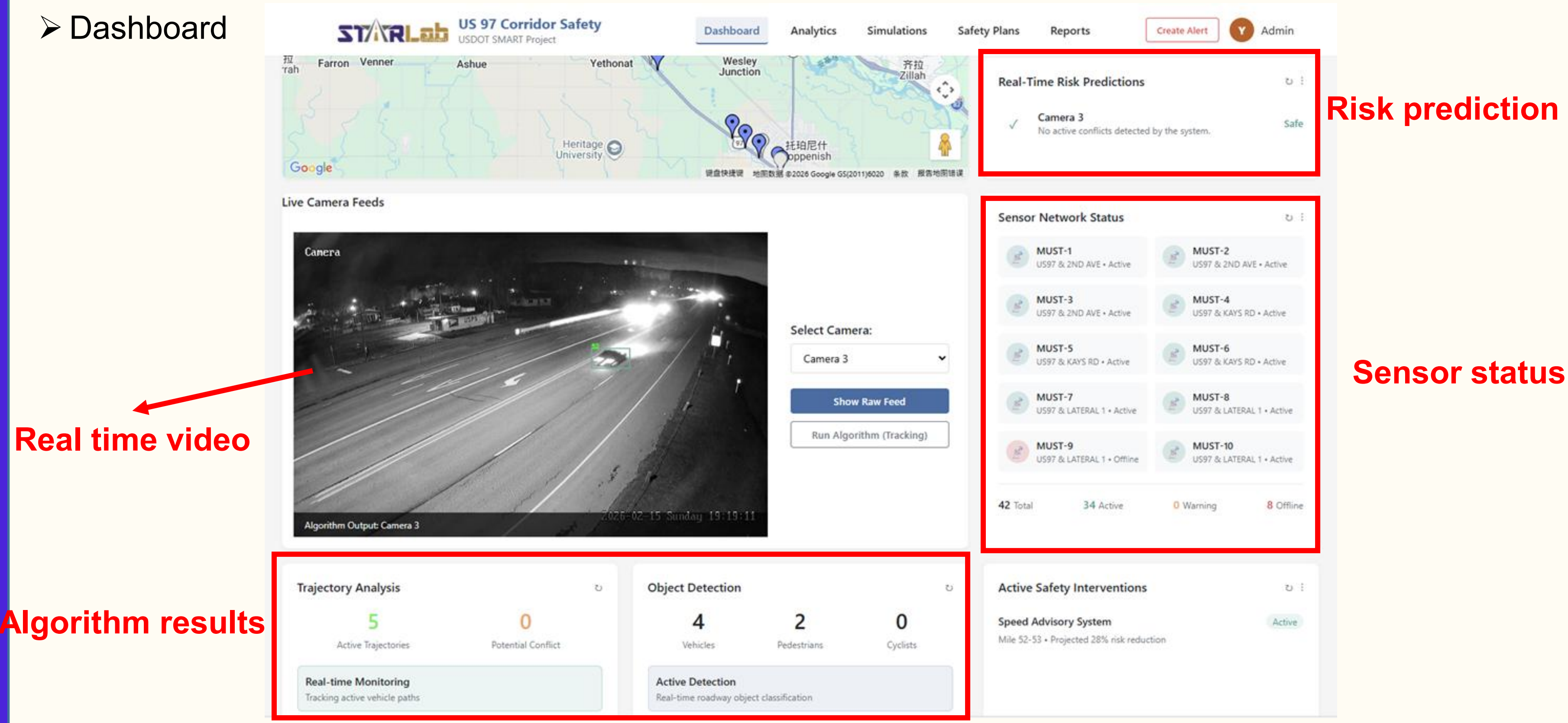
SUMO configured with safety analytics (TTC, PET, DRAC)

3D Simulation

Weather Scenario, intervention

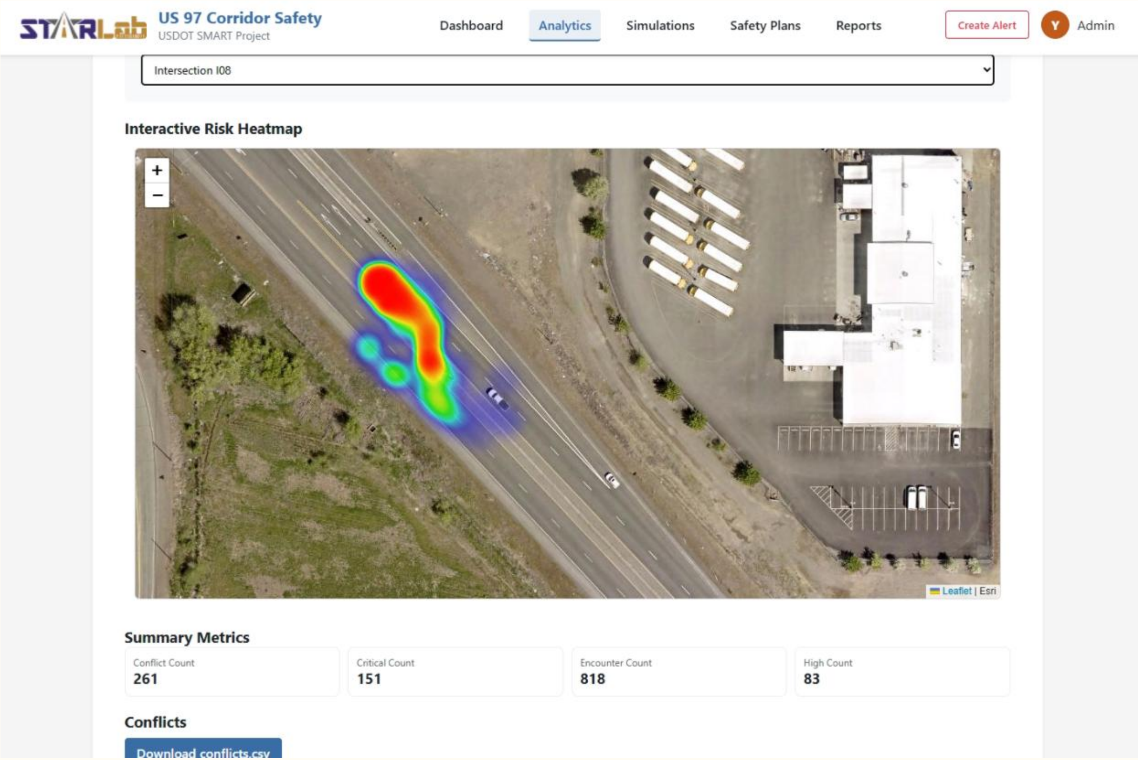
Integrated Digital Twin System

- Dashboard



Integrated Digital Twin System

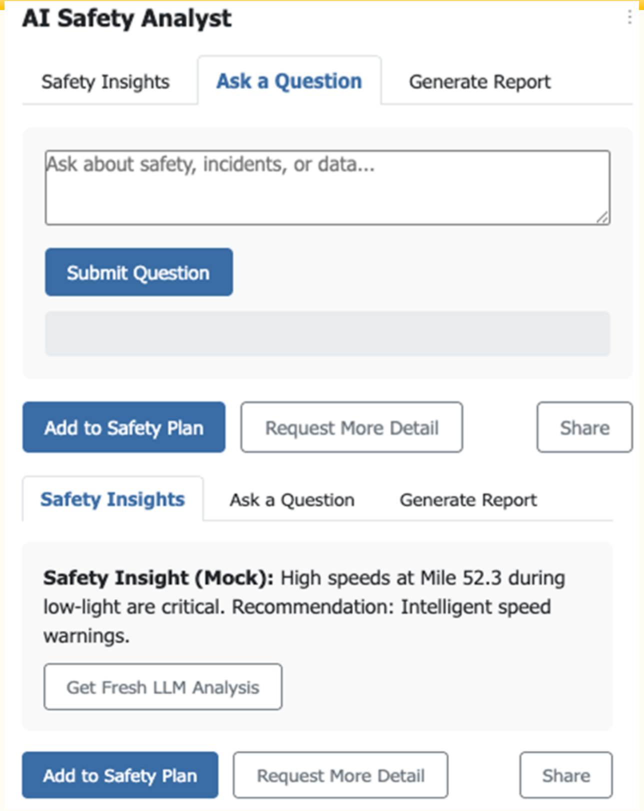
- ➢Dashboard



Integrated Digital Twin System

➢LLM safety intelligence engine

- **Risk Pattern Recognition:** Identifies complex danger scenarios
- **Input:** real-time data streams
- **Predictive intelligence:** forecasts emerging risk conditions



Future Directions

1 **Scalable, real-time data integration**
across sparse and heterogeneous sources
→ edge–cloud coordination

2 **Variable Environments**
Robust sensing under extreme conditions
→ *nighttime, weather, occlusion*

3 **Generalizable models for rural environments**
→ *Low data, high variability*

4 **End-to-end system integration**
Sensing → analytics → decision support → feedback loop

Questions?

Nutvara Jantarathaneewat

Department of Civil and Environmental Engineering,
University of Washington

nutvaraj@uw.edu

UNIVERSITY of WASHINGTON

Nature-Based Slope Repair Technique Using Vetiver Grass for Low-Volume Roads

Presented by

Fariha Rahman

PhD Student,

Department of Civil and Environmental Engineering,

Jackson State University,

Jackson, Mississippi

Supervising Faculty

Sadik Khan, Ph.D., P.E.

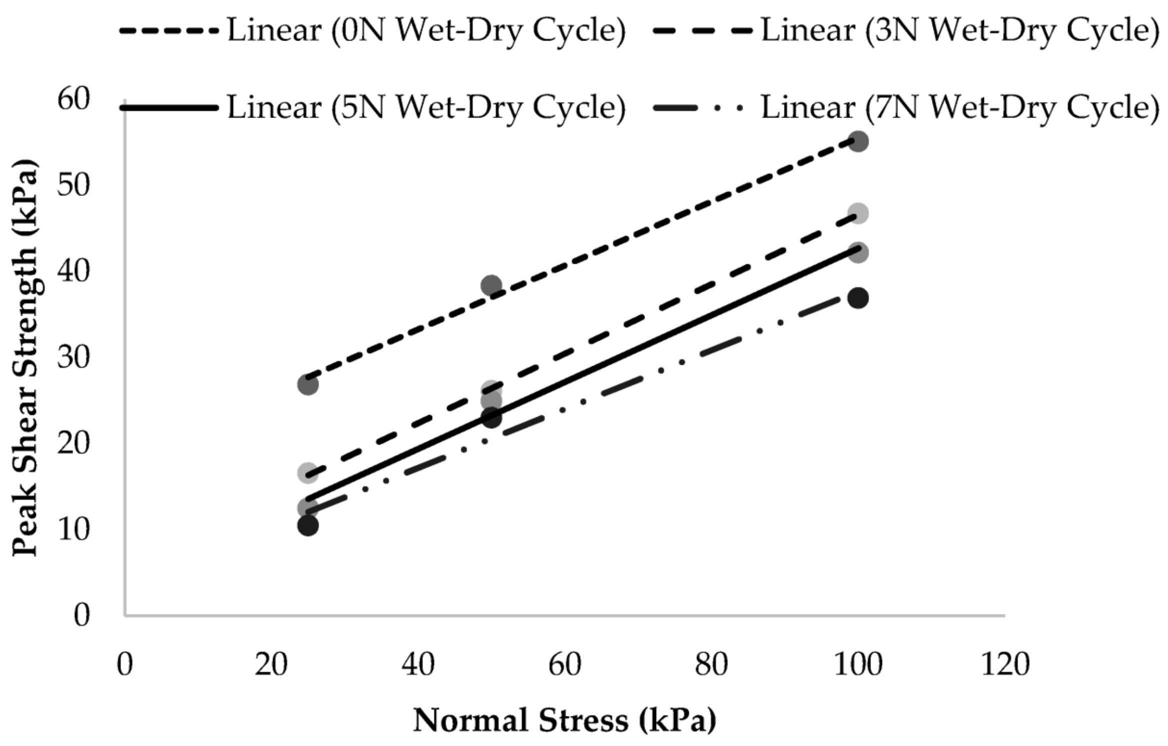
Associate Professor

Department of Civil and Environmental Engineering,

Jackson State University,

Jackson, Mississippi

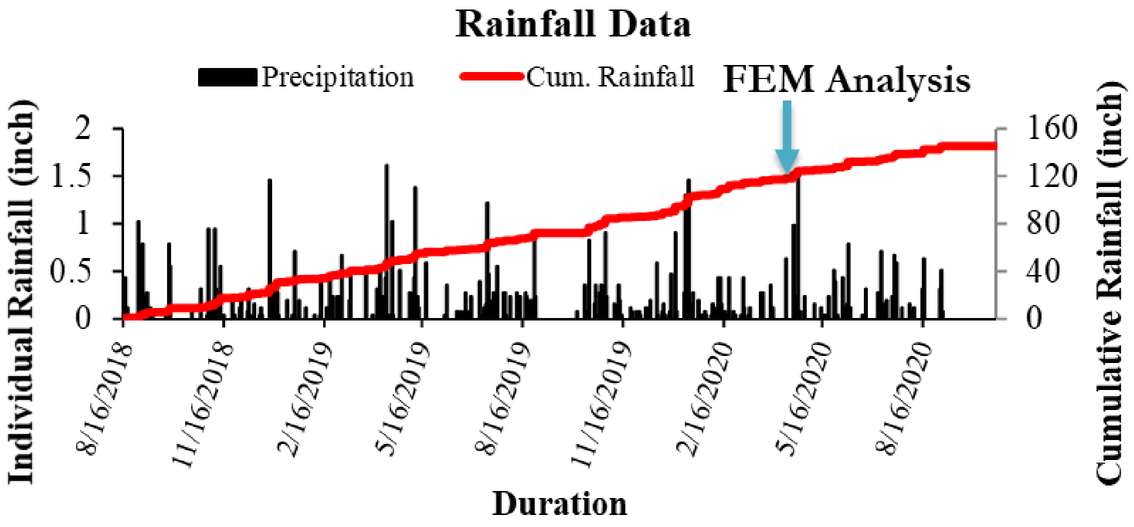
Effect of Wet-Dry Cycles on Yazoo Clay

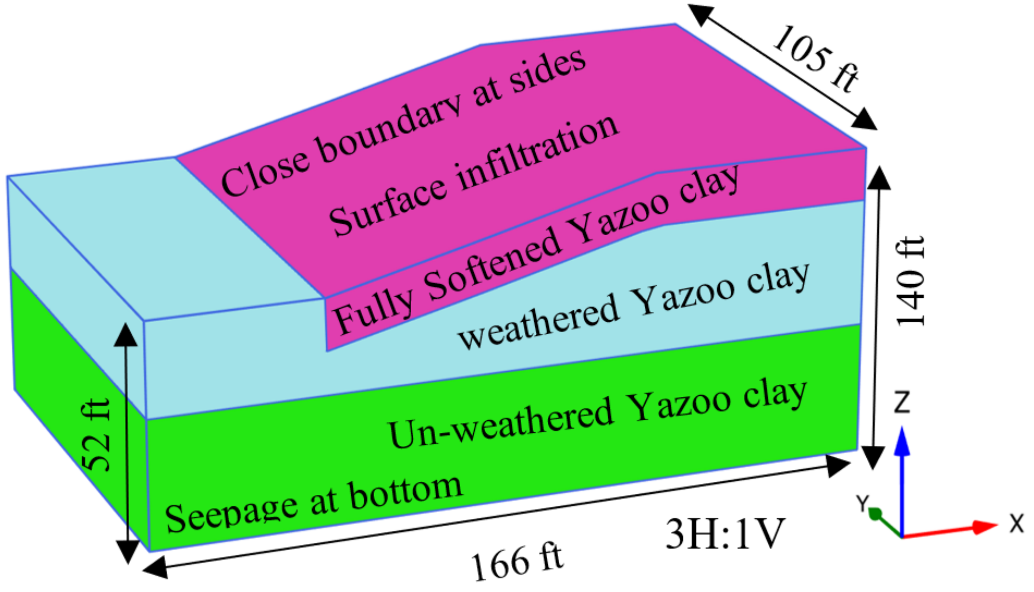


Source: Khan et al., 2019

- Highway slopes built on expansive soil are prone to rainfall-induced failure
- During the wet season, the rainwater infiltrates into the soil
- In drying periods, the soil shrinks and desiccation cracks are formed.
- As the number of wet–dry cycles increases, the shear strength becomes lower at the same normal stress
- An increase in wet–dry cycling leads to a higher void ratio, which in turn reduces the shear strength envelope .
- Overall, wet–dry cycles make expansive clay weaker and more vulnerable to failure, especially near the surface where normal stress is low.

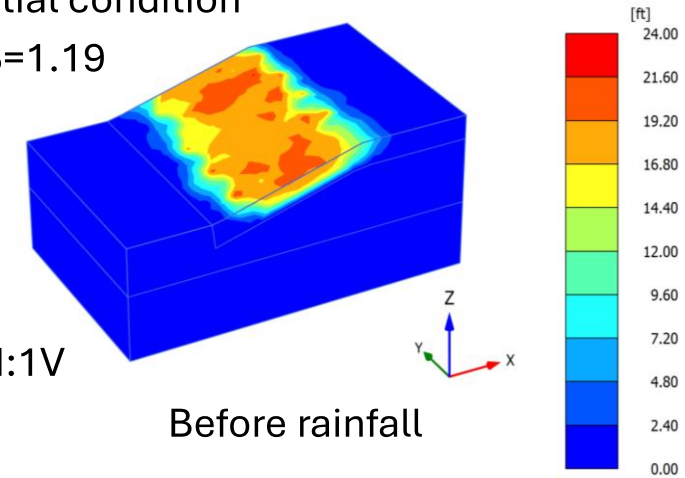
Numerical Analysis to Understand the Performance under Extreme Events





Numerical Analysis to Understand the Performance under Extreme Events

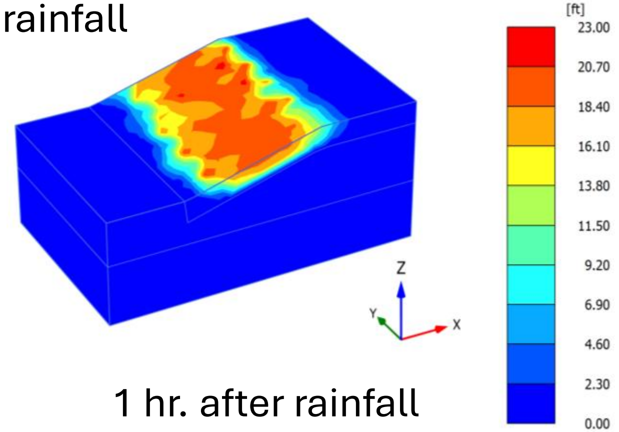
Initial condition
FS=1.19



3H:1V

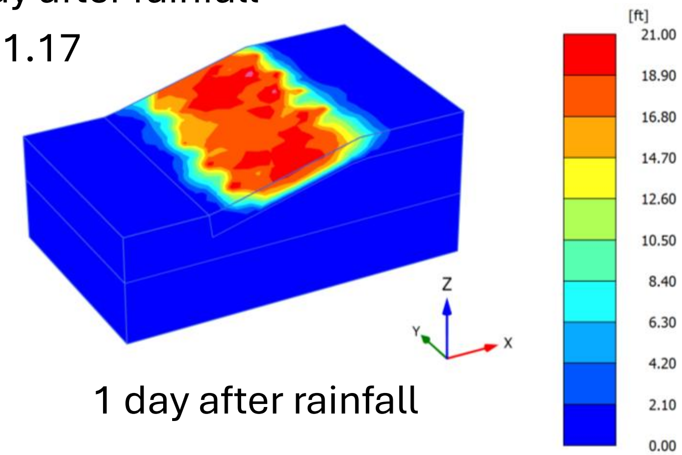
Before rainfall

1 hr after rainfall
FS=1.18



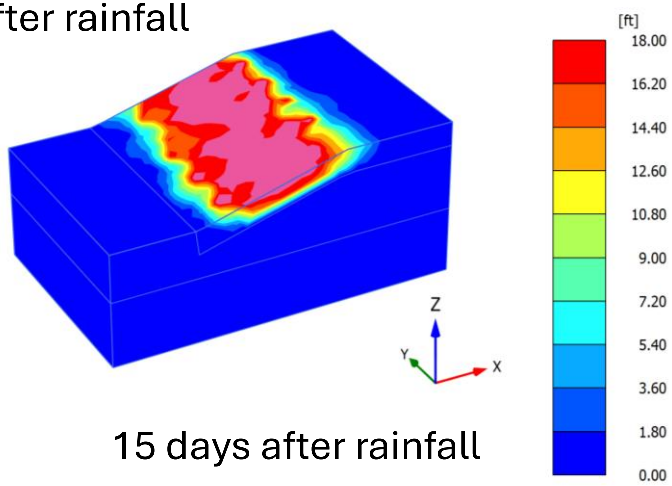
1 hr. after rainfall

1 day after rainfall
FS=1.17



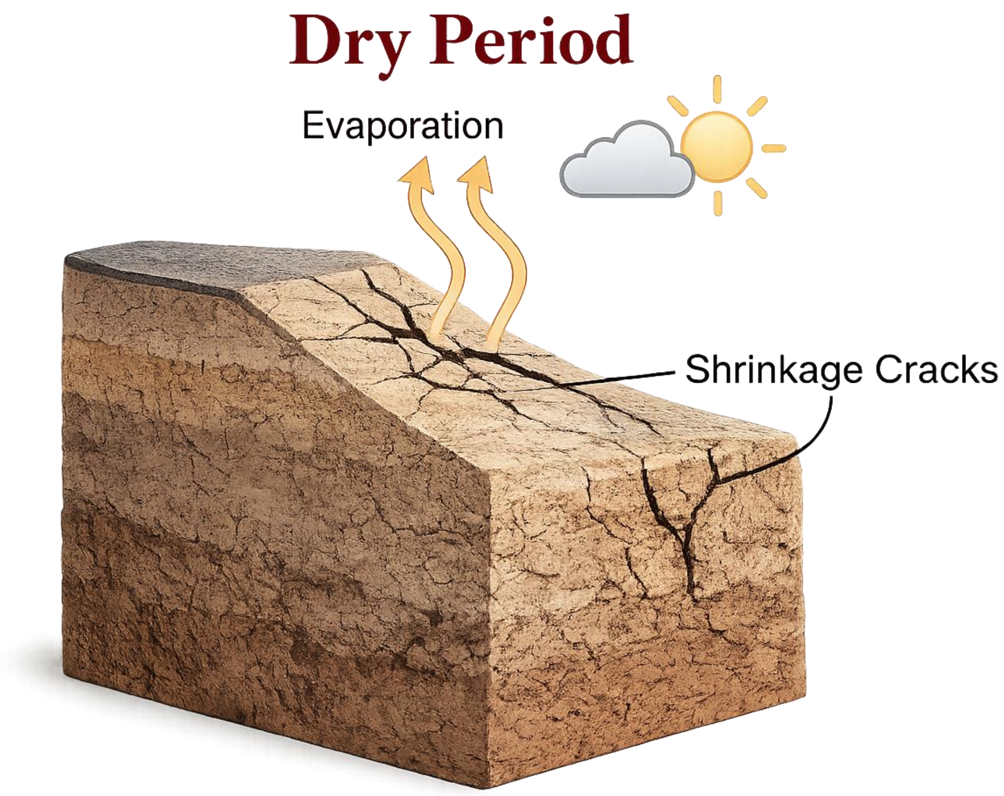
1 day after rainfall

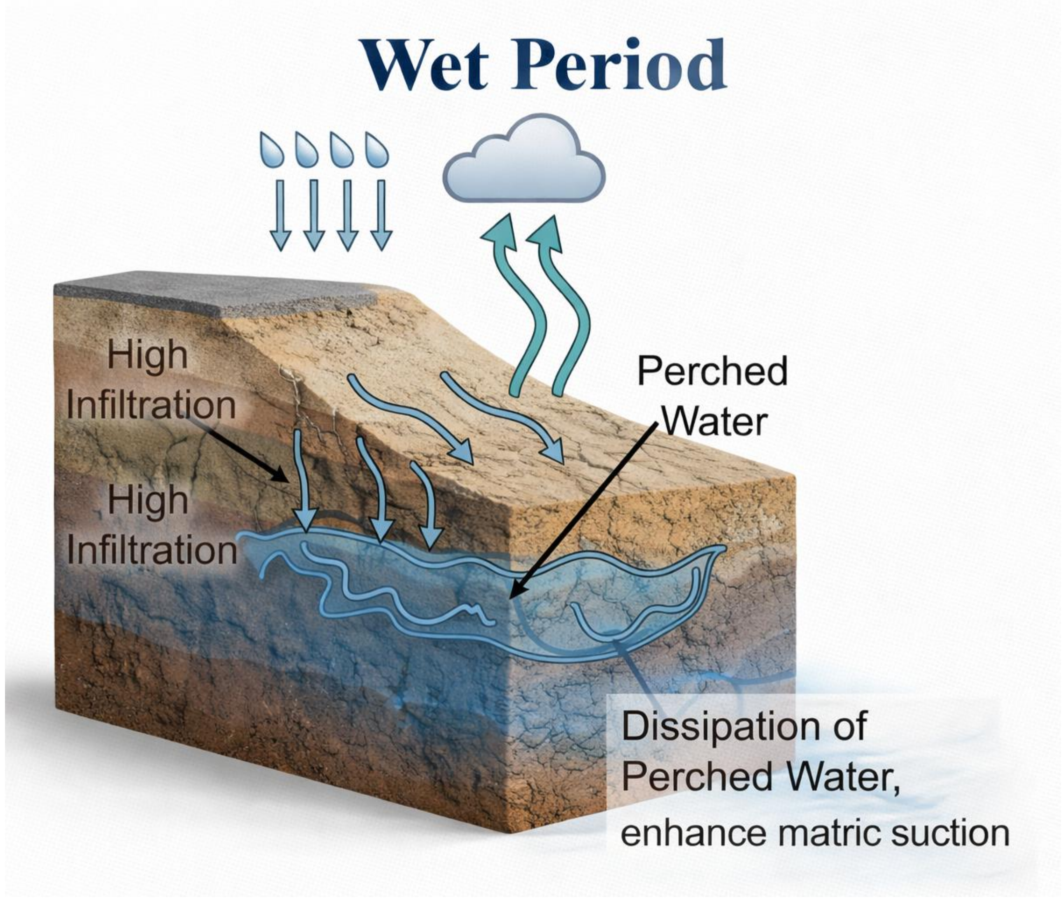
15 days after rainfall
FS=1.1



15 days after rainfall

Rainfall Infiltration Behavior within the Slope





Different Slope Repair Techniques

Source: Redi-Rock

Retaining Structure

Source: Geo-Stabilization International

Soil Nailing

Source: Geopier

Pile

Source: Cirtex

Geosynthetic

Source: LANHI

Slope Anchor

Limitations of Existing Slope Repair Techniques

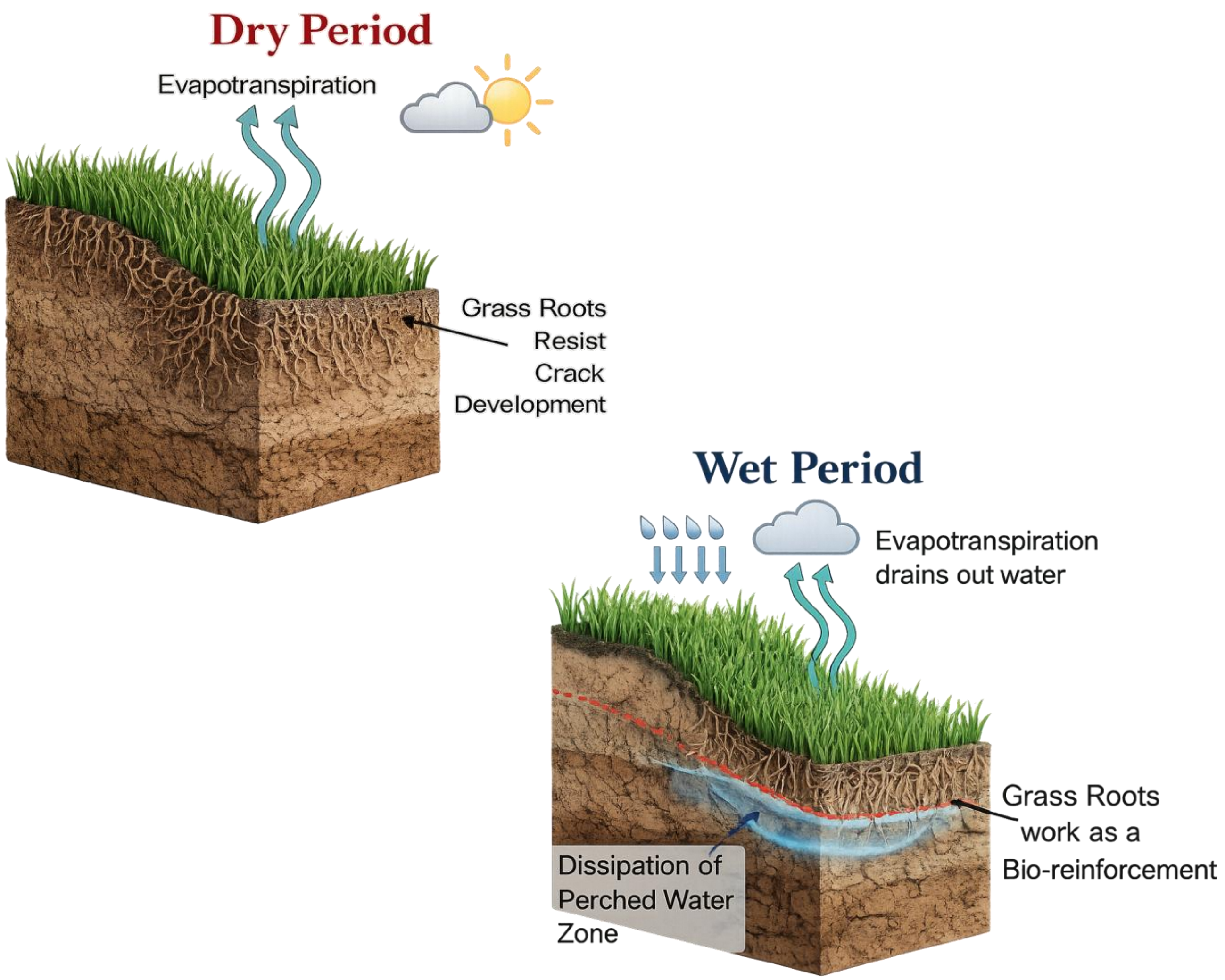
- Expensive
- Require detailed engineering design
- Special installation equipment
- Skilled workforce
- In some cases, ground improvement
- May involve excavation and improvements to the drainage system
- Not climate-resilient

Vetiver Grass

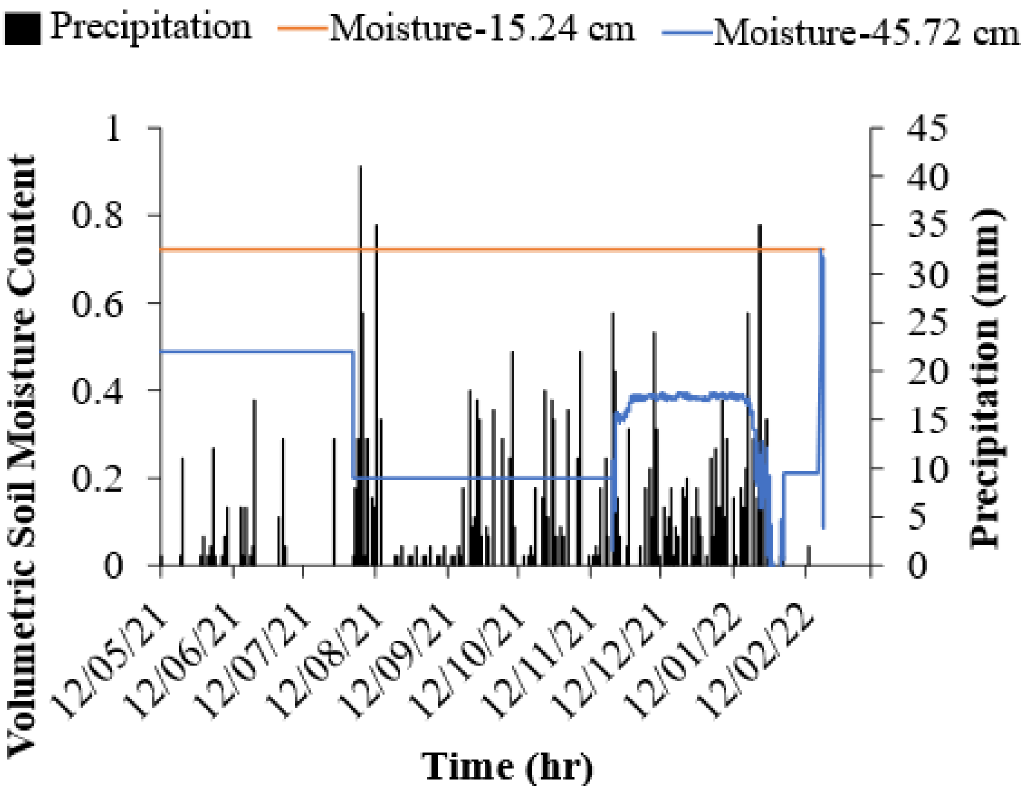
- A perennial grass species
- Fibrous deep root system grows up to 12 ft. within a year
- Can withhold adverse environments and extreme temperatures from -15°C to +55°C
- Survives in areas with annual rainfall from 20 to 200 inches
- Can survive in soil with pH from 3.3-12.5 without amendment
- Highly tolerant to hazardous materials
- Significant phytoremediation capability

Vetiver Grass for Slope Stabilization

- Deep root system draws water from the soil
- Reduces soil moisture content
- Root-soil interaction increases soil shear strength
- Increases factor of safety of the slope
- The root system works as a moisture barrier

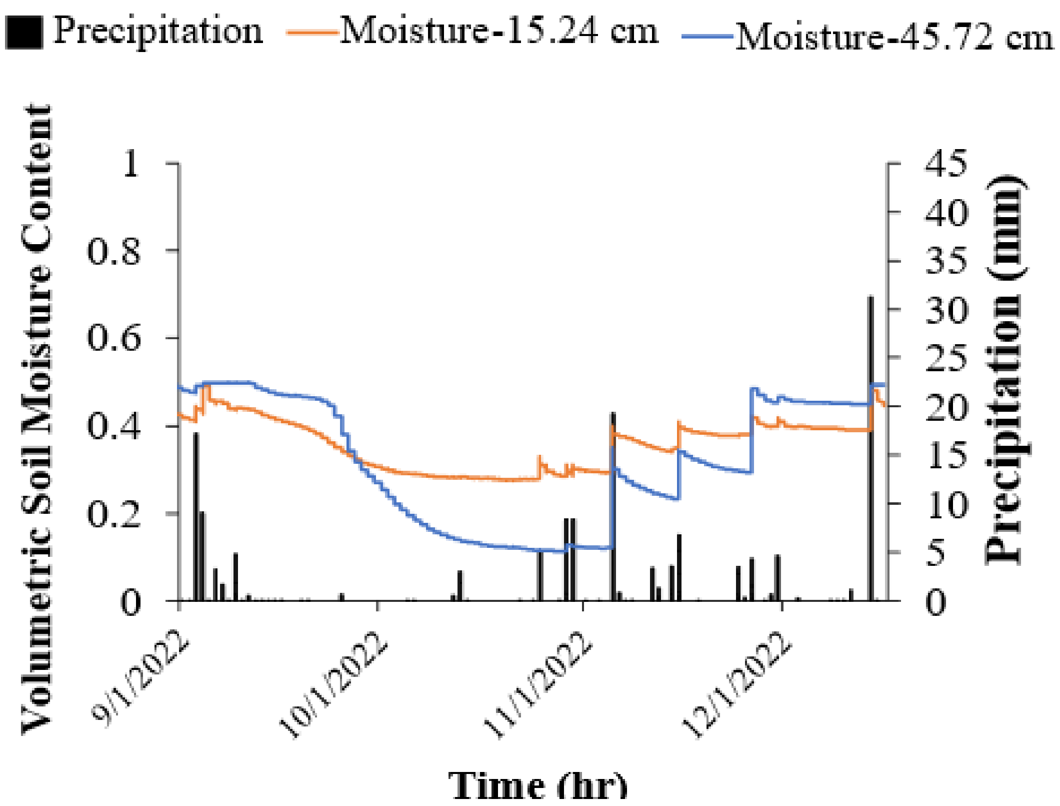


Vetiver Grass in Reducing Soil Moisture Content



May 2021-March 2022

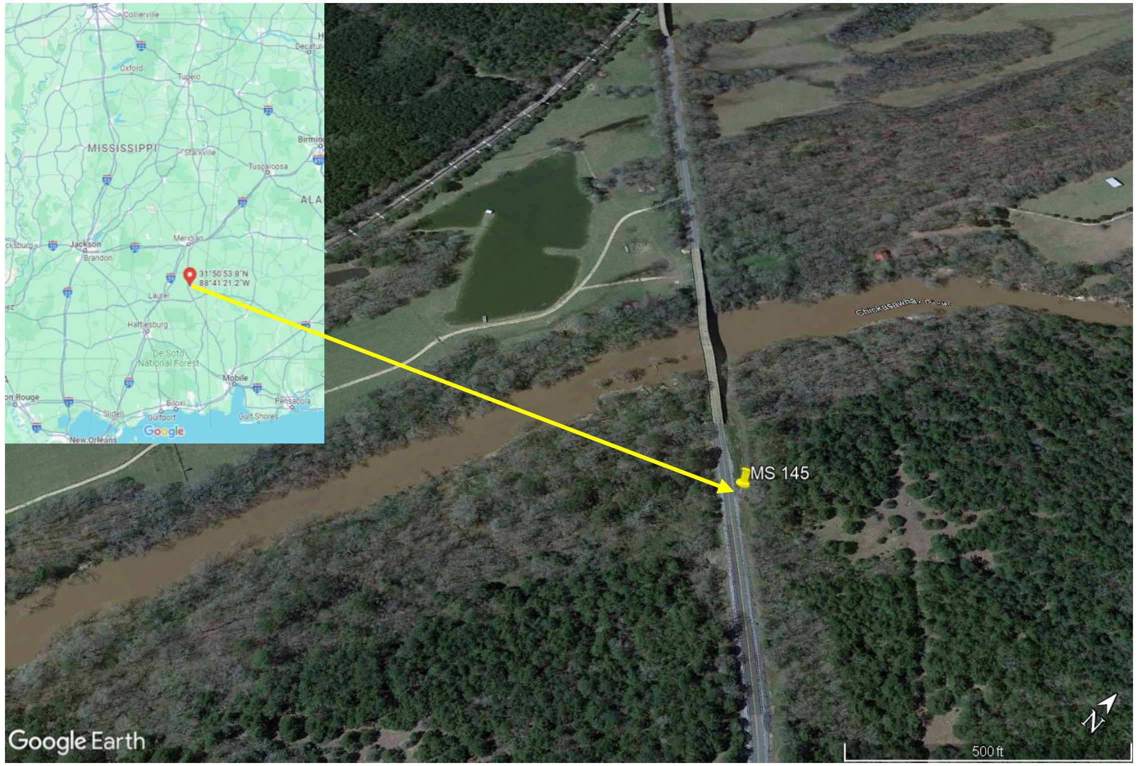
During the growth of vetiver root



September 2022-December 2022

After the full maturation of the vetiver root

Site Location



- Along MS 145 near Shubuta, Mississippi
- Slope Area: 165 ft×20 ft
- 3H:1V slope

Planting of Vetiver

- Repair of the whole slope area
- Total two sections
- 9-inch× 9-inch spacing in Section 1
- 12-inch (Along 90 ft length)× 9-inch (along 20 ft width) spacing in Section 2
- Plantation of around 4500 Vetiver

Planting of Vetiver

Plantation took place in October 2023

Site Conditions

Before Plantation (September 2023)

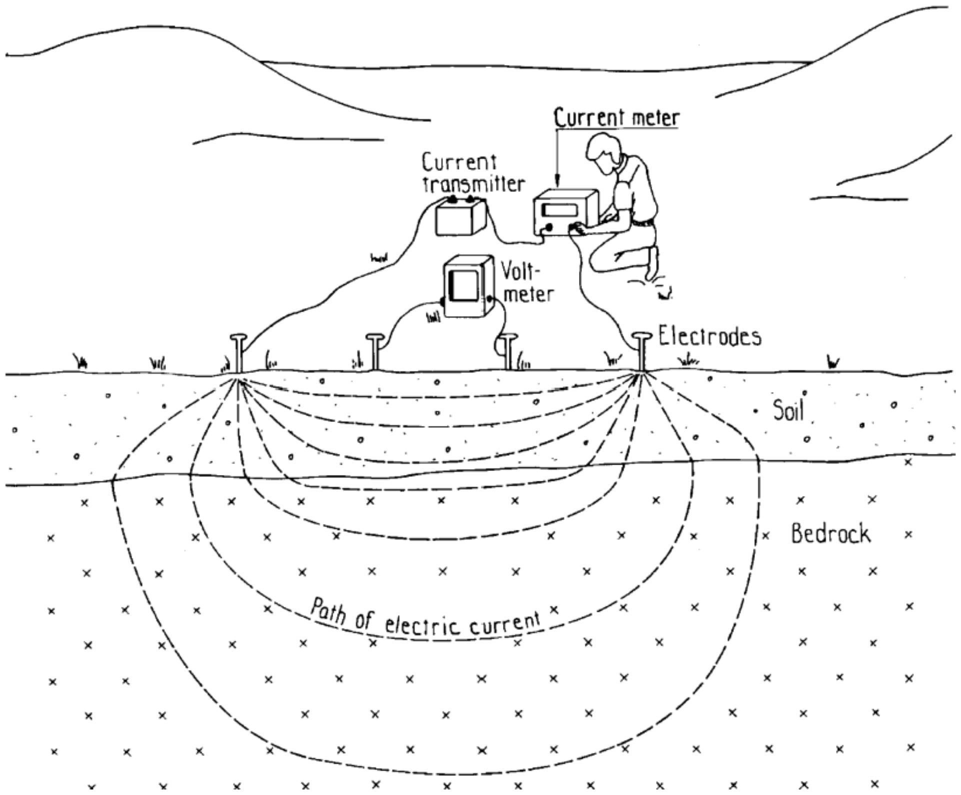
After Plantation (May 2024)

Electrical Resistivity Imaging (ERI)

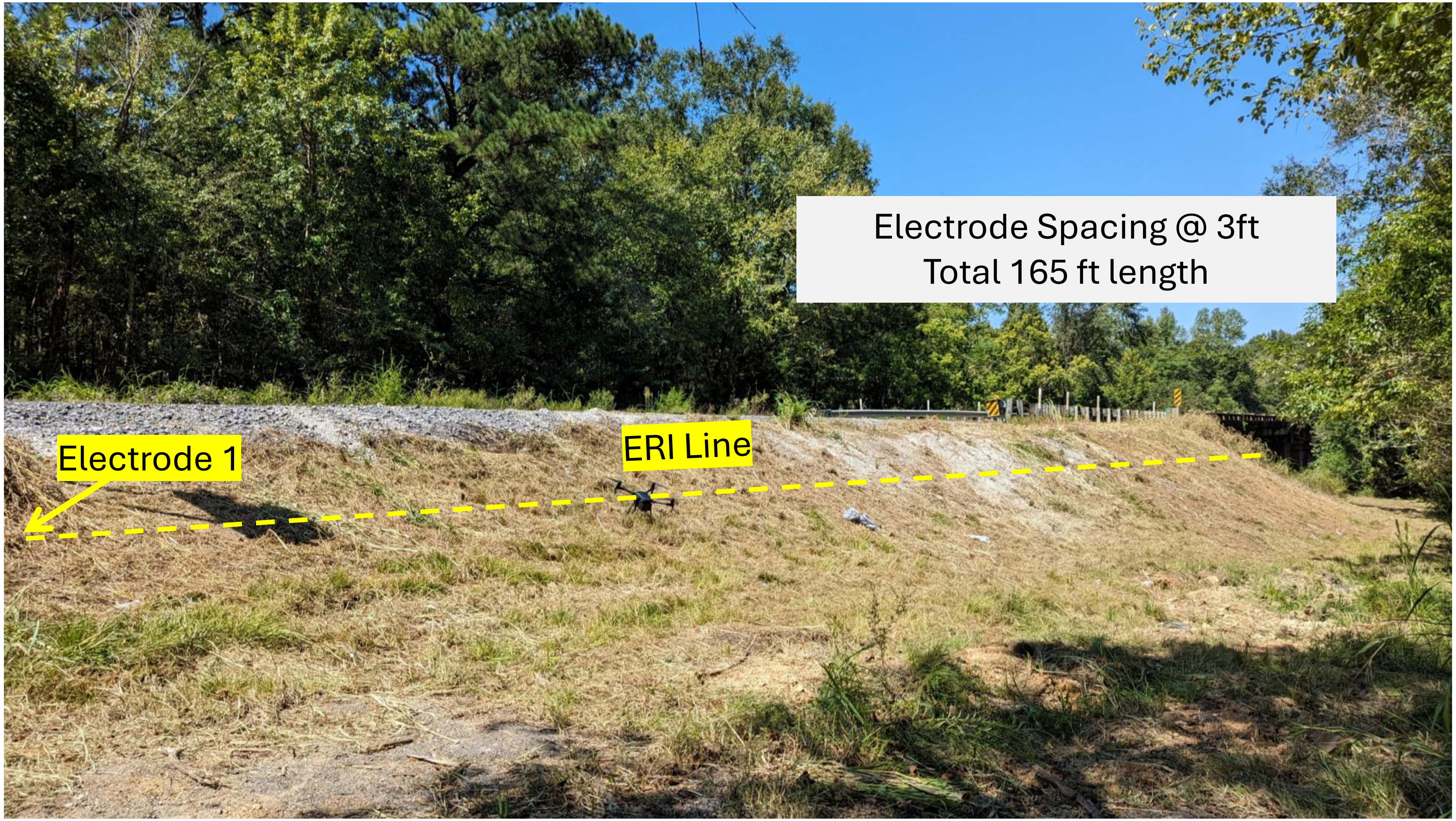
- Effective and non-destructive method for subsurface investigation
- Time efficient
- Can detect potential failure zones, slope movement and perched condition

Electrical Resistivity Imaging (ERI) (Contd.)

- Resistivity is a measure of how strongly a material opposes the flow of electric current.
- Different subsurface materials (e.g., rock, soil, water) have different resistivities.
- Based on Ohm's Law: V=IR
- A current is injected into the ground through a pair of electrodes, and the resulting potential difference (voltage) is measured between another pair of electrodes.
- Electrical resistivity of the soil decreases with increasing moisture content



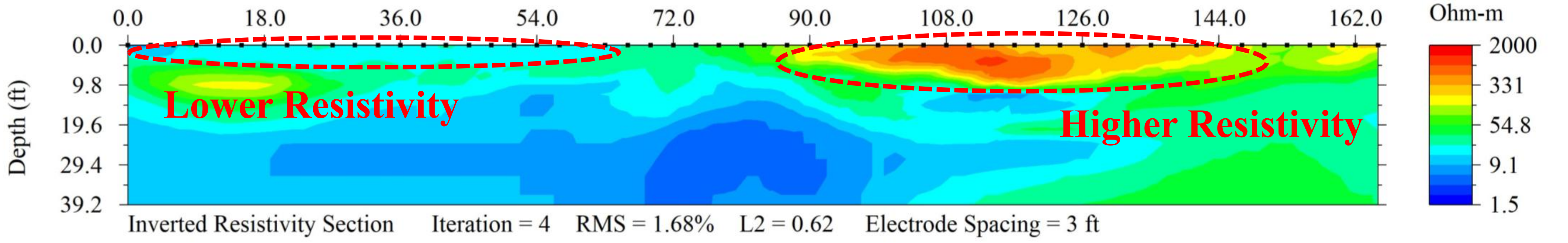
ERI Test on the Site



ERI Test on the Site

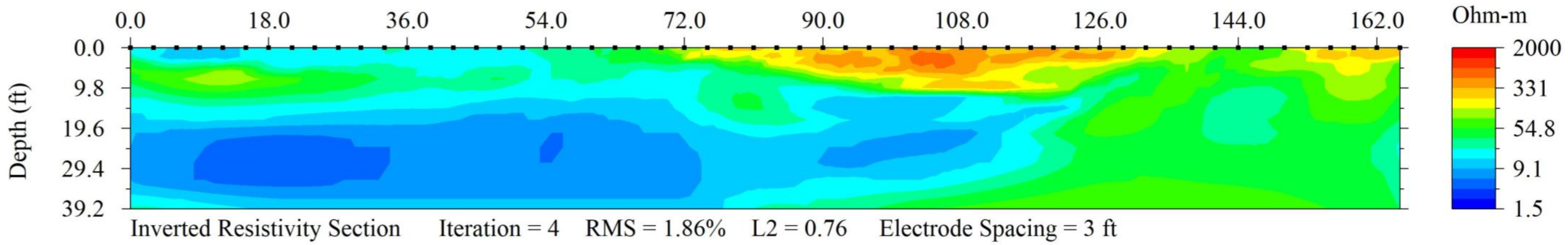
- Tests were conducted along the center of the slope
- No. of Electrodes: 56
- Apparent resistivity (r) data were collected using a SuperSting R8/IP device
- EarthImager 2D software was used for data analysis

ERI Profiles



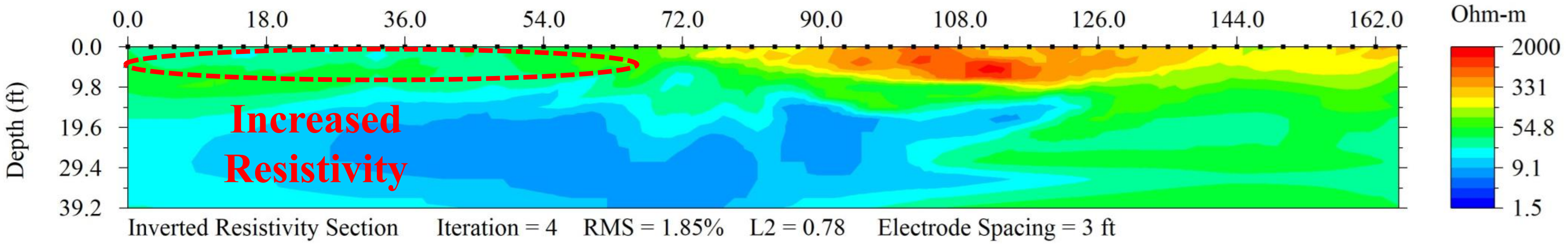
September 2023

After Plantation

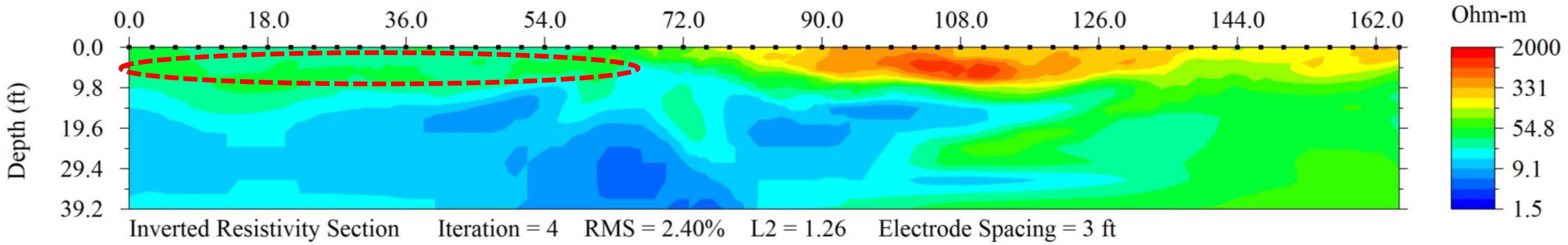


February 2024

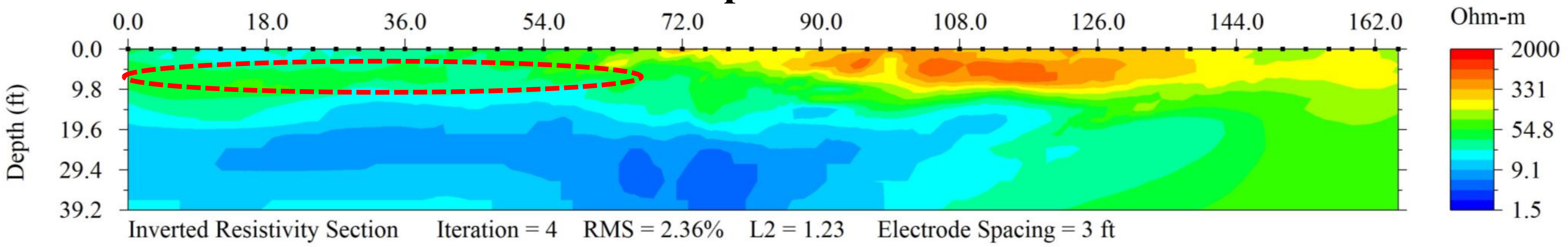
ERI Profiles (Contd.)



March 2024



April 2024



May 2024

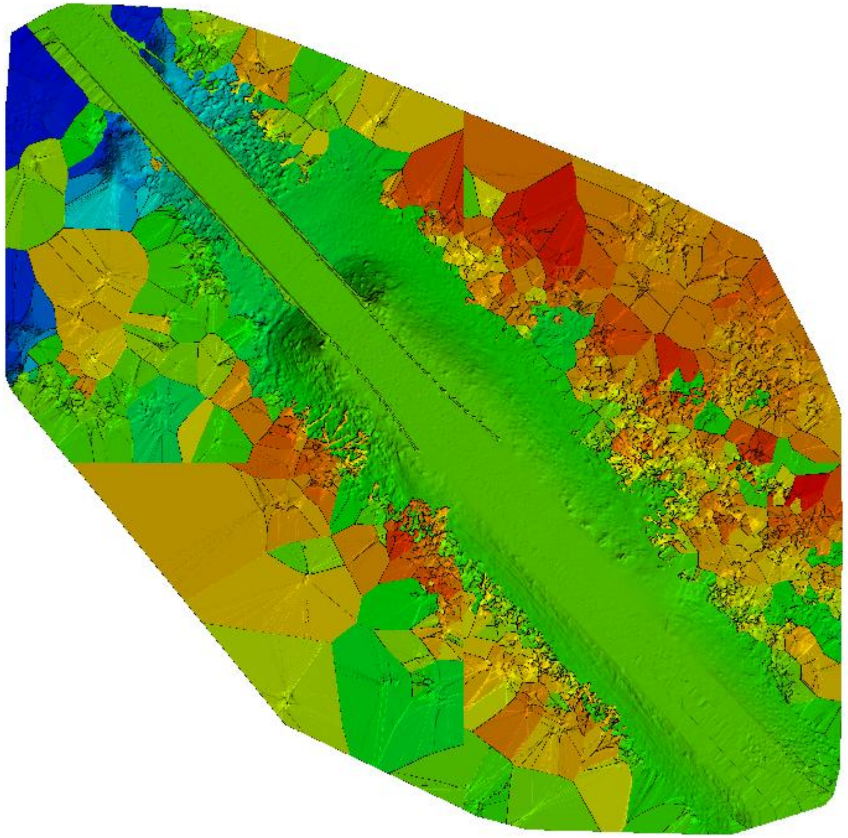
Findings from the ERI Profiles

- Lower resistivity (around 9.1 Ohm-m) represents the presence of a higher moisture zone in September 2023
- Significant increase in the resistivity value (around 54.8 Ohm-m) in the same zone from March 2024, with the growth of Vetiver
- Higher resistivity from 90 ft to 144 ft along the ERI line denotes a drier zone or void
- The higher resistivity zone was identified as critical for failure and closer spacing was used in that zone

LiDAR Survey- 3D Point Cloud

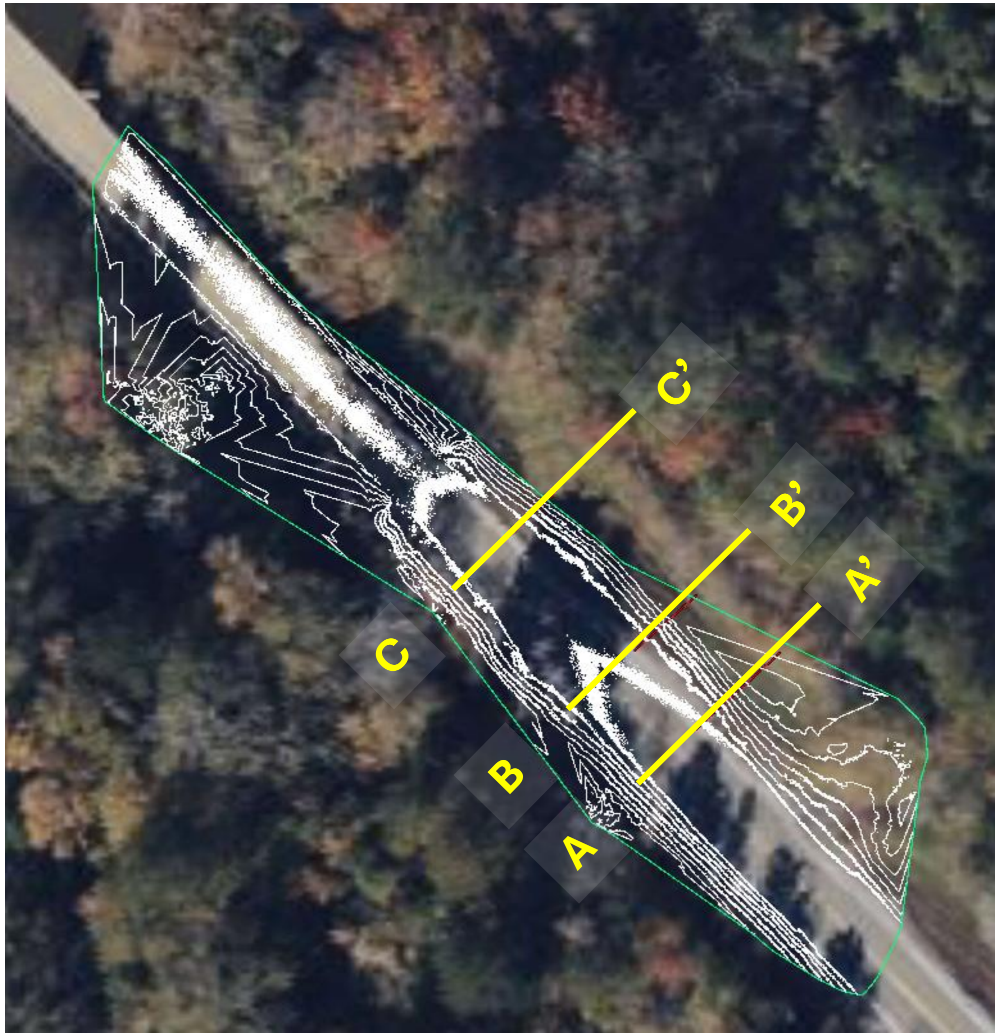
Drone Survey Result

3D Digital Model

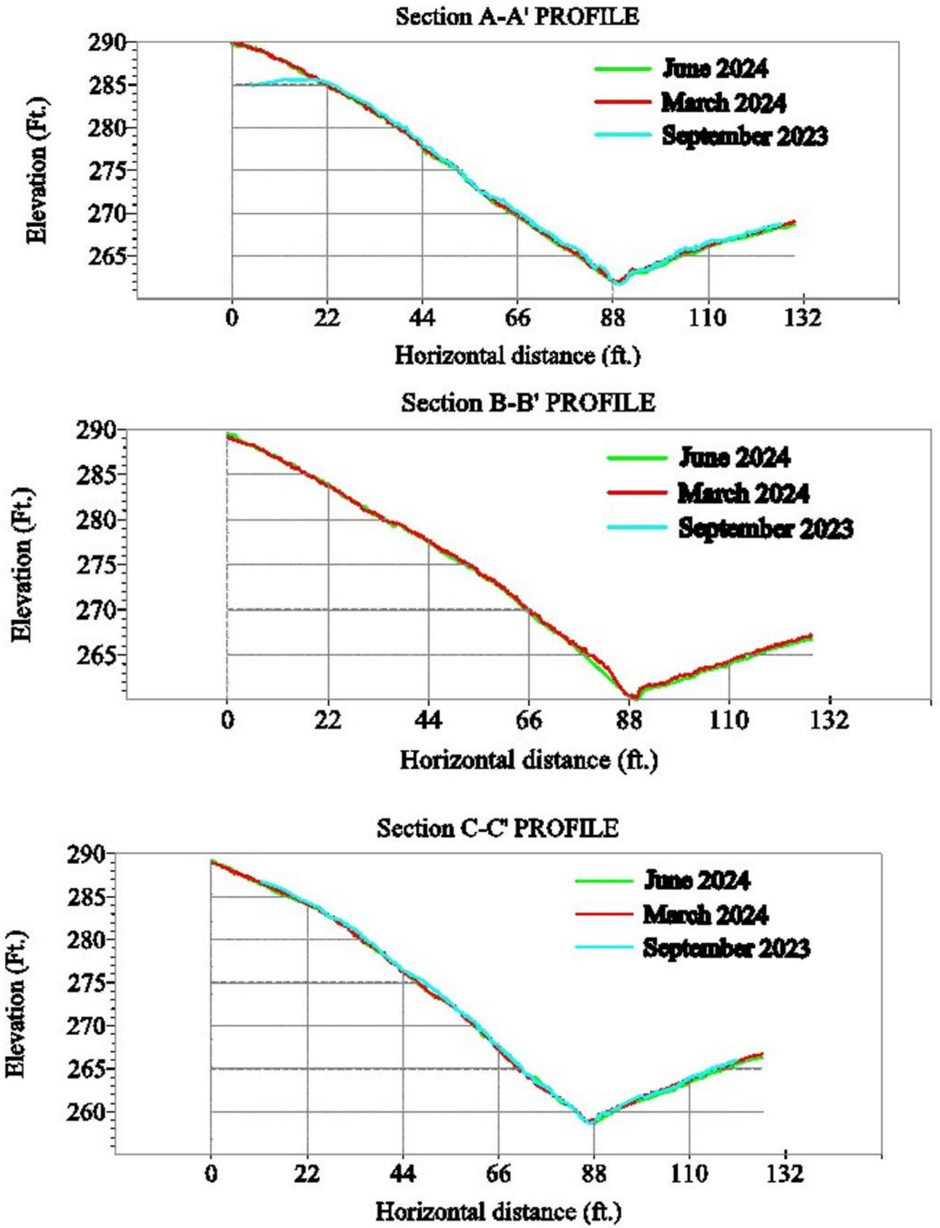


Digital Terrain Model

3D LiDAR Scanning



Topography (February 2024)



Profile View

Summary of the Study

- With maturation, Vetiver was able to draw a significant amount of water from the soil, leading to an increase in resistivity values
- Vetiver root improved the soil moisture condition
- Subsurface investigation with ERI test showed the reduced moisture condition within the slope with the growth of Vetiver
- LiDAR profiles showed no significant movement of the slope
- Vetiver grass demonstrated strong hydro-mechanical stabilization, where deep roots extracted soil moisture and improved matric suction conditions

Acknowledgement

NSF

CMMI Award No. 2046054
CAREER: Climate Resilient Landslide Repair on Expansive Soil Using Vetiver Grass

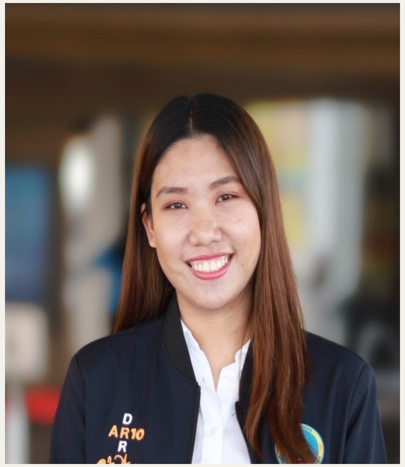
MDOT
MISSISSIPPI DEPARTMENT OF TRANSPORTATION

Sate Study 332
Green Landslide Repair Using Deep Rooted Vetiver Grass for MDOT

Thank You

Today's Presenters

Laura Fay
laura.fay1@montana.edu
Montana State University Western Transportation Institute



Nutvara Jantarathaneewat
nutvaraj@uw.edu
University of Washington

Farshad Kamran
farshad.kamran.1@ulaval.ca
Université Laval

Fariha Rahman
j00986301@students.jsums.edu
Jackson State University

Upcoming events for you

May 8, 2026

TRB Webinar: Data Governance in State DOTs—Insights and Practitioner Perspectives

https://webinar.mytrb.org/Webinars/Details/1923

January 10-14, 2027

2027 TRB Annual Meeting

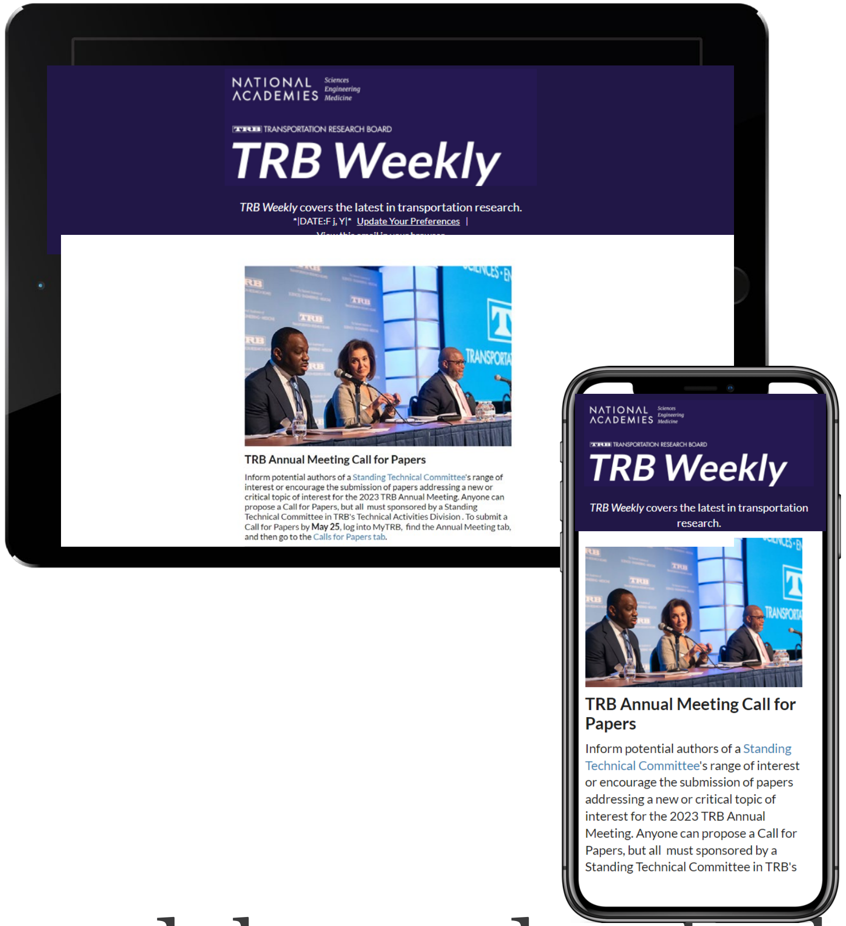
https://trb-annual-meeting.nationalacademies.org/

Subscribe to *TRB Weekly*

If your agency, university, or organization perform transportation research, you and your colleagues need the *TRB Weekly* newsletter in your inboxes!

Each Tuesday, we announce the latest:

- RFPs
- TRB's many industry-focused webinars and events
- 3-5 new TRB reports each week
- Top research across the industry



Spread the word and subscribe!

https://bit.ly/ResubscribeTRBWeekly

Discover new TRB Webinars weekly

Set your preferred topics to get the latest listed webinars and those coming up soon every Wednesday, curated especially for you!

https://mailchi.mp/nas.edu/trbwebinars

And follow #TRBwebinar on social media

@NASEMTRB
@NASEMTRB
Transportation Research Board

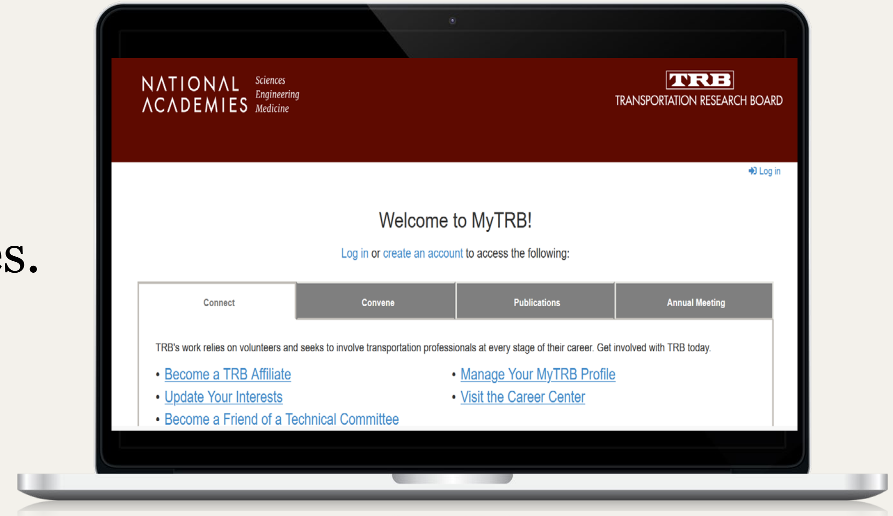
NATIONAL ACADEMIES Sciences Engineering Medicine
TRB TRANSPORTATION RESEARCH BOARD

Get involved

TRB mobilizes expertise, experience, and knowledge to anticipate and solve complex transportation-related challenges.

TRB's mission is accomplished through the hard work and dedication of **thousands of volunteers**.

https://www.nationalacademies.org/trb/get-involved



We want to hear from you

- **Take our survey**
- **Tell us how you use TRB Webinars in your work at trbwebinar@nas.edu**

NATIONAL ACADEMIES *Sciences Engineering Medicine*