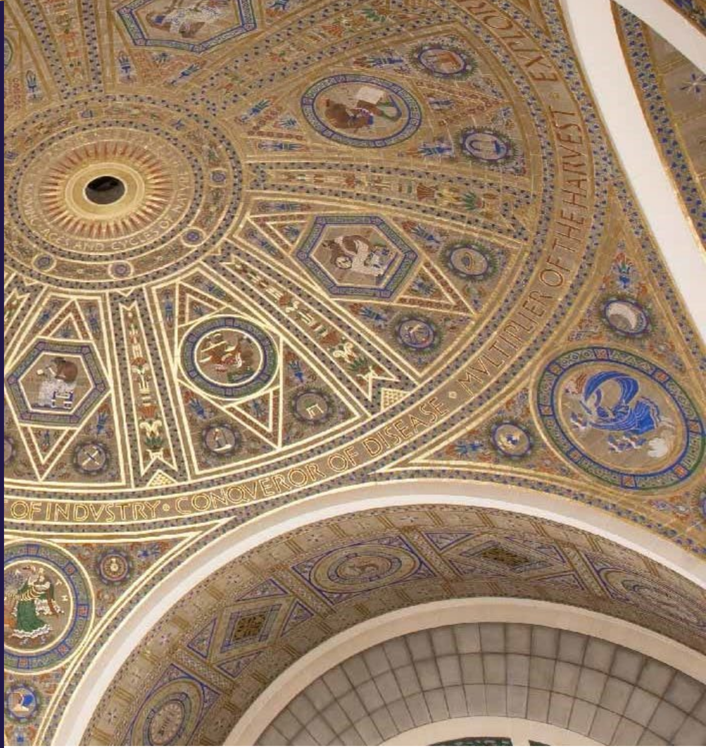
NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Geotechnical Asset Performance in a Changing Climate

July 13, 2022

2:30 – 4:00 PM



PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Beth Ewoldsen at Bewoldsen@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

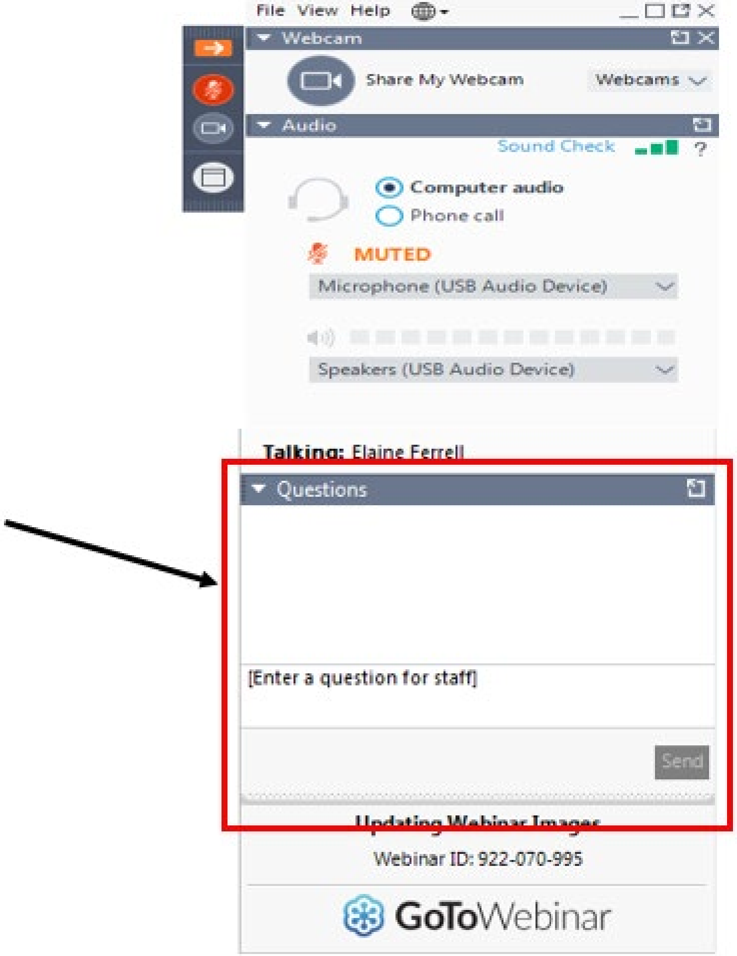
RCEP
REGISTERED CONTINUING EDUCATION PROGRAM

Learning Objectives

- Evaluate the impact of climate change on infrastructure construction
- Use soil-moisture satellite data to evaluate infrastructure performance
- Consider moisture variation in highway slopes on expansive soil

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

Mike LeBeau
mlebeau@DuluthMN.gov
City of Duluth, Minnesota

Mehran Mazari
mmazari2@calstatela.edu
Califomia State University, Los Angeles

Sadik Khan
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Jackson State University

John Siekmeier
john.siekmeier@state.mn.us
Minnesota Department of Transportation

Geotechnical Asset Performance in a Changing Climate

Transportation Research Board Webinar
July 13, 2022

Moderator: John Siekmeier P.E. M.ASCE
TRB AKG40 “Mechanics and Drainage of Saturated and Unsaturated Geomaterials”
Minnesota DOT Advanced Materials and Technology, Maplewood, Minnesota

Sponsoring Committees

- Mechanics and Drainage of Saturated and Unsaturated Geomaterials (AKG40)
- Geotechnical Instrumentation and Modeling (AKG60)
- Geo-Environmental and Climatic Impacts on Geomaterials (AKG30)
- Subcommittee on Geotechnical Asset Management AKG00(1)

Today's Agenda

Introduction and Opportunities (5 minutes)

Three Presentations (20 minutes each)

- Local Government Perspective, Midwest
- Remote Sensing, Global
- DOT Infrastructure, Southern United States

Discussion (25 minutes)

Opportunity to Address Code of Federal Regulations

A state asset management plan includes:

1. Summary of assets on NHS including condition;
2. Asset management objectives and measures;
3. Performance gap identification;
4. Lifecycle cost and risk management analysis;
5. Financial plan; and
6. Investment strategies.

23 U.S.C. 119(e)(4), MAP-21 § 1106

Opportunity to Address State Priorities

2021 Minnesota Statutes, 174.03, Subdivision 12

Trunk highway performance, resiliency, and sustainability.

(a) The commissioner must implement performance measures and annual targets for the trunk highway system in order to construct resilient infrastructure, enhance the project selection for all transportation modes, improve economic security, and achieve the state transportation goals established in section 174.01.

(b) At a minimum, the transportation planning process must include an inventory of transportation assets, including but not limited to bridge, pavement, geotechnical, pedestrian, bicycle, and transit asset categories.

Geotechnical Asset Measures and Targets

Lag, and where practicable lead, performance measures, and annual targets that are statewide and district-specific in each asset category for a period of up to 60 years identified in collaboration with the public.

Gap identification and an explanation of the difference between performance targets and current status.

Life cycle assessment and corridor risk assessment as part of asset management programs in each district of the department.

This section is effective July 1, 2021. The initial performance implementation report under this section is due December 15, 2022.

Today’s Presentations

“Adaptation on the Middle Coast: A Proactive Approach to Climate Challenges” Mike LeBeau, City of Duluth, Minnesota

“Using Soil-Moisture Satellite Data to Evaluate the Performance of Transportation Infrastructure Foundations” Mehran Mazari, California State University, Los Angeles, California

“Climate Change Effects on Moisture Variation in Highway Slopes on Expansive Soil” Sadik Khan, Jackson State University, Mississippi

Constructing Infrastructure with Climate Change in Mind

Adaptation on the Middle Coast: A Proactive Approach to Climate Challenges

Michael LeBeau | Construction and Energy Project Supervisor | City of Duluth, MN

Introduction

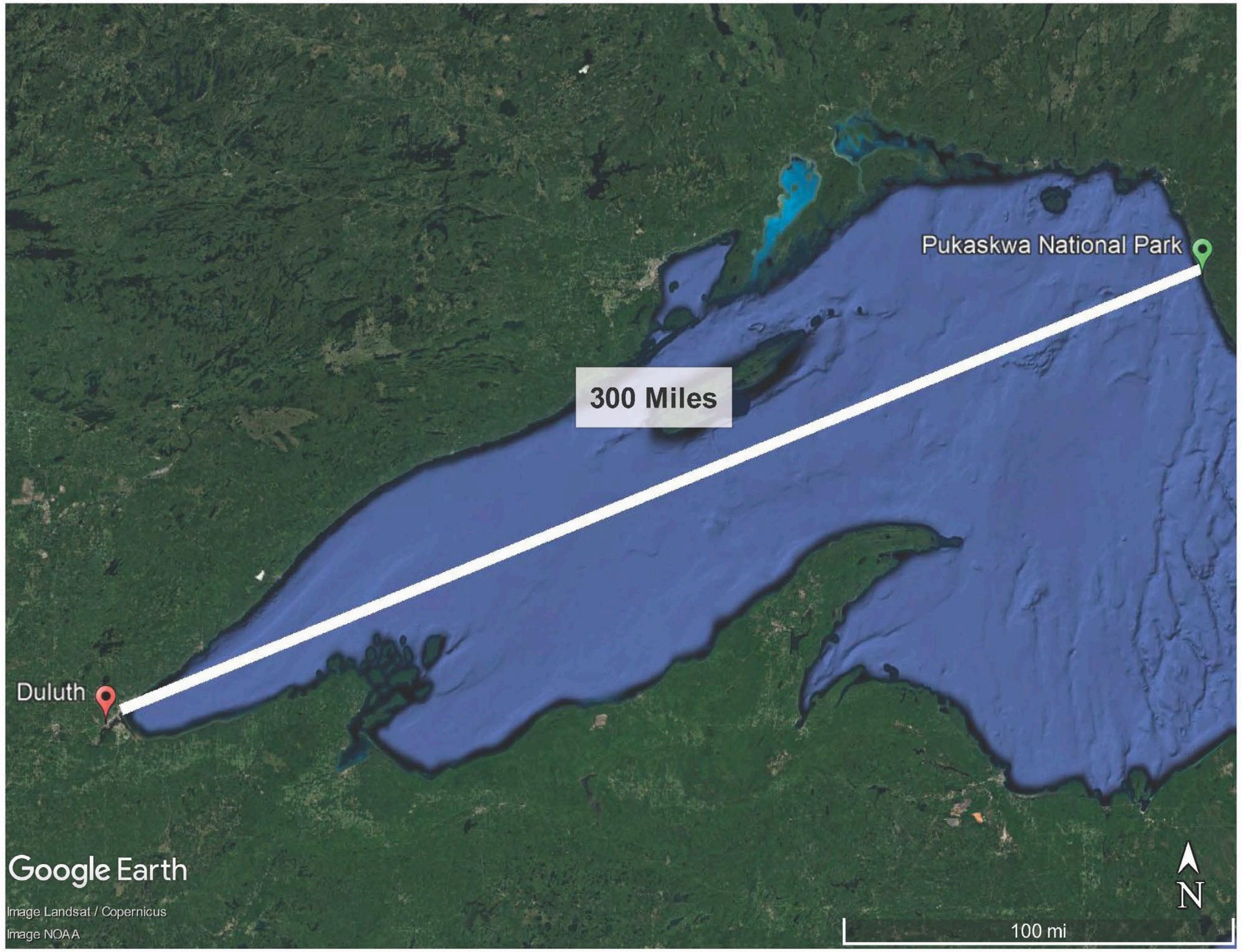
- I supervise a team that manages all construction projects on City property except roads and utilities
    - Building construction and renovation
    - Energy efficiency and conservation
    - Renewable energy
    - Trails
    - Other Park amenities
    - Shoreline repairs and hazard mitigation

Learning Objectives

- To understand the unique climate challenges a Great Lakes exposure creates for Upper Midwest communities
- To learn about recent indications of increasing intensity and frequency of storms in the western great lakes.
- To learn about how Duluth, MN is transitioning from reactive to proactive approaches to climate resiliency.
- To learn about the implications of federal and State disaster funding on restoration and resiliency projects

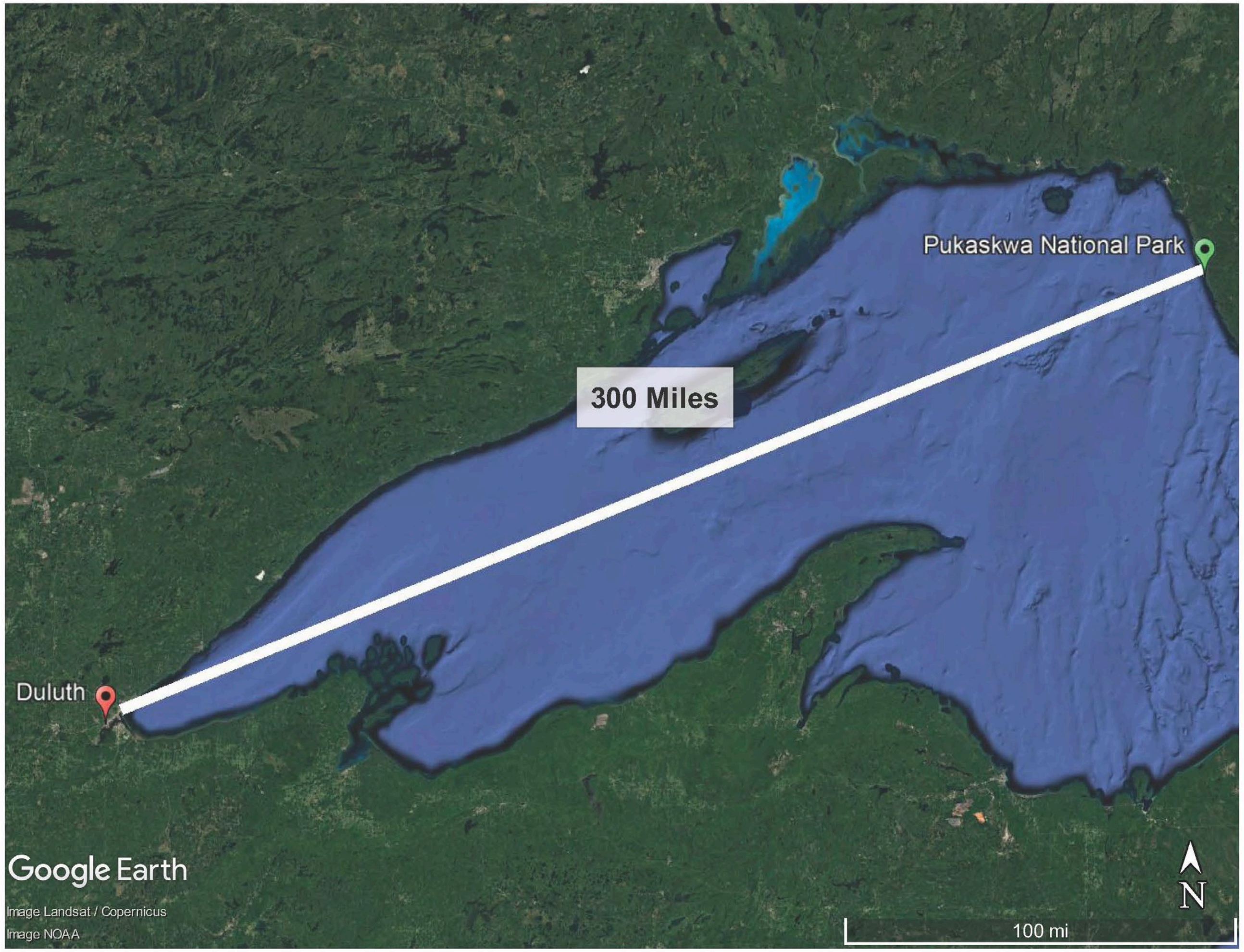
Lake Superior

- Lake enhanced storms often come with strong NE winds
- 300 miles of open lake
- Lake levels fluctuate cyclically historically
- Big storms on Superior are nothing new
- Fairly young shoreline



Lake Superior

- NE winds can pile up water in western arm of lake causing surge (seiche) of several feet at times
- Recent storms have brought 15–20 foot waves
- Shore orientation impacts exposure to wave action
- Winds clocked at over 100 mph



Unusual Storm Cycle 10/17 – 10/18

- Three major storms 6 months apart
- Two state and one federal disaster declarations
- Initial assessments after all three storms estimated approximately $30M in repairs on City shorelines
- A combination of high lake levels, strong surge and big waves

Storms 10/17 – 10/18

- Repairs to date ~ $26M
- Difficult to attribute damages to the 3 different events
- FEMA and State sent out assessors to review sites, assess damage and provide initial cost estimates

Storms 10/17 – 10/18 (cont.)

- Sites were involved in 1 – 3 disaster declarations
- Project cost tracking difficult and time consuming
- First State Led Federal Disaster in MN
- All of the State and Federal funding is in the form of reimbursements

Repairs + Mitigating Future Damage

- FEMA “public assistance” programs are based on putting things back to where they were just before the event at current local market costs
- Pre-disaster condition is very difficult to document and prove
- This trail was abandoned!

We Know What No Longer Works

- Much of the failed shoreline was just unengineered fill
- FEMA will fund, additional “hazard mitigation” efforts to build better
- The state of MN adopted same policy with our projects

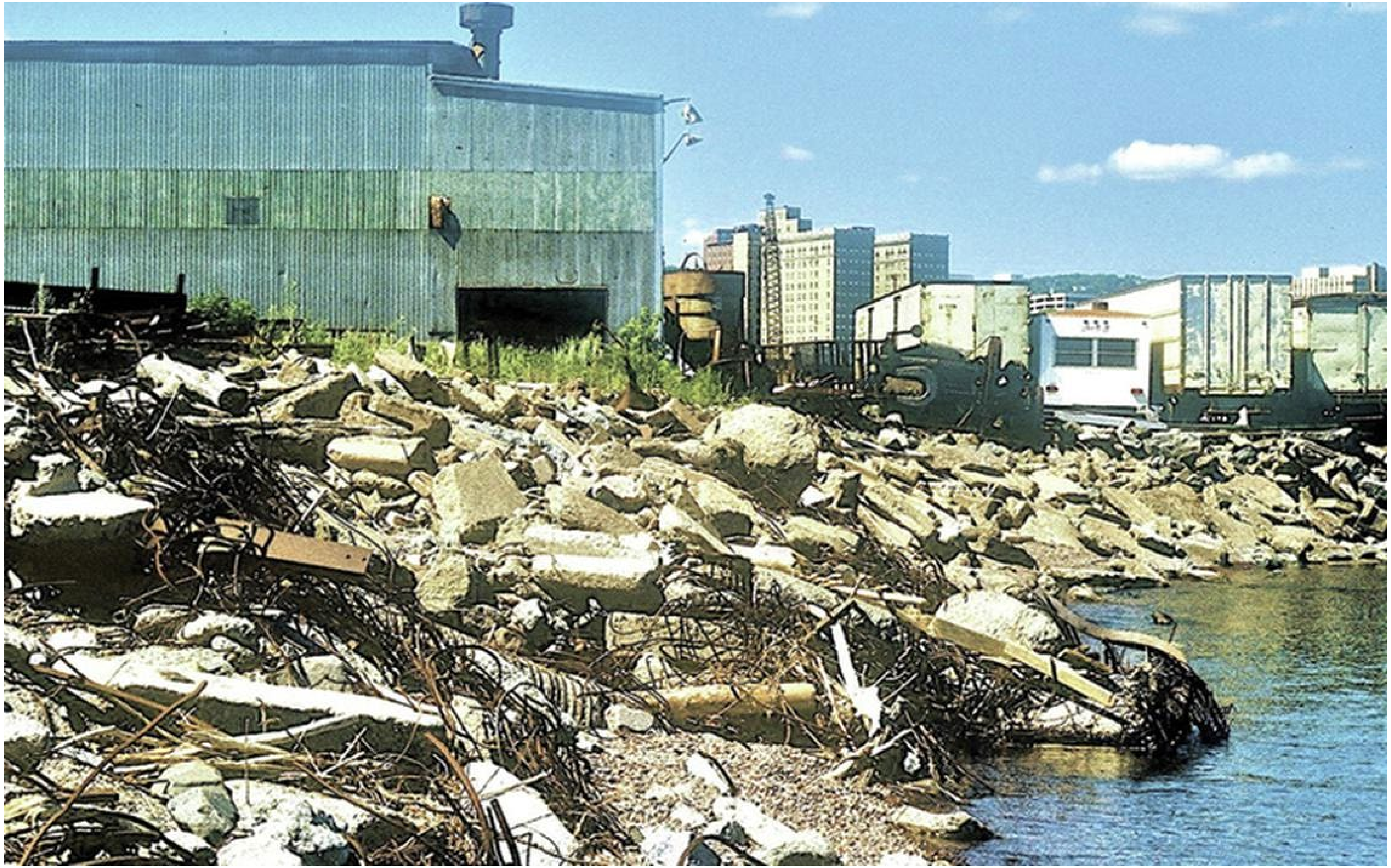

Fitgers
VEIT
CAT
VEIT

Sites Were Spread Out Across City Shoreline

Canal Park Shoreline and Lakewalk Damage

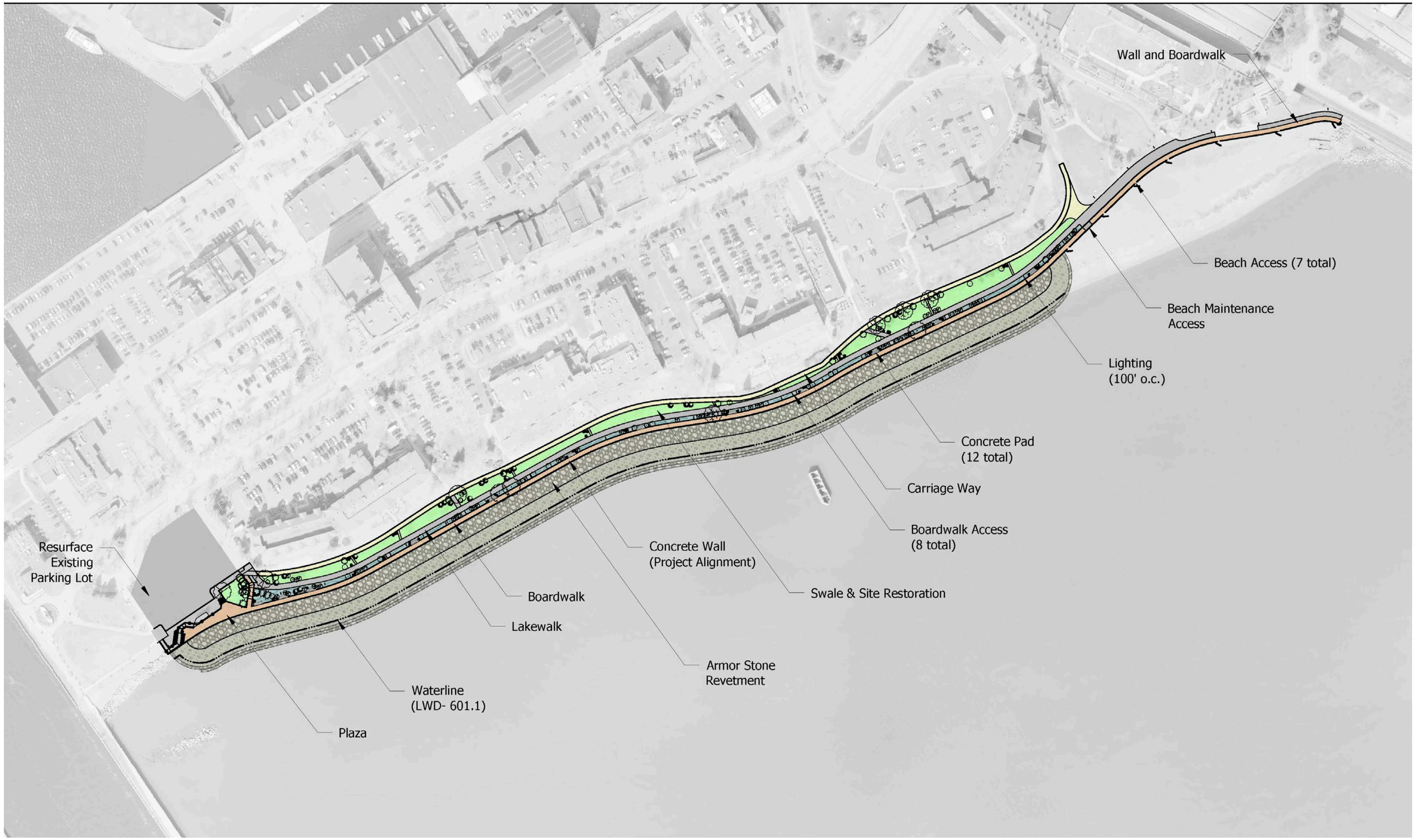
- Interstate 35 extension tunnels
- 179,000 tons rock moved
- 6.3 acres of new shoreline

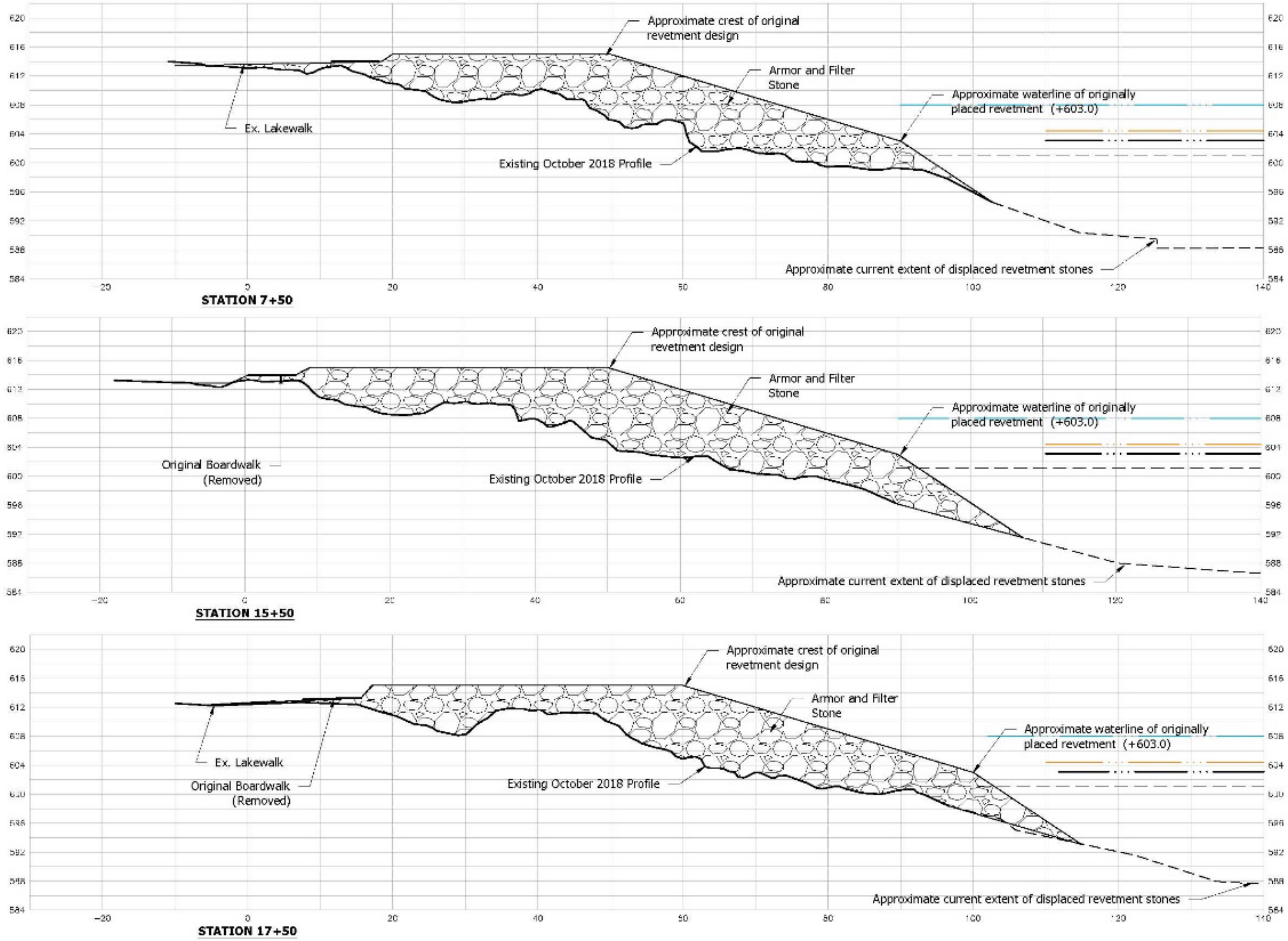
Canal Park Before Lakewalk

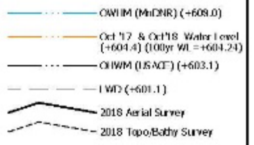


The Lake’s Fury: 1 Year - Three Major Storms

Canal Park Project Area







Notes:

Aerial data collected Nov 5th 2019 by Resolution Studio, LLC

Topo & bathy data collected by AMI Consulting Engineers, P.A.

Water level at time of survey: +602.5 IGLD85

Vertical Datum–NAVD88–IGLD85

[redacted]

Existing Cross Sections

Duluth Shoreline Rehabilitation - Canal Park

50% Construction Drawings

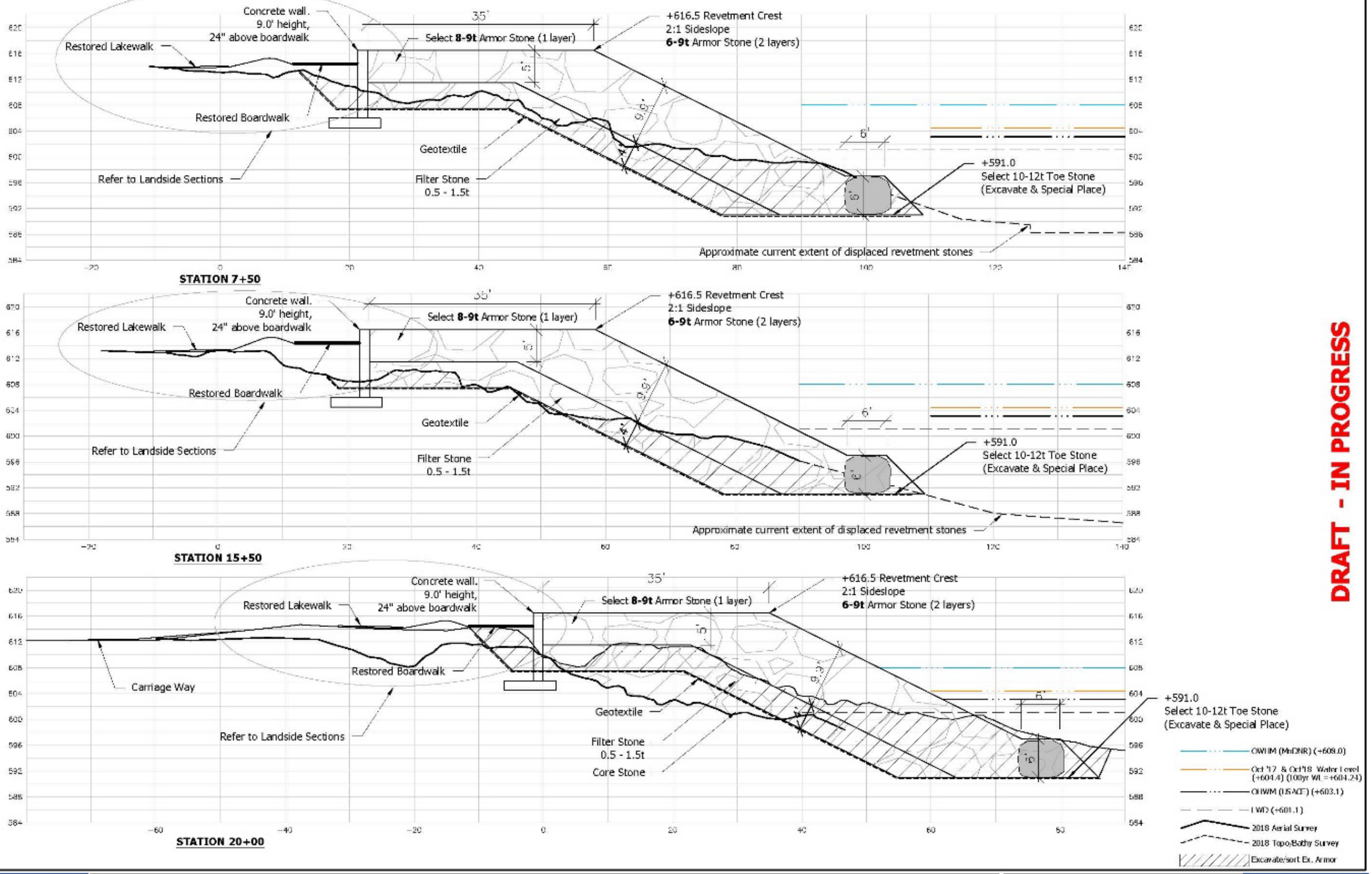
50% Complete CDs - Existing Cross Sections

171219-CD-CP-06

2020-01-03

[redacted]

Date Plotted: 1/8/2020 1:30:31 AM



DRAFT - IN PROGRESS

Notes:

Aerial data collected Nov 5th 2019 by Resolution Studio, LLC

Topo & bathy data collected by AMI Consulting Engineers, P.A.

Water level at time of survey: +600.5 IGLD85

Vertical Datum–NAVD88–IGLD85

[redacted]

Proposed Standard Cross Sections - Coastal

Duluth Shoreline Rehabilitation - Canal Park

50% Construction Drawings

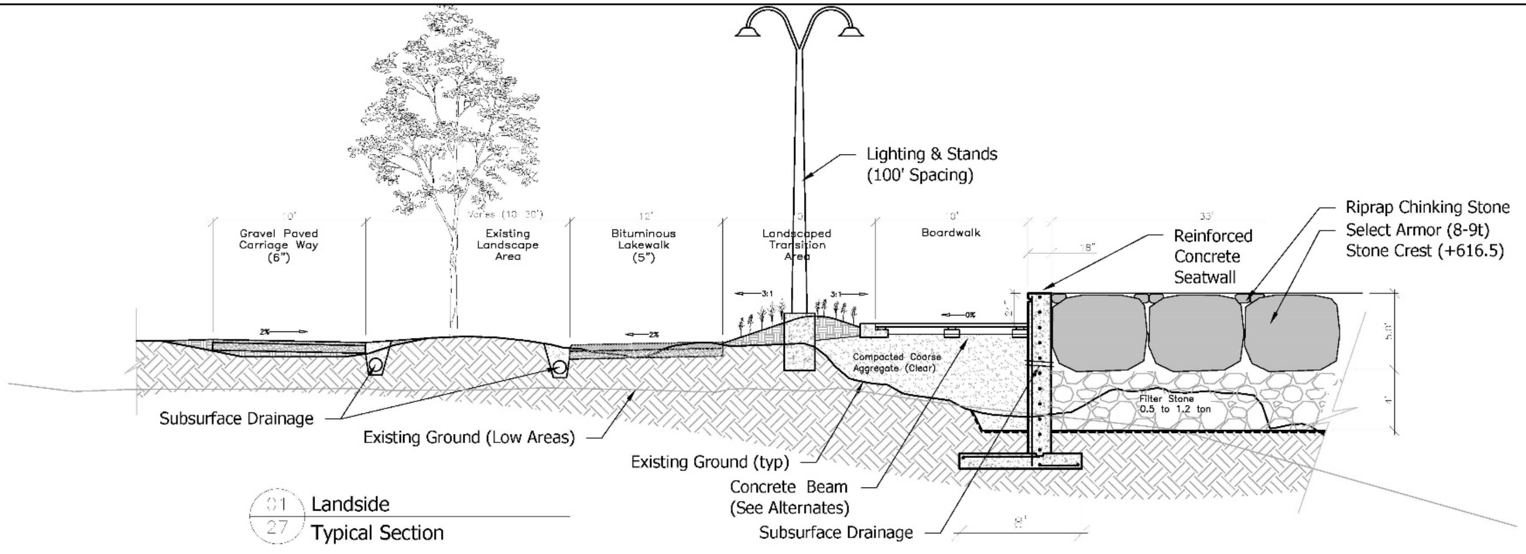
50% Complete CDs - Proposed Standard Cross Sections - Coastal

171219-CD-CP-25

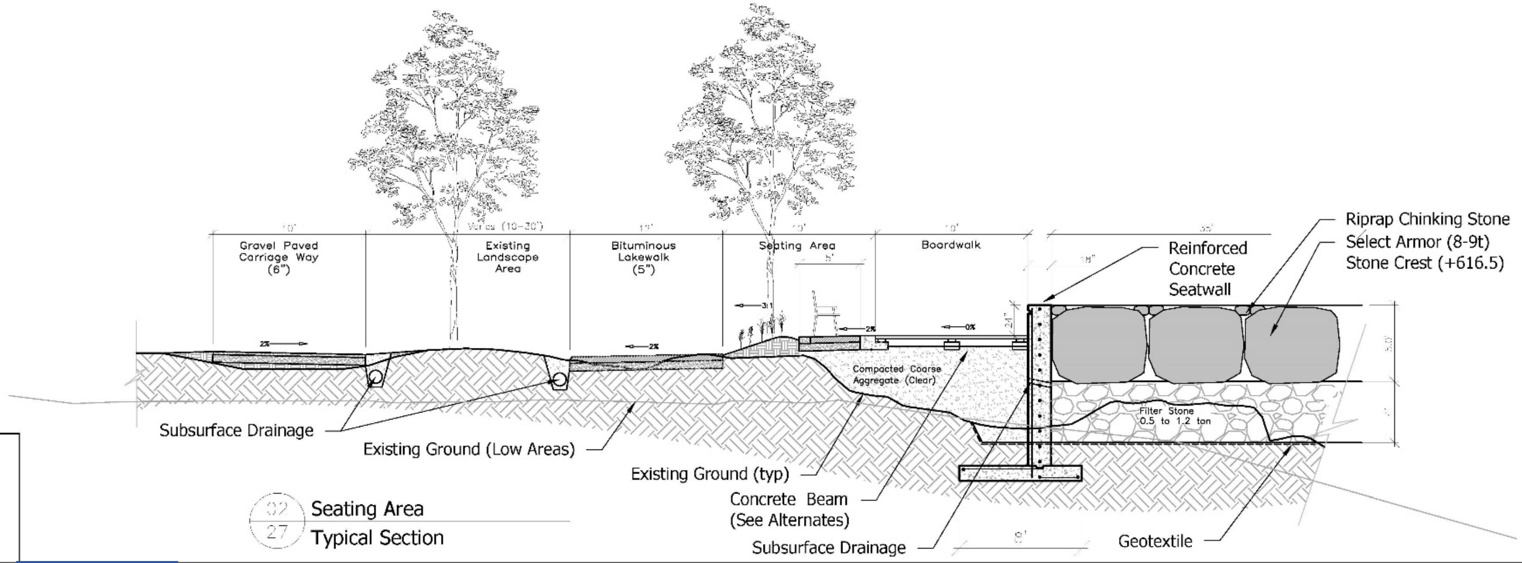
2020-01-03

[redacted]

Date Plotted: 1/8/2020 1:35:30 AM



01/27 Landside Typical Section



02/27 Seating Area Typical Section

DRAFT - IN PROGRESS

Notes:

[redacted]

Proposed Cross Sections - Landside 01

Duluth Shoreline Rehabilitation - Canal Park

50% Construction Drawings

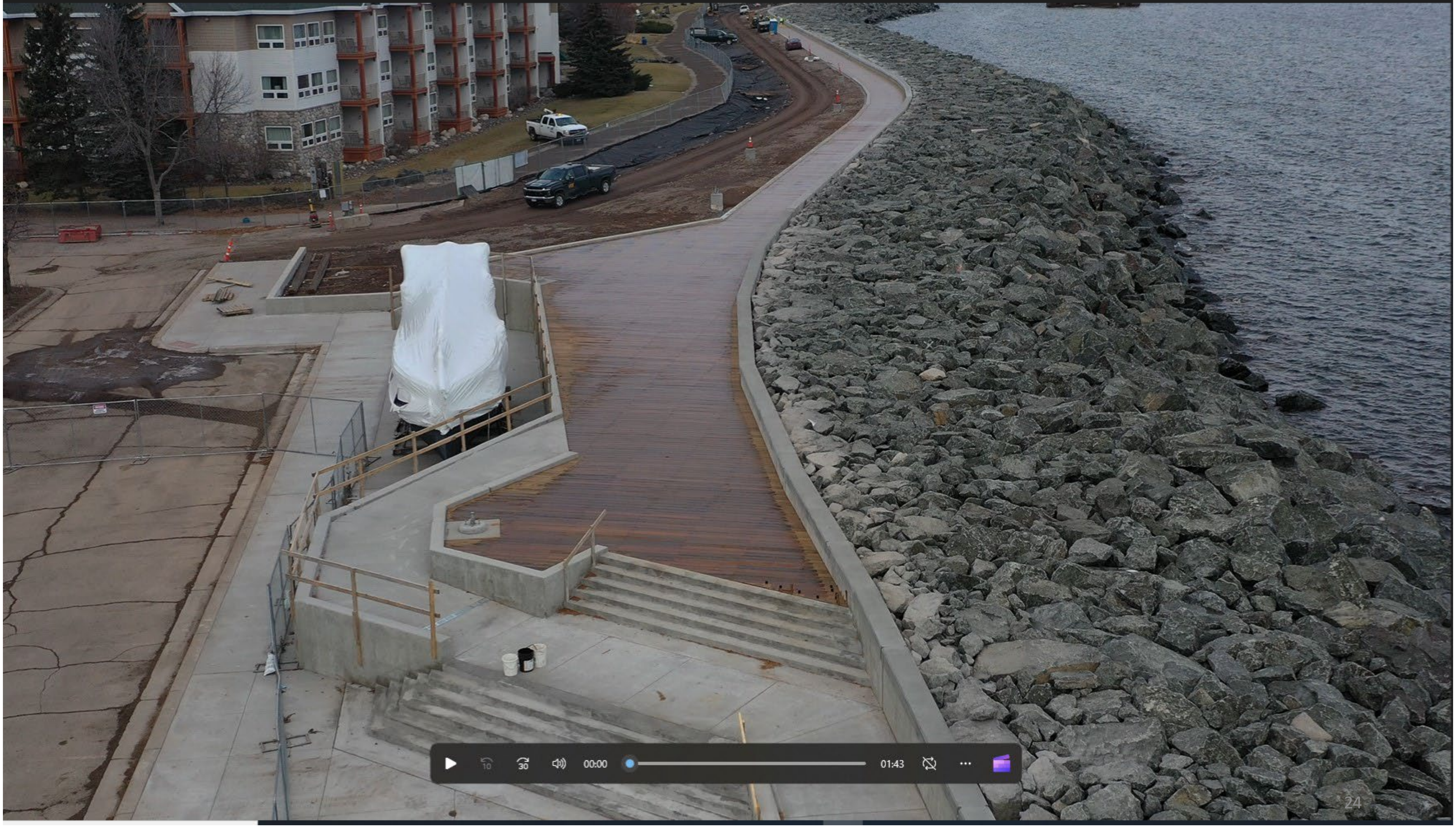
50% Complete CDs - Proposed Cross Sections - Landside 01

171219-CD-CP-27

Date: 2020-01-03

[redacted]


ZENITH MACHINE CO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Planning for Future Proactive Projects

- FEMA Hazard Mitigation Grant Program Advanced Assistance grant
- Joint effort with St. Louis County
- Covering remaining City sections of North Shore, County shoreline and bayside of Park Point Recreation Area
- Minnesota's north shore coast varies greatly in composition including competent rock faces, loose shelving rock and unstable eroding clay banks

Lessons Learned

- Retreat when possible
- Retreat can be vertical as well as horizontal
- Engineered systems including protected infrastructure, revetment and storm water management
- Abandonment and rewilding should be included in toolkit

EVALUATING INFRASTRUCTURE FOUNDATION PERFORMANCE WITH SOIL-MOISTURE SATELLITE DATA

Mehran Mazari, PhD
Associate Professor of Civil Engineering
Faculty Director, Sikand Center for Sustainable and Intelligent Infrastructure (SITI Center)
Founding Director, Sustainable Infrastructure Materials Laboratory (SIM-Lab)
California State University Los Angeles
mmazari2@calstatela.edu

Special thanks to our team

Undergraduate and graduate students:

- Simon Packman
- Joe Rosalez

Faculty collaborator:

- Dr. Sonya Lopez (hydrology and geosciences)

Why Infrastructure Resilience?

Climate Stressors

Flooding

Storm Surge & Waves

Sea Level Rise

Hurricanes

Droughts & Wildfires

Extreme Heat & Cold

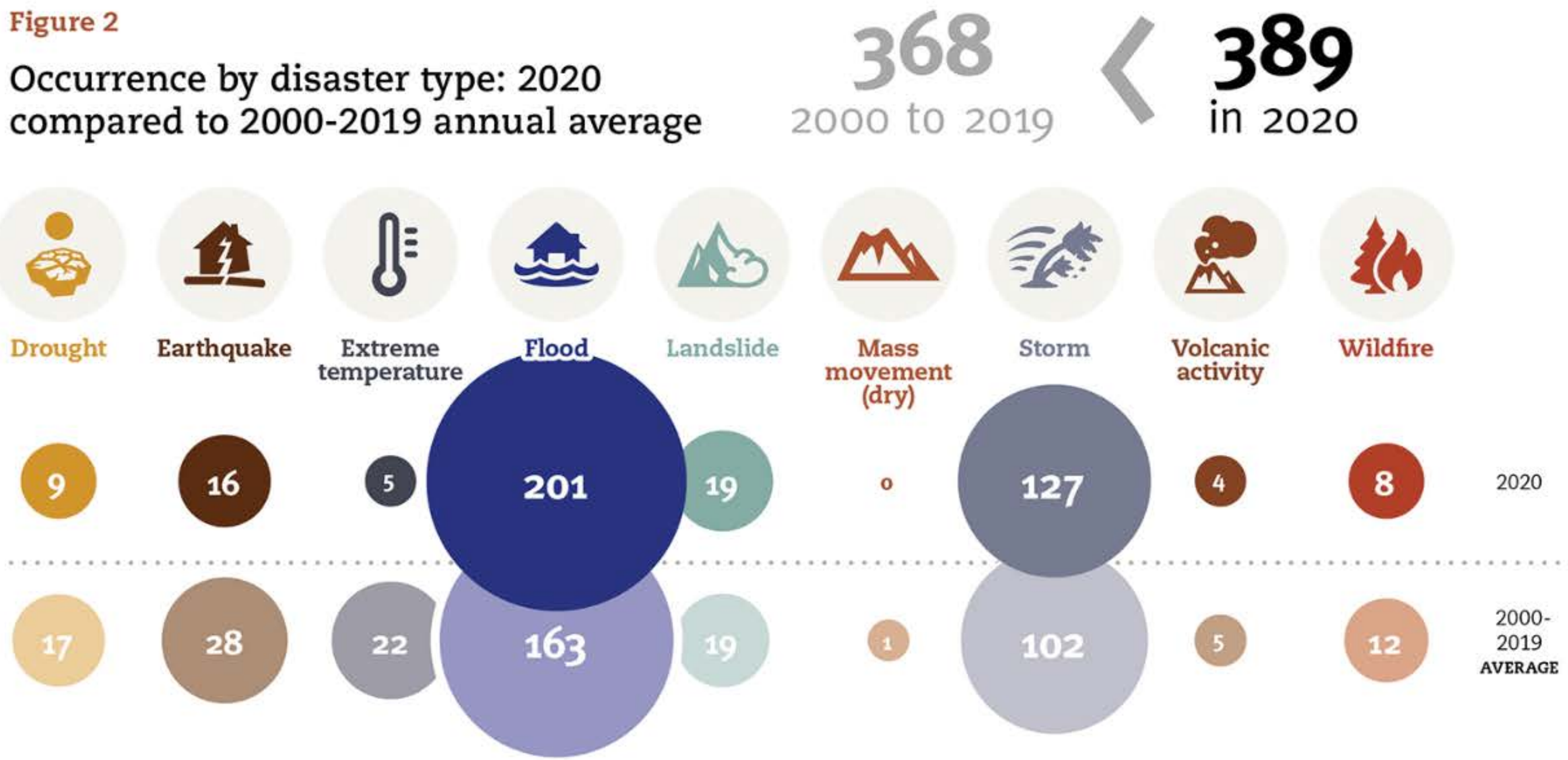
Hurricanes in the US

Hurricane Katrina
August 2005
Category 5
Estimated damage: **125 billion** USD

Hurricane Sandy
August 2012
Category 3
Estimated damage: **70 billion** USD

Hurricane Harvey
August 2017
Category 4
Estimated damage: **125 billion** USD

United Nations Office for Disaster Risk Reduction (UNDRR)



Source: UNDRR

Scan me for more information

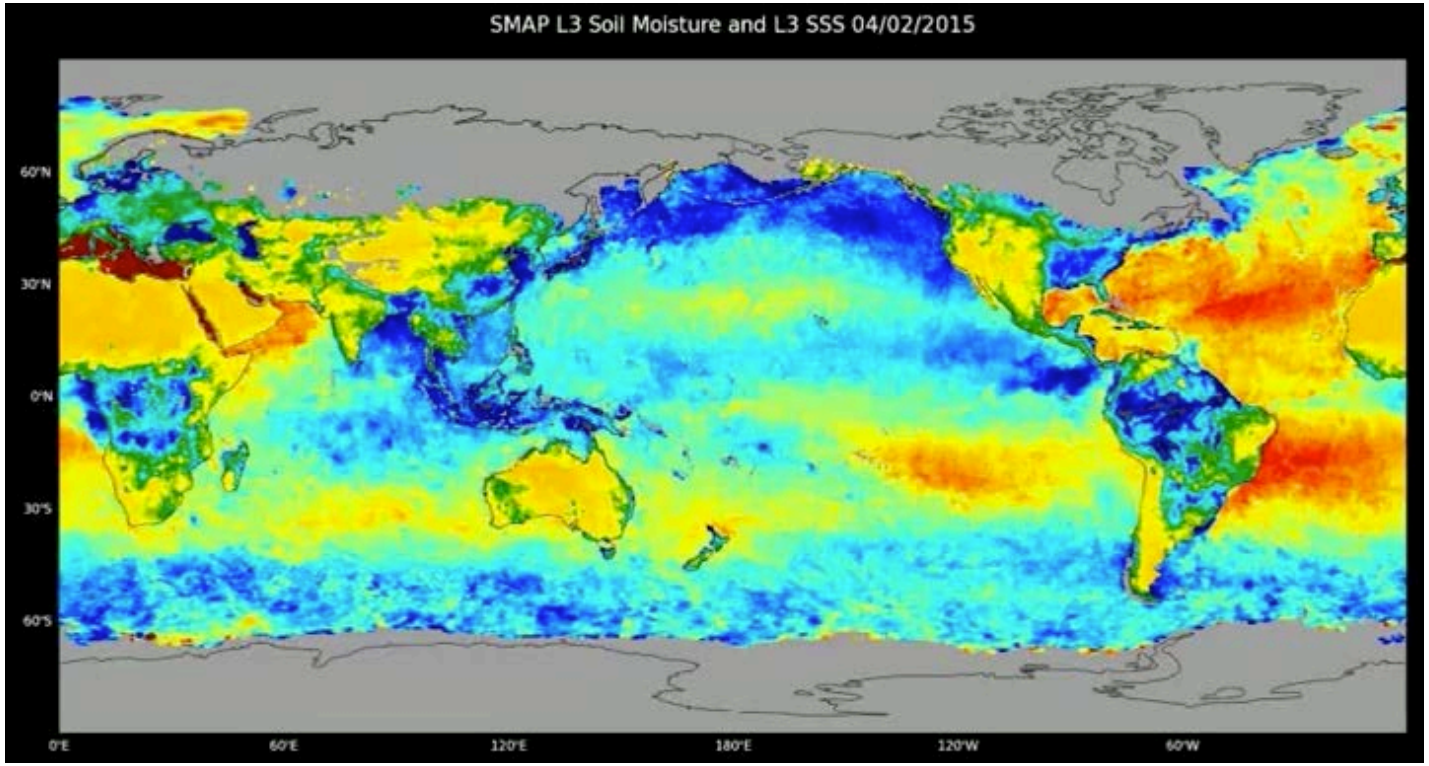
NASA Earth Observing Satellite Fleet

Courtesy of the NASA Goddard Visualization Lab

NASA-JPL

Soil Moisture Active-Passive (SMAP)

a NASA earth science mission



NASA-JPL

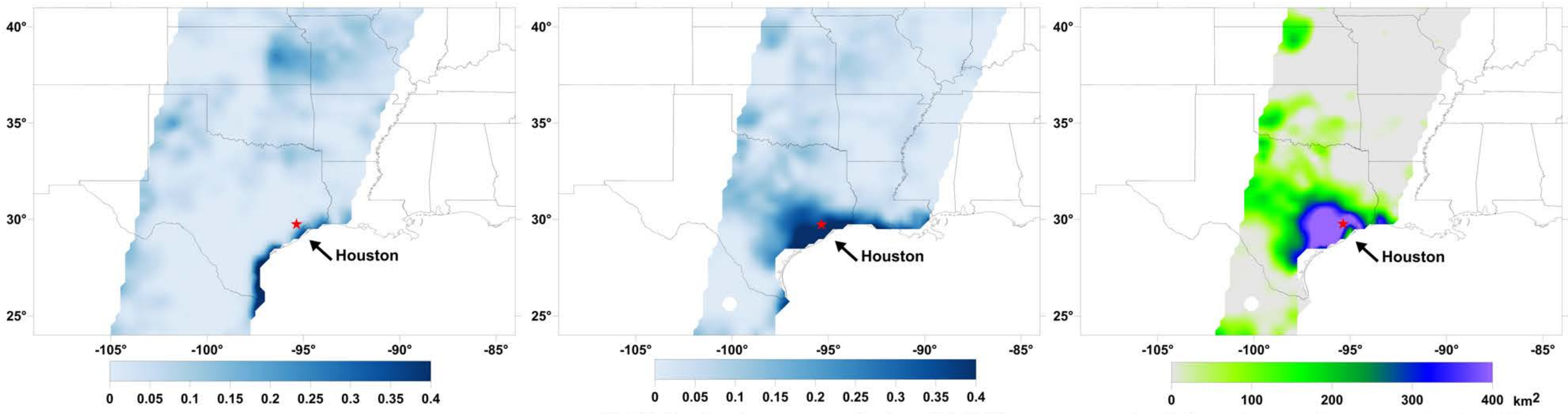
SMAP's Science Objective

To provide high-resolution, frequent-revisit, global observations of soil moisture and freeze/thaw state to:

- Link terrestrial water, energy and carbon-cycle processes
- Estimate global water and energy fluxes at the land surface
- Extend weather and climate forecast skills
- Develop improved flood and drought prediction capabilities

NASA-JPL

Case Study - Hurricane Harvey

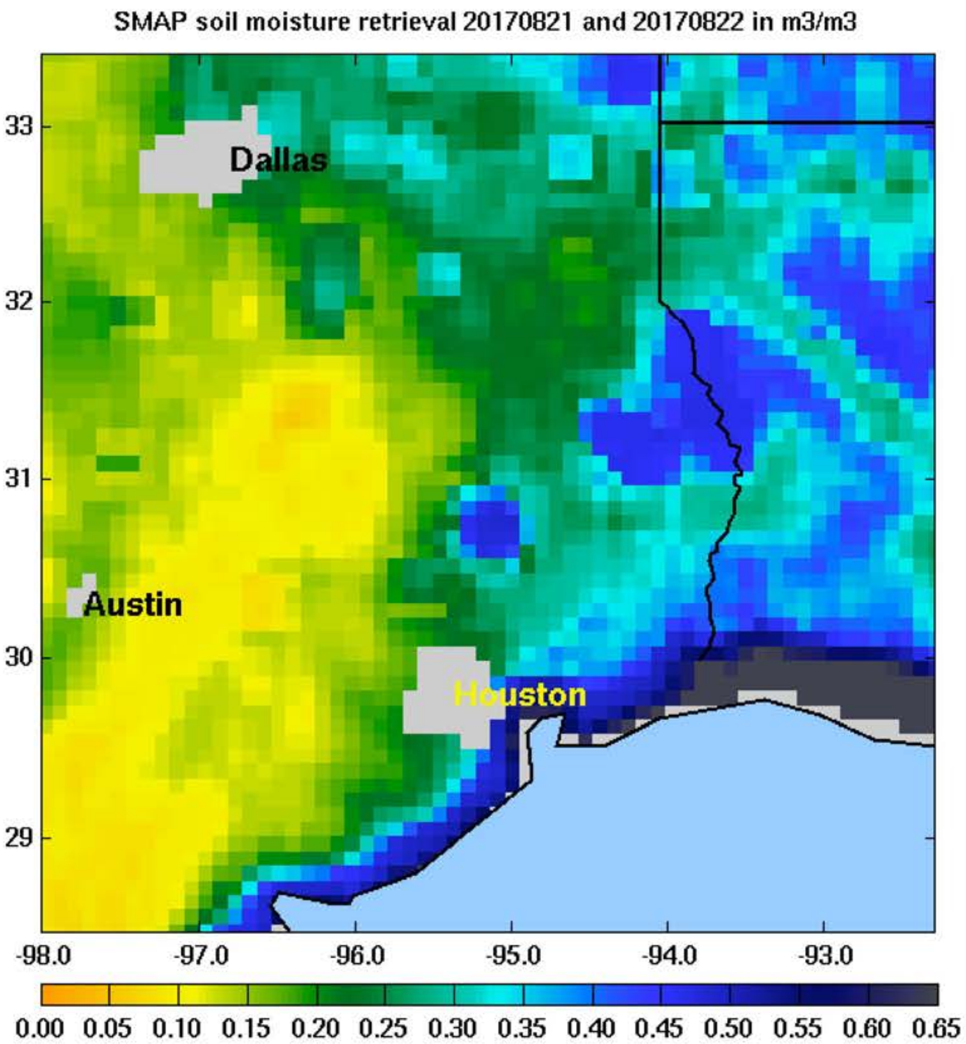


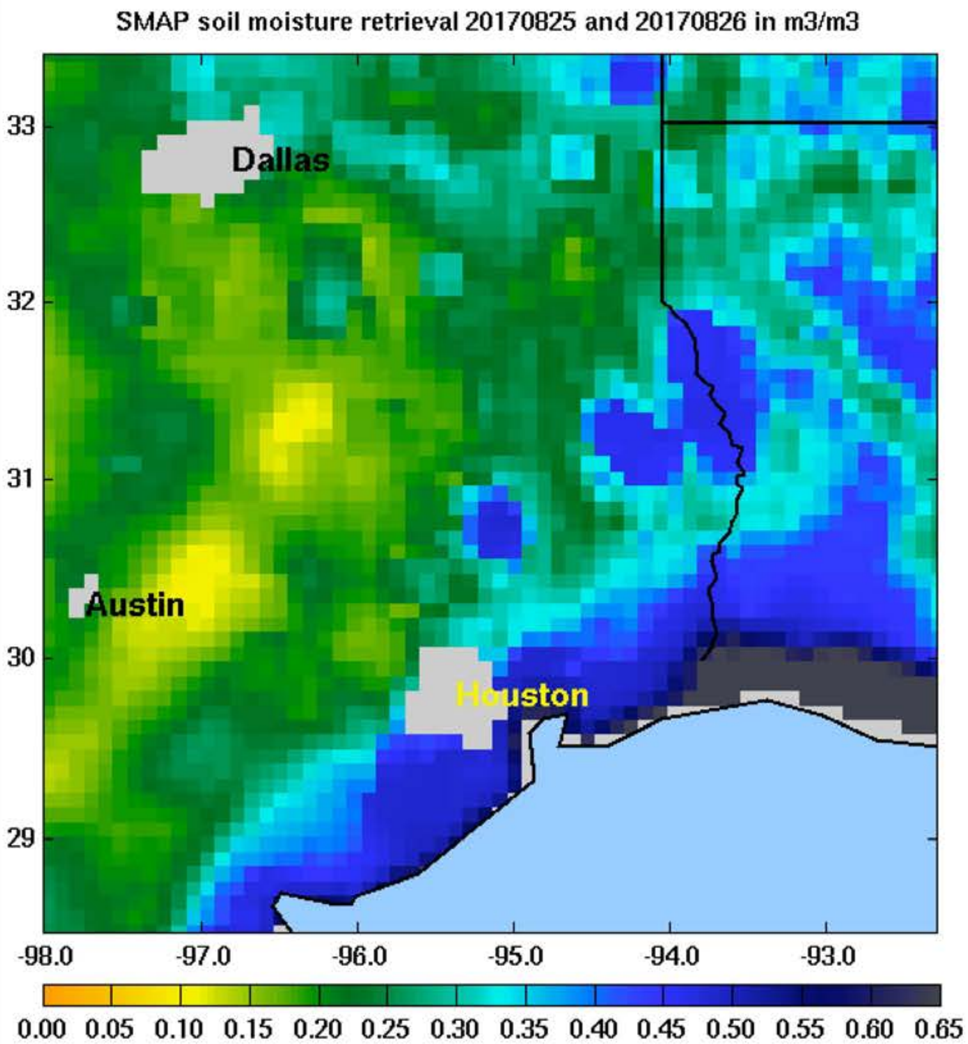
SMAP fractional open water for Aug. 22, 2017 SMAP fractional open water for Aug. 27, 2017 Flooded area increase from Aug. 22 to 27, 2017

NASA-JPL

The hardest hit areas (blue and purple shades) cover more than 23,000 square miles (about 59,600 square kilometers) and indicate a more than 1,000-fold increase in surface water cover from rainfall-driven flooding. SMAP's low-frequency (L-band) microwave radiometer features enhanced capabilities for detecting surface water changes in nearly all-weather conditions and under low-to-moderate vegetation cover.

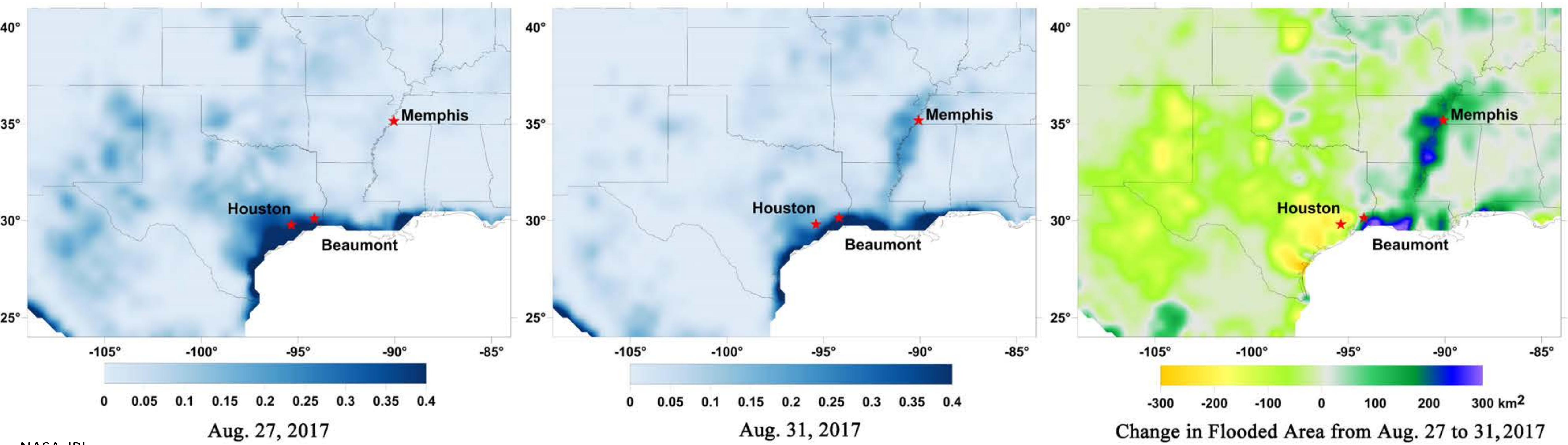
Case Study - Hurricane Harvey





NASA-JPL

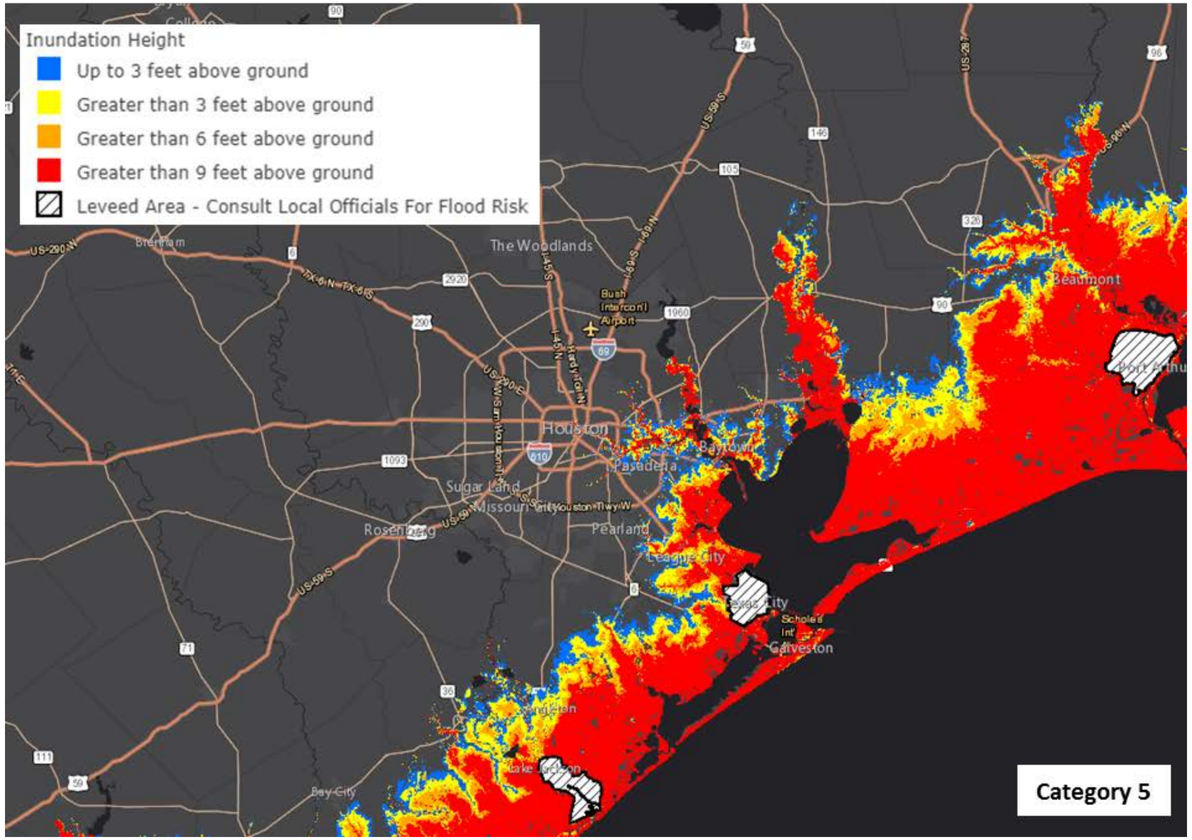
Aftermath of Hurricane Harvey



NASA-JPL

Scope of Research

To evaluate the feasibility of using remote sensing and satellite data to estimate the performance of transportation infrastructure foundation layers



NOAA

Flooded Pavements

- Effect of flooding on long-term performance
- Guidelines for highway agencies to assess short-term and long-term impacts

Coomer, 2017

Moisture-Modulus Correlations

Inverse correlation between resilient modulus and moisture content

Environmental Factor

$$MR = F_{env} \times MR_{opt}$$

Resilient Modulus at a specific moisture level

Resilient Modulus at optimum moisture content

Regression parameters

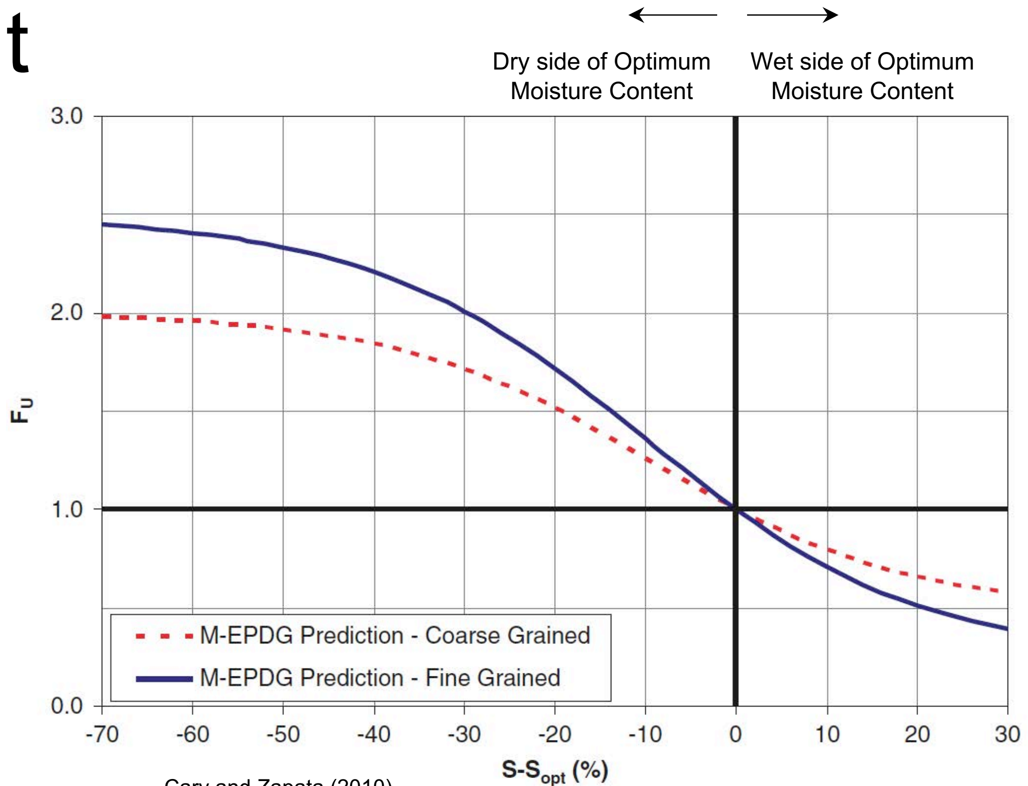
$$\log(F_{env}) = log\left(\frac{M_R}{M_{Ropt}}\right) = a + \frac{b-a}{1+e^{\left(ln\frac{-b}{a}+k_m\times\left(S-S_{opt}\right)\right)}}$$

Regression parameters

Change in degree of saturation

Cary and Zapata (2010)

Witczak et al. (2004)



Cary and Zapata (2010)

Moisture-Modulus Correlations (cont.)

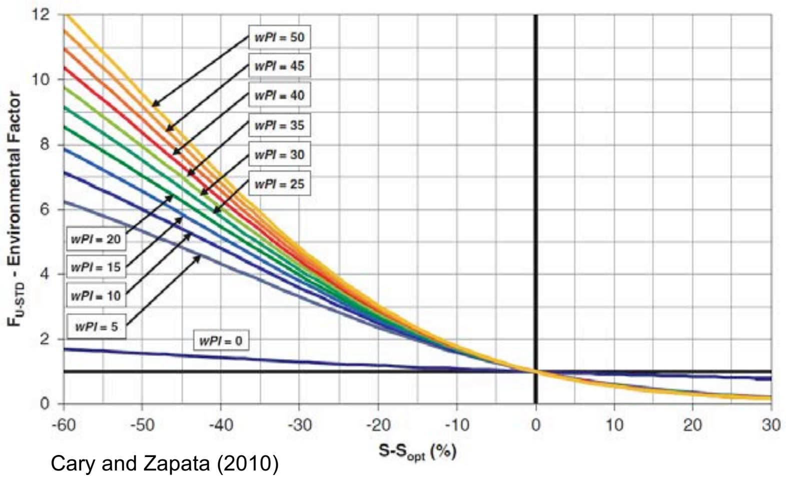
Regression parameters

$$\log(F_{env}) = (\alpha + \beta \times e^{-wPI})^{-1} + \frac{(\delta+\gamma\times wPI^{0.5})-(\alpha+\beta\times e^{-wPI})^{-1}}{1+e^{\left(ln\left(\frac{-(\delta+\gamma\times wPI^{0.5})}{(\alpha+\beta\times e^{-wPI})^{-1}}\right)+(\rho+\omega\times e^{-wPI})^{0.5}\times\left(\frac{S-S_{opt}}{100}\right)\right)}}$$

w = percent fines (passing #200 sieve)
PI = Plasticity Index

Regression parameters

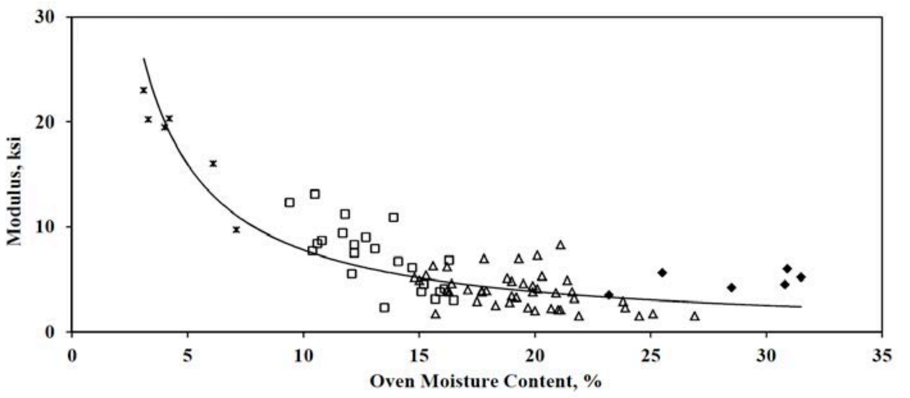
Cary and Zapata (2010)



Cary and Zapata (2010)

wPI = 0 ⟶

$$\log F_{env} = \left[(-0.40535) + \frac{1.20693}{1+e^{\left[0.68184+1.33194\times(\frac{S-S_{opt}}{100}\right]}}\right]$$



Nazarian et al. (2014)

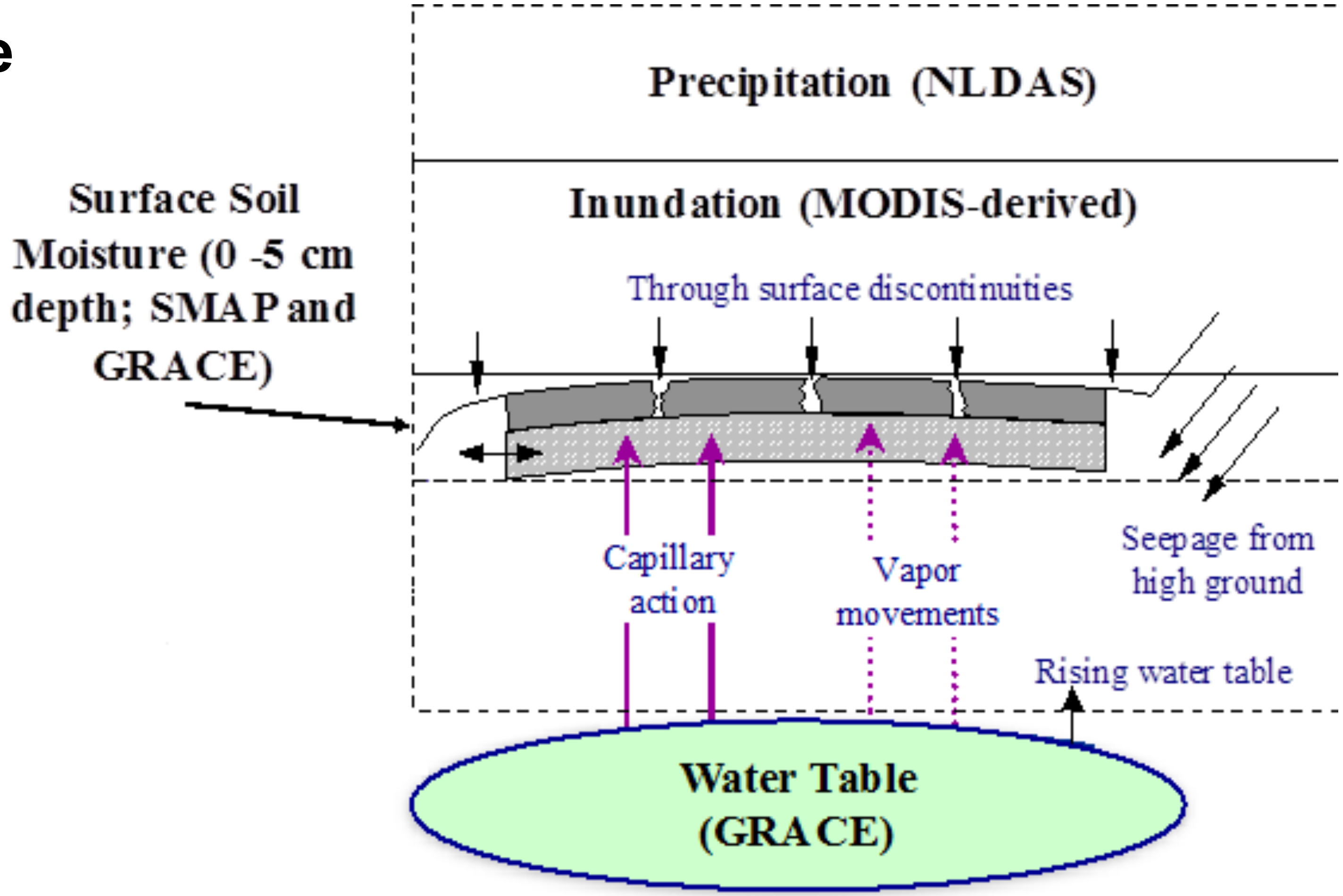
Satellite Data and Pavement Flooding

Gravity Recovery and Climate Experiment (GRACE)

North American Land Data Assimilation System (NLDAS)

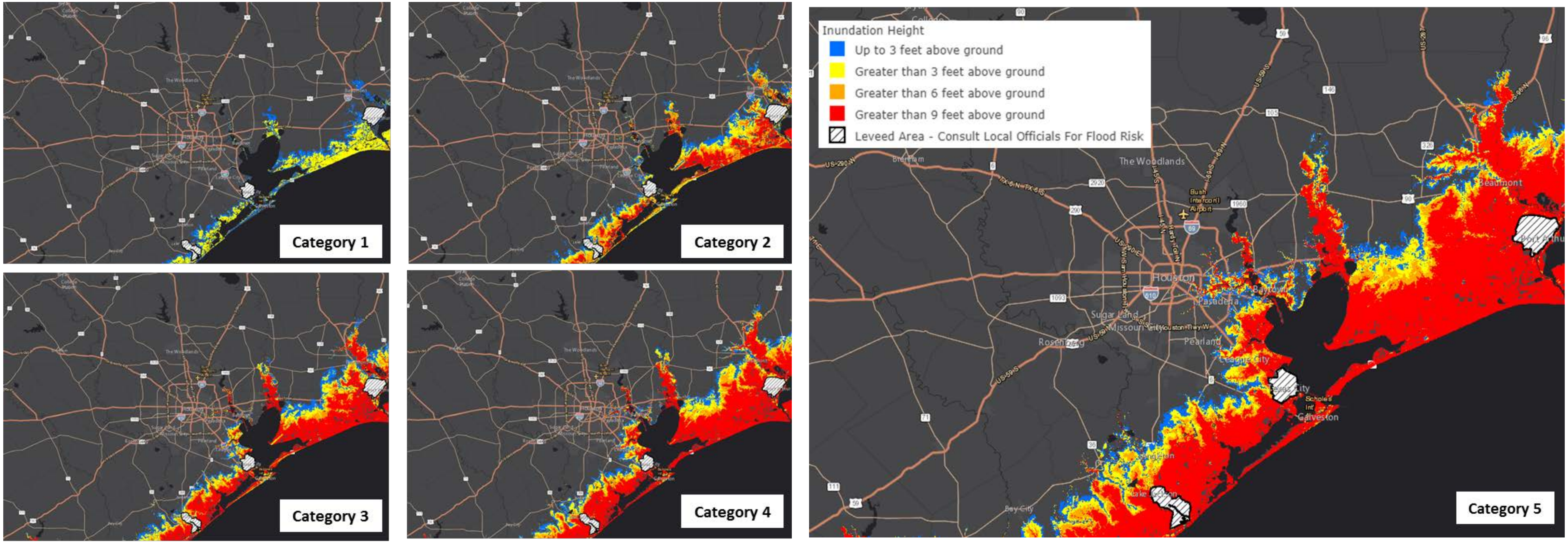
Moderate Resolution Imaging Spectroradiometer (MODIS)

Soil Moisture Active Passive (SMAP)



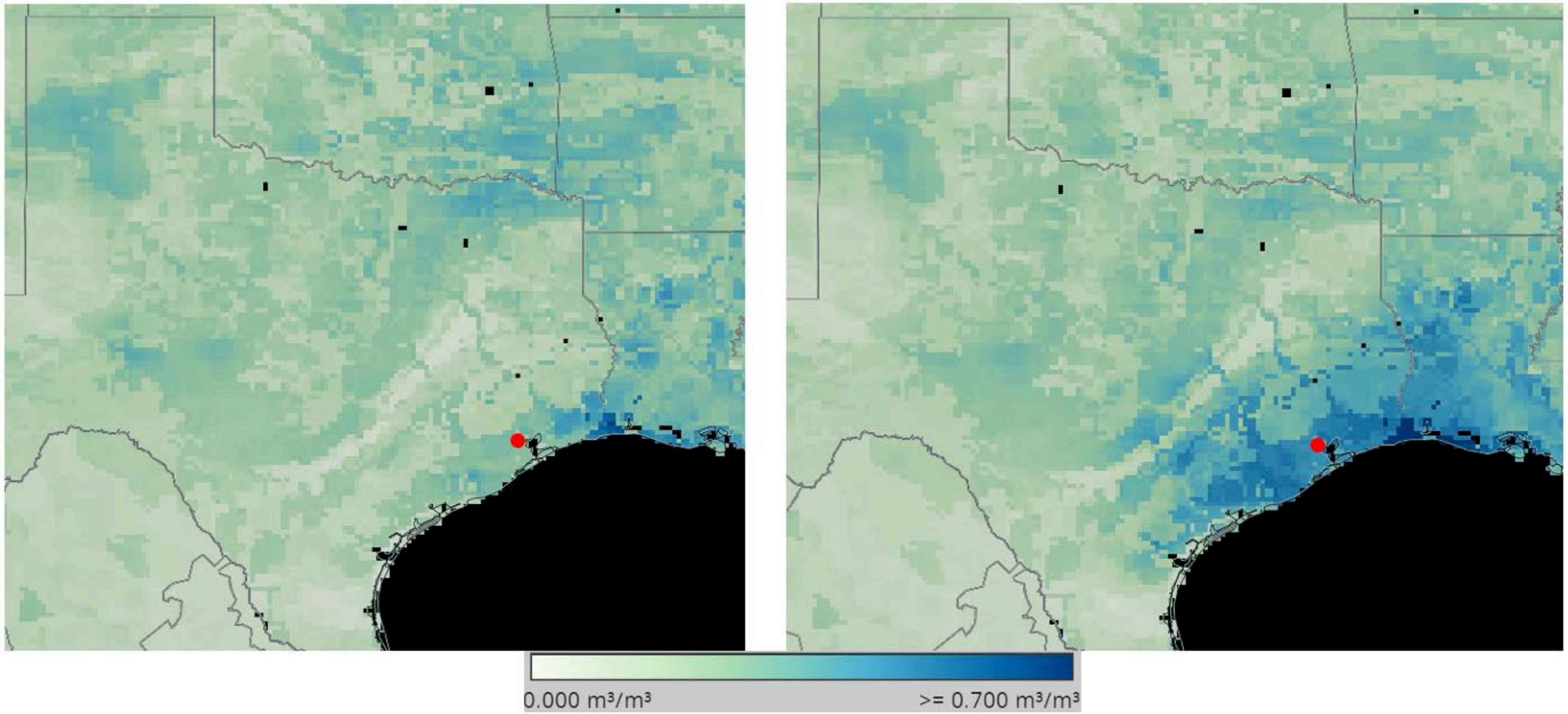
Christopher et al. (2006) and Packman et al. (2018)

NOAA Inundation Simulator



NOAA

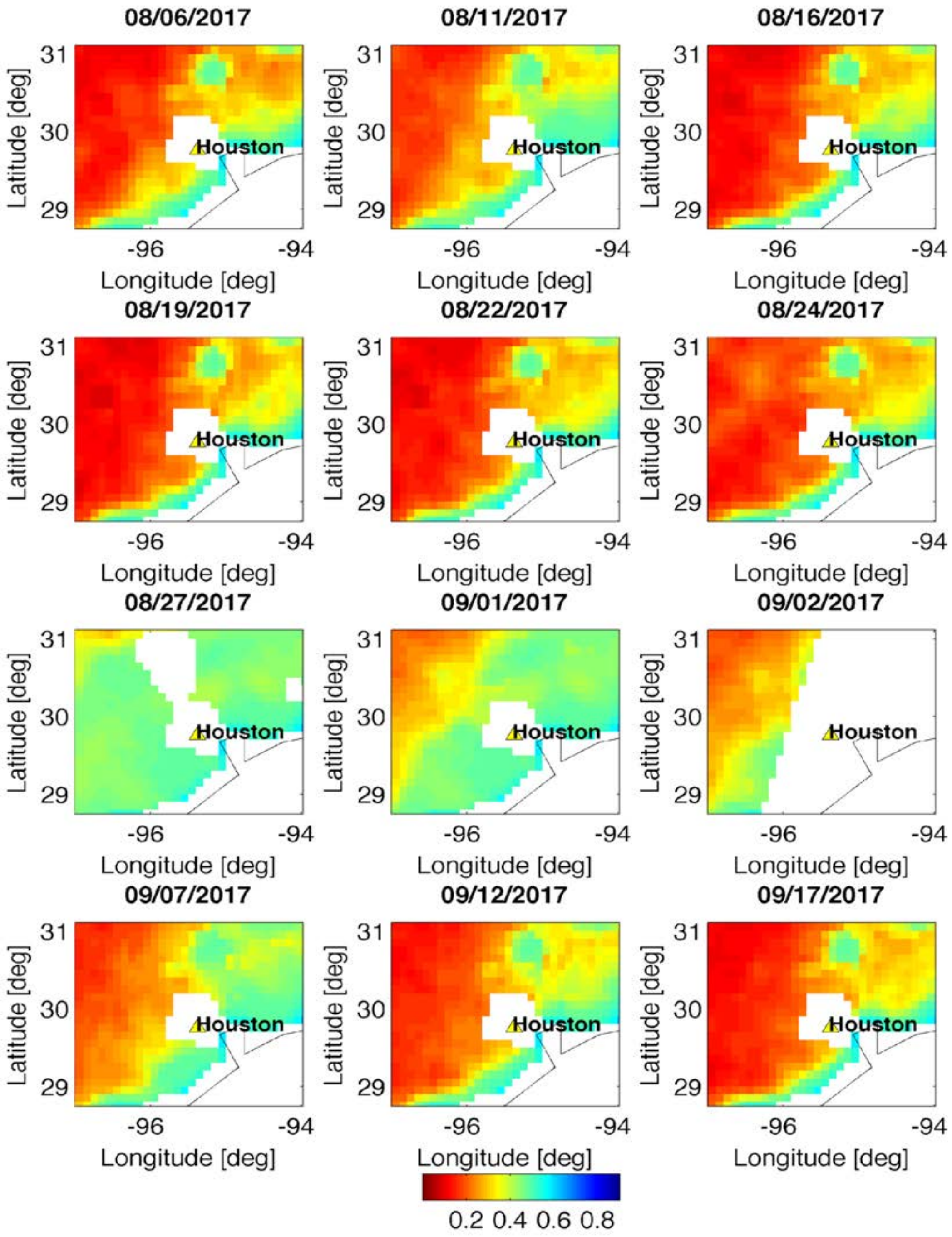
Satellite Data Extraction



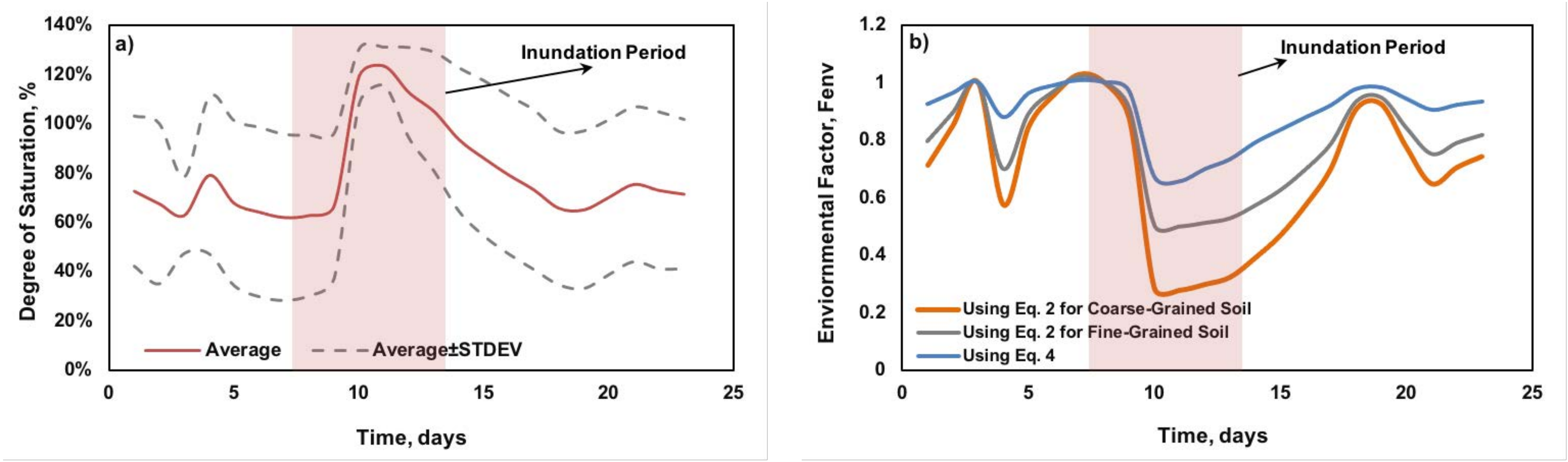
Comparison of SMAP Root Zone Volumetric Soil Moisture (m^3/m^3) within the Coast of Texas before and during Hurricane Harvey

Satellite Data Extraction
(cont.)

Variation of Volumetric Surface Moisture Content (cm^3/cm^3) throughout the Study Area during the Storm Surge



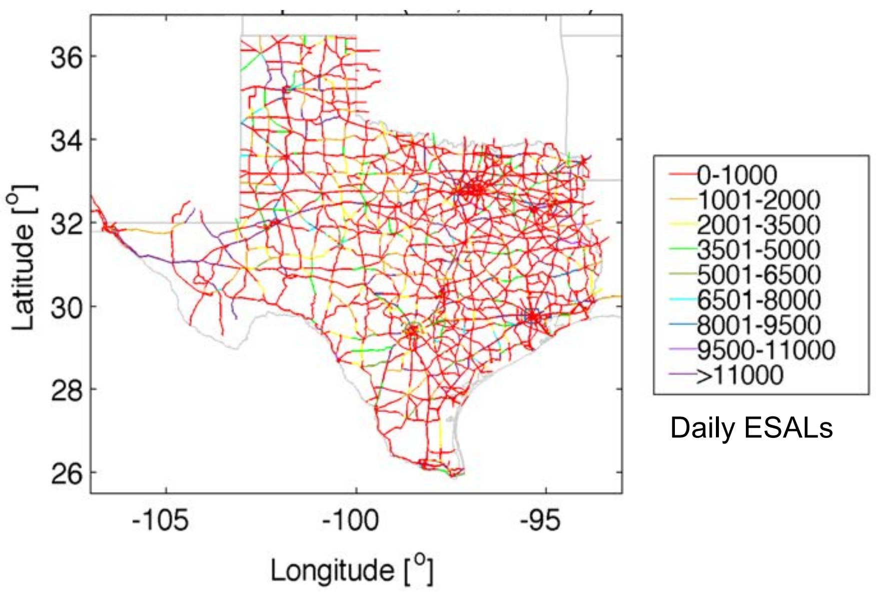
Observations



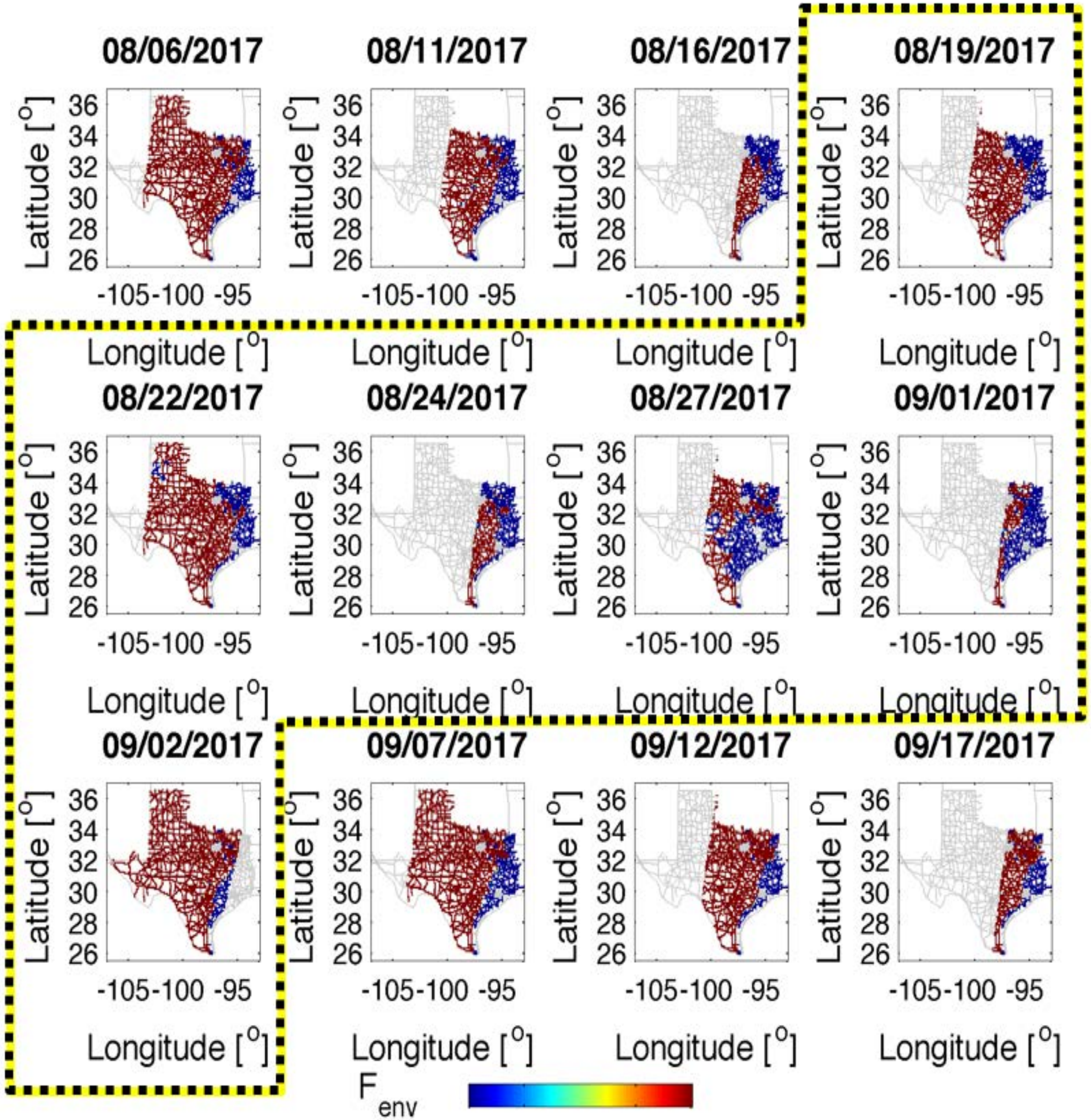
a) Variation of Soil Degree of Saturation based on Satellite Data, and b) Variation of Pavement Foundation Modulus for Different Soil Types before, during, and after Hurricane Harvey

Satellite Data and Road Network

Variation of environmental factor (F_{env}) for the Study Area during the Storm Surge



Daily ESALs



Acknowledgment

This study was partially funded by NASA Data Intensive Research and Education Center for STEM (DIRECT-STEM) at California State University Los Angeles.

Thank you

Climate Change Effect on Moisture Variation in Highway Slopes on Expansive Soil

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Associate Professor
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Annual Precipitation Compared to 20th Century Average

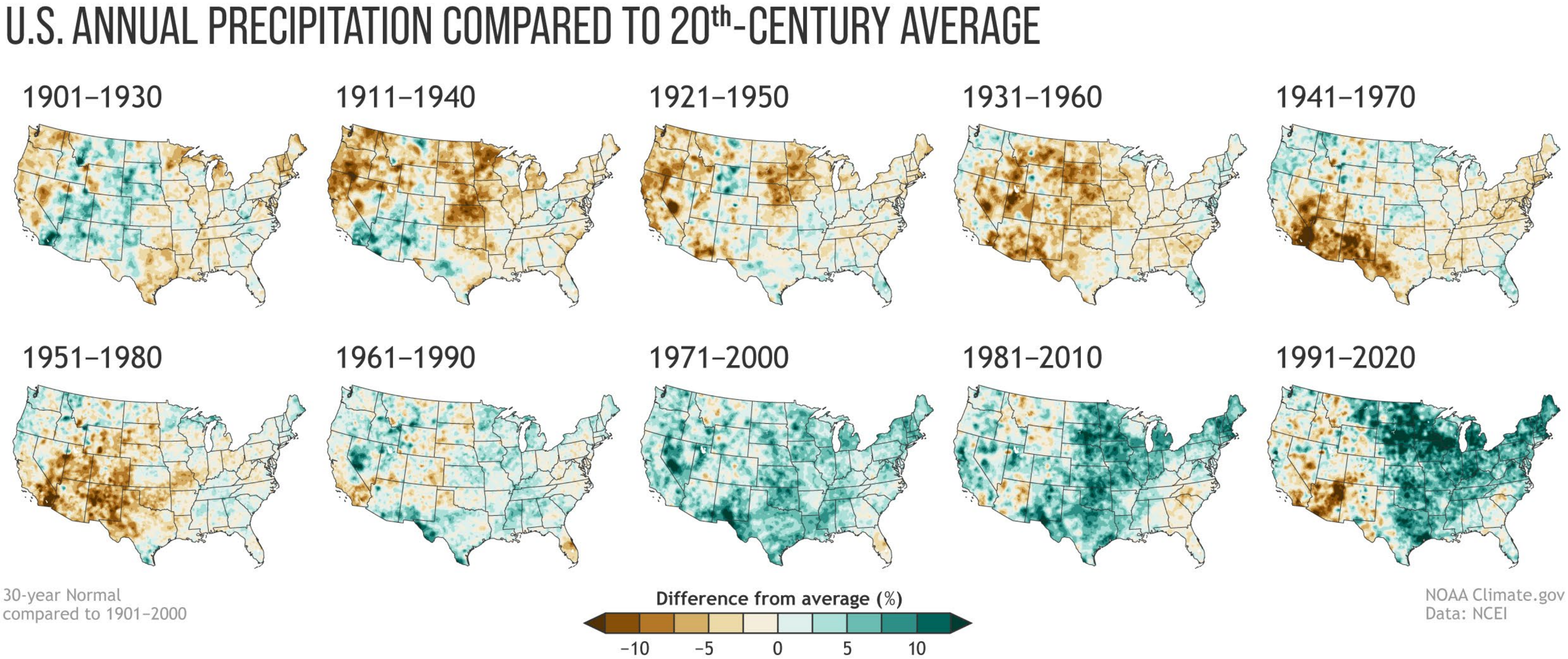
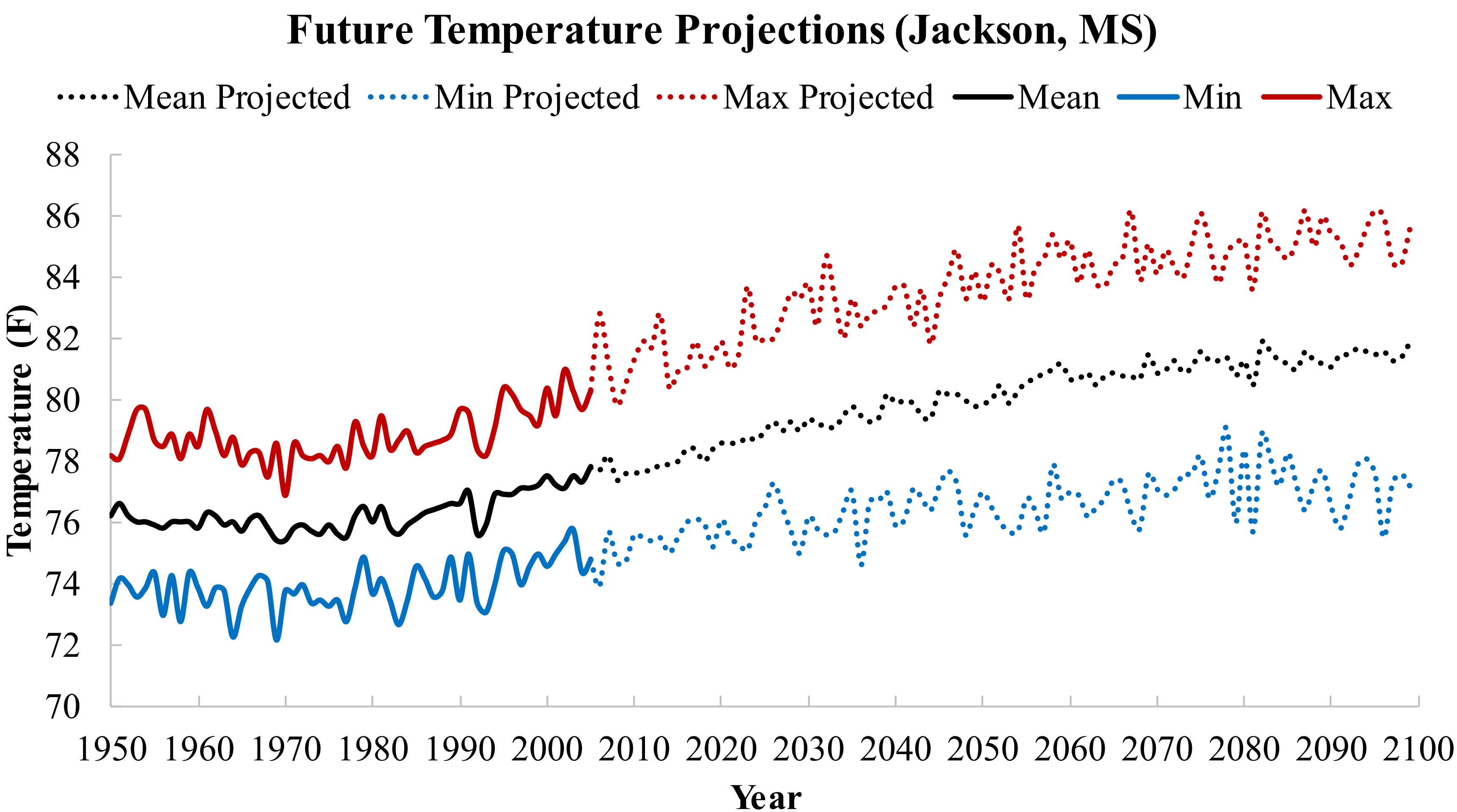


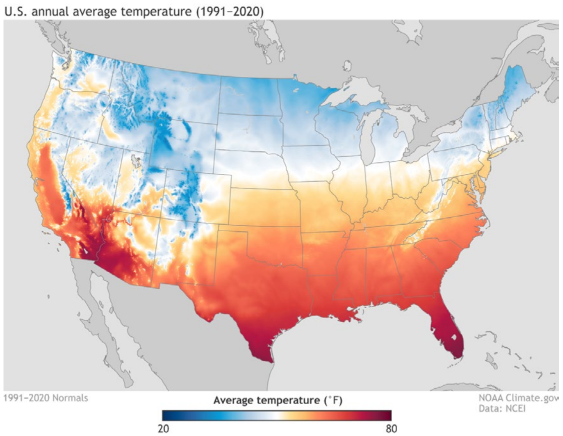
Image Source: NOAA Climate.gov

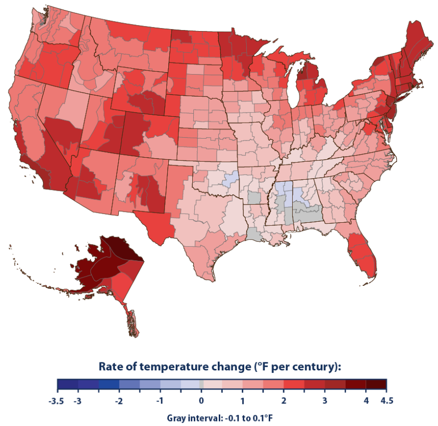
Temperature Projection

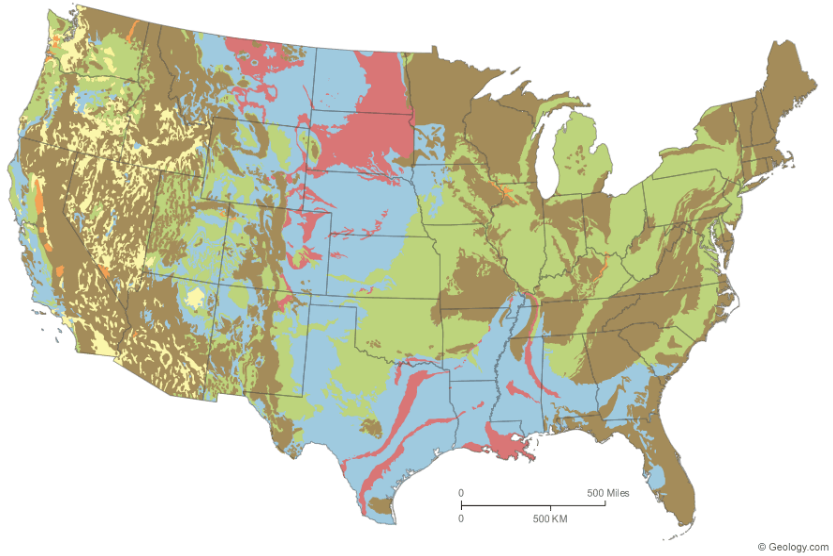


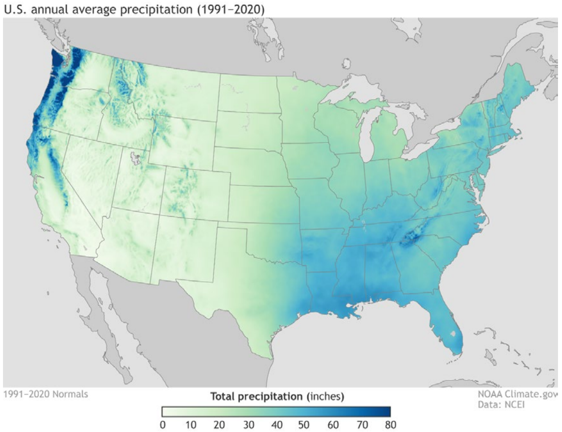
Data Source: NOAA Climate.gov

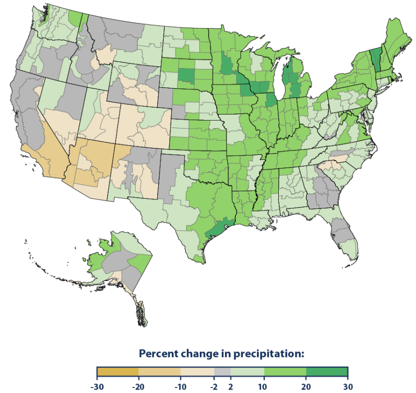
Temperature and Precipitation Variation Due to Climate Change









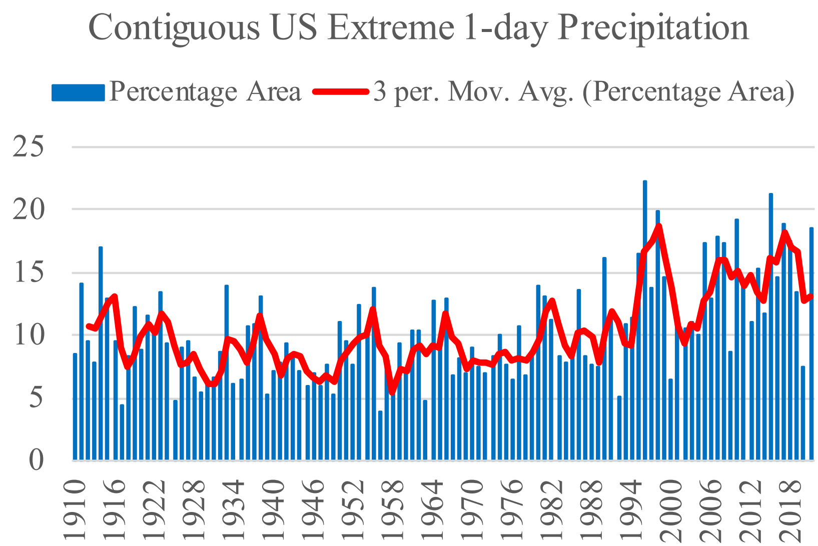


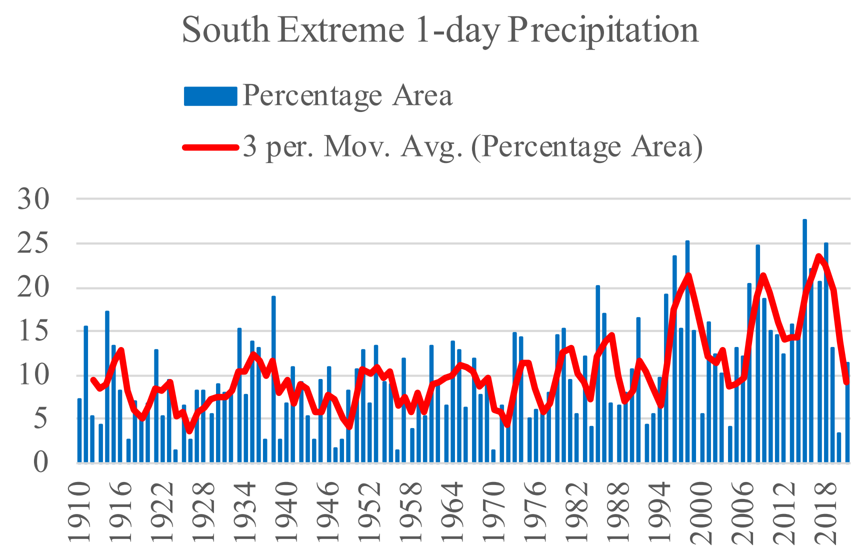
Legend:
Red: Clay having high swelling potential
Blue: Less than 50% of clay contents having high swelling potential
Orange: Clay content having slight to moderate swelling potential
Green: Less than 50% of clay contents having slight to moderate swelling potential
Brown: Little or no swelling clay
Yellow: Insufficient data

Image Source: NOAA Climate.gov

Effect of Temperature Increase on Precipitation

For every 1 °C (1.8 °F) rise in temperature, the water-holding capacity of the atmosphere increase by about 7%.





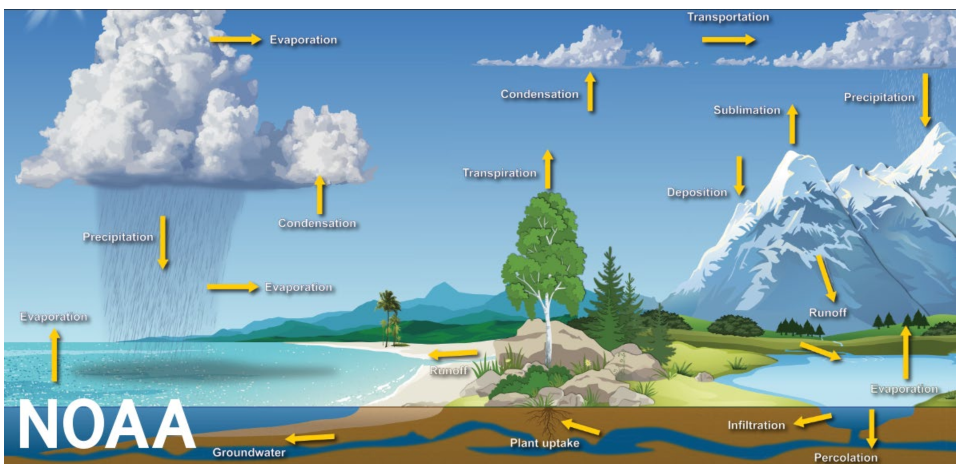
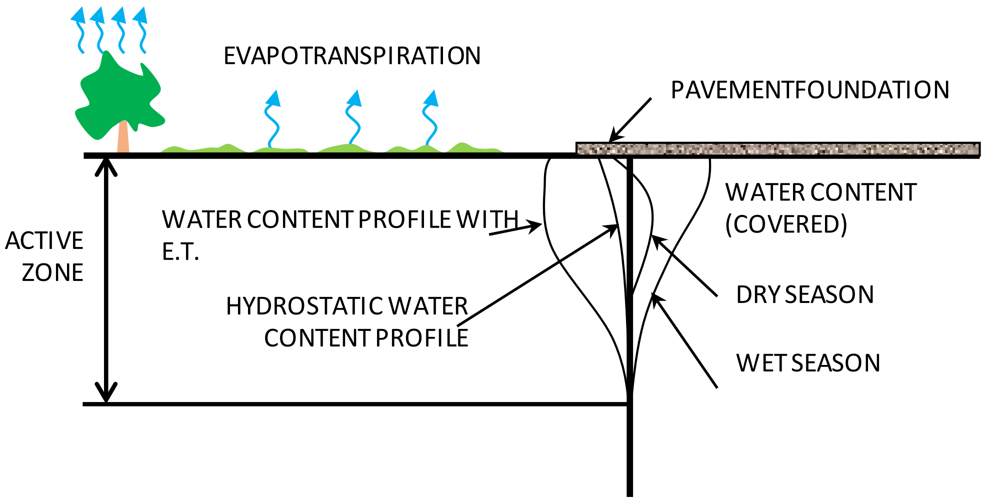
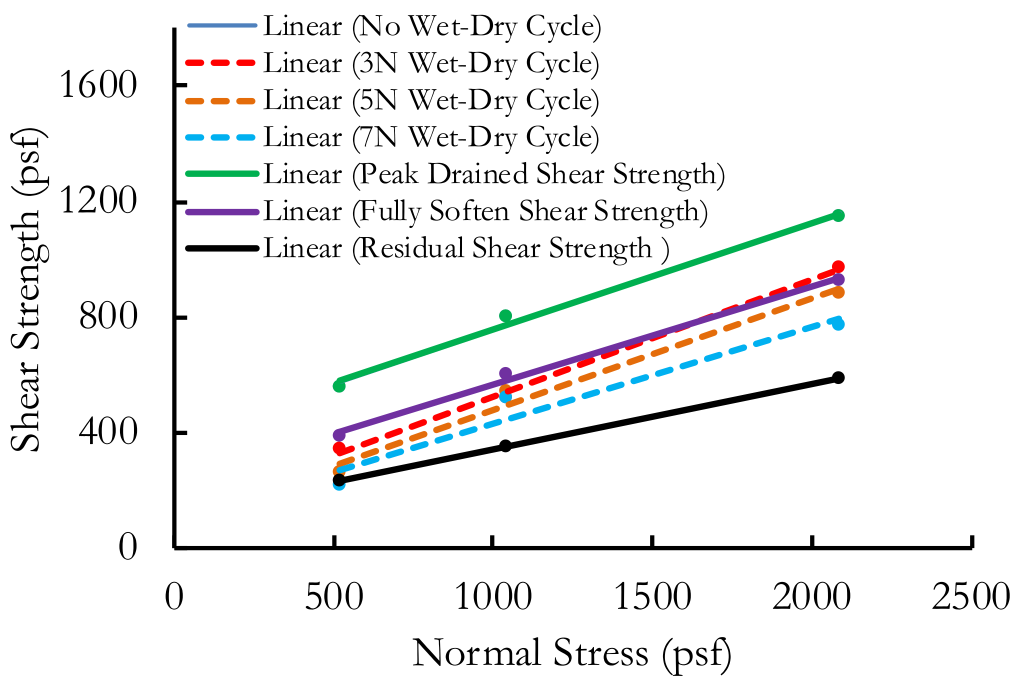


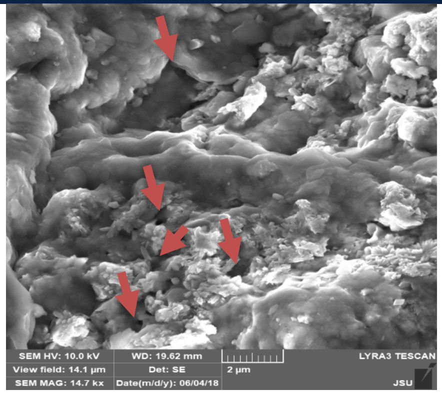
Image & Data Source: NOAA Climate.gov

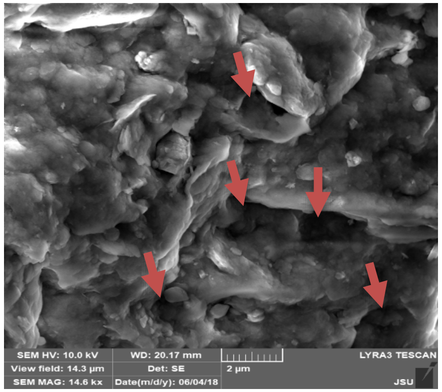
Effect of Wet-Dry Cycles on Expansive Clay





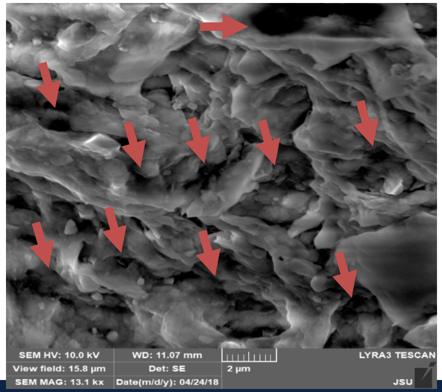
3N Wet-Dry Cycles





5N Wet-Dry Cycles

7N Wet-Dry Cycles



Expansive Formational Clays in Mississippi

A. Yazoo Clay Formation

B. Porters Creek Clay Formation

C. Zilpha Formation

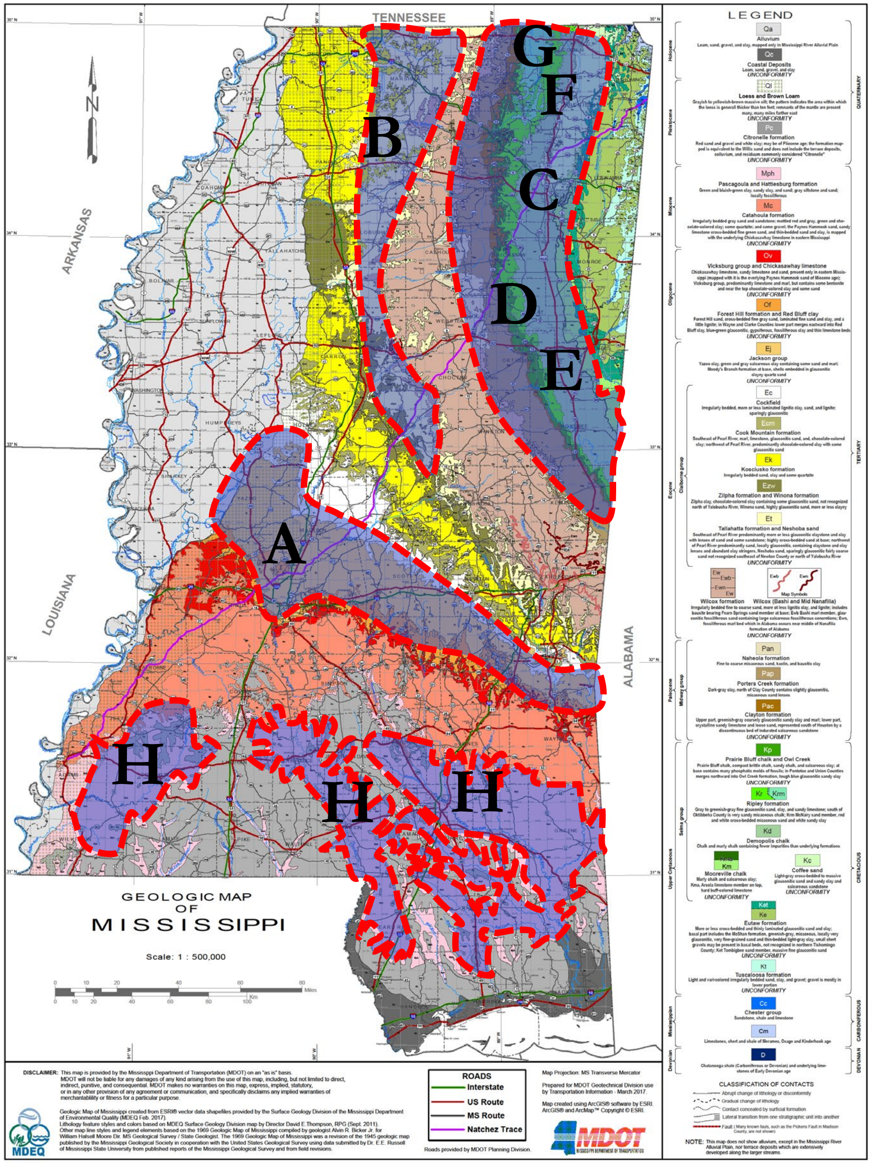
D. Prairie Bluff / Owl Creek Formation

E. Ripley Formation

F. Demopolis Chalk Formation

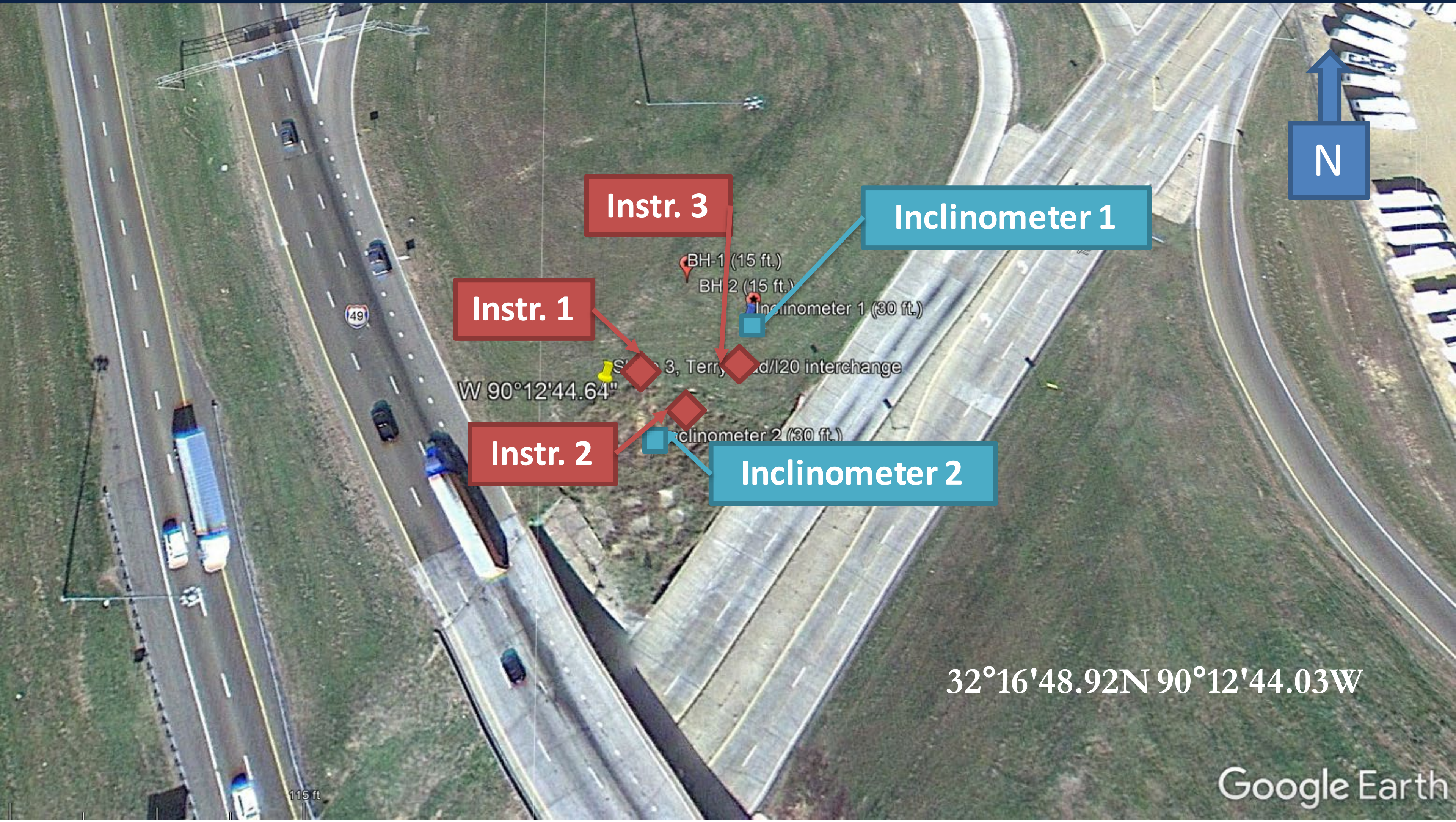
G. Mooreville Chalk Formation

H. Hattiesburg/Pascagoula Formation

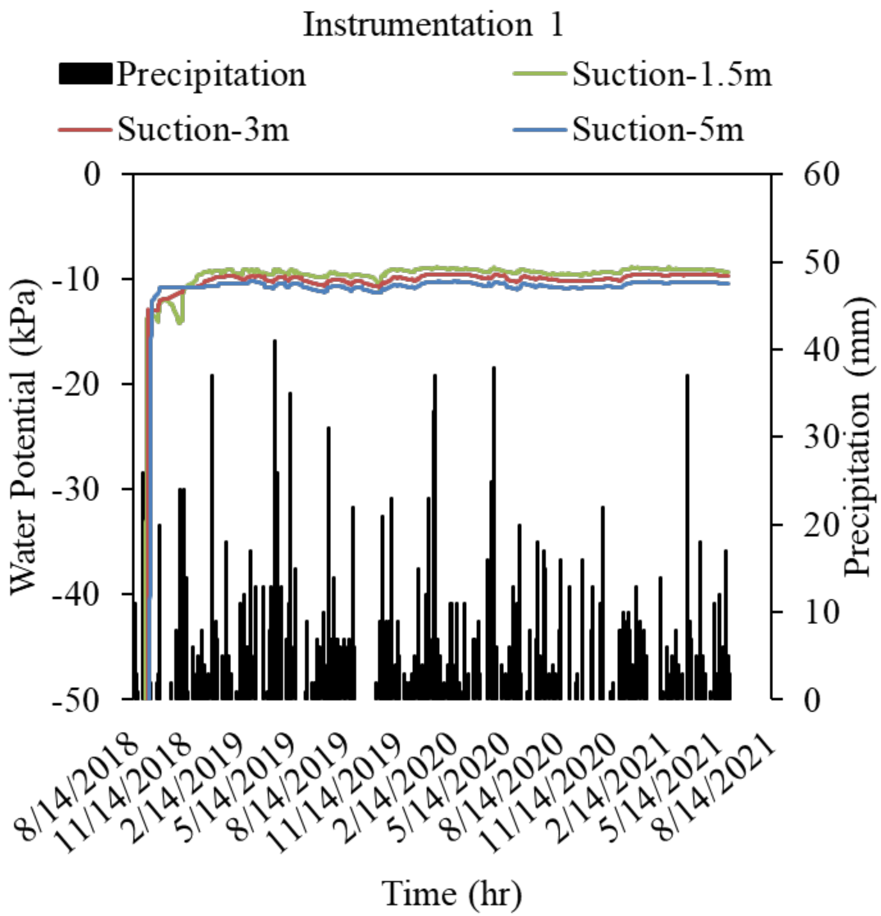


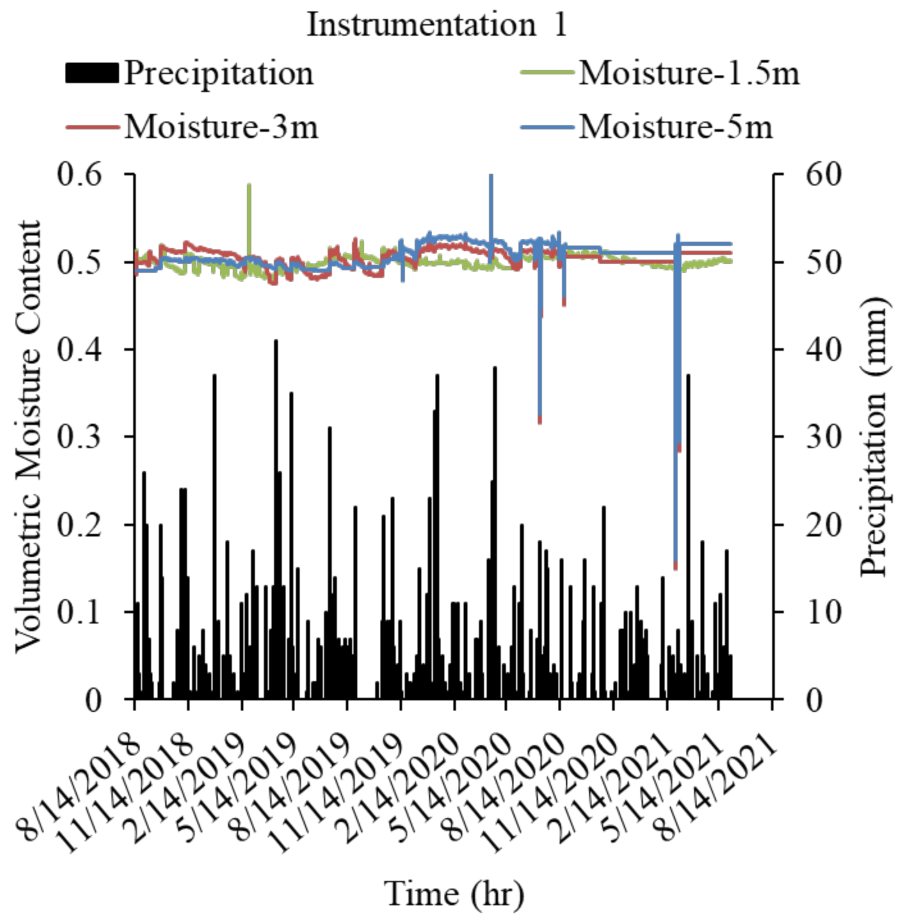
Landslides on Expansive Soil in Mississippi

Investigation of Highway Slopes using In-situ Instrumentation
Slope Along I20W and Terry Road

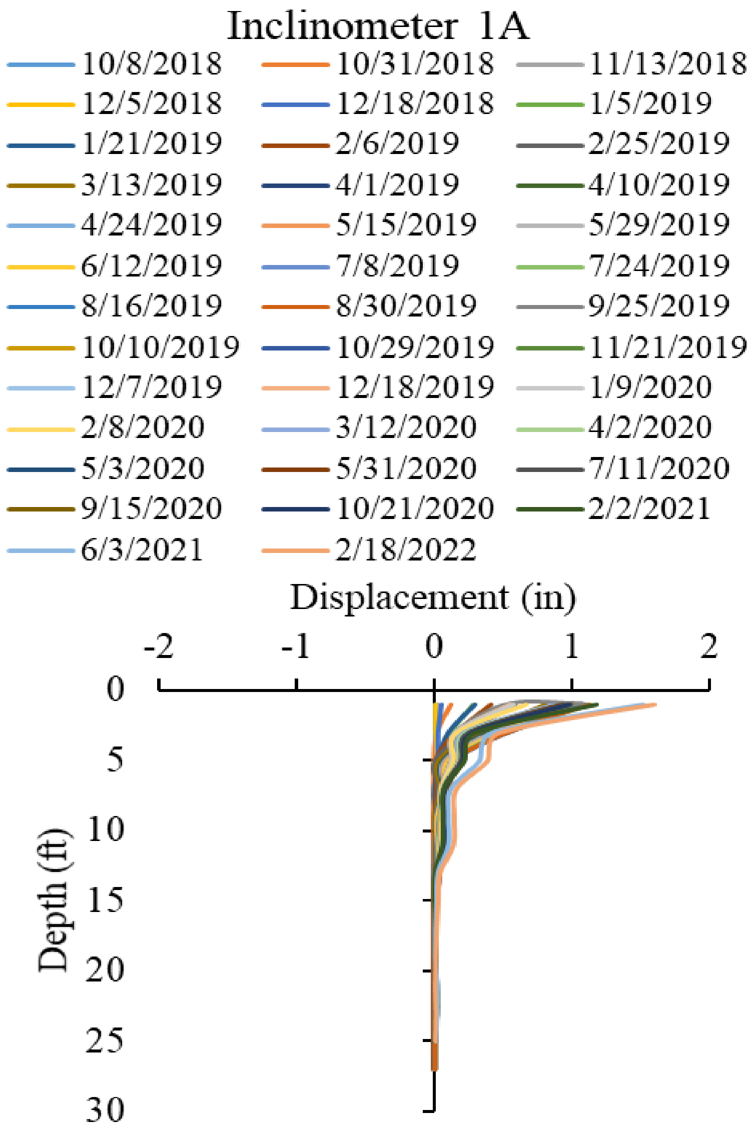


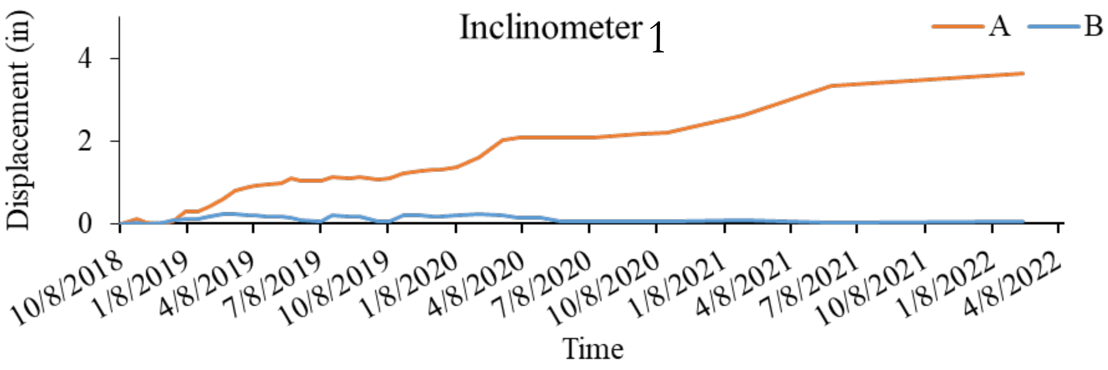
Slope Along I20W and Terry Road
Moisture and Matric Suction Variation





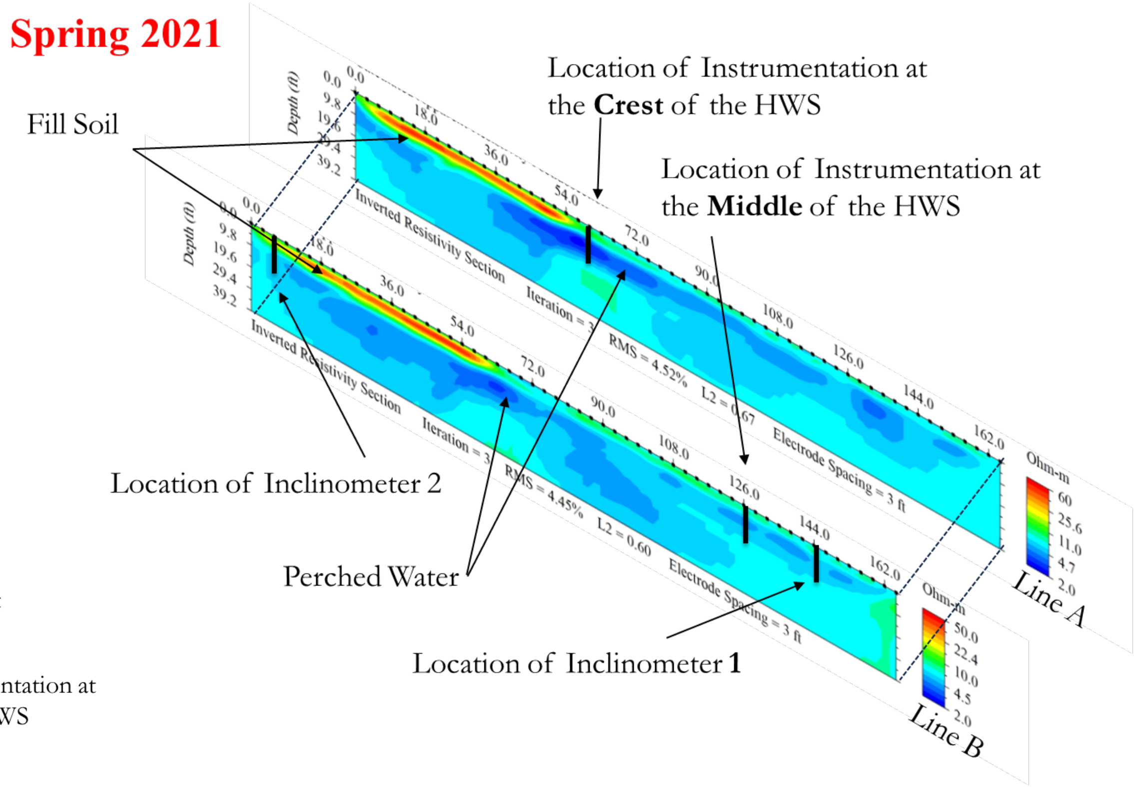
Slope Along I20W and Terry Road
Slope Inclinometer Results

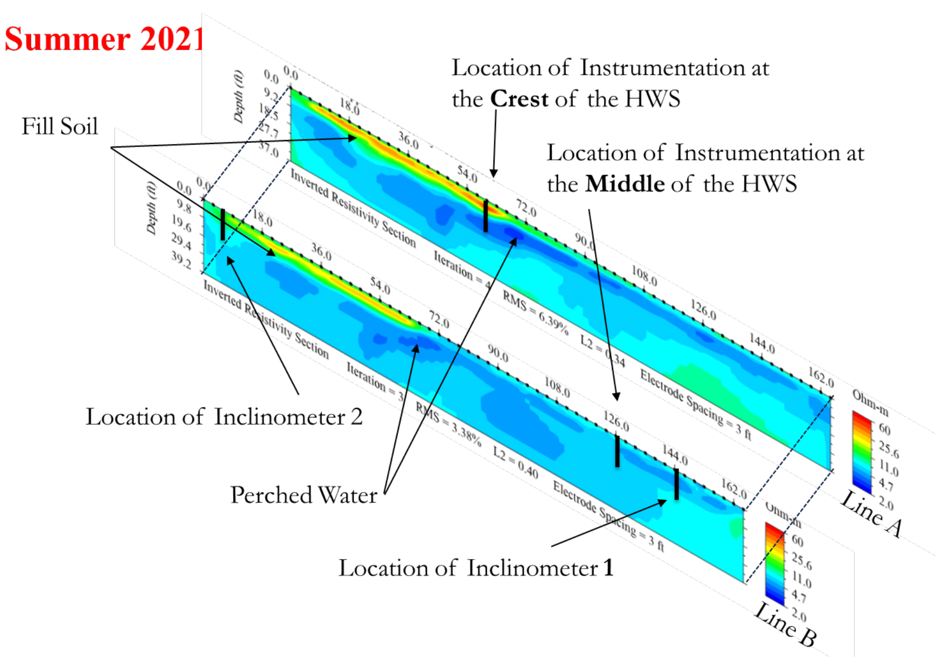




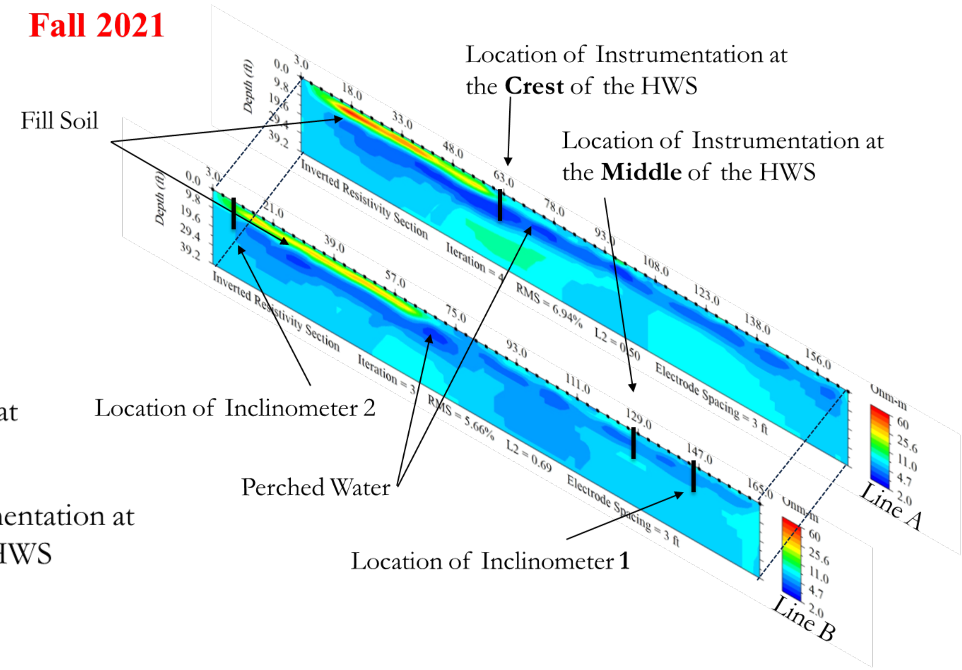
Slope Along I20W and Terry Road
Electrical Resistivity Imaging (ERI) Testing

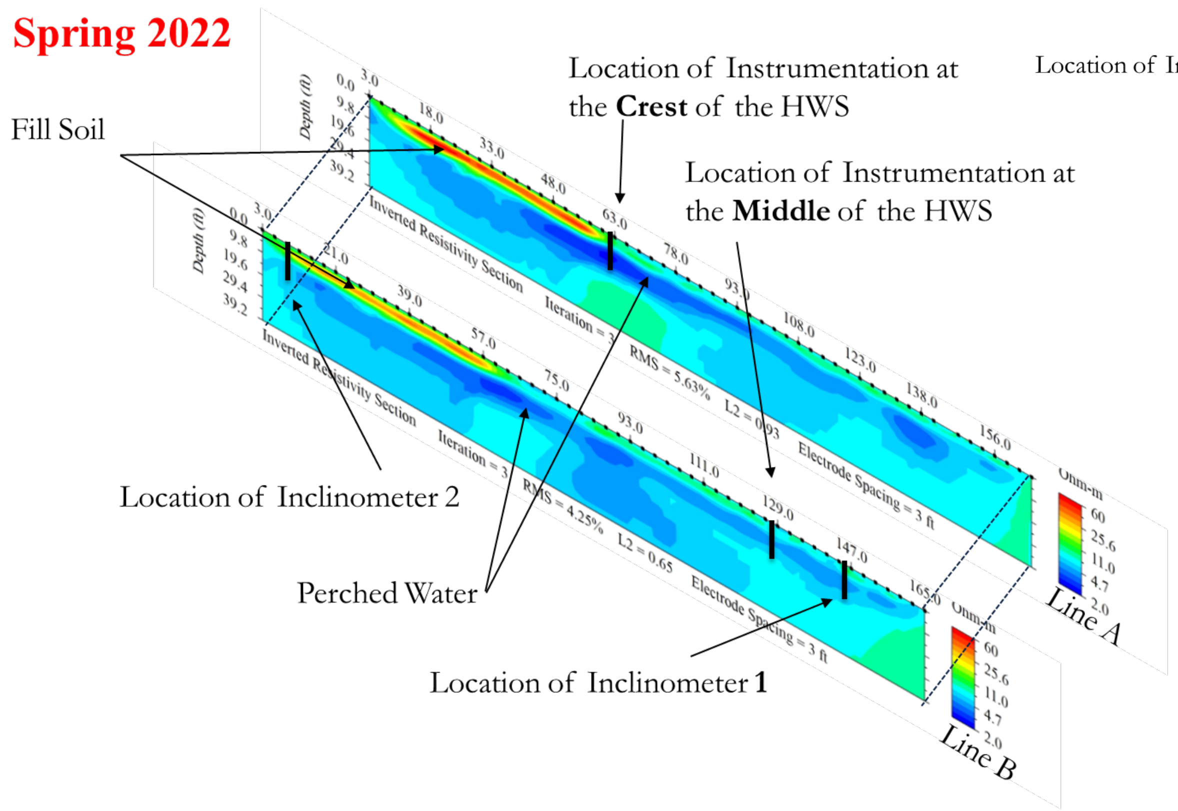
Slope Along I20W and Terry Road Seasonal Variation



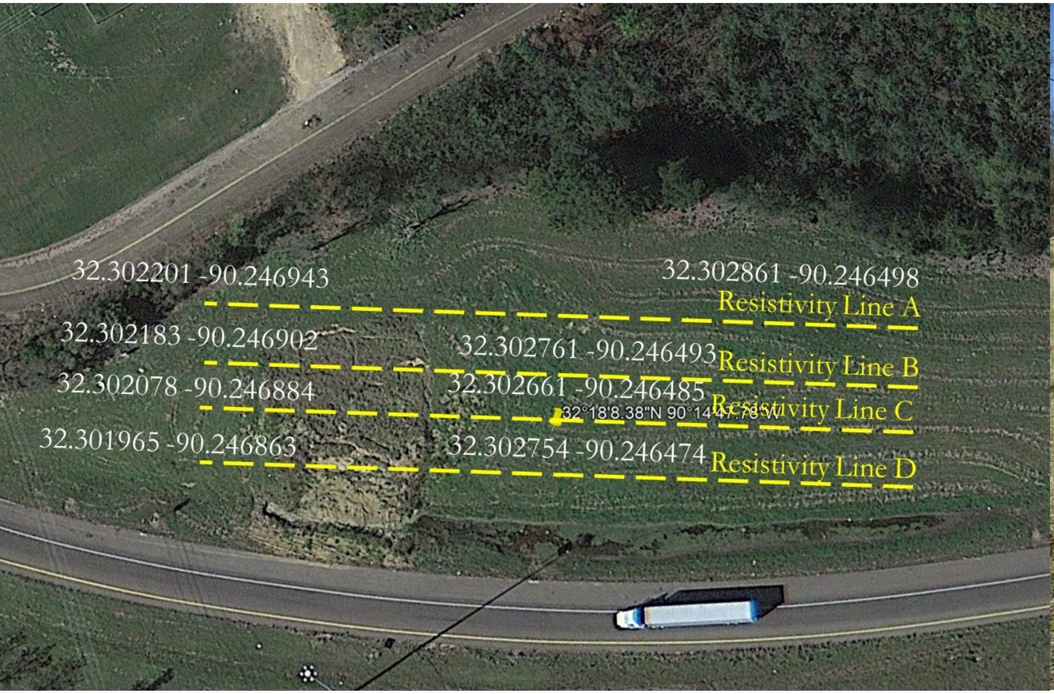


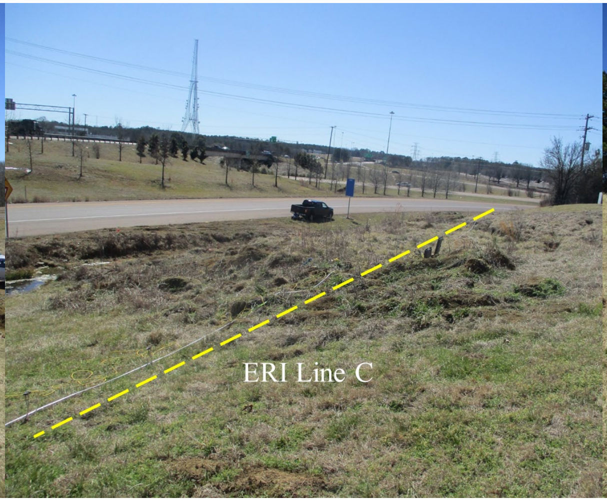
Slope Along I20W and Terry Road Seasonal Variation

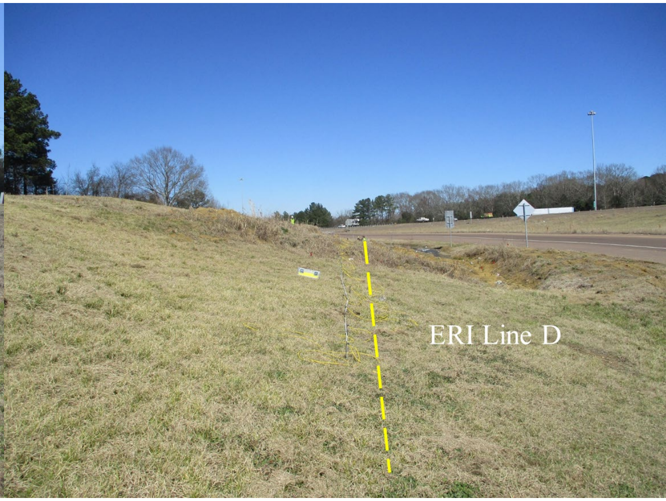




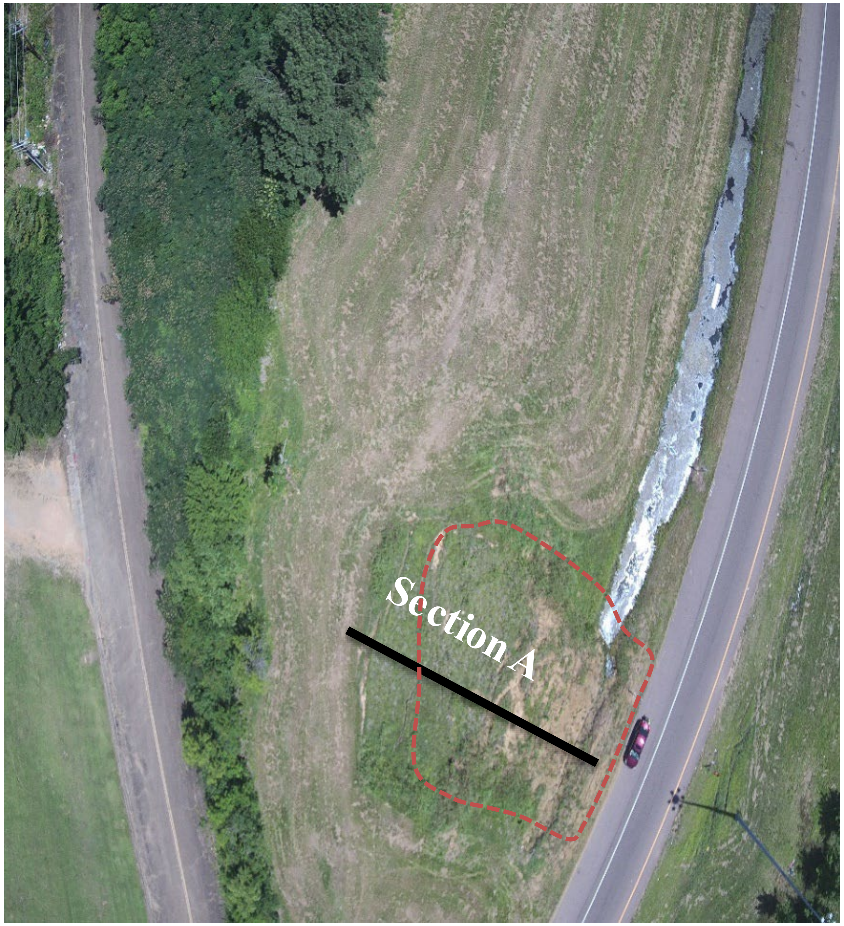
Slope Along I220S near Metro Center
ERI Layout



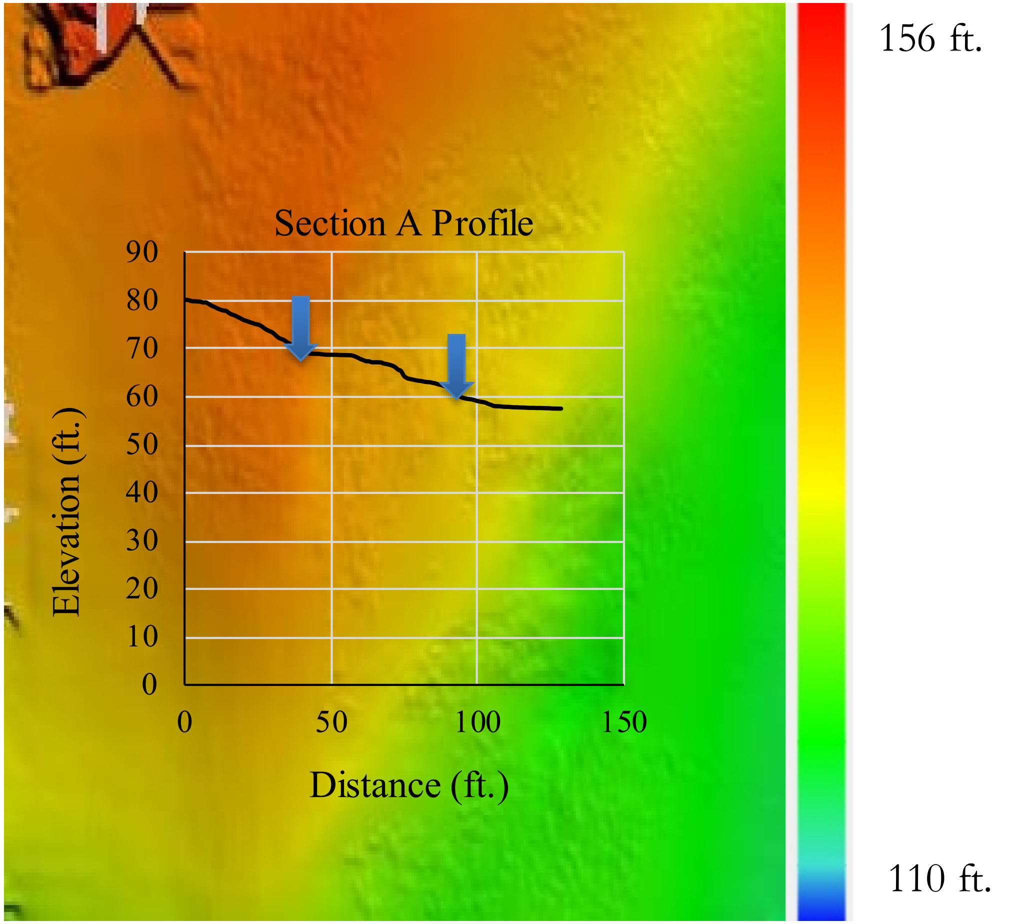




Slope Along I220S near Metro Center
3D Model Based on Drone Imaging

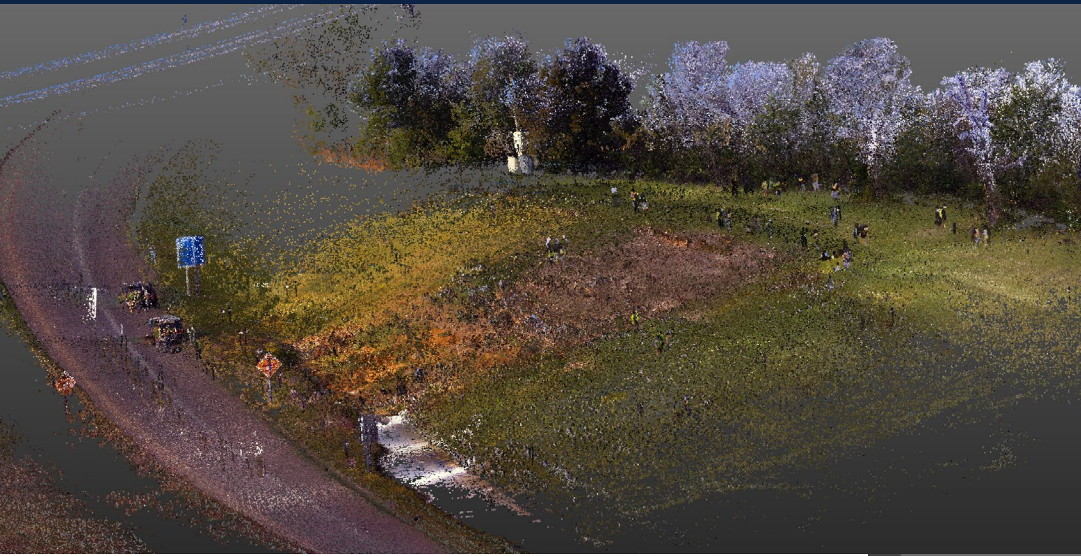


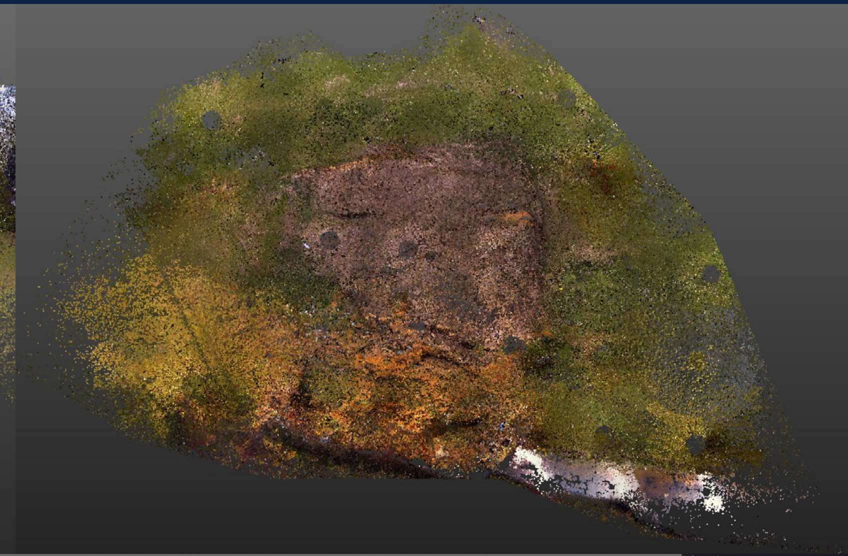
3D Digital Model

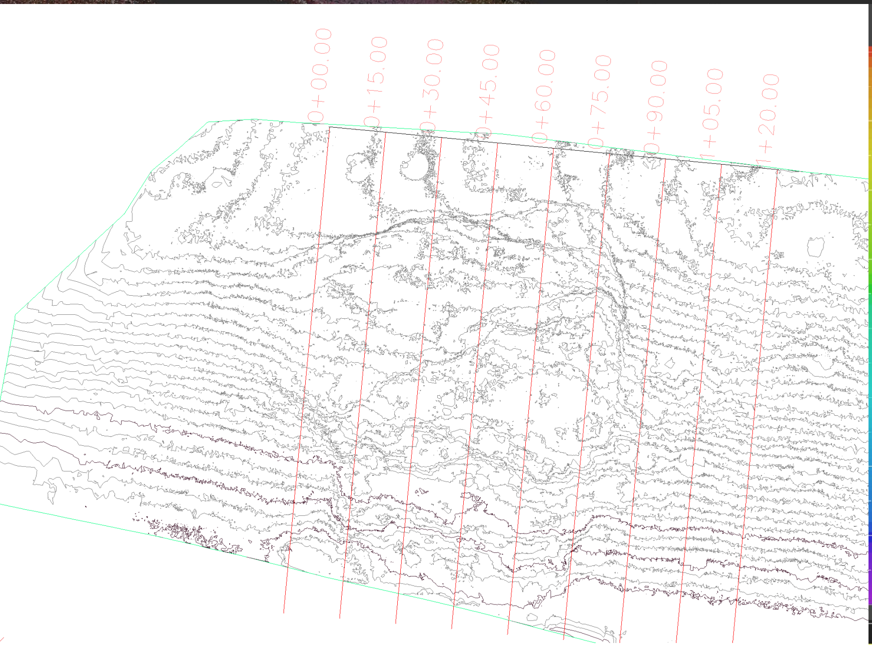


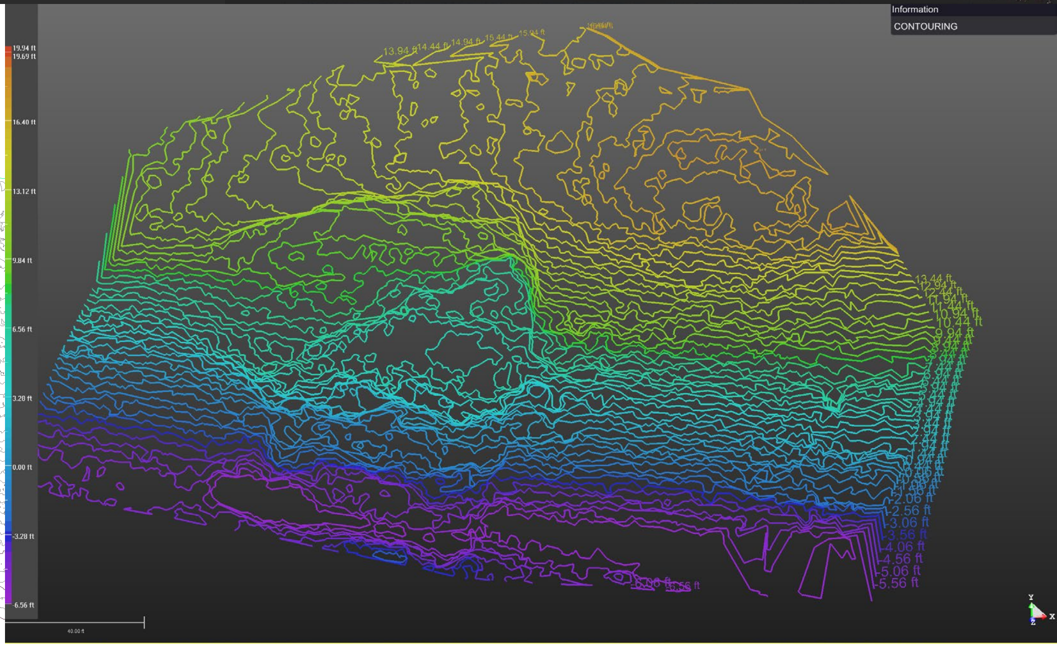
Digital Terrain Model

Slope Along I220S near Metro Center
3D Imaging Based on LiDAR Point Cloud

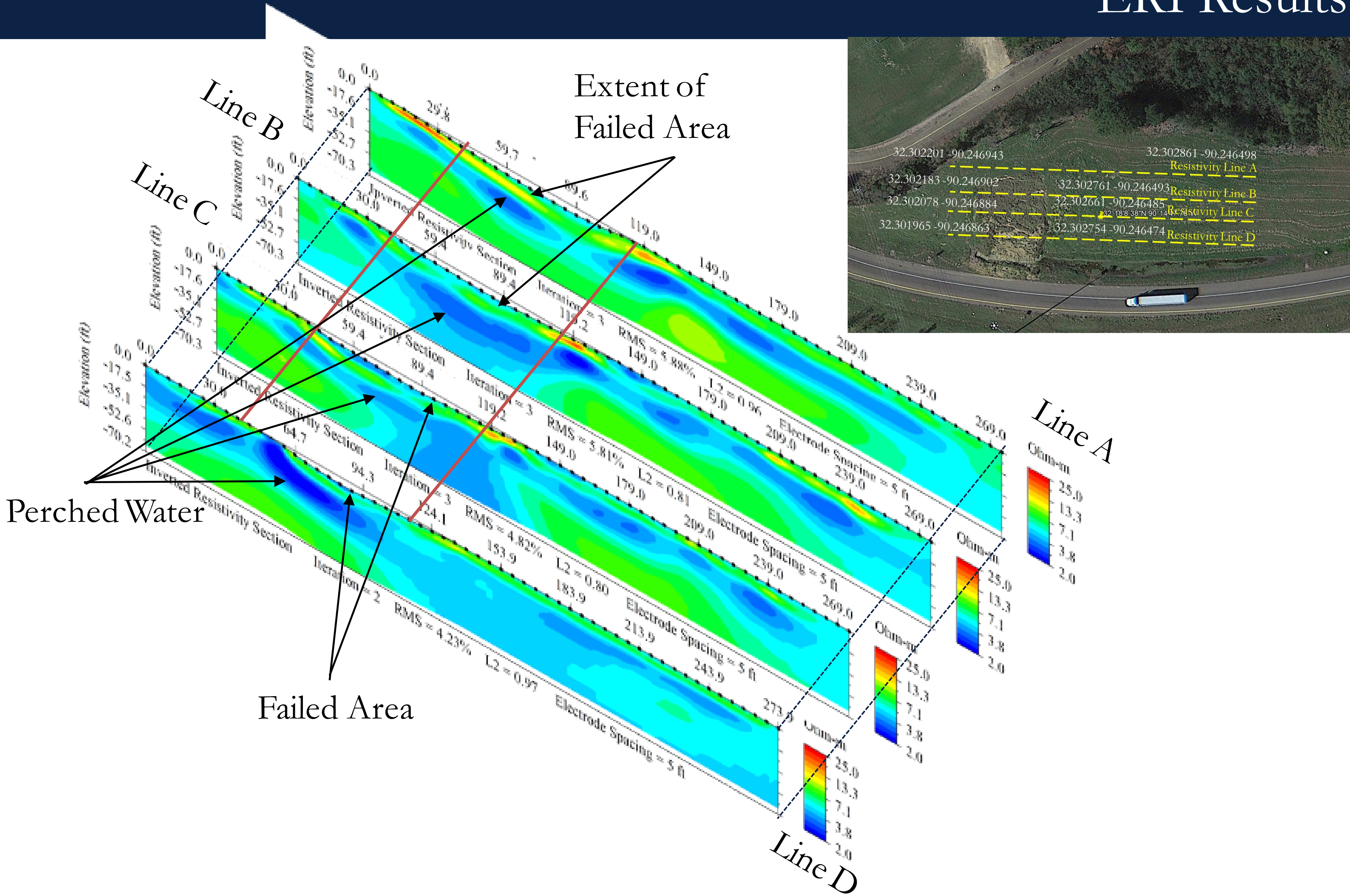






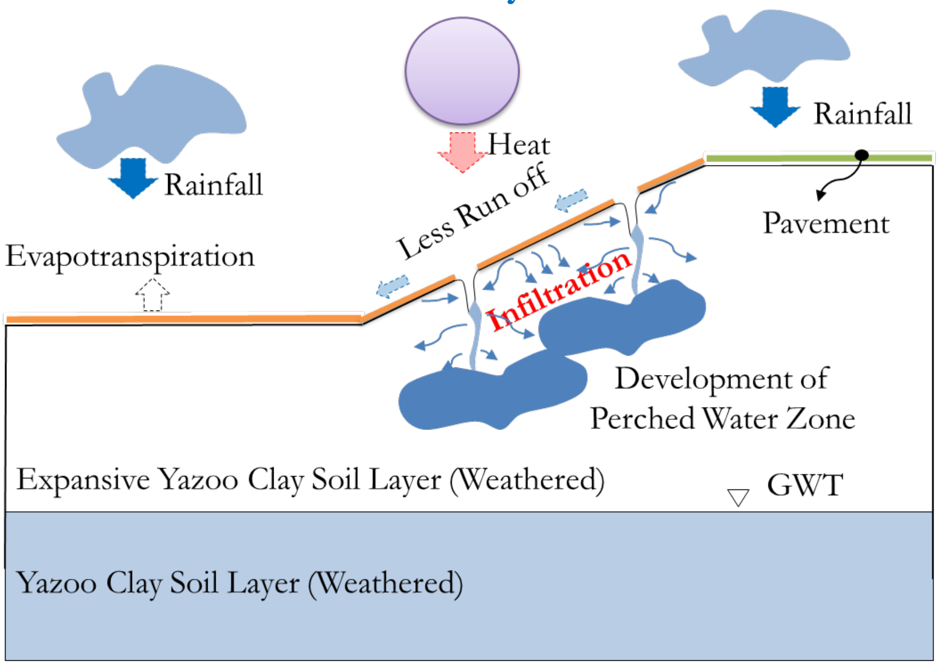


Slope Along I220S near Metro Center
ERI Results



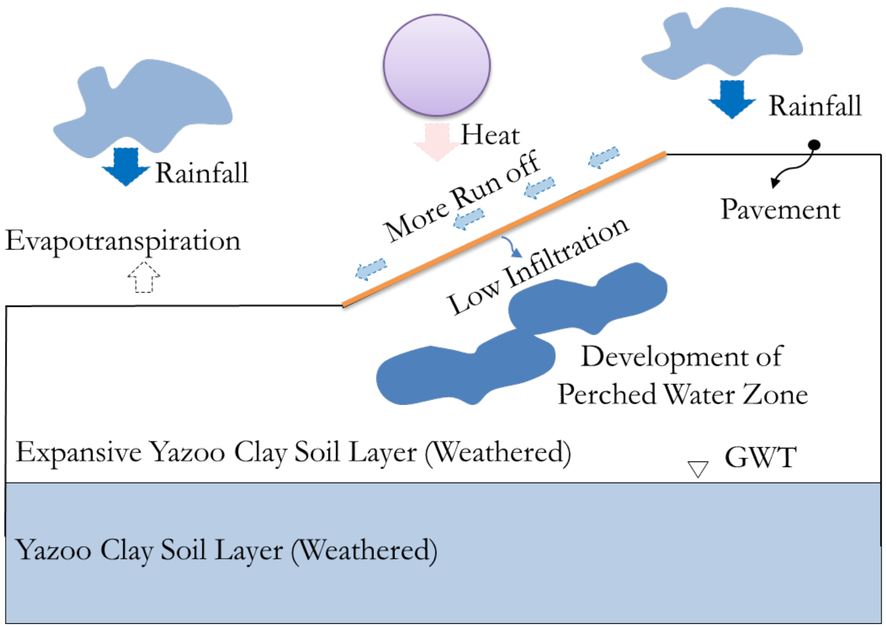
Infiltration Behavior

Summer to Early Fall



Presence of desiccation cracks increase vertical permeability which increase infiltration and develop moisture build up

End of Fall to Spring



As soil gets wet, the desiccation cracks disappear which decrease infiltration. However infiltrated water retained in the slope

With Increment in the Temperature and Rainfall volume, the soil near the surface develops visible shrinkage cracks during the summer, which usually disappear after the rainfall. In addition, with high intensity rainfall event, the infiltration volume has increased, and slopes tends to have a constant moisture content. A high infiltration within the slopes is increasing the landslide risk in High PI clay

Thank You!

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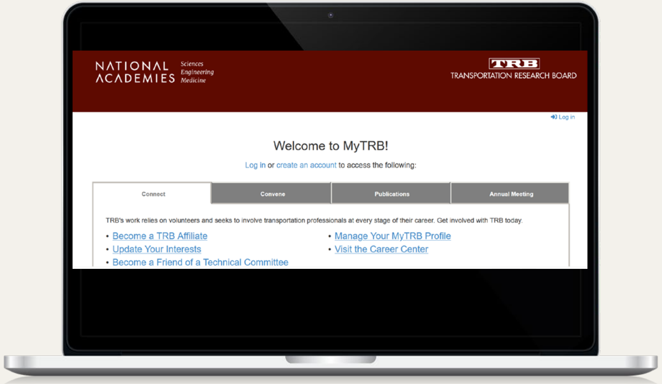

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