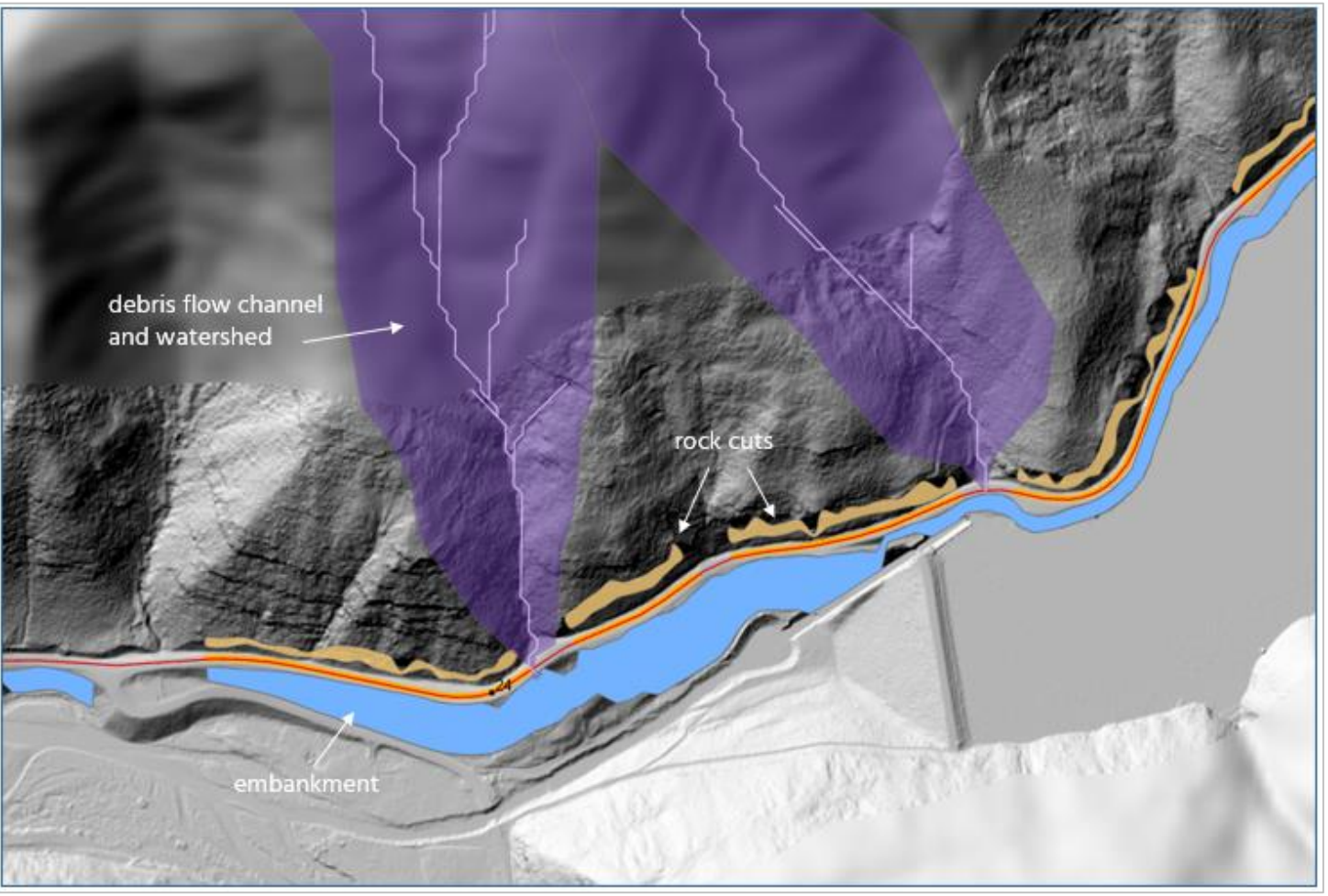


CDOT Geohazard Management Plan Evolution

A leap forward with open source lidar and new algorithms

Presented by:

Mark Vessely, P.E., BGC Engineering

Date:

May 21, 2024

COLORADO
Department of Transportation

BGC

Agenda

- Why evolve?
- Evolving from event-based inventory
- Using lidar for statewide inventory
- Measuring and forecasting risk

Why evolve?

Geohazard and geotechnical risk management is a critical tool for building resilience

The objectives of our practice are evolving

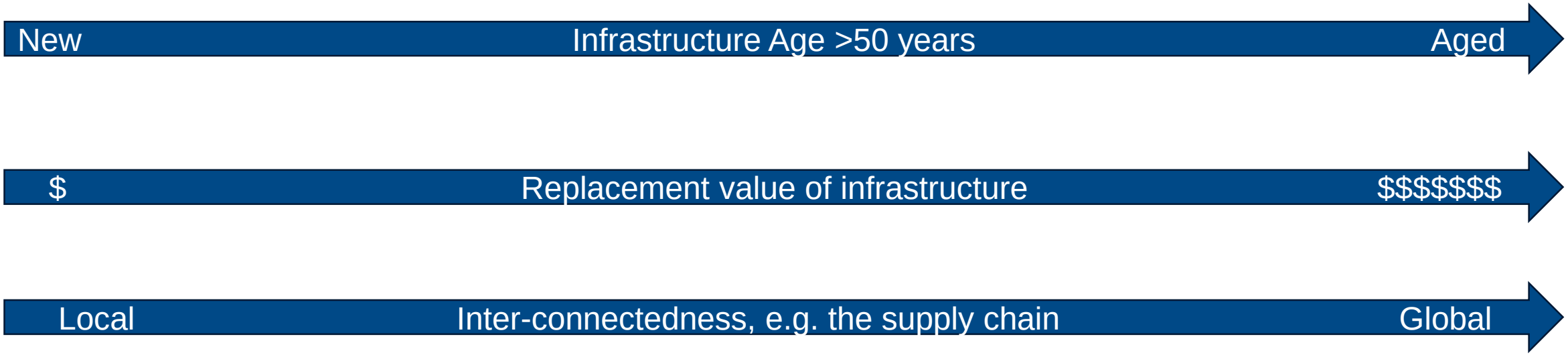
Construction of new assets
1950s-80s

→

Emergence of technology
2000-2020s

→

Preservation and resilience
Today



The intersection of infrastructure with natural hazards is a substantial threat to resilience

Former FDA Commissioner Congressional Testimony following Hurricane Maria:

"The impact of Puerto Rican manufactured medical products to the public health of all Americans is significant."

It’s a different era with much less tolerance for impact

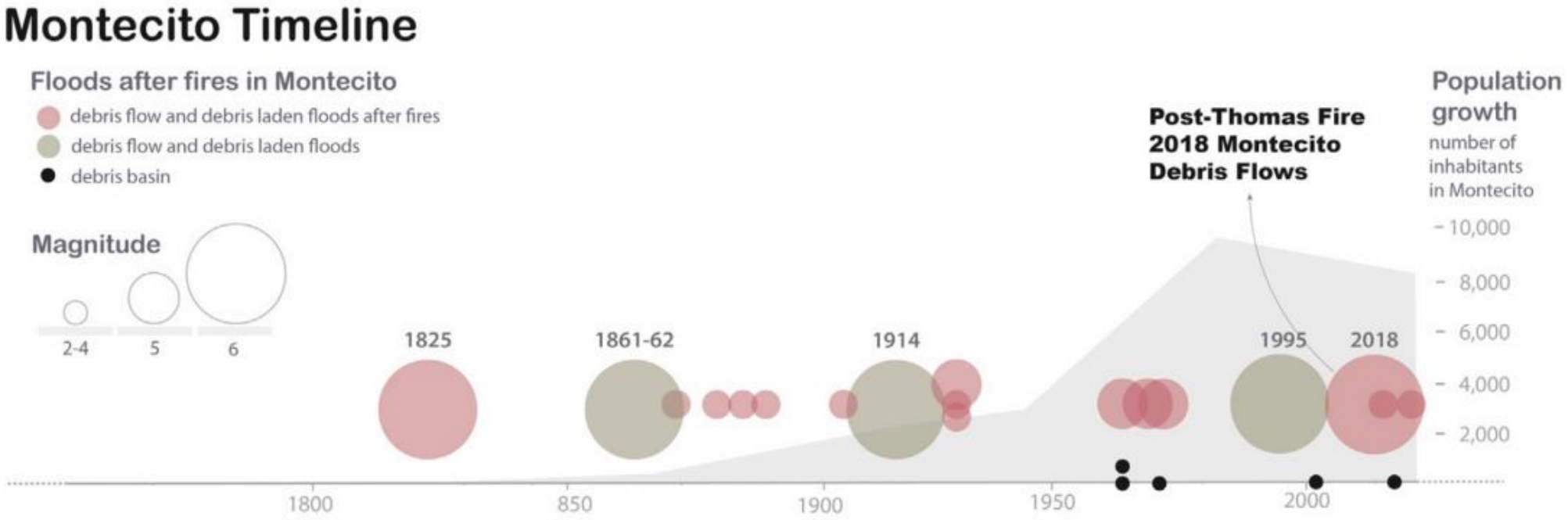


Image source
Serra-Llobet et al. 2023

Geo-professionals reduce risk and build resilience to natural hazards

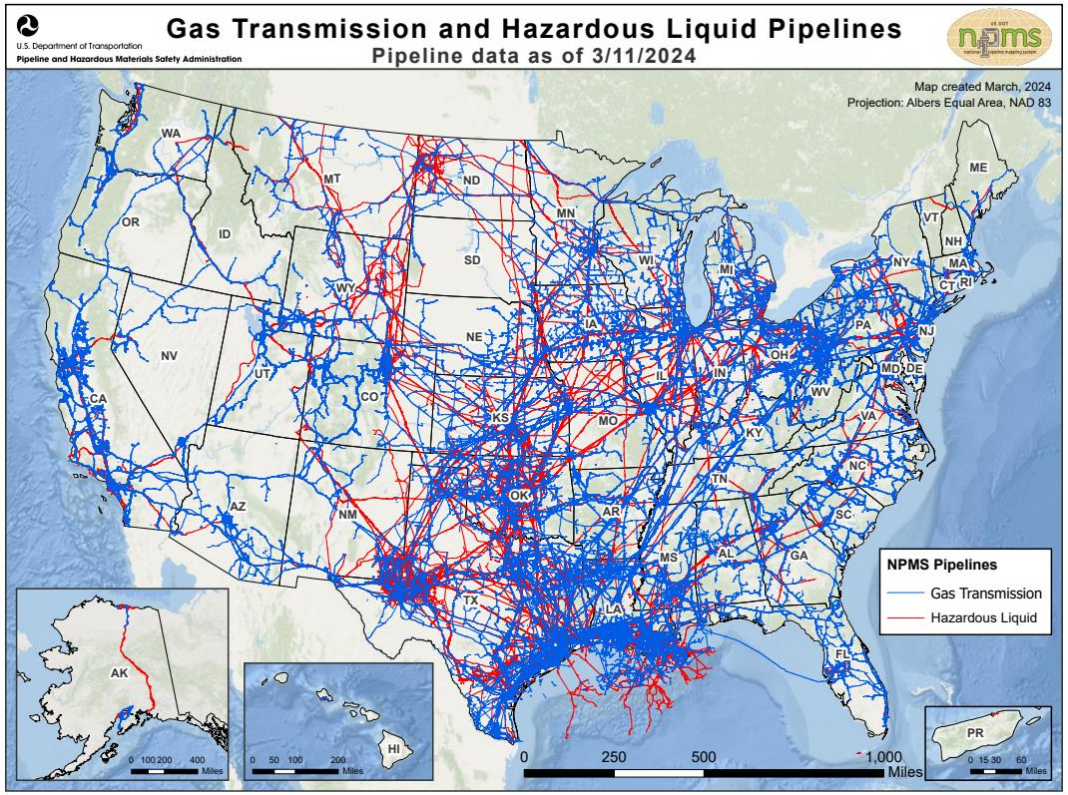
Energy

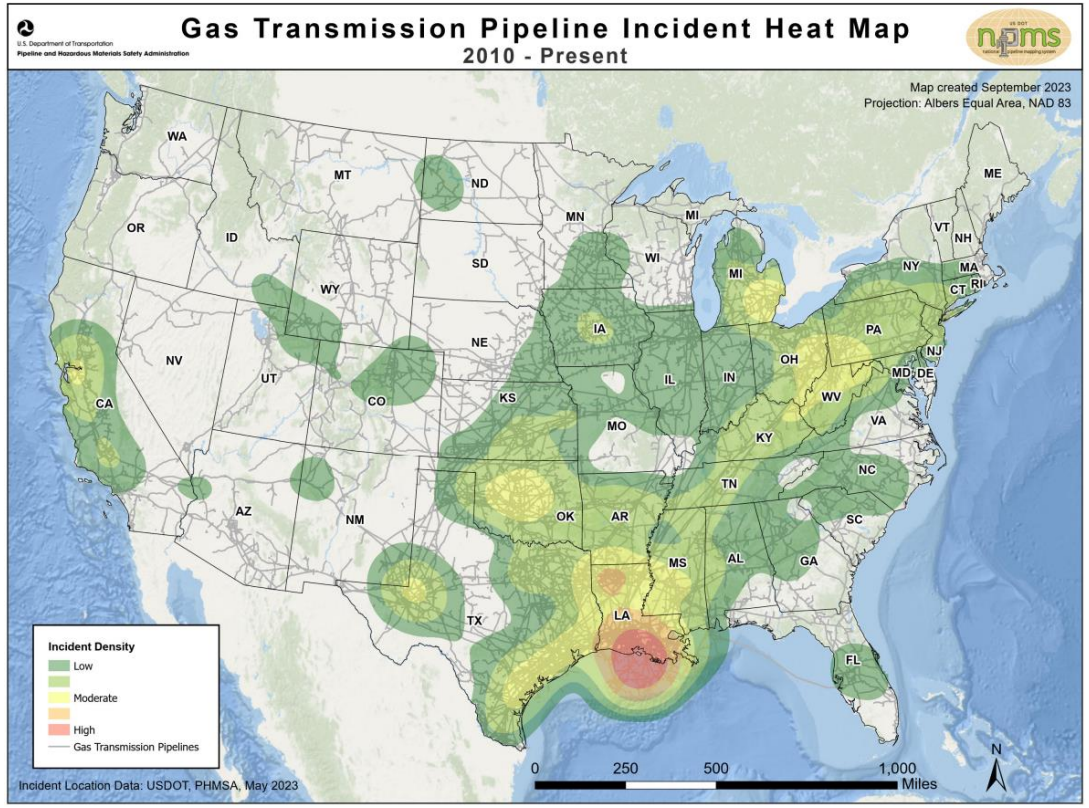
Enbridge says TETCO gas pipeline ready to return to full service

Jul. 26, 2021 11:54 AM ET | **Enbridge Inc. (ENB) Stock, ENB:CA Stock** | ENB, ENB:CA | By: Carl Surran, SA News Editor | 4 Comments

Hoptocopter/E+ via Getty Images

- Enbridge (ENB +0.6%) says its Texas Eastern Transmission unit provided all information requested by federal safety regulators and will raise pressure in the pipeline as soon regulators approve.
- TETCO had declared force majeure on May 28 after the U.S. Pipeline and Hazardous Material Safety Administration required Enbridge to reinstate a 20% pressure restriction on two of three lines that make up the system.





In the last 20 years, pipeline operators have reduced geohazard caused failures by up to 80%

Evolving from event-based inventory

Managing Geohazards and Geotechnical Assets where they have and have not happened

30 years of GAM evolution at CDOT

1990-94

"Rockfall is a safety threat"

Rockfall Hazard Rating System (RHRS) initiated

2004

RHRS Colorado Specific Improvements

Colorado RHRS Initiated

2012-14

"What about all geohazards and risk to other objectives?"

CDOT Geohazard Management Plan (GMP) initiated

2020-24

"What about locations without events?"

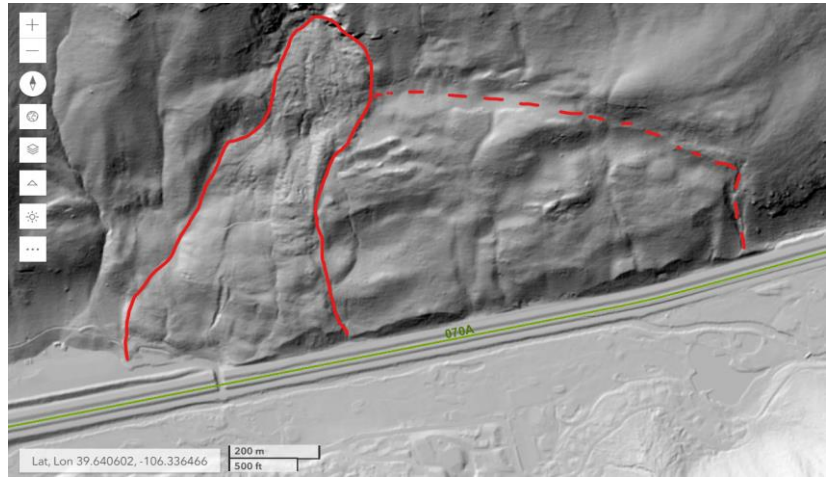
GMP v2 initiated with recognition of credible hazard locations

Inventory is event-based – meaning an adverse event has already happened

What is in the Geohazard Management Plan?

Geotechnical asset deterioration and geohazards are system-wide

Hazards from outside the right-of-way



Slopes within the right-of-way

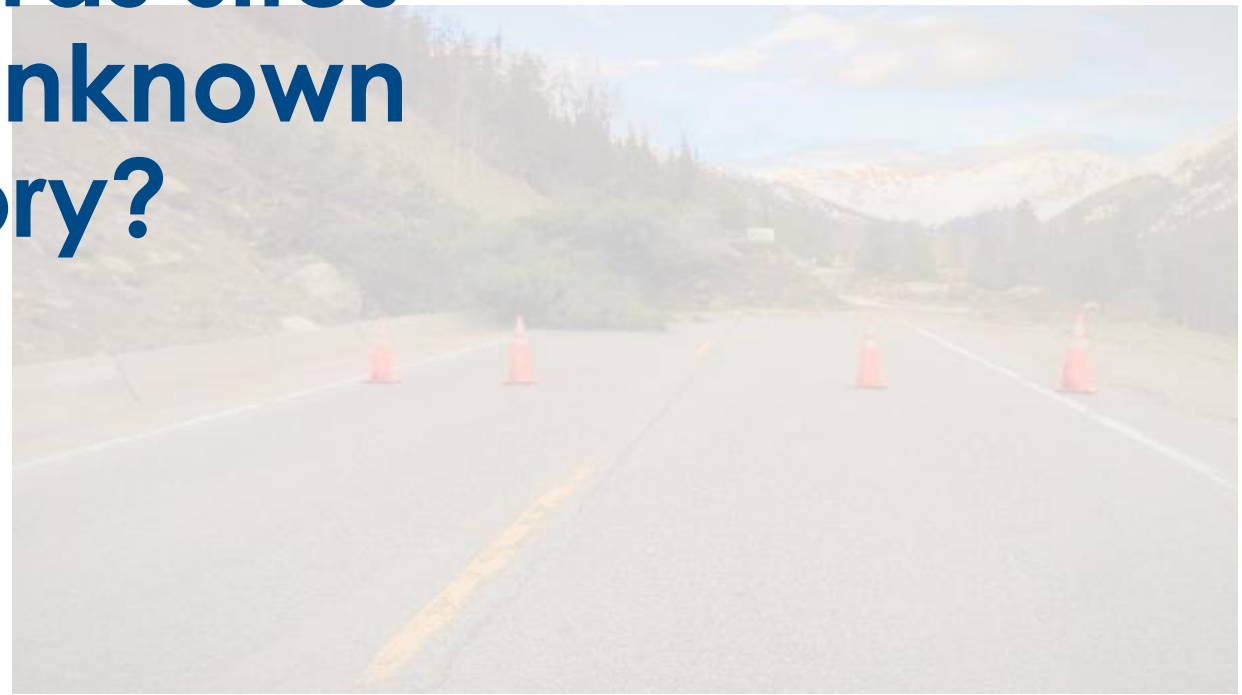

All assets
crossing steep
creeks


All assets
crossing deep
seated landslides


Geotechnical
assets:
embankments


Geotechnical
assets: cut slopes

How do we quickly find credible geohazards sites with an unknown history?



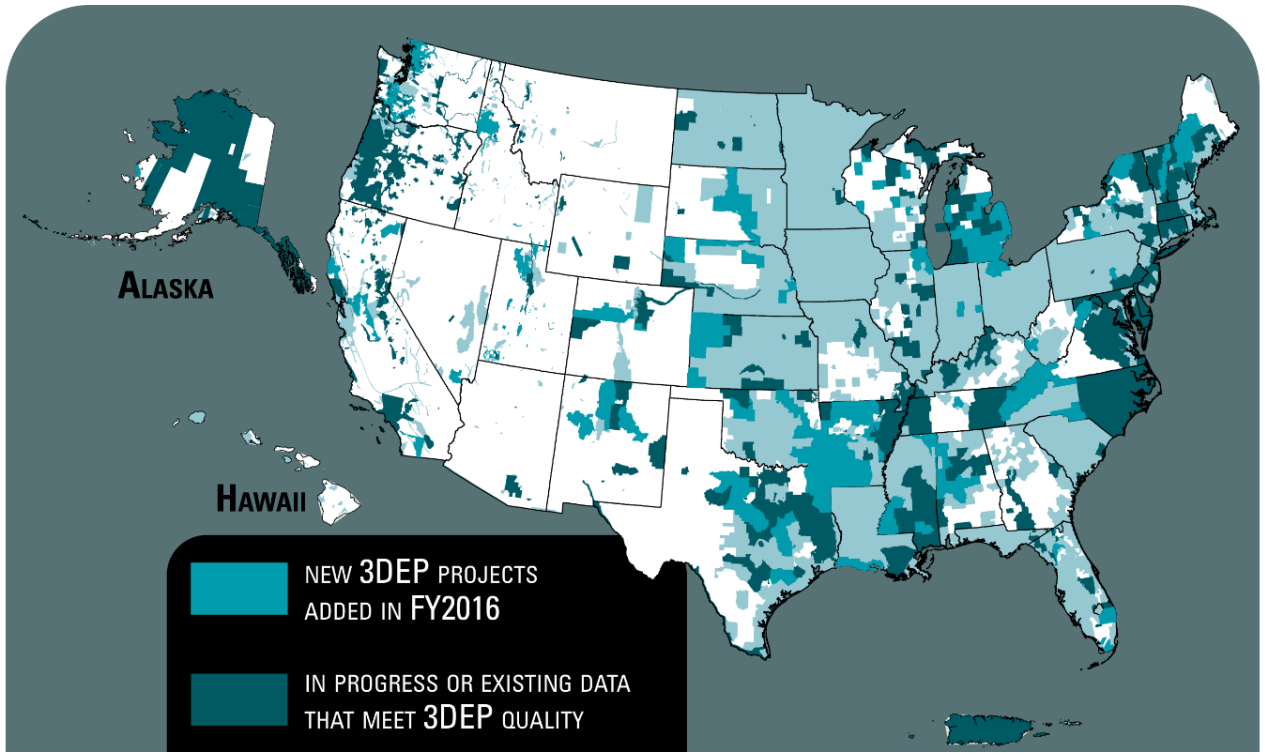
Using lidar to answer the question

What does lidar enable in GAM that wasn’t feasible before?

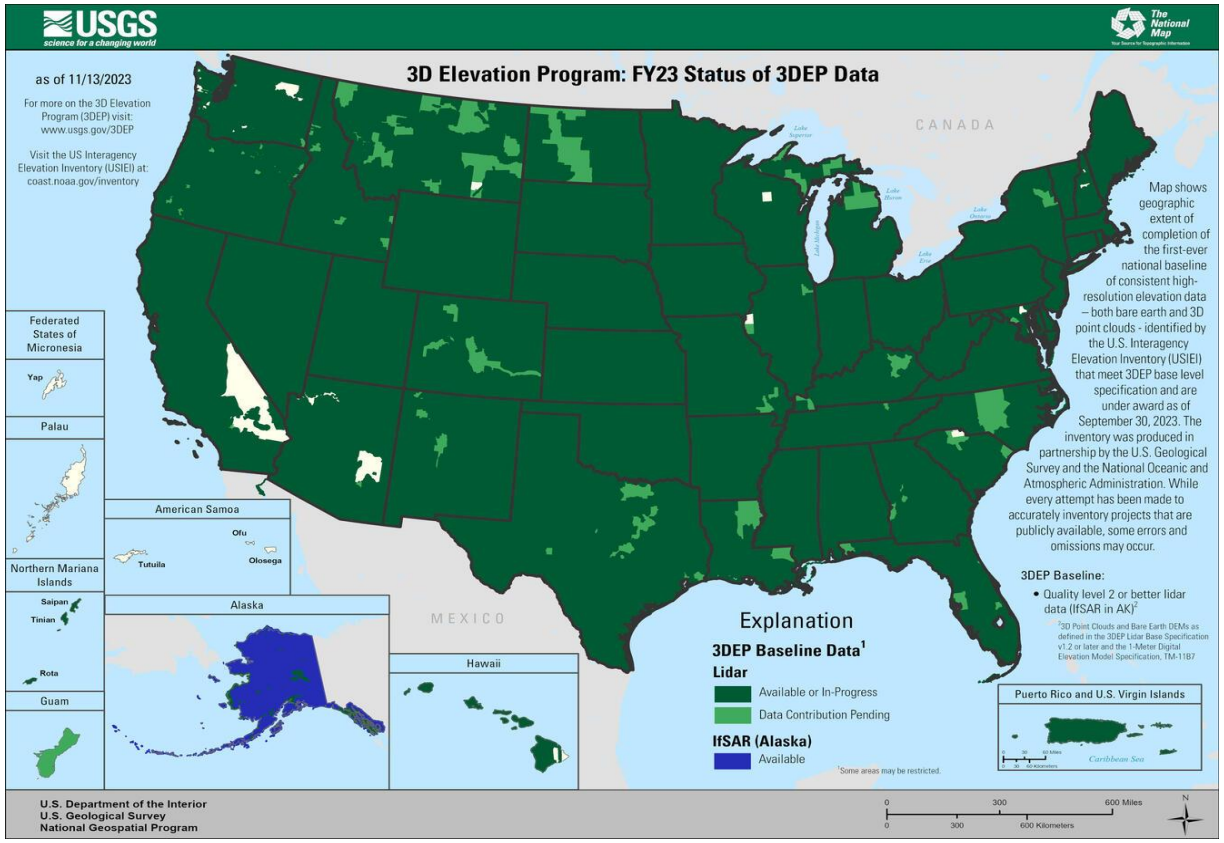
It's different now

Near complete country-wide high resolution lidar coverage evolution from USGS, regional efforts, and agency projects

Public high-resolution lidar 2016

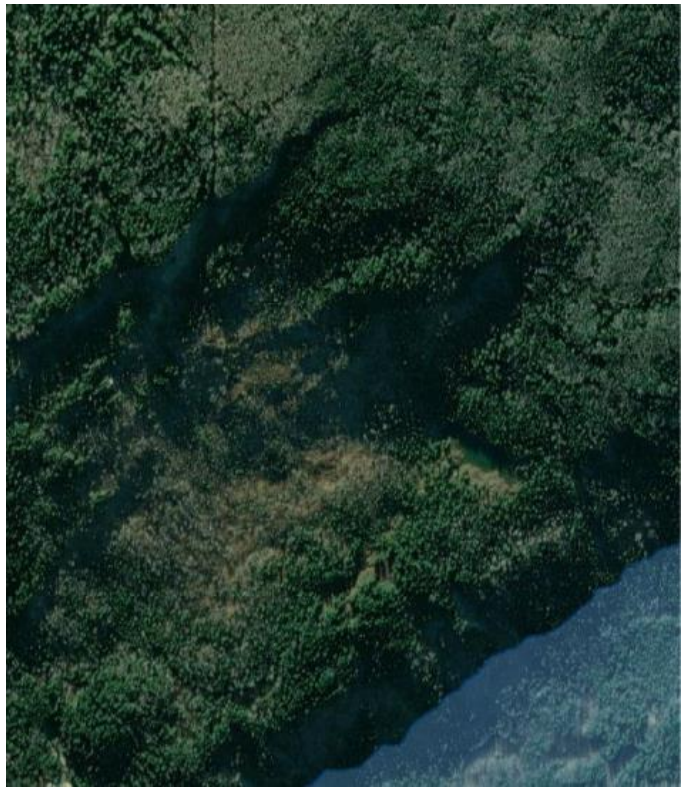


Public high-resolution lidar 2023



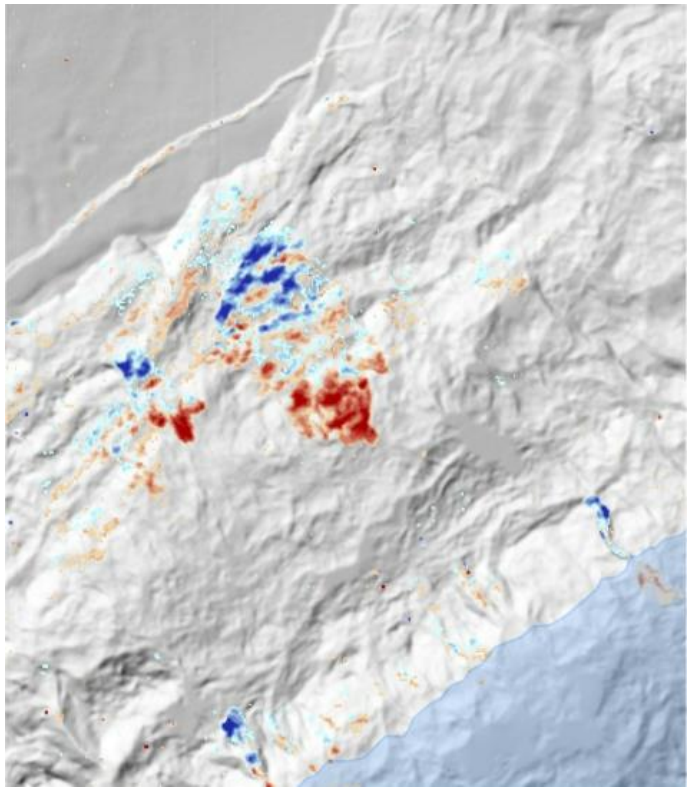
USGS 3DEP Status

Bare earth lidar enables evolution in geo-practice



AERIAL PHOTOGRAPHY

LIDAR SURVEY



LIDAR CHANGE DETECTION

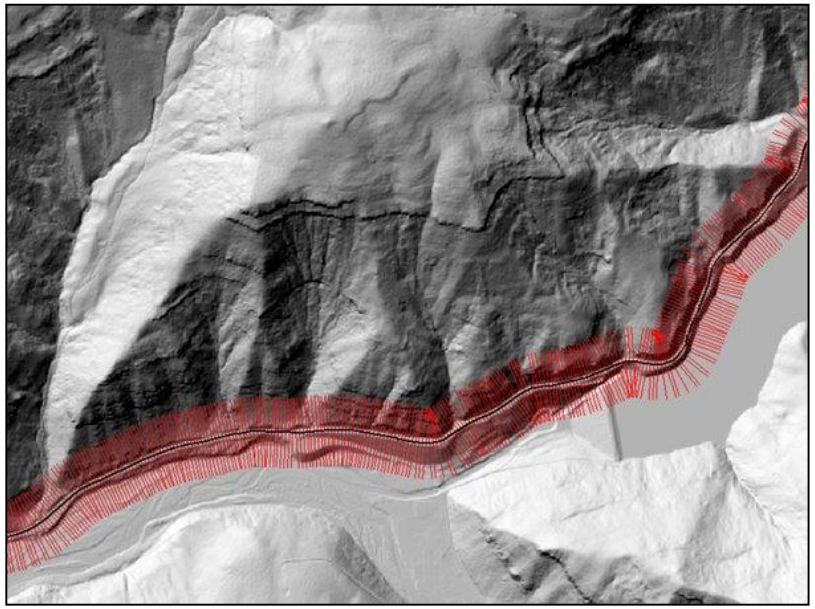
Evolution is good

From: Daily Life in the 1800's Prior to the Invention of the X Ray, 2014.

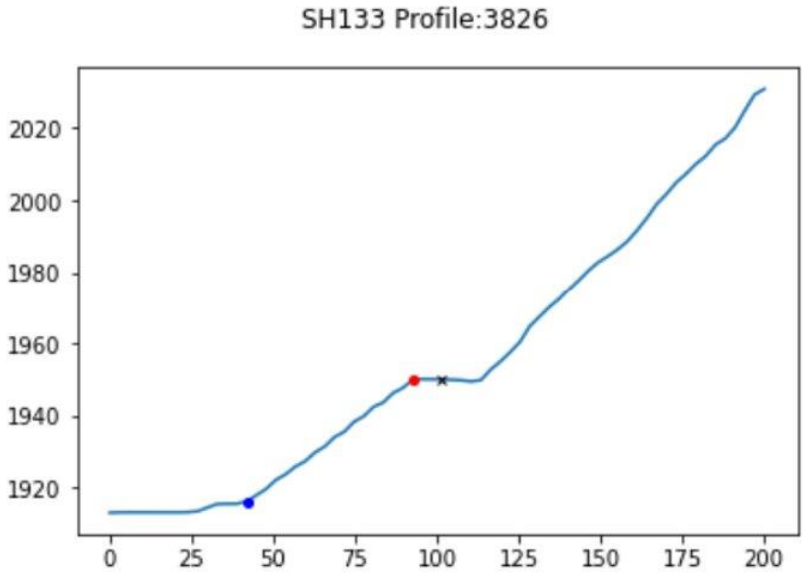
Aerial imagery vs. Bare Earth Lidar

Lidar Analysis for Automated CDOT Geohazard Inventory

Desktop/office-based screening algorithm example



(1) Draw elevation profiles perpendicular to the roadway



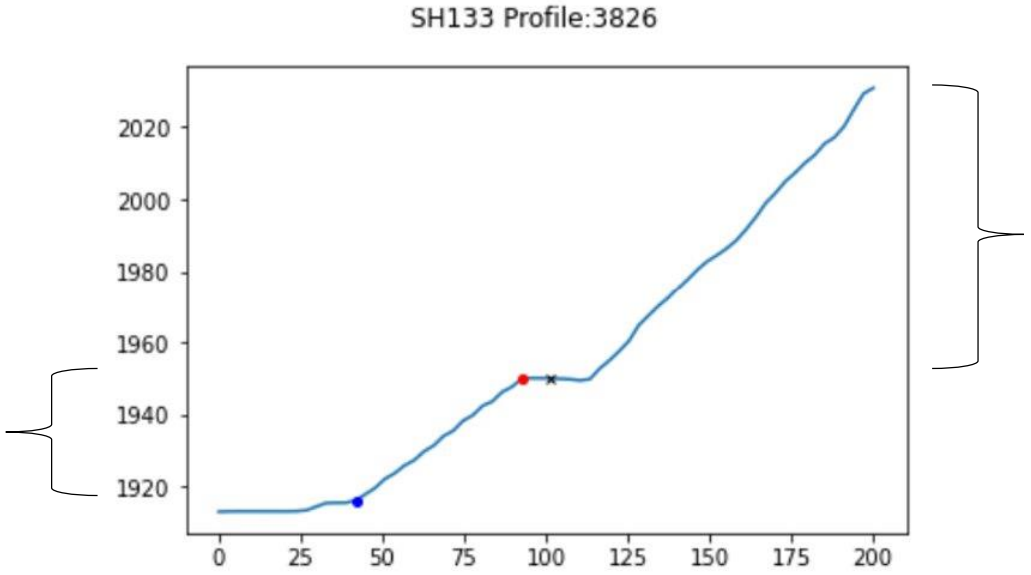
(2) Identify continuous slopes over a specified gradient, height and distance to the roadway

(3) Outputs include polygons representing the credible geo-asset or geohazard

Lidar Analysis

Example algorithm input

Treat upslope and downslope "sides" of the transect separately:



Downslope parameters (looking for embankments):

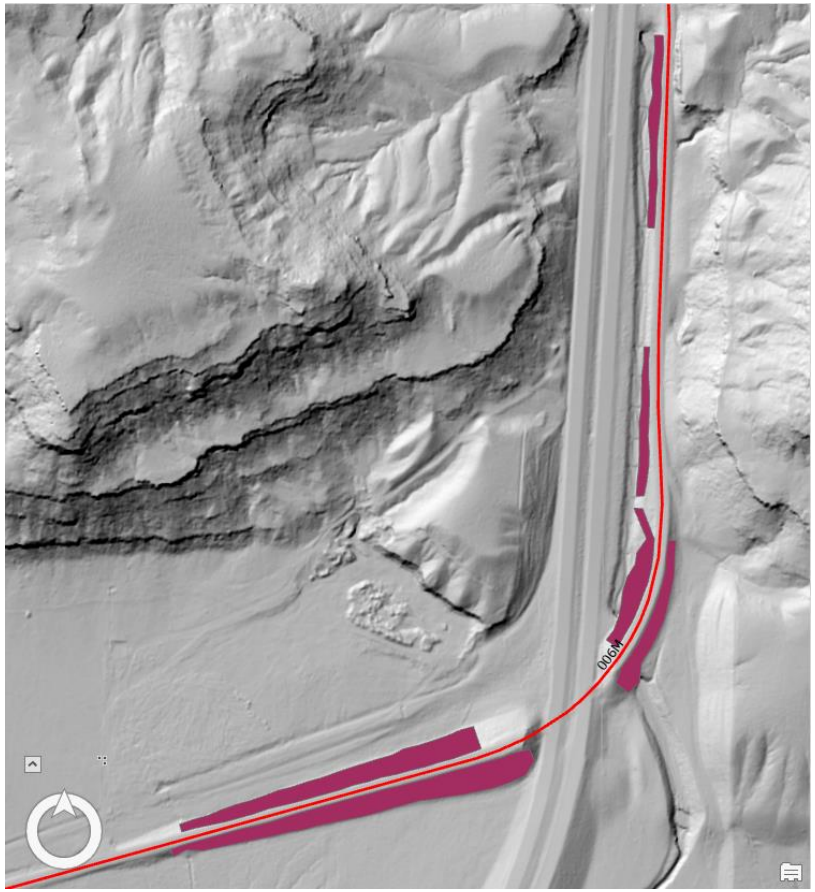
- 1/3 slope (~18 degrees)
- >2.9 m in height
- Distance from the slope crest to the roadway shoulder of <25 m

Upslope parameters (looking for rock cuts):

- 45 degrees
- >3 m in height
- Shadow angle from the crest of the cut to the roadway shoulder of > 30 degrees

Lidar Analysis

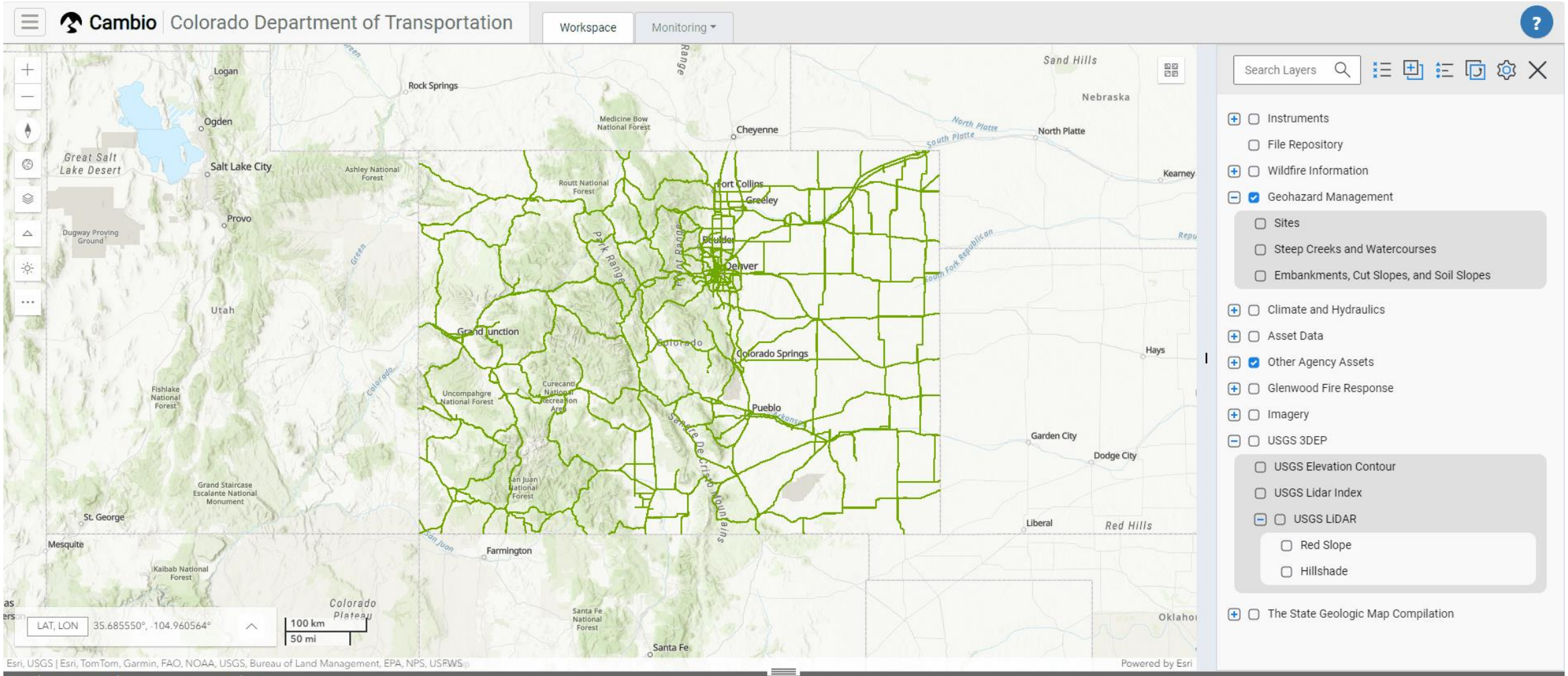
Example output – embankment assets



Lidar Analysis

Example output – retaining walls

Screening Output example



Site ID	Site Name	Route	Inspection Status	Inspection Date	Inspection Form Type	Inspection Type	Inspector	Inspector Organization
9526	RFC-145A-SB-33.56-33.8	145A	WIP	May 23, 2023	Rock Slope Inspection	Office	aswift	BGC

Rows: 230 Selected: 0

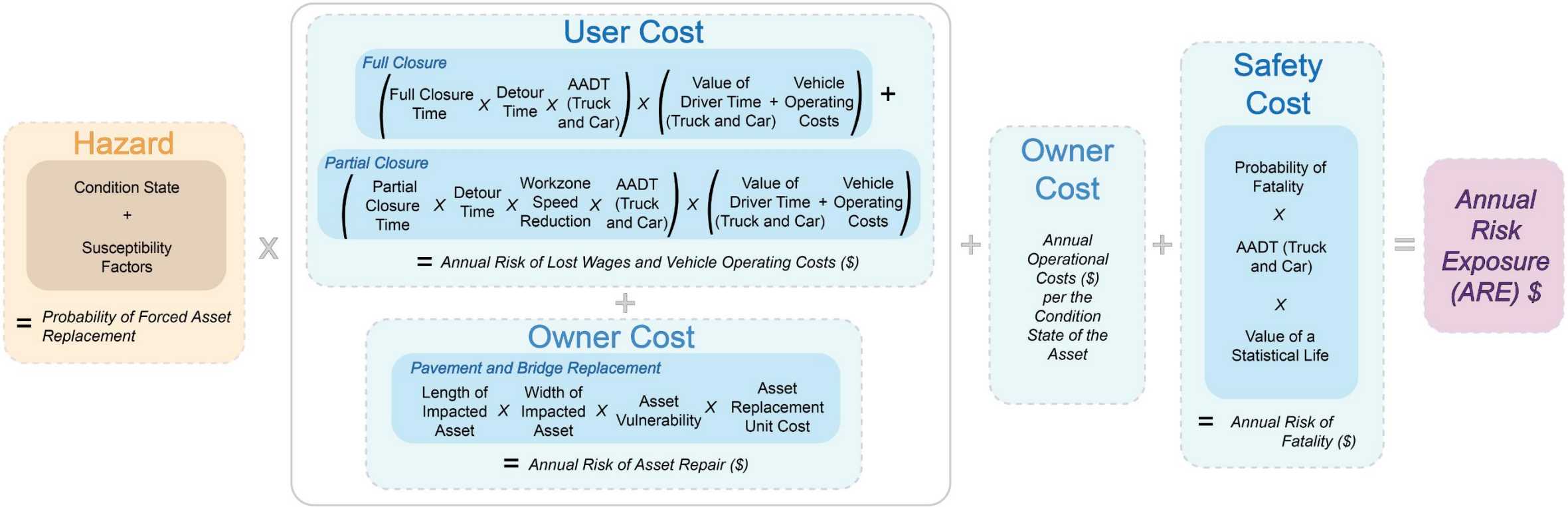
Measuring and forecasting the credible geohazard risk exposure

What is the future risk with deterioration, varying investment levels, and changes in climate

Annual Risk Exposure (ARE) and Total ARE (TARE)

Site and statewide annual risk (in $) from geohazards for asset management reporting

Annual Risk Exposure (ARE) Calculations for an Embankment or Proximal Steep Slope



Example of ARE algorithm for embankment assets; from CDOT Embankment Risk Assessment Framework, 2024 (in progress)

Going from site level to statewide measurement

- Each exposed highway segment has annual annual risk exposure value
  ($$ in impacts to safety, mobility, operations, and assets)

- Risk exposure is categorized into grades for asset management reporting at each segment

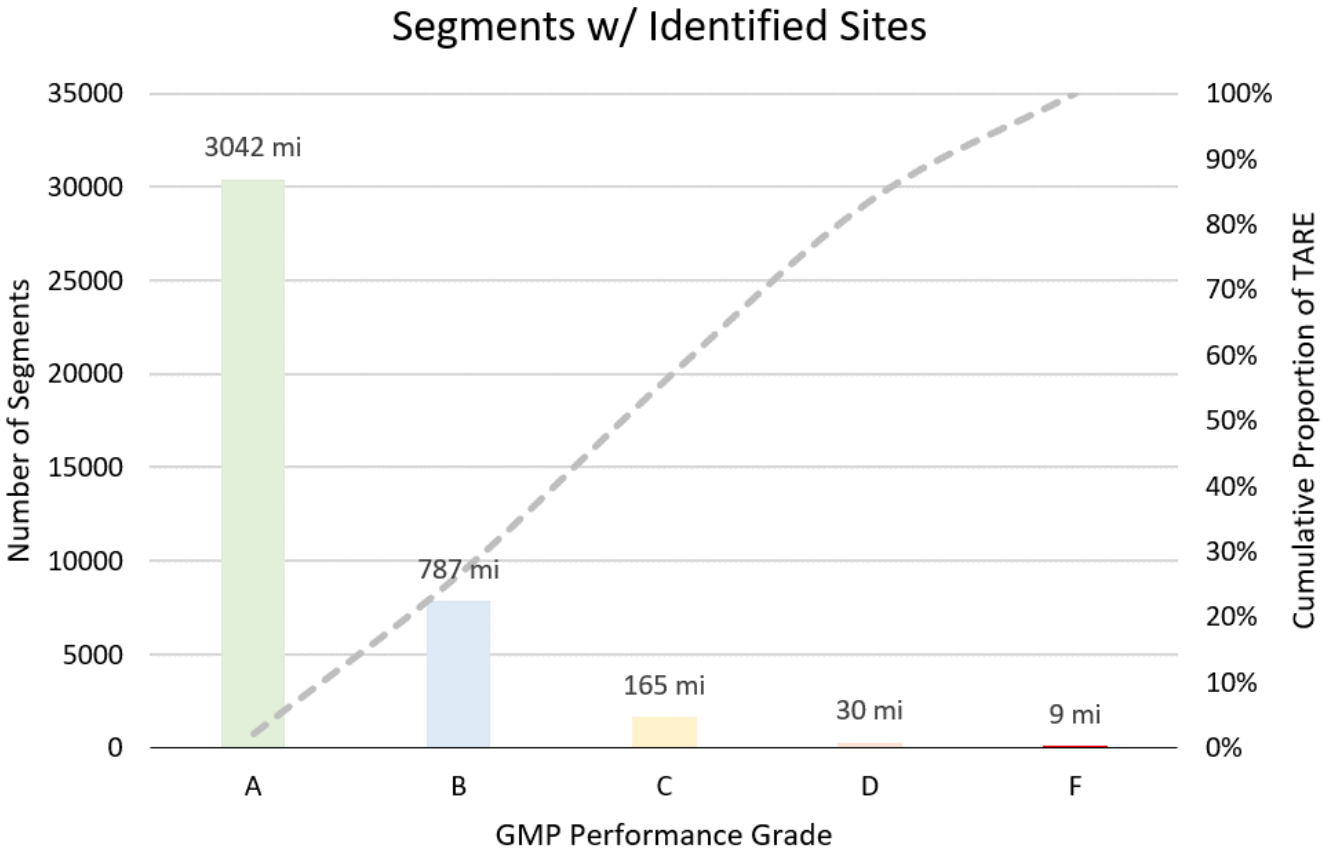
- Total of all highway segment exposures is the Total Annual Risk Exposure (TARE) for geohazards in Colorado

GMP Segment Performance State	Total Risk Exposure by Segment Dollar Value	
	Lower Bound	Upper Bound
A	$0	$500
B	$500	$5,000
C	$5,000	$25,000
D	$25,000	$100,000
F	$100,000	

Total ARE for all highway segments *with identified geo-assets or geohazards*:

$ 55,996,914

Risk Exposure and Decision Support

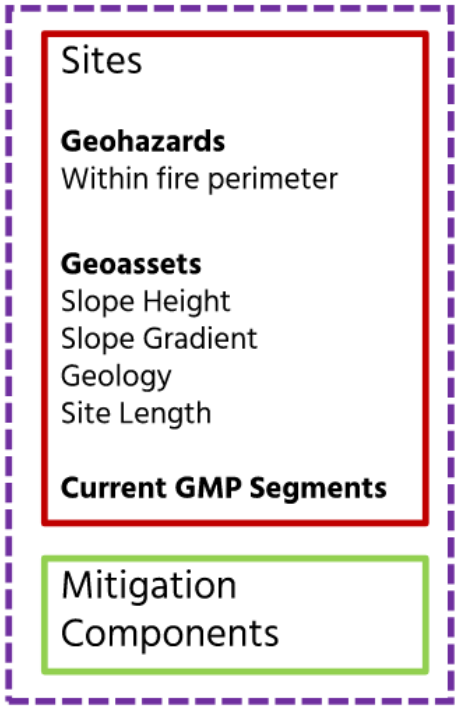


- Find candidates for risk and resilience investment
-
- Model risk exposure change with investment scenarios
- Sudden change in risk exposure (e.g. wildfire) can quickly be measured and communicated

Modeling Change in Risk Over 20 Years

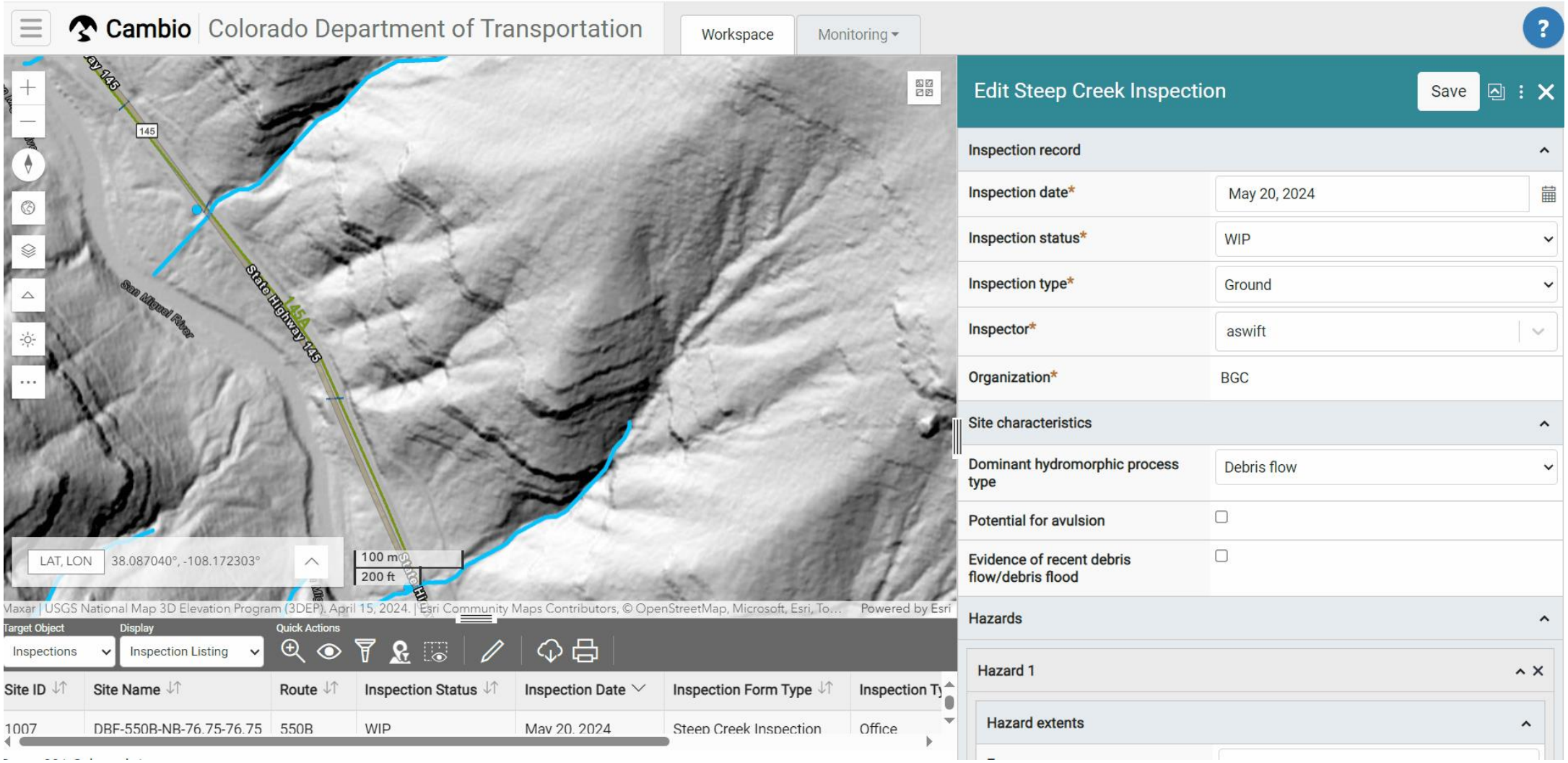
Deterioration Model Assignment

Criteria	Deterioration Model	Change Rate	Percentage of Reported Segments
Debris flow crossings and slow-moving landslides without mitigation	None	0%	1.61%
All screened geo-assets and current GMP sites	Slow	2%	95.93%
All sites with mitigation, 20% of shale embankments, and all shale cuts > 40 ft in height	Fast	4%	2.45%



Deterioration Model

Evolution continues – adding data where data is needed



Contact us

Mark Vessely, P.E.

Principal Engineer

mvessely@bgcengineering.com

www.bgcengineering.ca

Bob Group, P.E.

Geohazards Services Manager

Robert.Group@state.co.us

https://www.codot.gov/