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NEW ENGLAND TRANSPORTATION CONSORTIUM

NETC 19-2 Multi-Scale Multi-Season Land-Based Erosion Modeling and Monitoring for Infrastructure Management

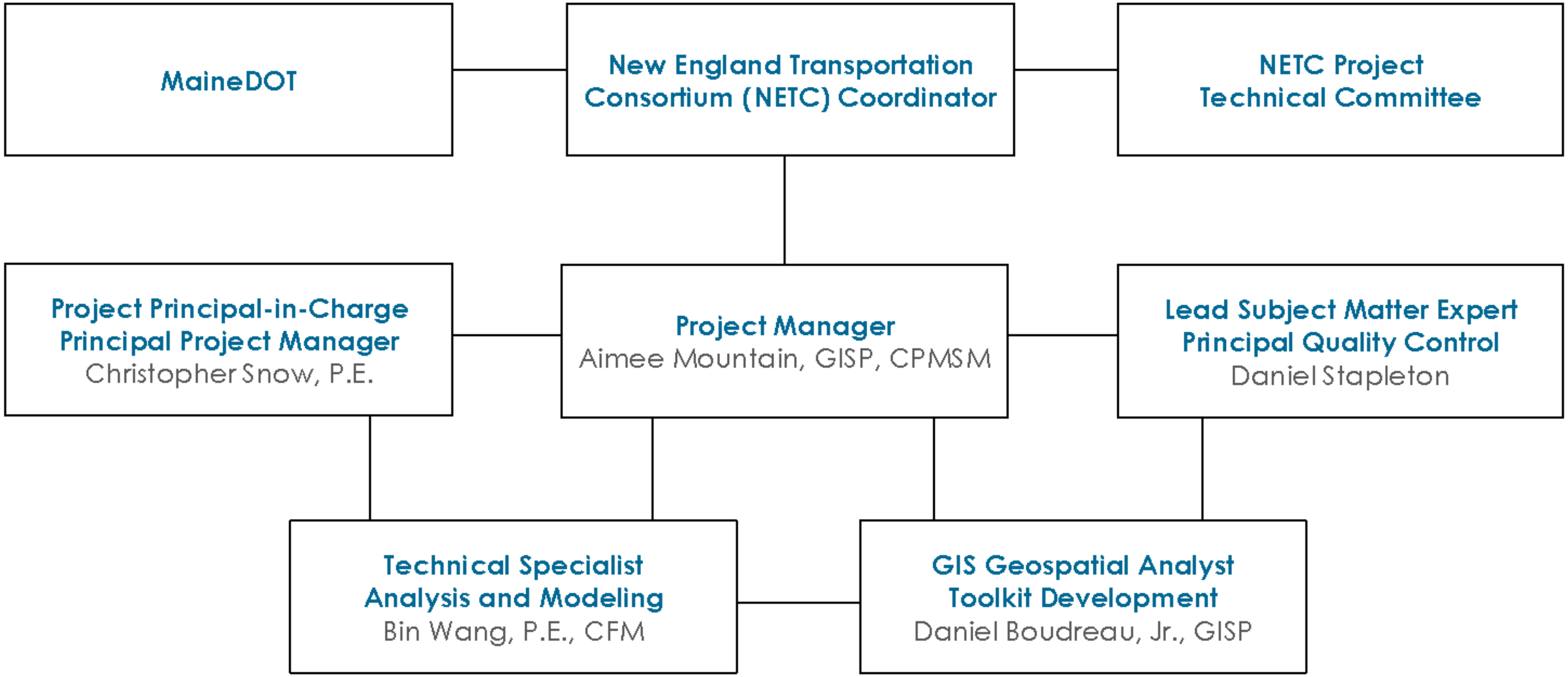
Webinar

December 14, 2021

MaineDOT

Project Team

Organizational Chart



MaineDOT

New England Transportation Consortium (NETC) Coordinator

NETC Project Technical Committee

Project Principal-in-Charge
Principal Project Manager
Christopher Snow, P.E.

Project Manager
Aimee Mountain, GISP, CPMSM

Lead Subject Matter Expert
Principal Quality Control
Daniel Stapleton

Technical Specialist
Analysis and Modeling
Bin Wang, P.E., CFM

GIS Geospatial Analyst
Toolkit Development
Daniel Boudreau, Jr., GISP

Additional Technical Staff, as needed

Project Problem Statement

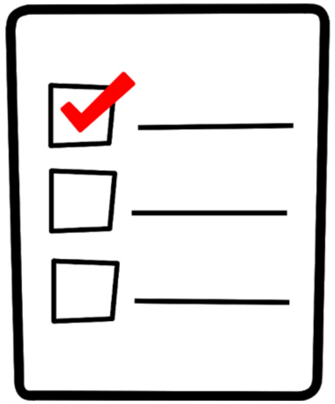
In the New England region, erosion-prone zones have been the main sources of erosion, particularly when major storms occur. With recent and continuing climate change influencing weather patterns (specifically causing an increase in high-intensity rainfall events, and rainfall events following snow events), soil erosion and landslides are a major concern for planners, designers, and maintainers of transportation networks and other critical infrastructure. With minimal operational resources and funding available for maintenance and repairs, effective screening tools used for modeling, monitoring, and forecasting erosion can aid in assessing erosion and landslide susceptibility, which is critical for regional operations and planning.

Source: Maine RFP# T201908002

Project Objectives

Develop a slope stability **model** that:

- Can be used as an effective screening tool for **monitoring**, **forecasting** and **prioritizing** areas of erosion and slope instability
- Will be used to create an effective, **multi-scale** assessment toolkit
- Is scalable to all New England state DOTs
- Can be implemented as a proof-of-concept on a limited area (Maine)



GZA Presentation Outline / Agenda

- Project overview by tasks (Bin) – 15 min Task 1 thru 4
- GIS “Model Builder” and data layers (Dan B.) – 5 min Task 4/5
- Example engineering application (Chris) – 5 min
- Toolkit live demo (Aimee) – 5 min
- Summary and thoughts for future improvement (Dan S.) – 5 min

Project Tasks

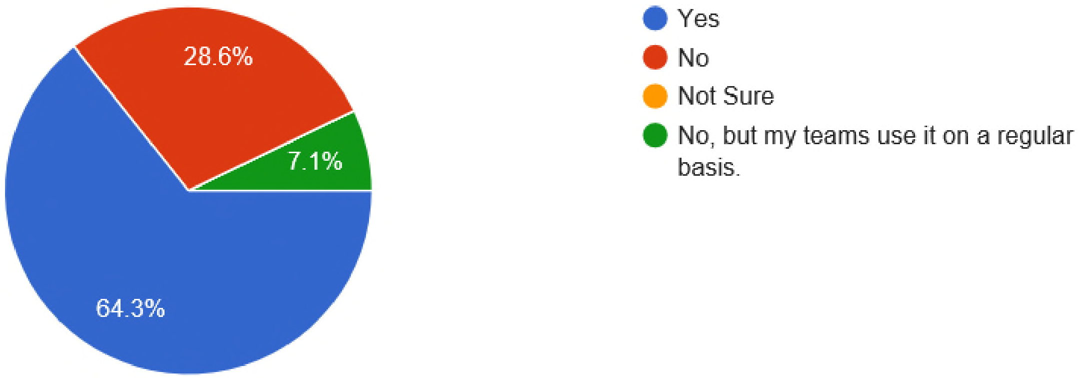
1. Literature Review and Survey
2. Analysis and Modeling
3. Ground Truthing and Monitoring
4. Toolkit Development
5. Toolkit Refinement

Task 1. Literature Review and Survey

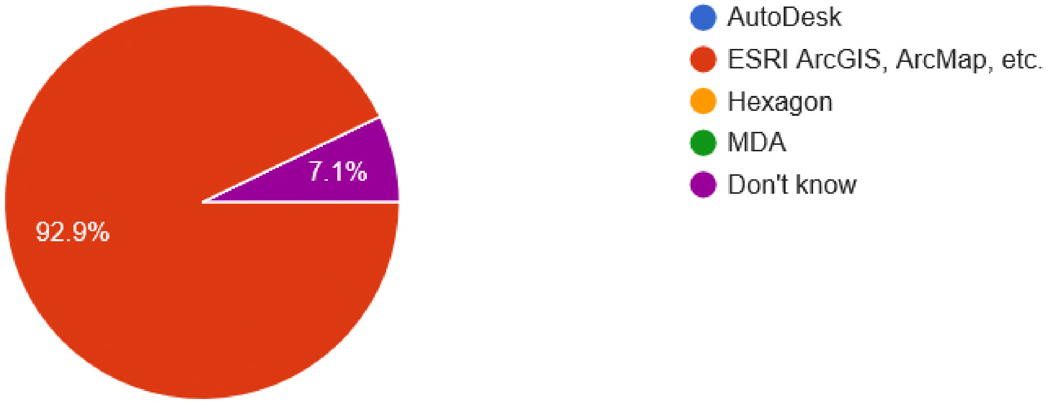
- Identify GIS platforms used by each state DOT
- Identify each New England state DOT toolkit needs, existing data and capabilities
- Research and identify current state-of-the art modeling capabilities and similar applications
- Collect existing slope stability and landslide map data
- Identify the availability of DOT and state land data

Task 1. Survey Results

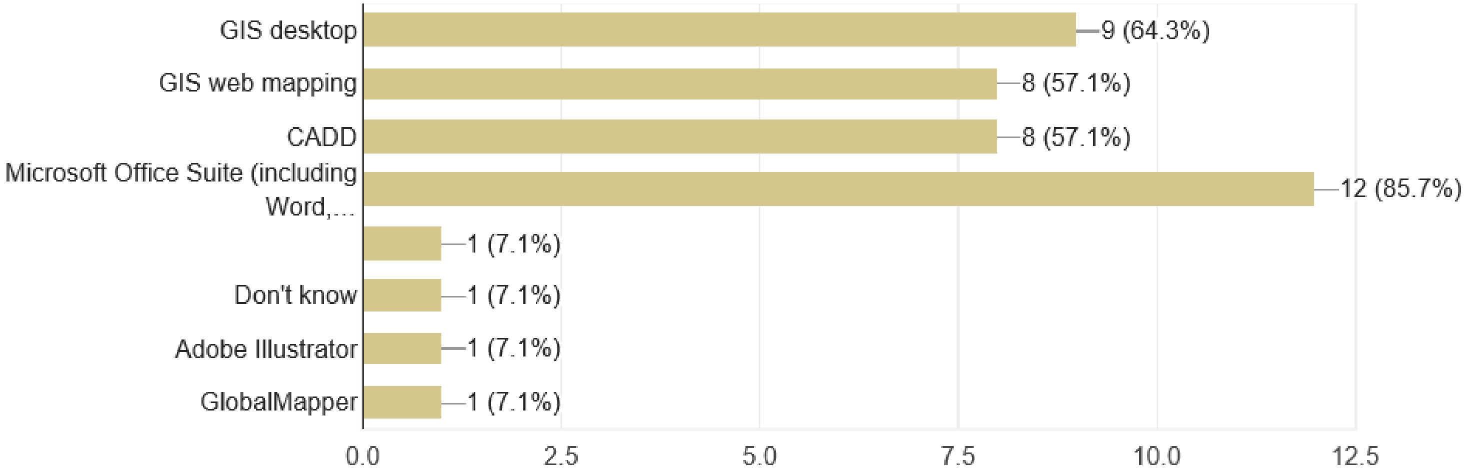
Q: Use of GIS for work ?



Q: GIS platform your office is currently using?

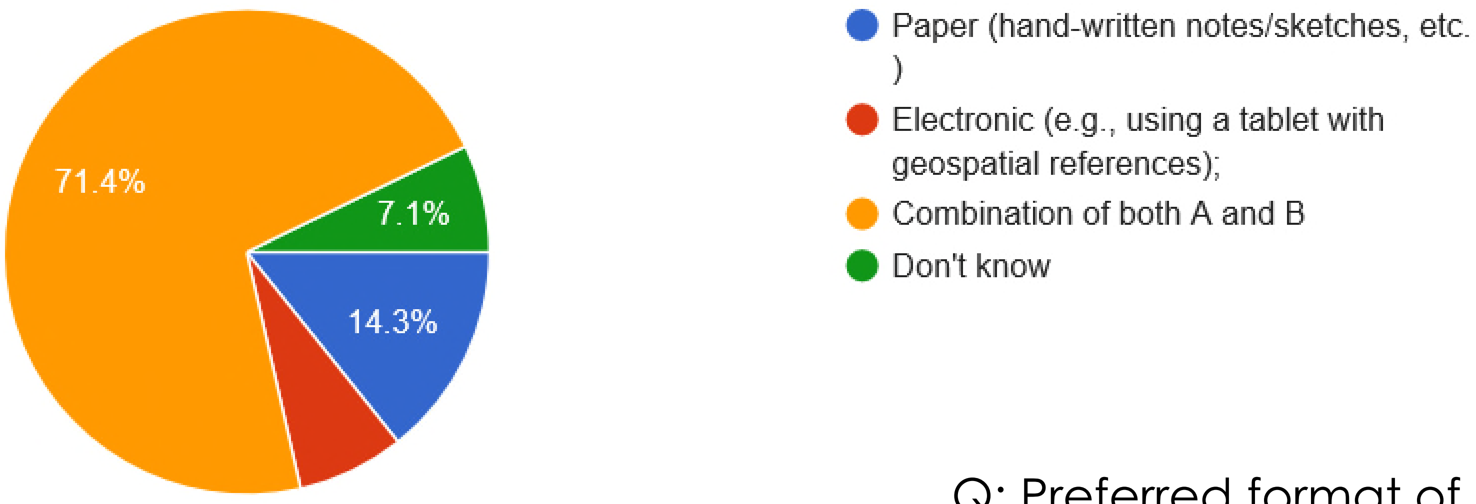


Q: Geographic or design software packages

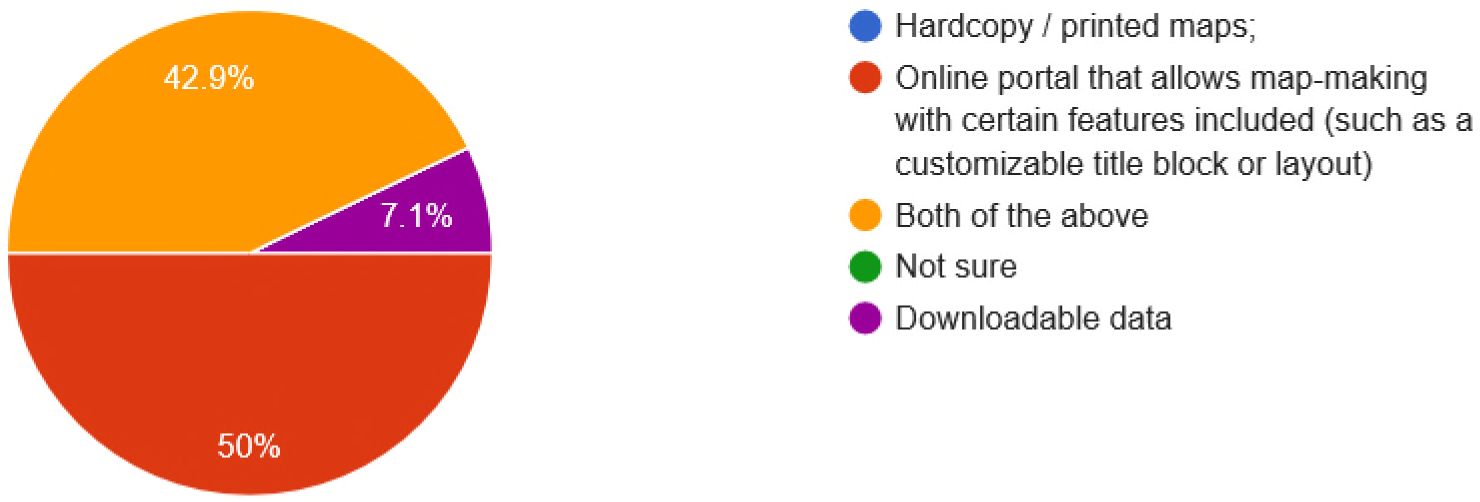


Task 1. Survey Results

Q: Method for collecting field data.

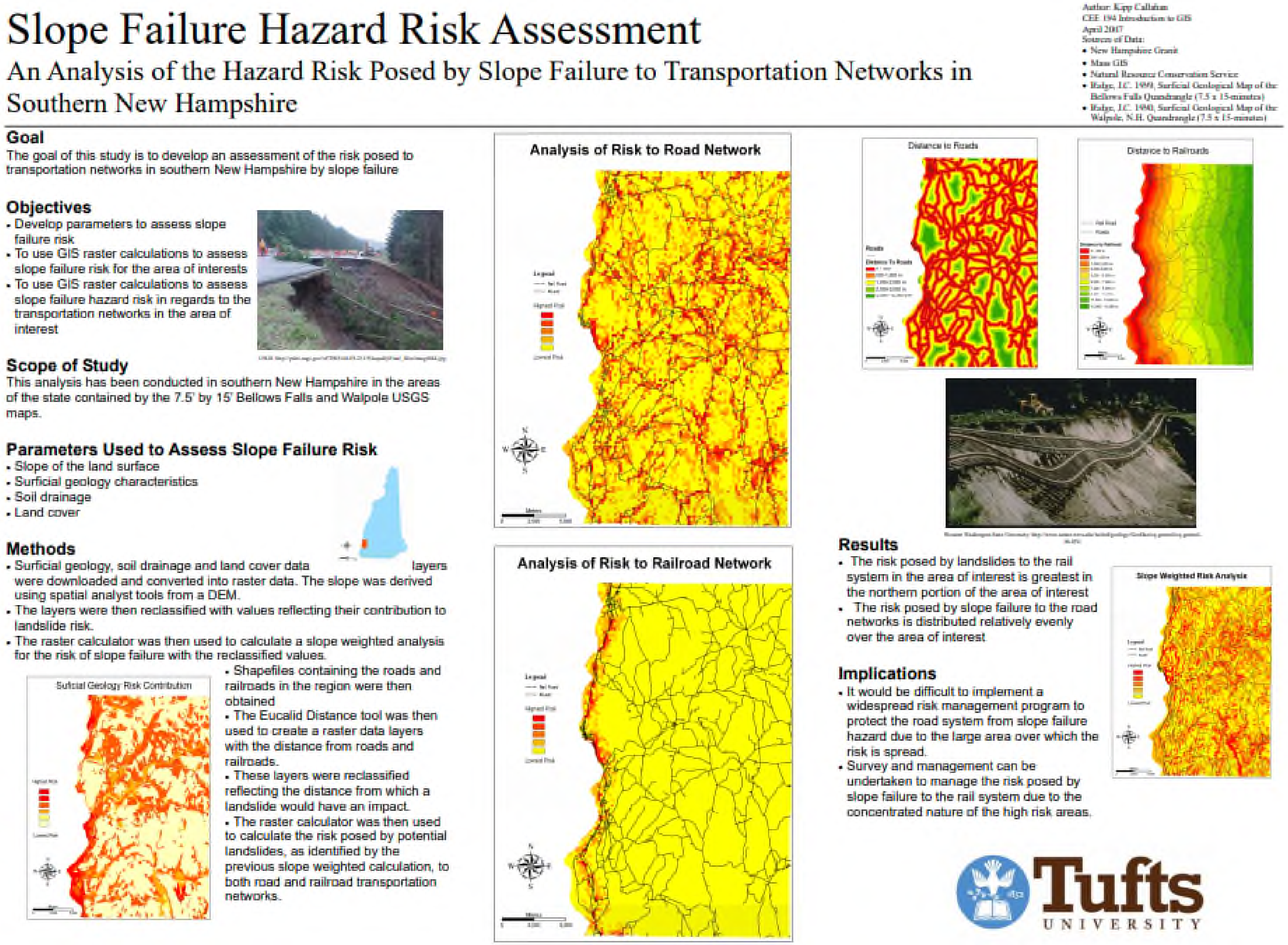


Q: Preferred format of maps



Task 1. Literature Review

Example



Slope Failure Hazard Risk Assessment

An Analysis of the Hazard Risk Posed by Slope Failure to Transportation Networks in Southern New Hampshire

Author: Kipp Callahan
CEE 194 Introduction to GIS
April 2007
Sources of Data:
- New Hampshire Granit
- Mass GIS
- Natural Resource Conservation Service
- Ridge, J.C. 1999, Surficial Geological Map of the Bellows Falls Quadrangle (7.5 x 15-minutes)
- Ridge, J.C. 1990, Surficial Geological Map of the Walpole, N.H. Quadrangle (7.5 x 15-minutes)

Goal

The goal of this study is to develop an assessment of the risk posed to transportation networks in southern New Hampshire by slope failure

Objectives

- Develop parameters to assess slope failure risk
- To use GIS raster calculations to assess slope failure risk for the area of interests
- To use GIS raster calculations to assess slope failure hazard risk in regards to the transportation networks in the area of interest

Scope of Study

This analysis has been conducted in southern New Hampshire in the areas of the state contained by the 7.5' by 15' Bellows Falls and Walpole USGS maps.

Parameters Used to Assess Slope Failure Risk

- Slope of the land surface
- Surficial geology characteristics
- Soil drainage
- Land cover

Methods

- Surficial geology, soil drainage and land cover data layers were downloaded and converted into raster data. The slope was derived using spatial analyst tools from a DEM.
- The layers were then reclassified with values reflecting their contribution to landslide risk.
- The raster calculator was then used to calculate a slope weighted analysis for the risk of slope failure with the reclassified values.
- Shapefiles containing the roads and railroads in the region were then obtained
- The Eucalid Distance tool was then used to create a raster data layers with the distance from roads and railroads.
- These layers were reclassified reflecting the distance from which a landslide would have an impact.
- The raster calculator was then used to calculate the risk posed by potential landslides, as identified by the previous slope weighted calculation, to both road and railroad transportation networks.

Suficial Geology Risk Contribution

Analysis of Risk to Road Network

Analysis of Risk to Railroad Network

Distance to Roads

Distance to Railroads

Results

- The risk posed by landslides to the rail system in the area of interest is greatest in the northern portion of the area of interest
- The risk posed by slope failure to the road networks is distributed relatively evenly over the area of interest

Implications

- It would be difficult to implement a widespread risk management program to protect the road system from slope failure hazard due to the large area over which the risk is spread.
- Survey and management can be undertaken to manage the risk posed by slope failure to the rail system due to the concentrated nature of the high risk areas.

Slope Weighted Risk Analysis

Tufts UNIVERSITY

Task 1. Literature Review

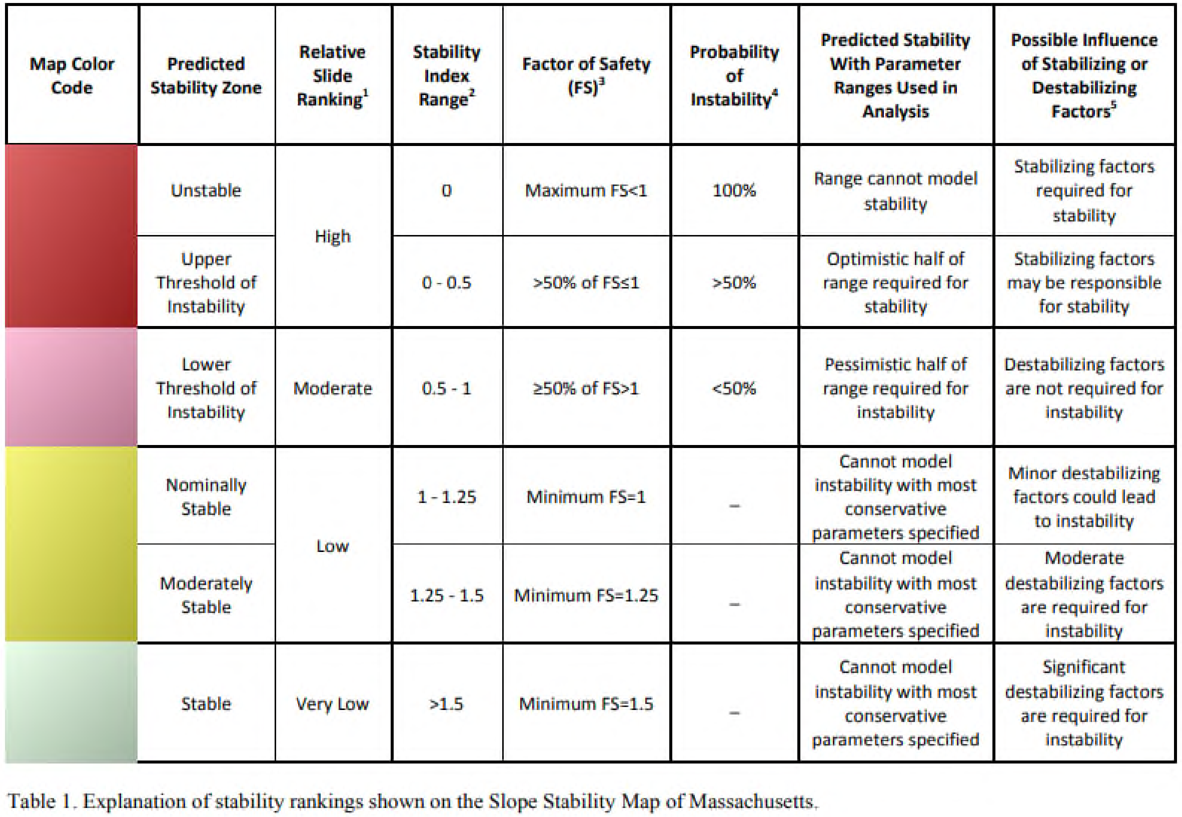
Example

Slope Stability Map of Massachusetts

Compiled by Stephen B. Mabee and Christopher C. Duncan

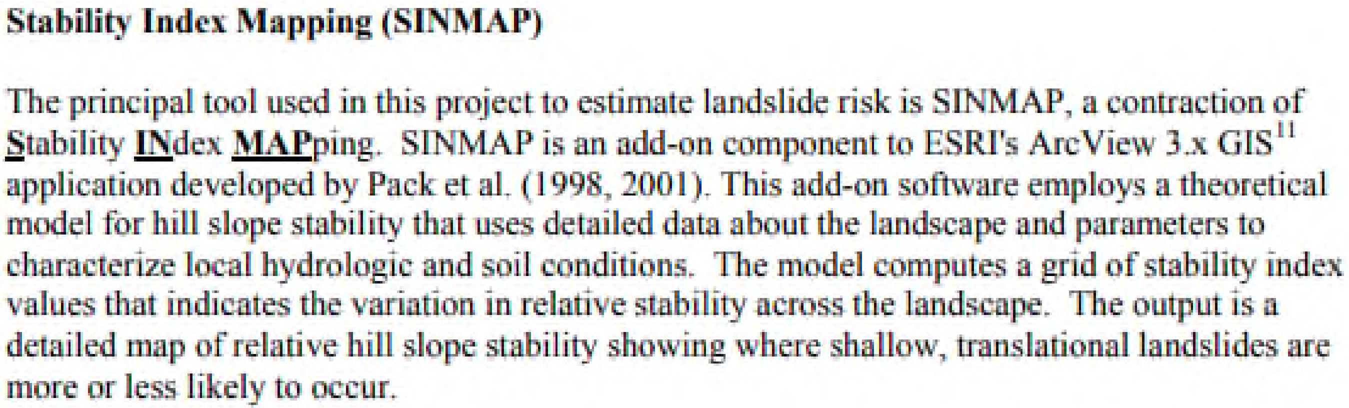
Prepared for the Massachusetts Emergency Management Agency, the Federal Emergency Management Agency and the Massachusetts Department of Conservation and Recreation

December 2013



Map Color Code	Predicted Stability Zone	Relative Slide Ranking^1	Stability Index Range^2	Factor of Safety (FS)^3	Probability of Instability^4	Predicted Stability With Parameter Ranges Used in Analysis	Possible Influence of Stabilizing or Destabilizing Factors^5
🟥	Unstable	High	0	Maximum FS<1	100%	Range cannot model stability	Stabilizing factors required for stability
	Upper Threshold of Instability		0 - 0.5	>50% of FS≤1	>50%	Optimistic half of range required for stability	Stabilizing factors may be responsible for stability
🟪	Lower Threshold of Instability	Moderate	0.5 - 1	≥50% of FS>1	<50%	Pessimistic half of range required for instability	Destabilizing factors are not required for instability
🟨	Nominally Stable	Low	1 - 1.25	Minimum FS=1	_	Cannot model instability with most conservative parameters specified	Minor destabilizing factors could lead to instability
	Moderately Stable		1.25 - 1.5	Minimum FS=1.25	_	Cannot model instability with most conservative parameters specified	Moderate destabilizing factors are required for instability
🟩	Stable	Very Low	>1.5	Minimum FS=1.5	_	Cannot model instability with most conservative parameters specified	Significant destabilizing factors are required for instability

Table 1. Explanation of stability rankings shown on the Slope Stability Map of Massachusetts.



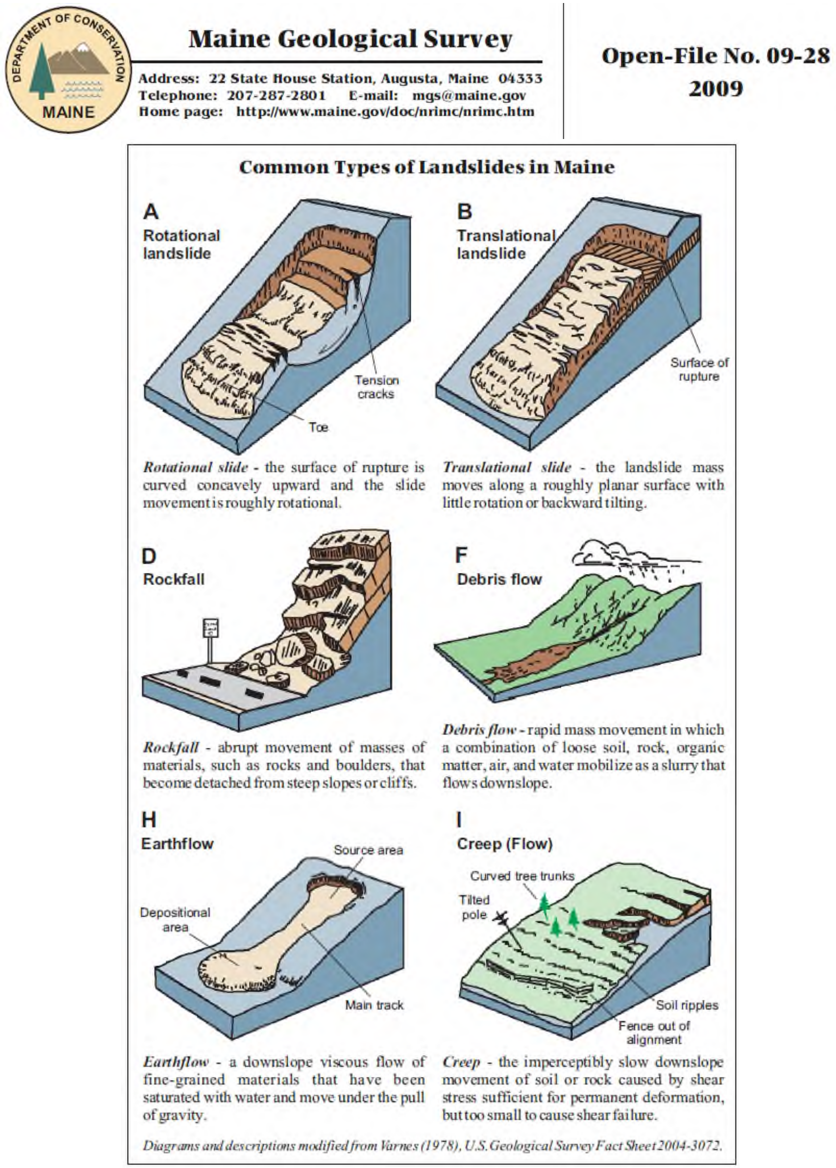
Stability Index Mapping (SINMAP)

The principal tool used in this project to estimate landslide risk is SINMAP, a contraction of Stability INdex MAPping. SINMAP is an add-on component to ESRI's ArcView 3.x GIS^{11} application developed by Pack et al. (1998, 2001). This add-on software employs a theoretical model for hill slope stability that uses detailed data about the landscape and parameters to characterize local hydrologic and soil conditions. The model computes a grid of stability index values that indicates the variation in relative stability across the landscape. The output is a detailed map of relative hill slope stability showing where shallow, translational landslides are more or less likely to occur.

http://www.geo.umass.edu/stategeologist/Products/Landslide_Map/Slope_Stability_Map_MA_Report.pdf

Task 1. Literature Review

Example



Maine Geological Survey

Address: 22 State House Station, Augusta, Maine 04333
Telephone: 207-287-2801 E-mail: mgs@maine.gov
Home page: http://www.maine.gov/doc/nrimc/nrimc.htm

Open-File No. 09-28
2009

Common Types of Landslides in Maine

Rotational slide - the surface of rupture is curved concavely upward and the slide movement is roughly rotational.

Translational slide - the landslide mass moves along a roughly planar surface with little rotation or backward tilting.

Rockfall - abrupt movement of masses of materials, such as rocks and boulders, that become detached from steep slopes or cliffs.

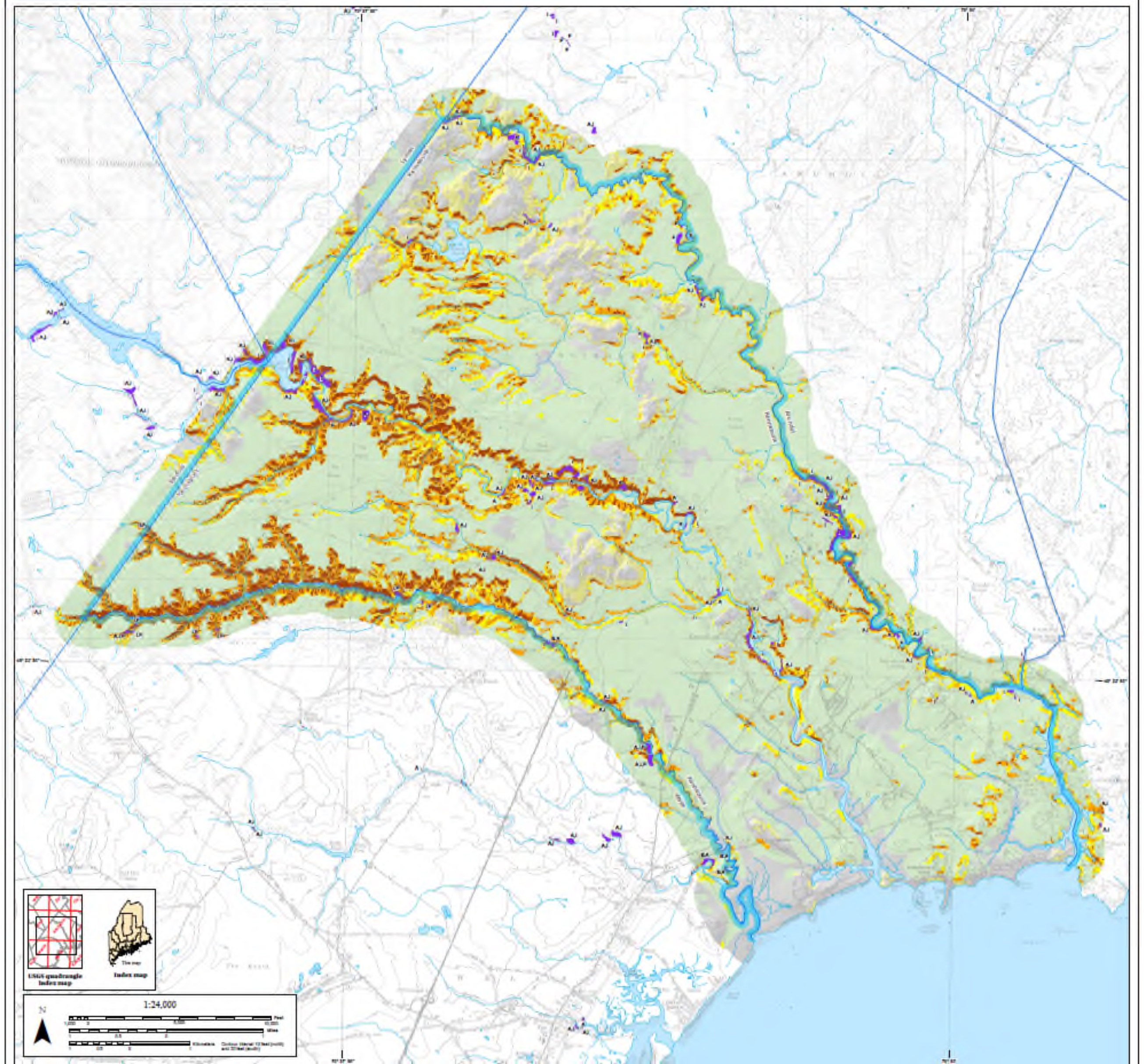
Debris flow - rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope.

Earthflow - a downslope viscous flow of fine-grained materials that have been saturated with water and move under the pull of gravity.

Creep - the imperceptibly slow downslope movement of soil or rock caused by shear stress sufficient for permanent deformation, but too small to cause shear failure.

Diagrams and descriptions modified from Varnes (1978), U.S. Geological Survey Fact Sheet 2004-3072.

Landslide Sites and Areas of Landslide Susceptibility
Kennebunk, Maine - Maine Geological Survey

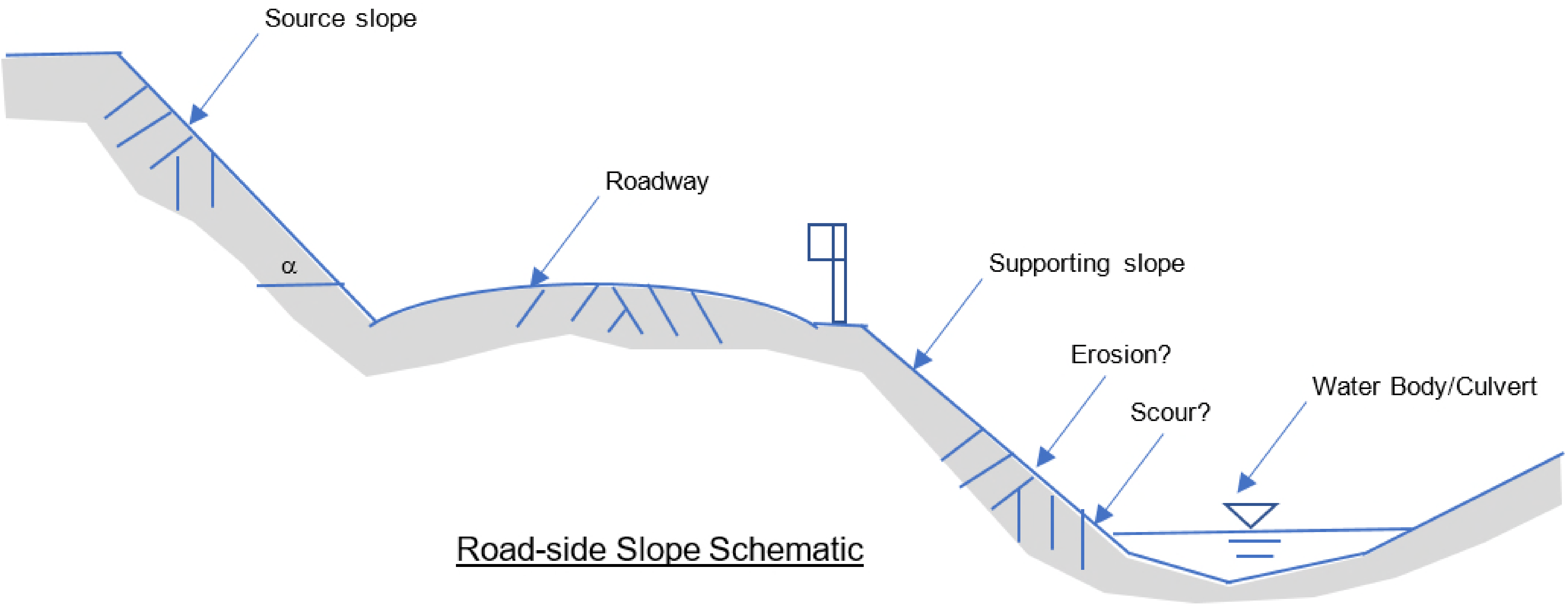


Task 2. Analysis and Modeling

Develop model applications to evaluate and screen for **erosion** (washout) and **landslide** (slope stability) risk along transportation corridors

Task 2. Model Development

Overview of Model



Road-side Slope Schematic

Task 2. Model Development

Overview of NETC 19-2 Model Input Data

Geospatial Site Data:	Environmental Data	Environmental Data – Real time data acquisition
• **Topographic data** • **Jurisdictional boundaries** • **Land Cover** • **Surficial geology** • **Roadways** • **Roadway bridge and drainage structures** • Available planimetric data • Additional asset data • **Flood mapping information**	• Precipitation • Soil moisture ← • Seismic ground acceleration • Coastal flood inundation • Coastal waves • River flood • **Groundwater conditions** • **Proximity to scouring source** (surface water and/or drainage structure) (current and w/ climate change)	• Precipitation • River flow and elevation gage data • Coastal water levels and predicted inundation limits • Other (for failure forecasting)

Note – **BOLD** indicates action included in current model/toolkit prototype

Task 2. Model Development

Simplified Work Flow (for <u>Pilot</u> Study)

1. Compile Input in GIS
2. Discretize Parameter Space
3. Prepare Reference Set
4. Match Pre-Simulated Node
5. Apply Response Function(s)

Task 2. Model Development

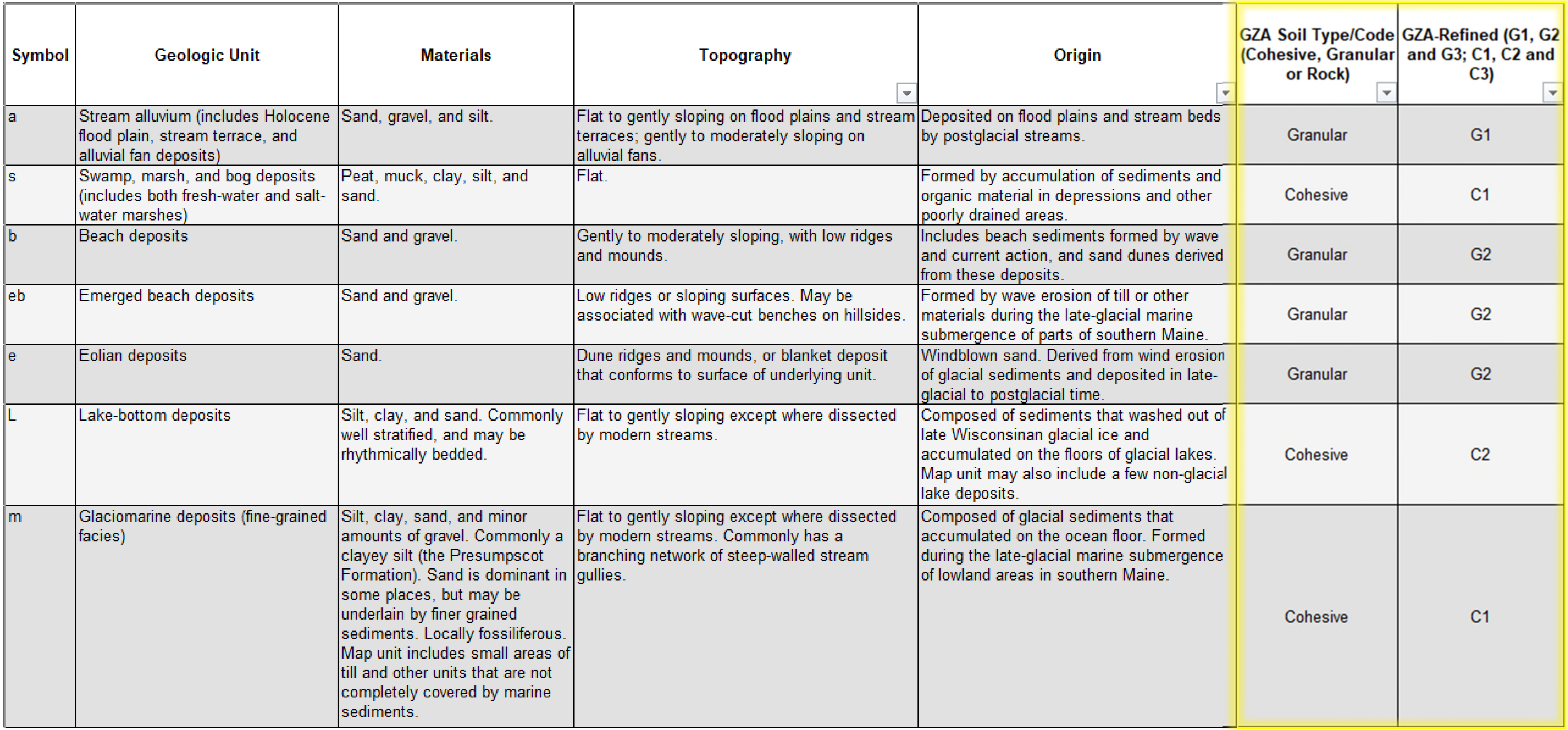
Input Data used for Pilot Study

1

Geospatial Site Data	Environmental Data	Environmental Data – Real time data acquisition
- **Northing-Easting (m)** - **Elevation (m)** - **Slope (%)** - **Aspect (°)** point loc road - **Road proximity (m)** - **Hydro proximity (m)** - **Culvert proximity (m)** - **Surficial Geology Code 250k** - **NLCD Land Cover Code**	**FEMA flood zone** - Riverine flood - Coastal flood inundation - Coastal waves - **Groundwater table** - **Proximity to scouring source** (surface water and/or drainage structure)	- N/A (future) Assumptions (shallow vs deep)

Task 2. Model Development

USGS/Maine Geological Survey 250K Surficial Geology



Symbol	Geologic Unit	Materials	Topography	Origin	GZA Soil Type/Code (Cohesive, Granular or Rock)	GZA-Refined (G1, G2 and G3; C1, C2 and C3)
a	Stream alluvium (includes Holocene flood plain, stream terrace, and alluvial fan deposits)	Sand, gravel, and silt.	Flat to gently sloping on flood plains and stream terraces; gently to moderately sloping on alluvial fans.	Deposited on flood plains and stream beds by postglacial streams.	Granular	G1
s	Swamp, marsh, and bog deposits (includes both fresh-water and salt-water marshes)	Peat, muck, clay, silt, and sand.	Flat.	Formed by accumulation of sediments and organic material in depressions and other poorly drained areas.	Cohesive	C1
b	Beach deposits	Sand and gravel.	Gently to moderately sloping, with low ridges and mounds.	Includes beach sediments formed by wave and current action, and sand dunes derived from these deposits.	Granular	G2
eb	Emerged beach deposits	Sand and gravel.	Low ridges or sloping surfaces. May be associated with wave-cut benches on hillsides.	Formed by wave erosion of till or other materials during the late-glacial marine submergence of parts of southern Maine.	Granular	G2
e	Eolian deposits	Sand.	Dune ridges and mounds, or blanket deposit that conforms to surface of underlying unit.	Windblown sand. Derived from wind erosion of glacial sediments and deposited in late-glacial to postglacial time.	Granular	G2
L	Lake-bottom deposits	Silt, clay, and sand. Commonly well stratified, and may be rhythmically bedded.	Flat to gently sloping except where dissected by modern streams.	Composed of sediments that washed out of late Wisconsinan glacial ice and accumulated on the floors of glacial lakes. Map unit may also include a few non-glacial lake deposits.	Cohesive	C2
m	Glaciomarine deposits (fine-grained facies)	Silt, clay, sand, and minor amounts of gravel. Commonly a clayey silt (the Presumpscot Formation). Sand is dominant in some places, but may be underlain by finer grained sediments. Locally fossiliferous. Map unit includes small areas of till and other units that are not completely covered by marine sediments.	Flat to gently sloping except where dissected by modern streams. Commonly has a branching network of steep-walled stream gullies.	Composed of glacial sediments that accumulated on the ocean floor. Formed during the late-glacial marine submergence of lowland areas in southern Maine.	Cohesive	C1

Task 2. Model Development

Methodology – Reference Set Parameter Combinations

Slope Type	Soil Types	Granular Soils (phi)	Cohesive Soils (Su)	Geometry (Slope)	Groundwater conditions
Support	Granular	G1 (28°)	C1 (350 psf)	6:1	Shallow (at toe)
Source	Cohesive	G2 (32°)	C2 (750 psf)	4:1	Deep (10’ below)
	Rock	G3 (38°)	C3 (1,250 psf)	3:1	
				2:1	
				1.5:1	
				1:1	

Interpretation based on
the 250K surficial
material dataset

Typical Slopes

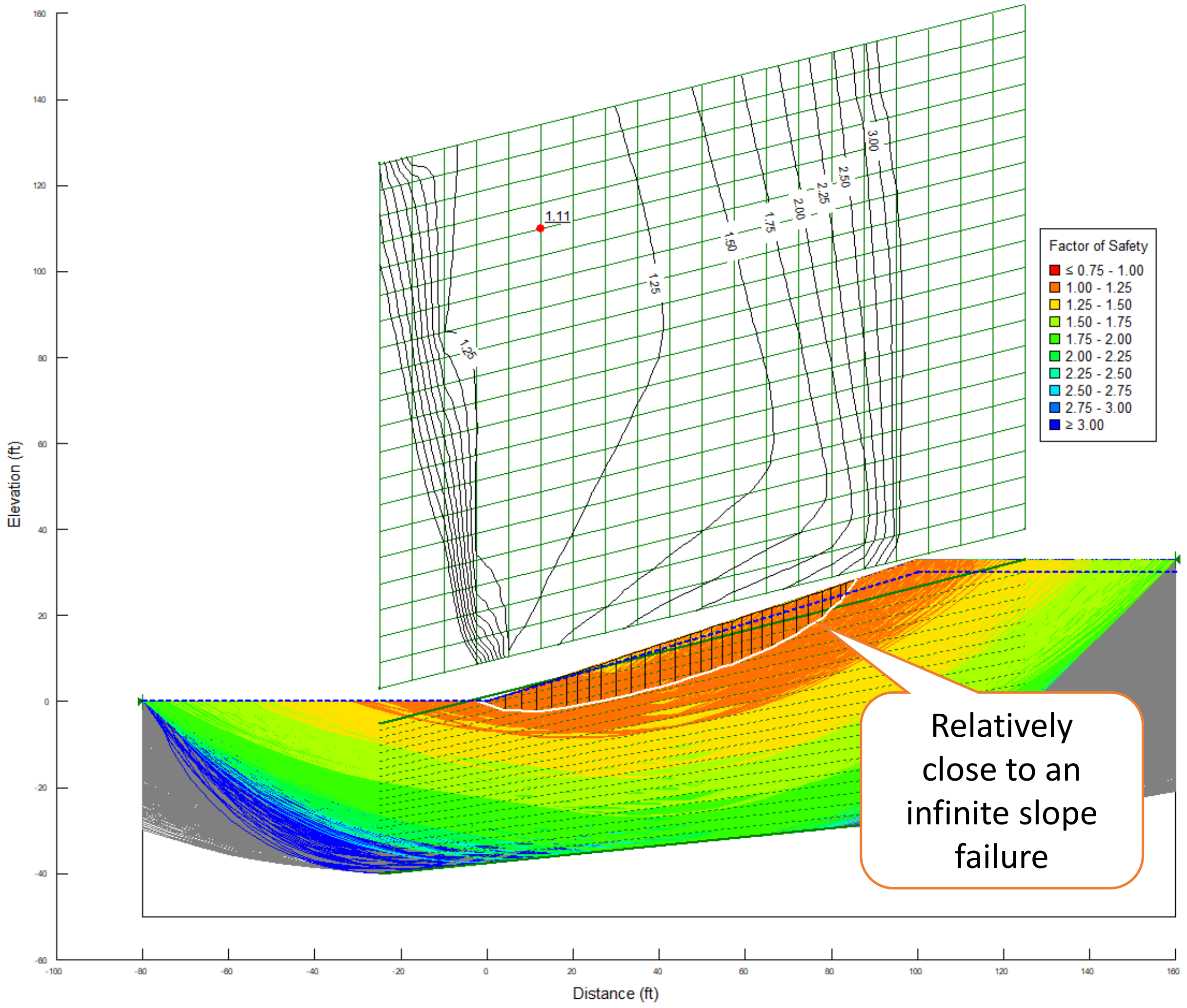
# of SLOPE/W Simulations = 72

Task 2. Model Development

Example SLOPE/W Simulation

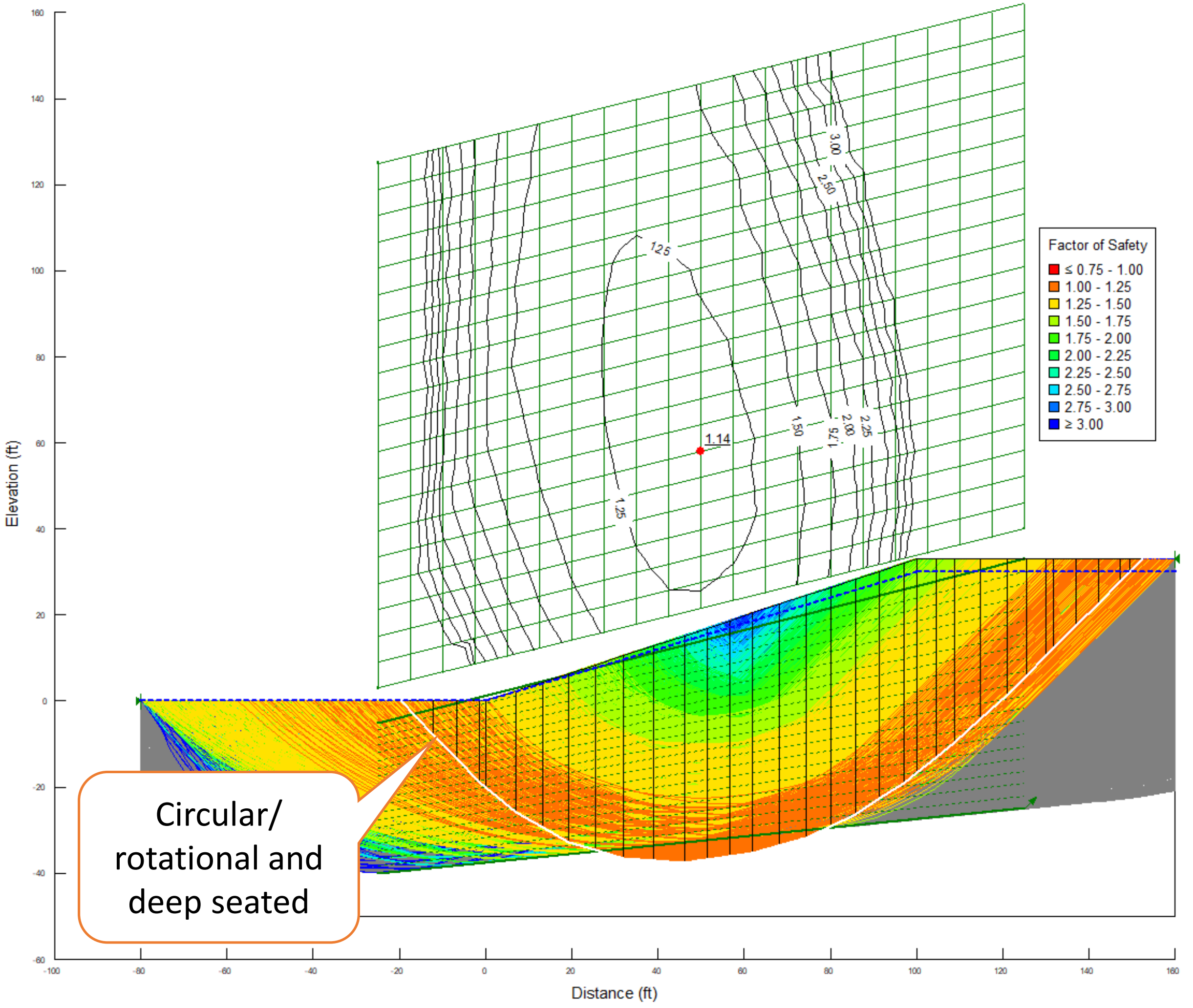
3

Task 2 Memo Figure A-6:
SLOPE/W-Calculated Factor of Safety Results – Medium Dense Sand (G2) on 3:1 Slope



Relatively close to an infinite slope failure

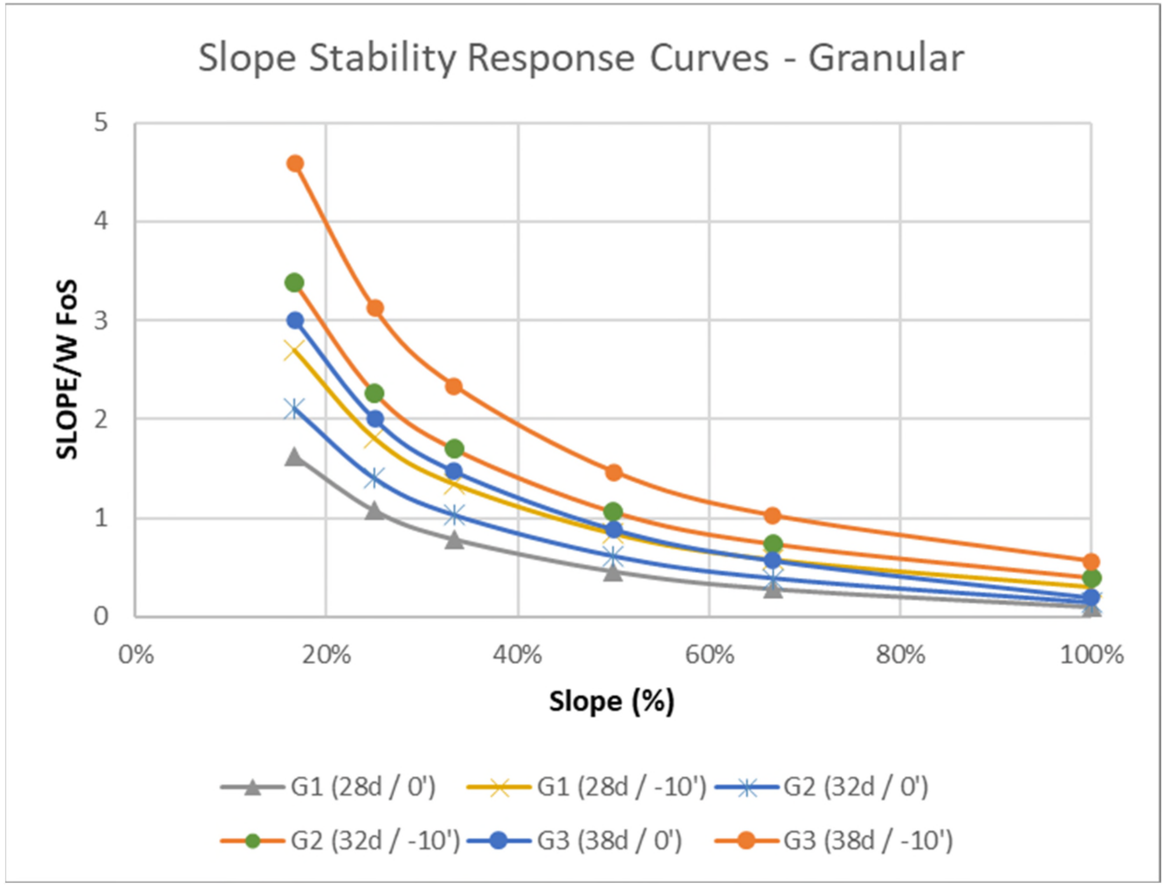
Task 2 Memo Figure A-8:
SLOPE/W-Calculated Factor of Safety Results – Medium Stiff Clay (C2) on 3:1 Slope

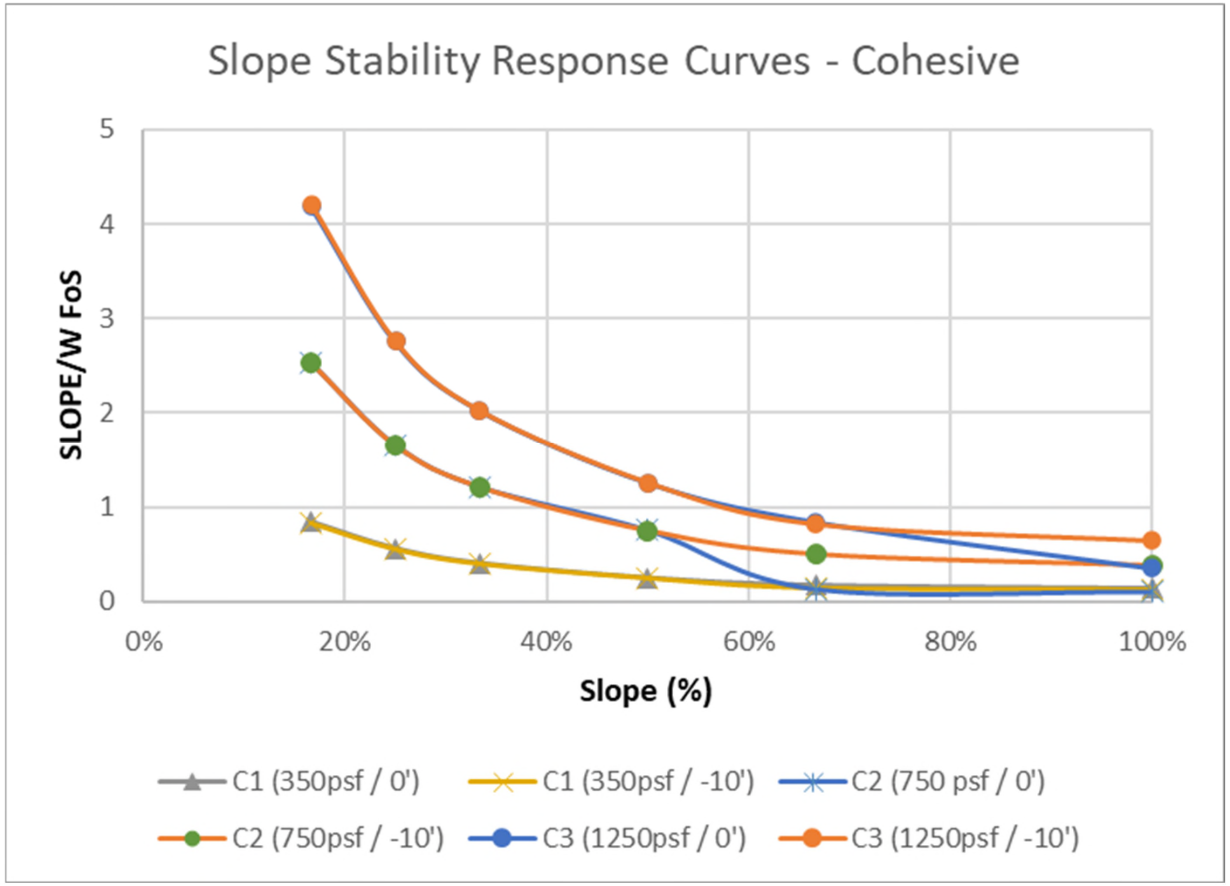


Circular/ rotational and deep seated

Task 2. Model Development

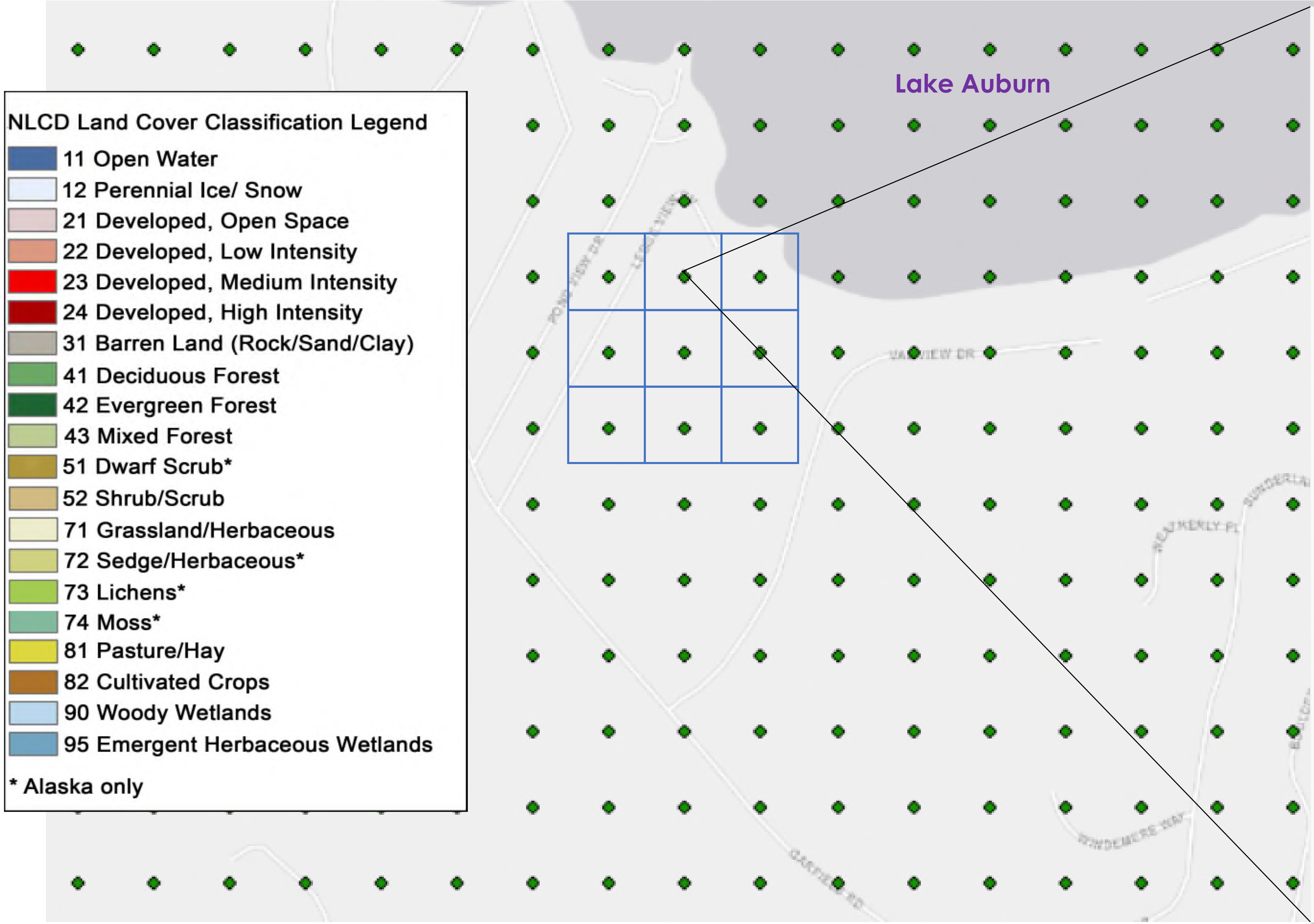
Methodology – Pre-simulated Reference Set





Task 2. Model Development

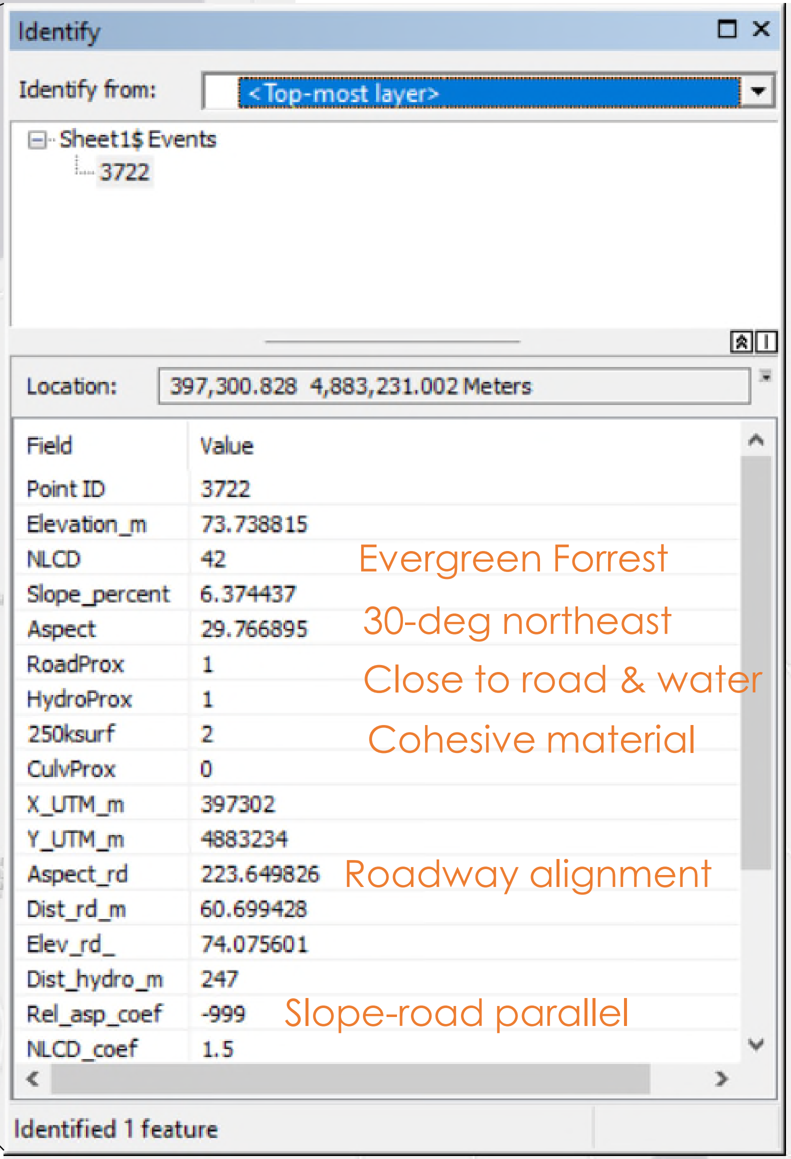
Methodology – Input Spatial Data w/ Environmental Information



NLCD Land Cover Classification Legend

■	11 Open Water
■	12 Perennial Ice/ Snow
■	21 Developed, Open Space
■	22 Developed, Low Intensity
■	23 Developed, Medium Intensity
■	24 Developed, High Intensity
■	31 Barren Land (Rock/Sand/Clay)
■	41 Deciduous Forest
■	42 Evergreen Forest
■	43 Mixed Forest
■	51 Dwarf Scrub*
■	52 Shrub/Scrub
■	71 Grassland/Herbaceous
■	72 Sedge/Herbaceous*
■	73 Lichens*
■	74 Moss*
■	81 Pasture/Hay
■	82 Cultivated Crops
■	90 Woody Wetlands
■	95 Emergent Herbaceous Wetlands

* Alaska only



Identify

Identify from: <Top-most layer>

Sheet1$ Events
3722

Location: 397,300.828 4,883,231.002 Meters

Field	Value
Point ID	3722
Elevation_m	73.738815
NLCD	42
Slope_percent	6.374437
Aspect	29.766895
RoadProx	1
HydroProx	1
250ksurf	2
CulvProx	0
X_UTM_m	397302
Y_UTM_m	4883234
Aspect_rd	223.649826
Dist_rd_m	60.699428
Elev_rd_	74.075601
Dist_hydro_m	247
Rel_asp_coef	-999
NLCD_coef	1.5

Identified 1 feature

Evergreen Forrest

30-deg northeast

Close to road & water

Cohesive material

Roadway alignment

Slope-road parallel

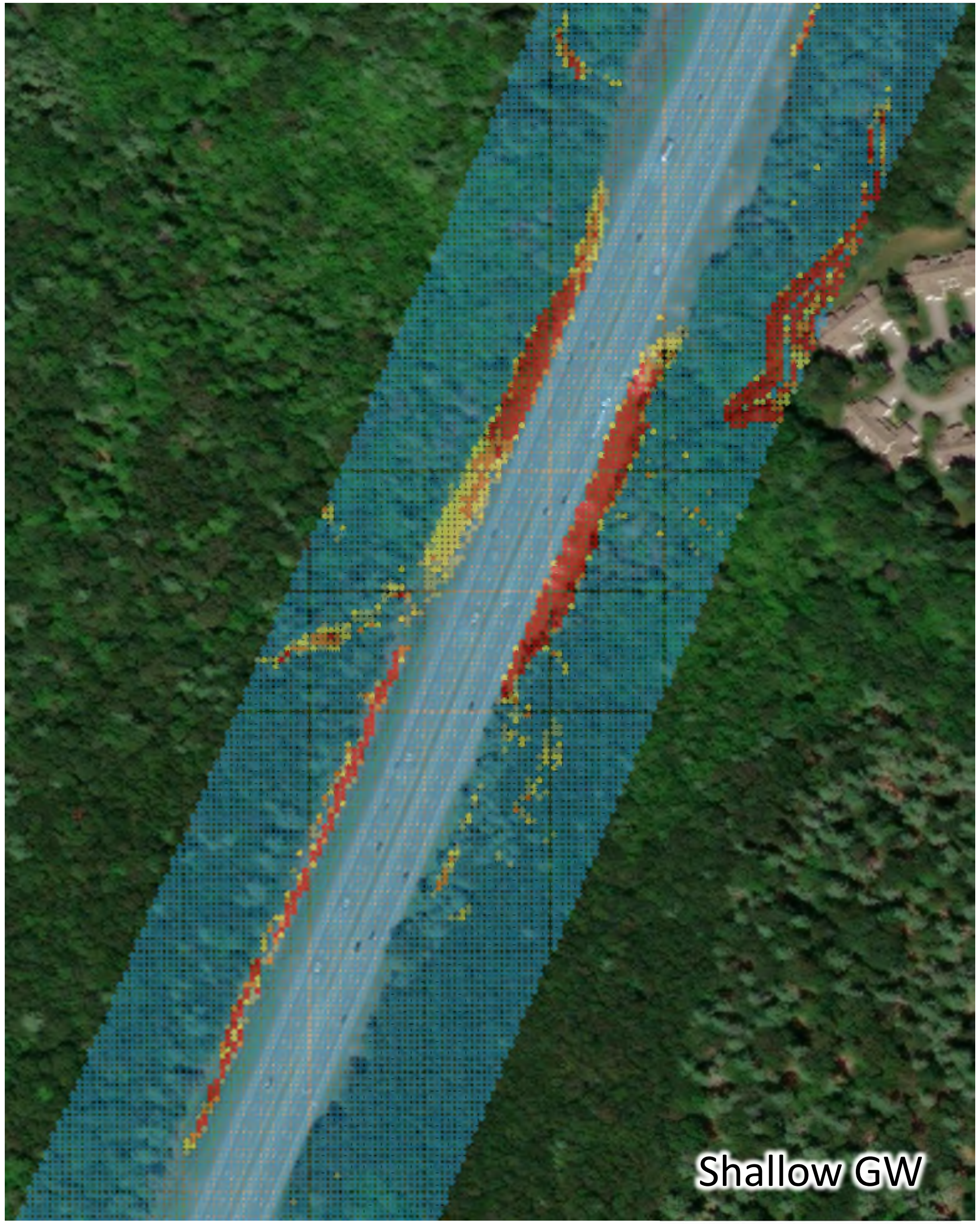
Task 2. Model Development

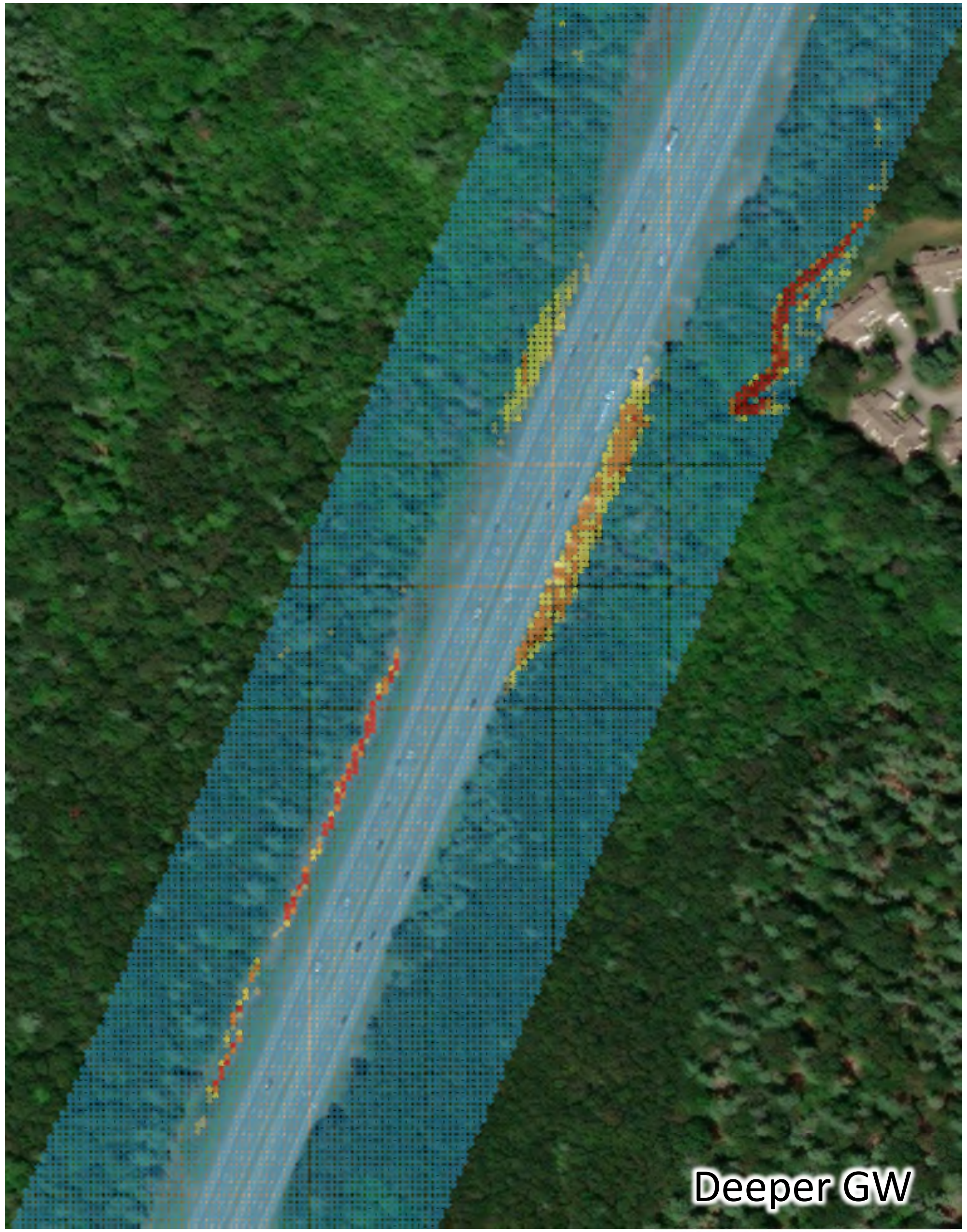
Mapping Product

Map Color Code	Predicted Stability Zone	Relative Hazard Ranking	Factor of Safety (FoS)	Probability of Instability	Possible Influence of Stabilizing or Destabilizing Factors
🟥	Unstable	Very High (5)	<0.9	90%	Stabilizing factors required for achieving/maintaining stability
🟧	Threshold of instability	High (4)	0.9 – 1.1	>50%	
🟨	Nominally stable	Moderate (3)	1.1 – 1.3	10%	Minor destabilizing factors needed
🟩	Moderately stable	Low (2)	1.3 – 1.5	--	Moderate destabilizing factors needed
🟩	Stable	Very Low (1)	>1.5	--	Significant destabilizing factors needed

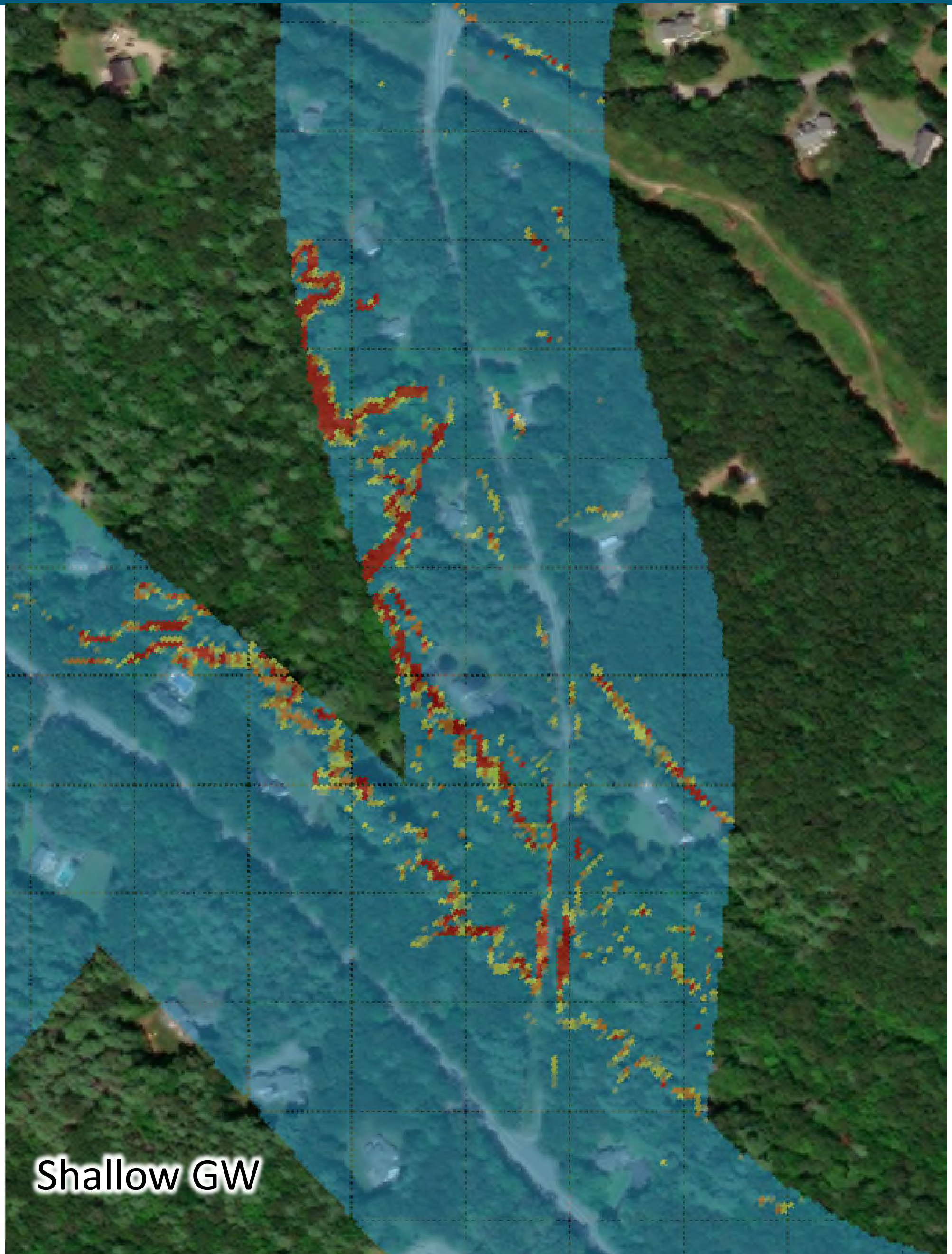
(Task 2 Memorandum)

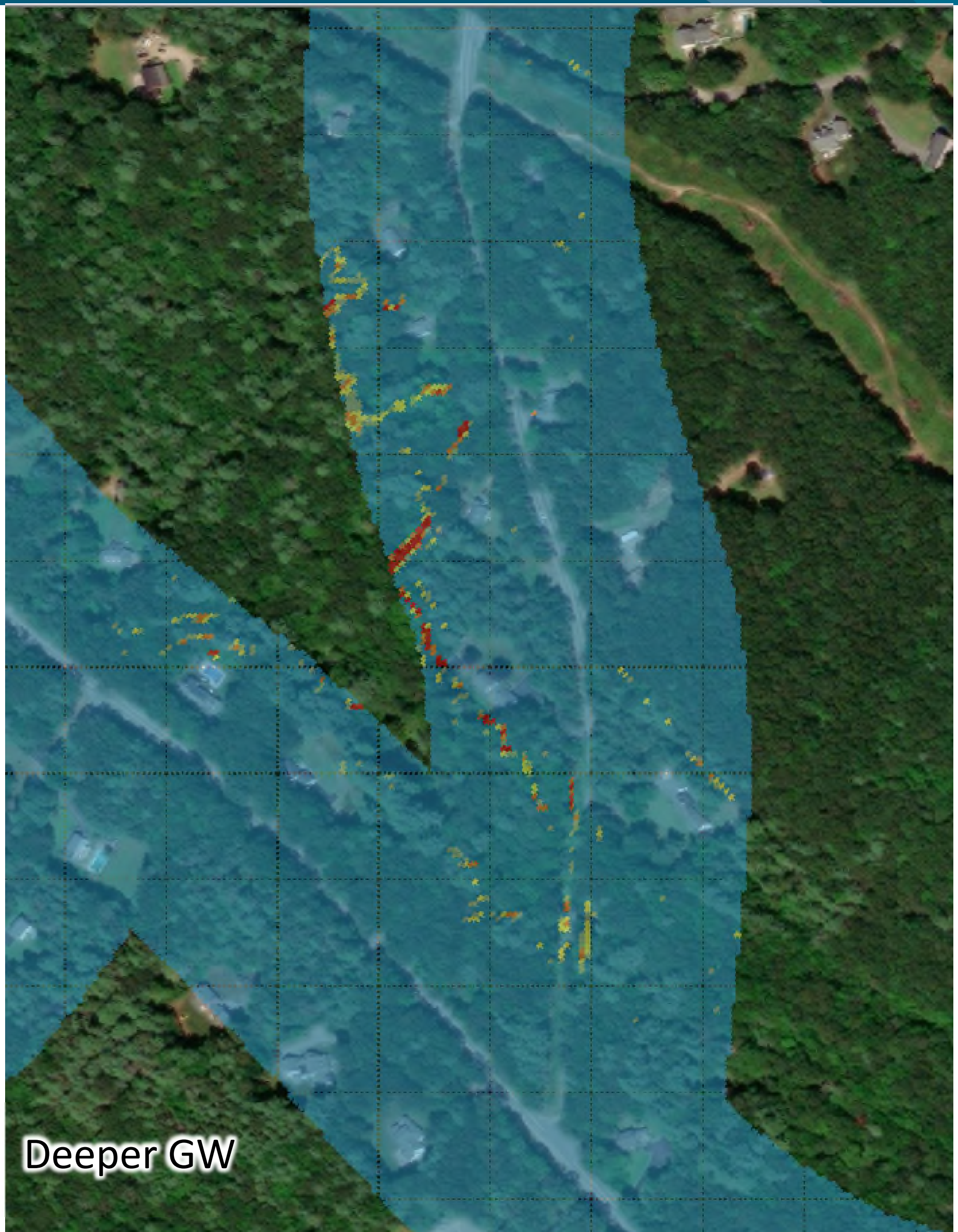
Task 2. Model Development





Task 2. Model Development





Task 2. Model Development

Model Challenges:

1. Computational intensity:
   - Large DEM file size – will need to utilize tiles
   - Model domain and grid – need high grid resolution (e.g., 10 x 10 feet)
   - Consider use of AI to reduce computational intensity

2. Human Performance:
   - Targeted to transportation infrastructure planners and decision makers
   - Users with varying levels of technical expertise
   - Multiple users (+/- 6 states x 30 users per state = 180)
   - Assume limited GIS skill by user survey

3. Adaptability:
   - Wide use of ESRI data layers, portals and technology. Growing availability of data - highly adaptable.

4. Availability of data:
   - Subsurface data

5. Data consistency – while most states use ESRI GIS, data fields are often inconsistent between towns, states and agencies

Modeling/Toolkit Development

GZA Model/Toolkit Approach:

- Utilize ESRI ArcGIS for the toolkit development and application platform
- Create a tool for use with existing state web mapping apps
- Design the app to support future capabilities to include:
    - a. Field data collection and input:
        - i. e.g., ESRI ArcGIS Collector
        - ii. e.g., public-facing website for crowd sourced data
    - b. Real-time data input (e.g., precipitation)
    - c. Failure forecast capabilities
- Utilize available hazard data/analysis (e.g., USGS, NWS, FEMA, NOAA, etc. layers and portals)
- Modular “plug and play” architecture
- Categorizes and ranks failure probability (e.g., high, medium, low, etc.)
- Capabilities to assess category of risk related to specific segments.

Task 3. Ground Truthing and Monitoring

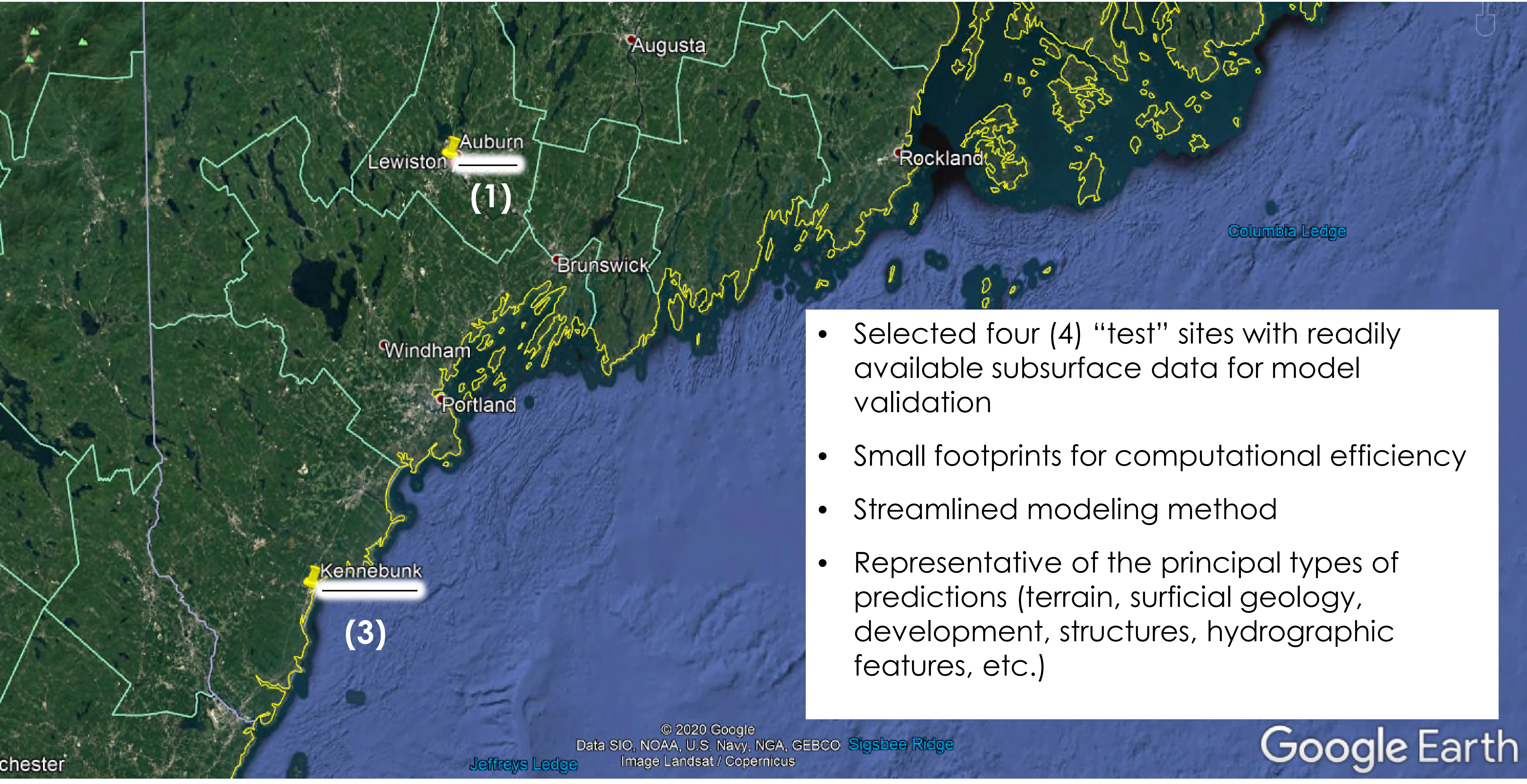
Proposed:

- Use the web mapping platform to screen for potential erosion and slope stability hazard zones.
- Provide recommendations ground-truthing sites and procedures
- Identify the appropriate field data and methods required for model verification and/or calibration.

Performed:

- Evaluated the model performance and modify as needed, upon completion of the site-specific data gathering.
- Selected four (4) sites with readily available subsurface data that we consider representative of the principal types of predictions that the model was developed to include.
- Visual reconnaissance of the areas of concern identified by screening may be employed to better refine the risk areas, e.g., minimizing false positives (project photos, field data, etc.)

Task 3. Ground Truthing and Monitoring

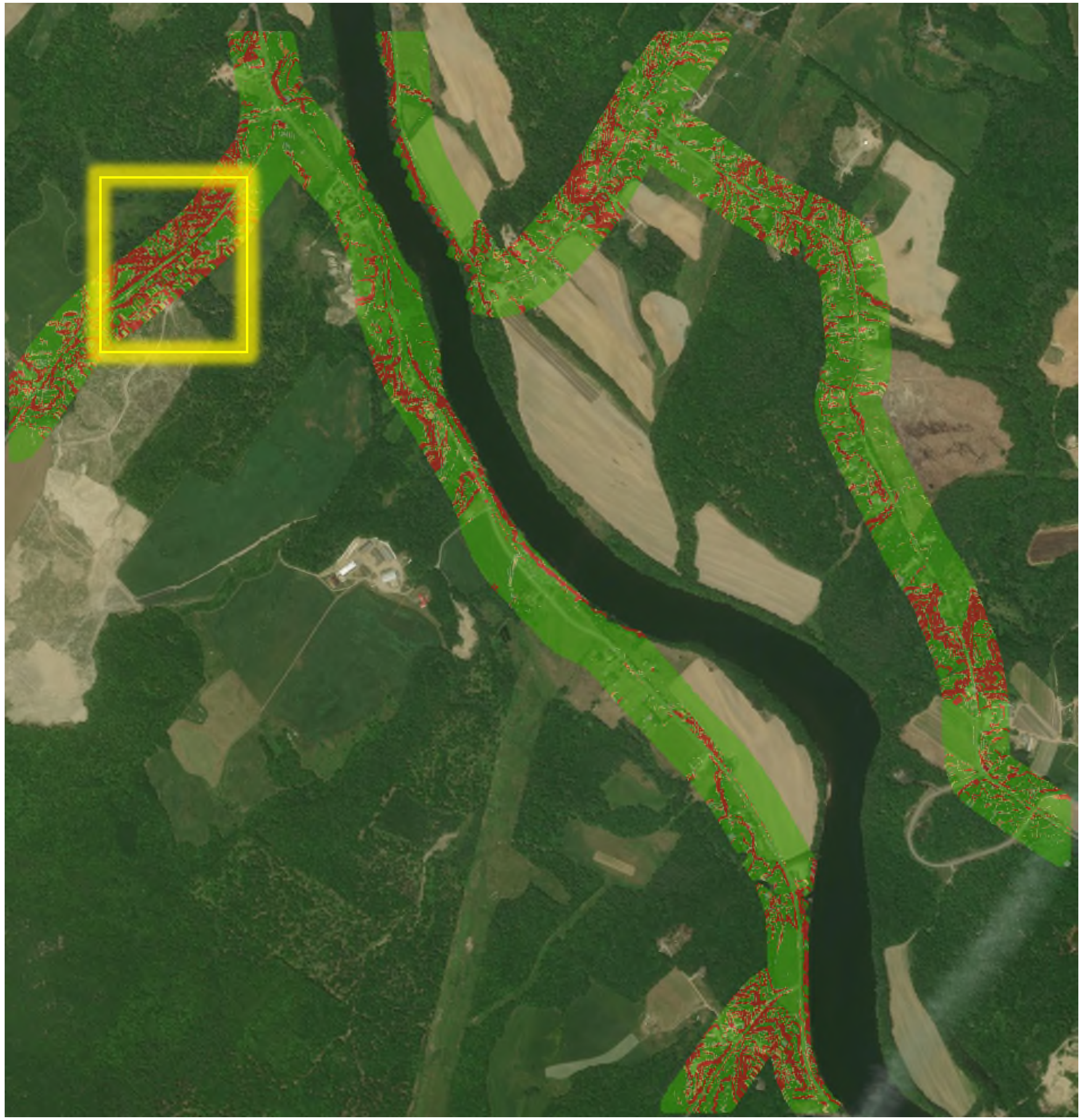


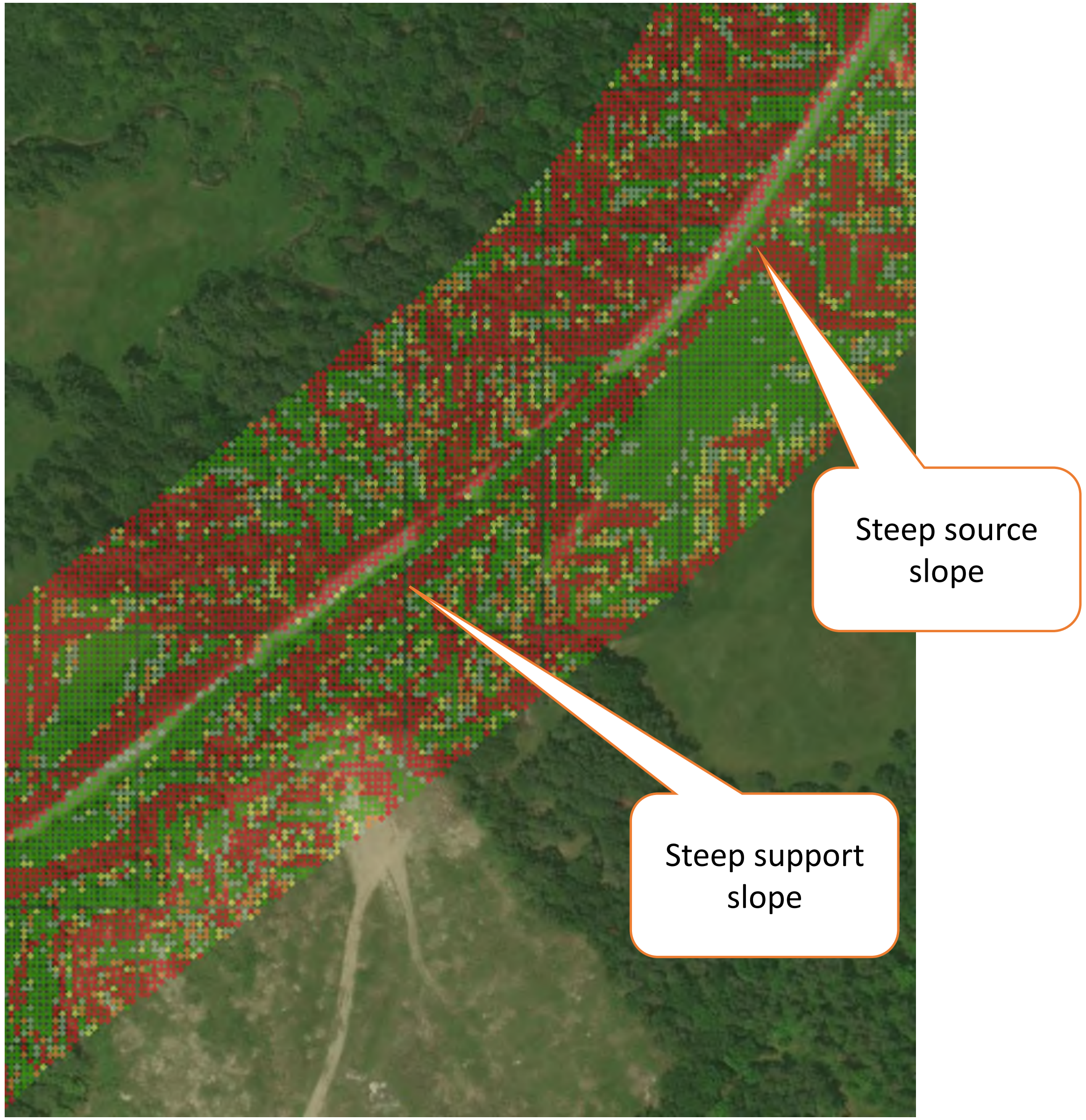
© 2020 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

- Selected four (4) "test" sites with readily available subsurface data for model validation
- Small footprints for computational efficiency
- Streamlined modeling method
- Representative of the principal types of predictions (terrain, surficial geology, development, structures, hydrographic features, etc.)

Task 3. Ground Truthing and Monitoring

Auburn, ME



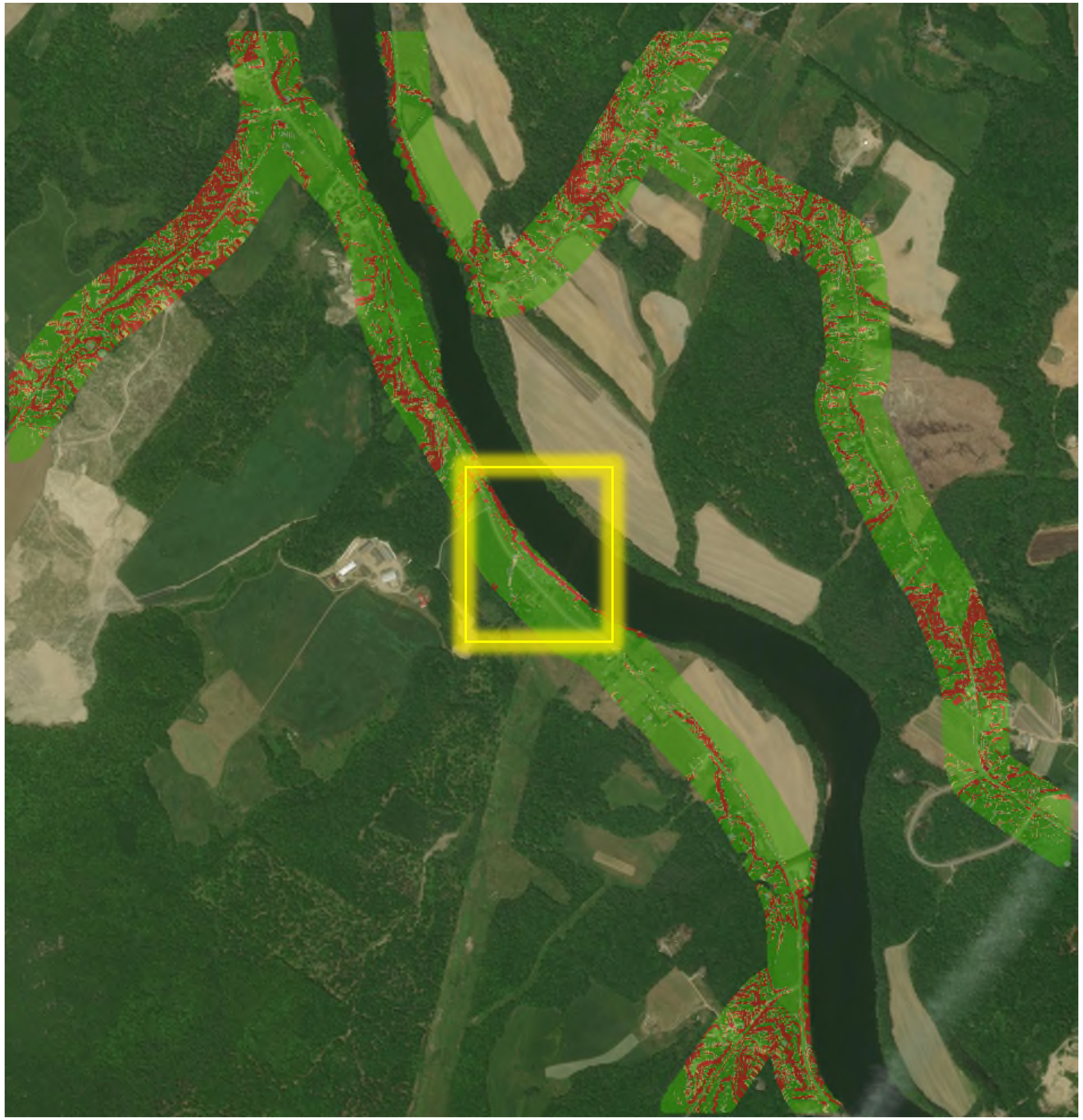


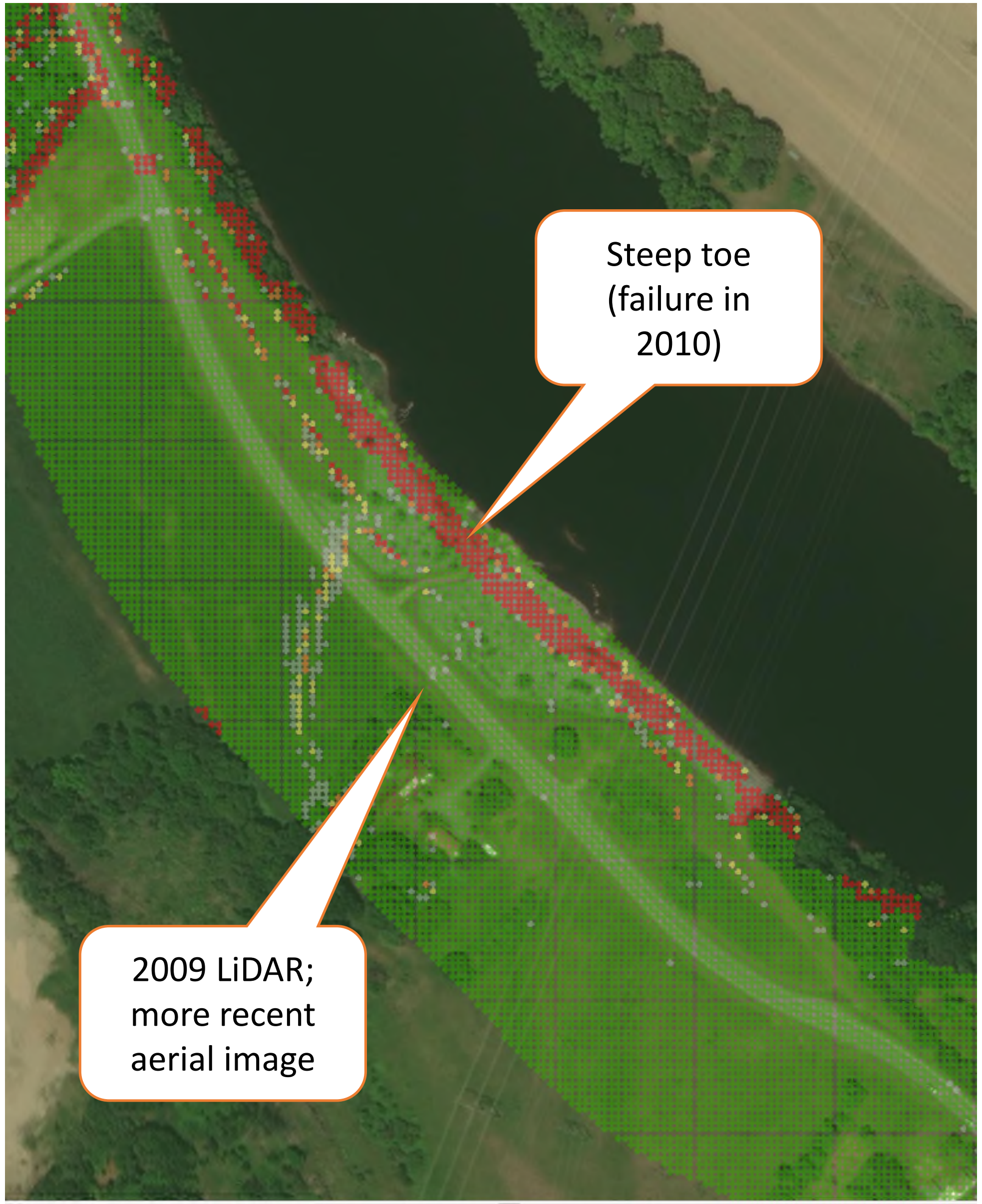
Steep source slope

Steep support slope

Task 3. Ground Truthing and Monitoring

Auburn, ME





Steep toe (failure in 2010)

2009 LiDAR; more recent aerial image

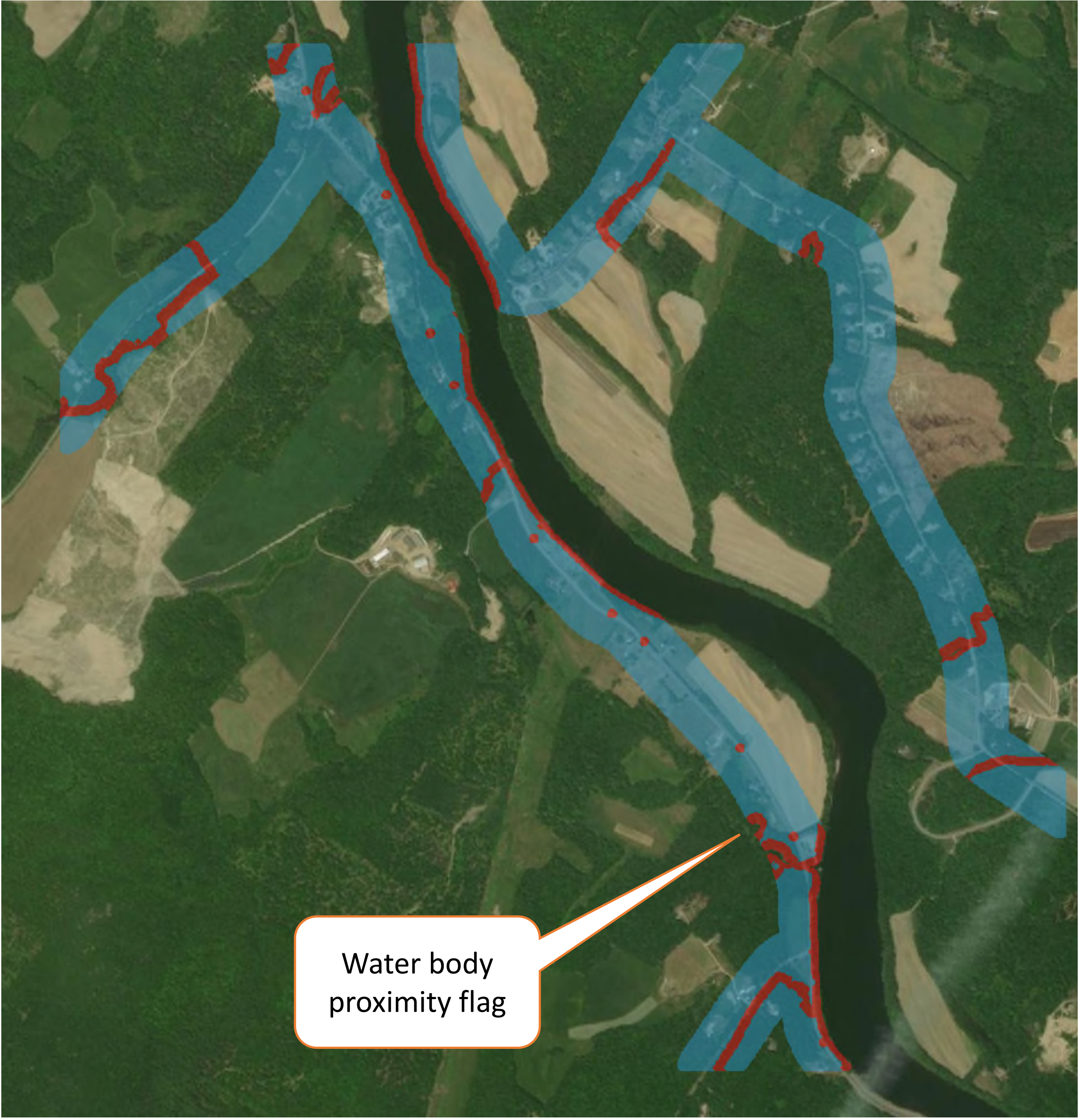
Task 3. Ground Truthing and Monitoring

Auburn, ME – Project Photos

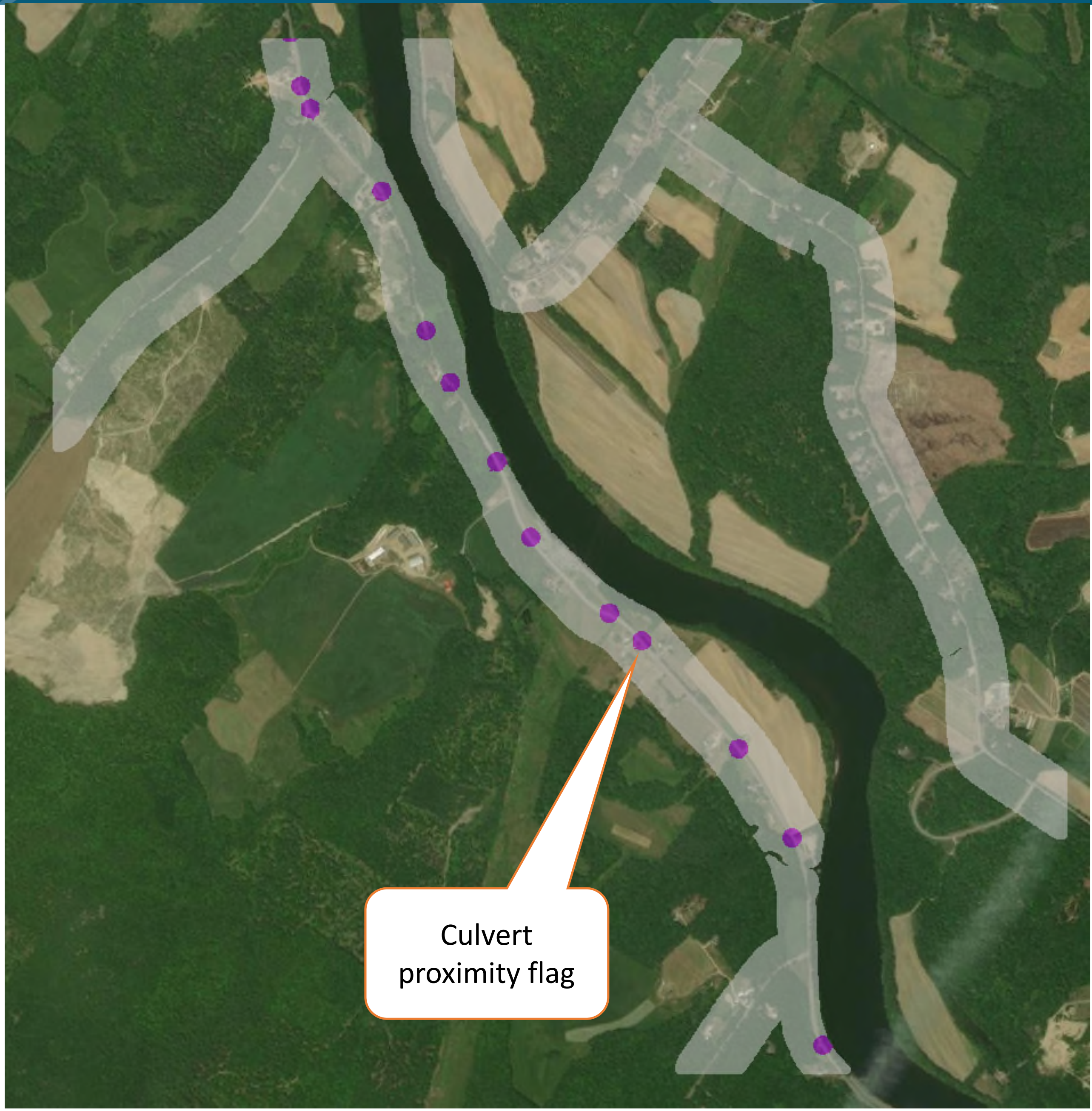
Slope Failure Summer 2010

Remediated Slope December 2010

Task 3. Ground Truthing and Monitoring

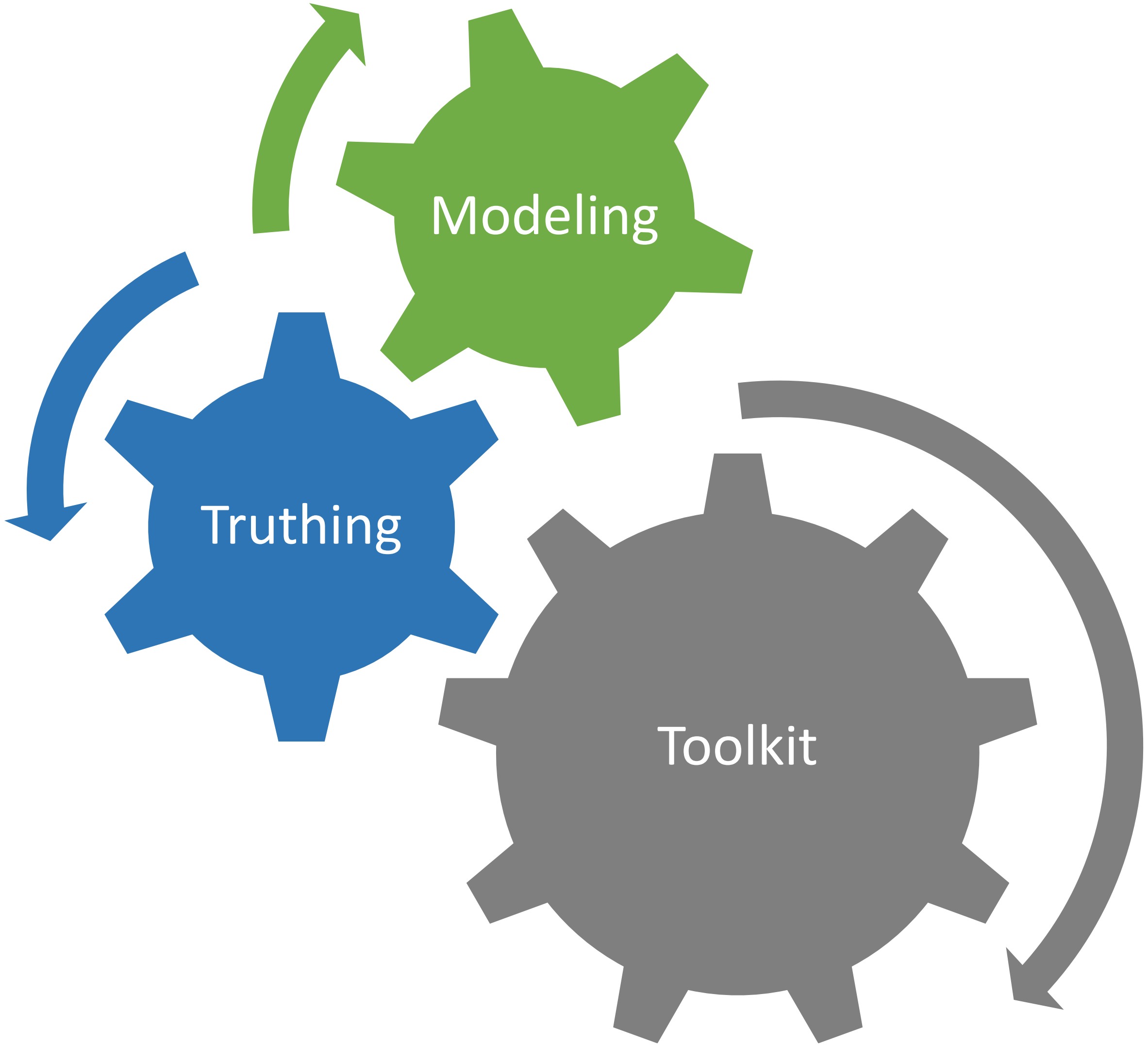


Water body proximity flag

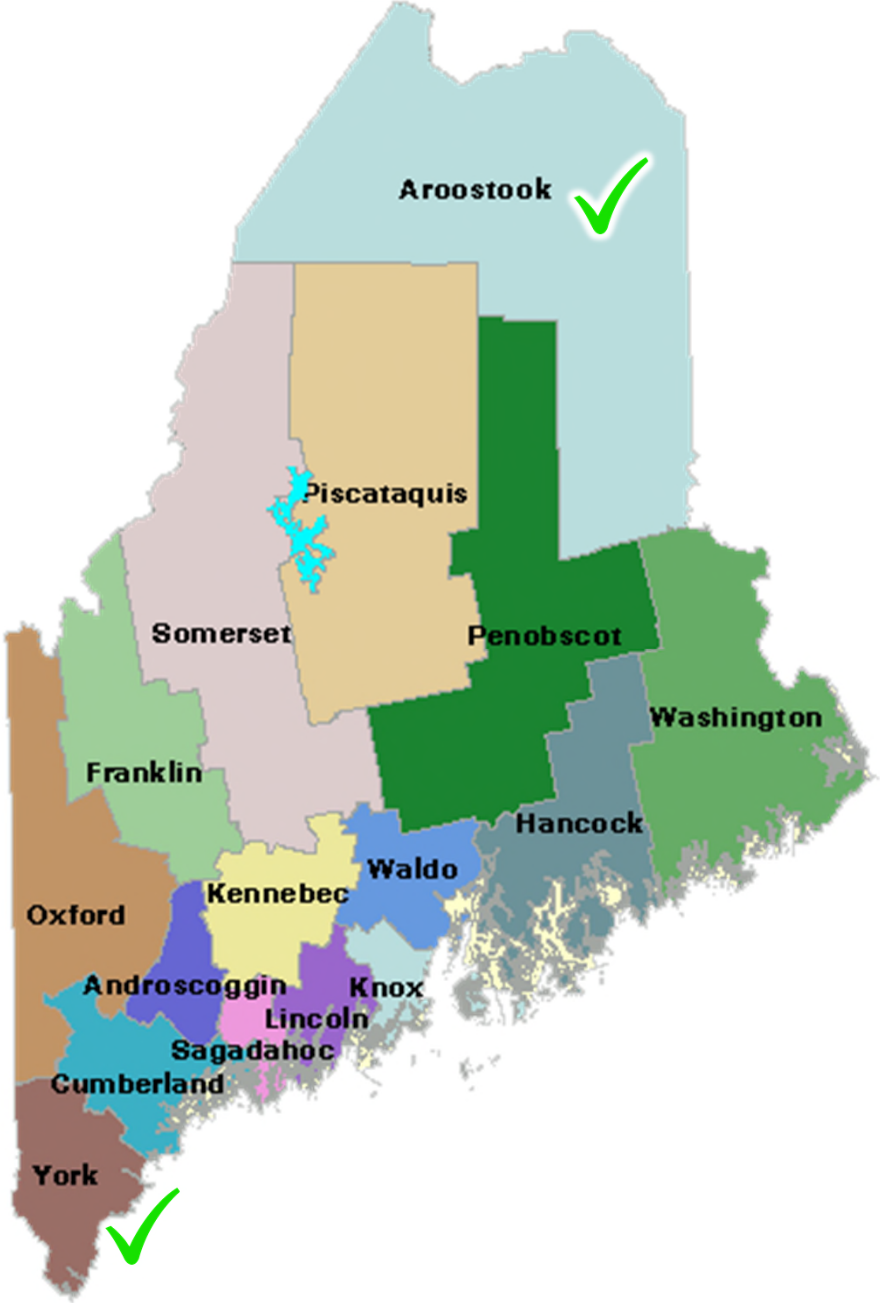


Culvert proximity flag

Task 4. Toolkit Development



Task 4. Toolkit Development



Pilot Results by County:

1) Aroostook County

- Large footprint with low roadway density;

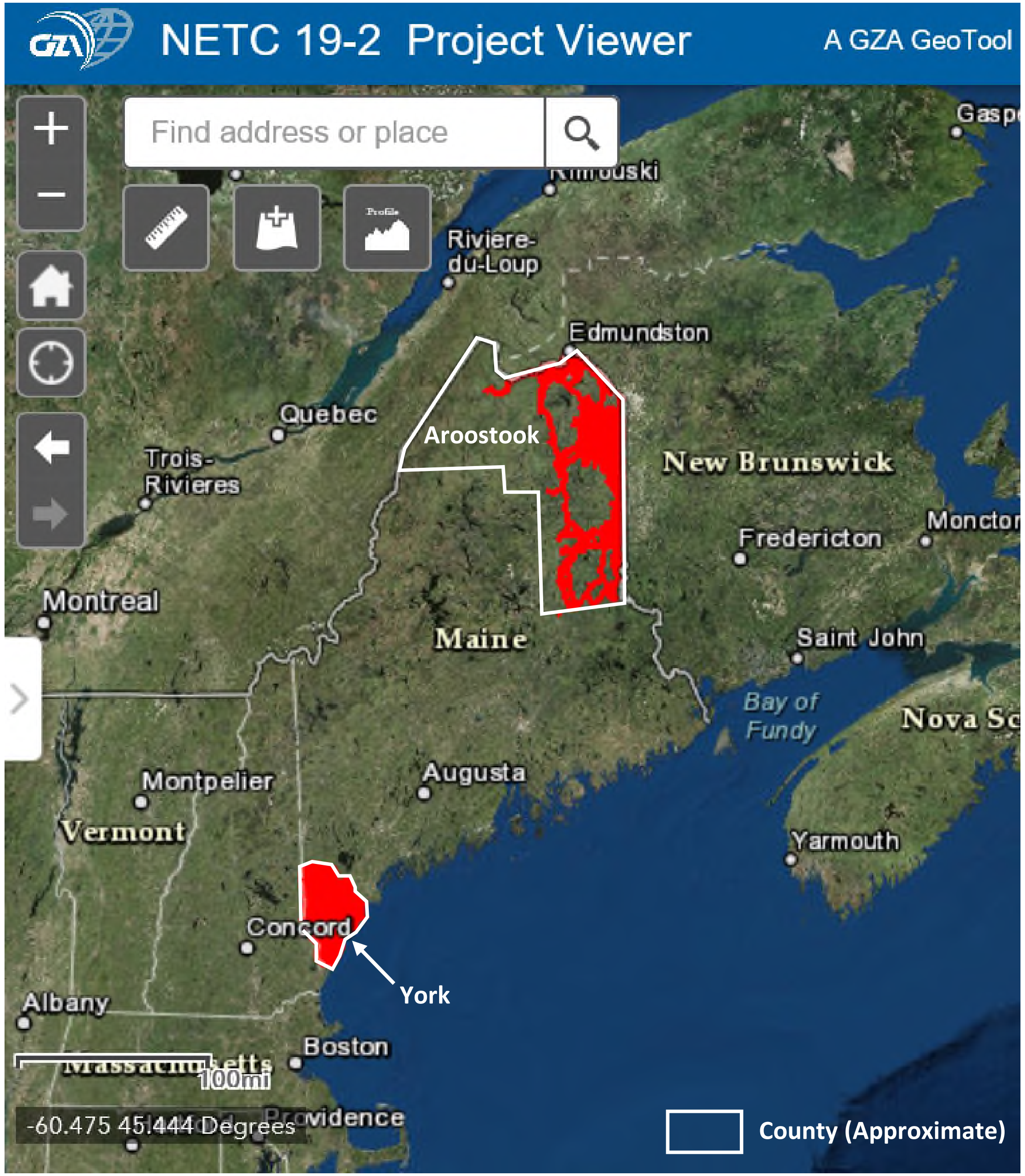
2) York County

- Small footprint with high roadway density;

✓ Smaller data size for efficient GIS processing; and

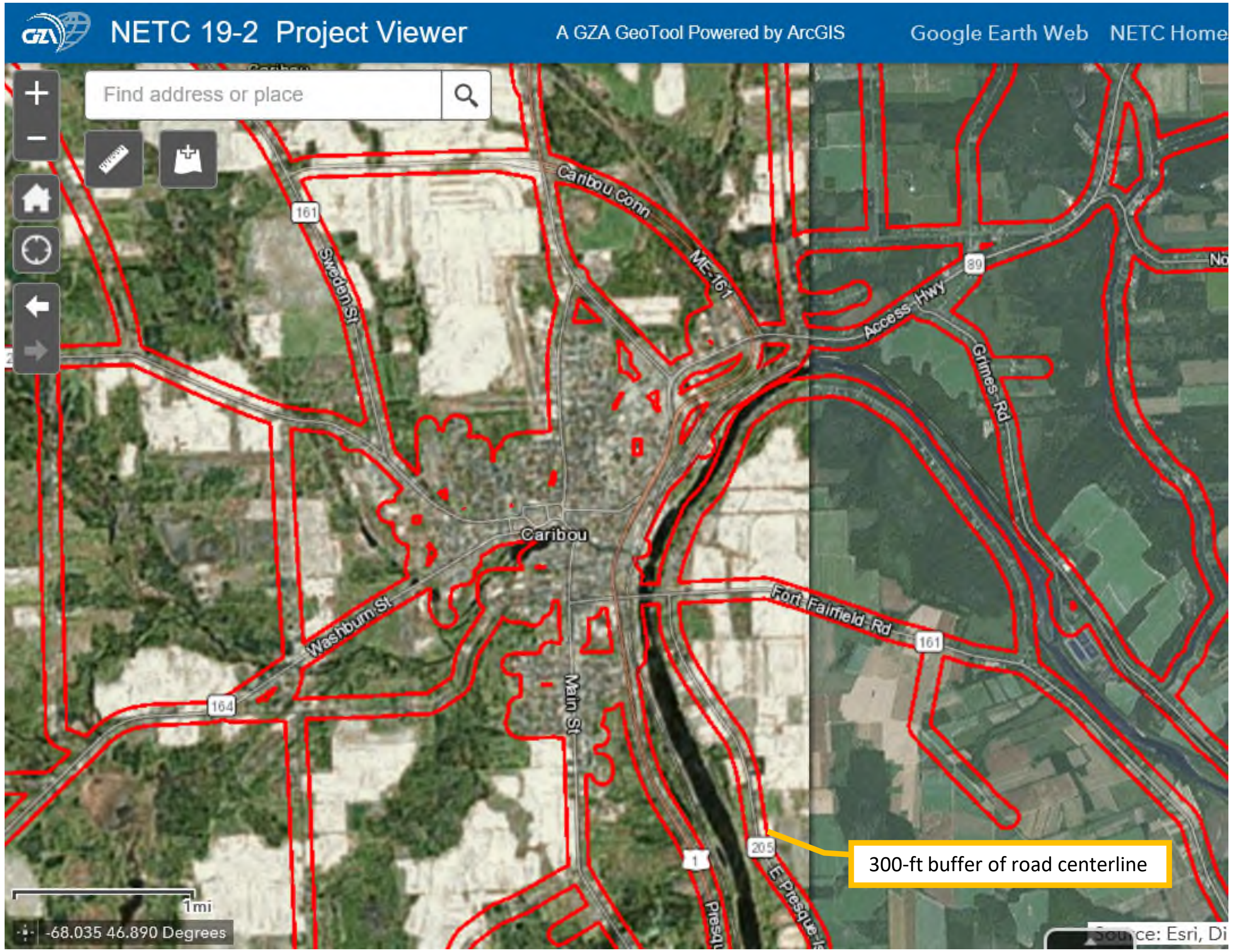
✓ Local knowledge/experience from ongoing projects

Task 4. Toolkit Development



Pilot Counties for Toolkit Development – Aroostook and York

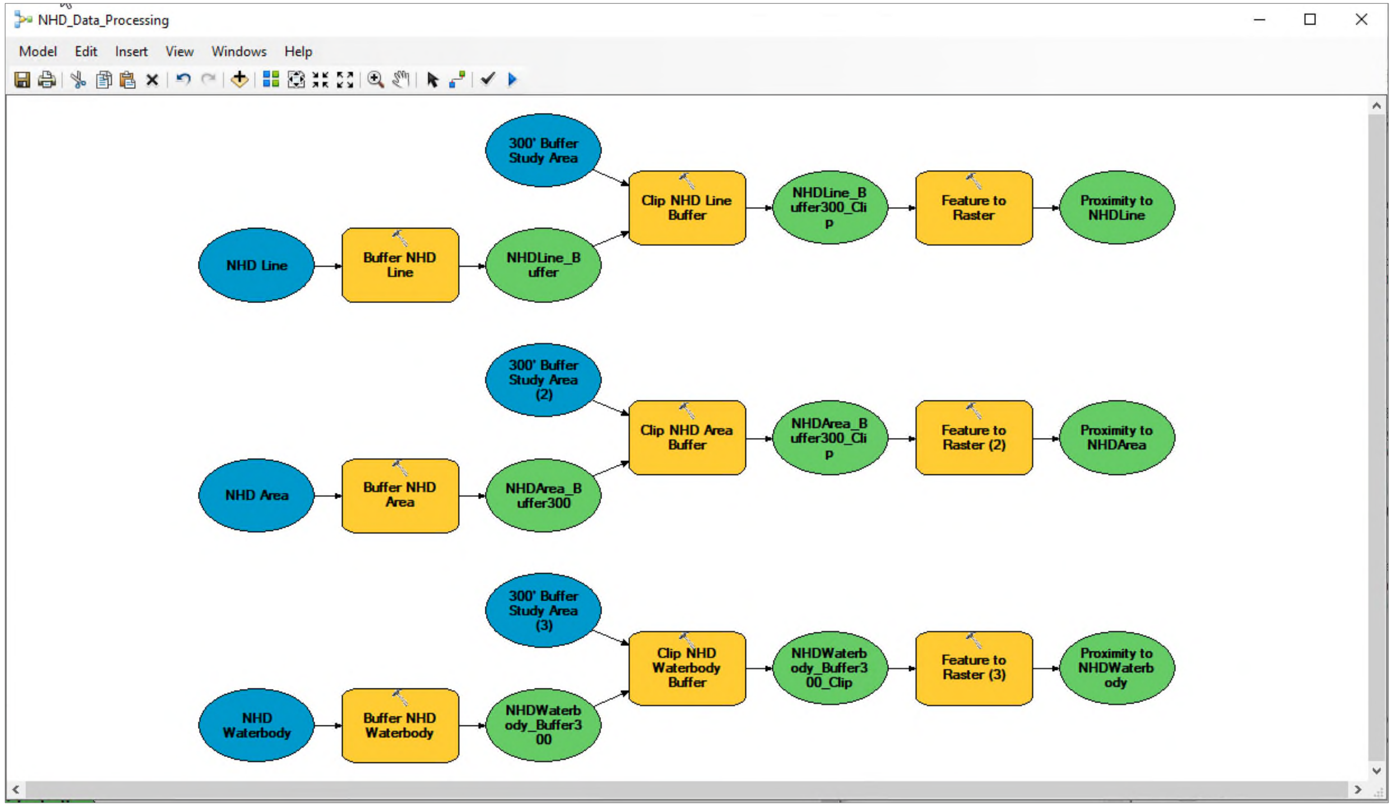
NETC 19-2 Study Area – 300 feet Buffer along Public Roadways



Task 4. Toolkit Development

Data Processing …

- Proximity to Surface Water;
- Proximity to Culverts;
- Proximity to FEMA’s Special Flood Hazard Area;
- Slope Type;
- Relative Aspect;
- Surficial Material Type;
- Factor of Safety;
- Hazard Index; and
- Culvert Hazard Index



Task 4. Toolkit Development

Layer ID	Layer Name	Layer Description
1	Proximity to Surface Water	Area within 100 feet (in distance) from surface water body from the National Hydrography Dataset (NHD) (including streams, ponds, lakes, and coastal water) (index value = 1)
2	Proximity to Culverts	Area within 100 feet (in distance) from existing culverts per Maine DOT's inventory of cross culverts and large culverts (index value = 1)
3	Proximity to FEMA SFHA's	Area within 100 feet (in distance) from FEMA's special flood hazard areas (i.e., 1% annual chance floodplain, including various A and V zones) (index value = 1)
4	Slope Types	Support slope – slopes that are lower in elevation than the nearest roadway segment (index value = 0); Source slope – slopes that are higher in elevation than the nearest roadway segment (index value = 1);
5	Relative Aspect	Nearly Parallel Slope: "included angle" between aspect of slope and aspect of the nearest roadway segment less than +/- 22.5 degrees (index value = 0) Perpendicular Slope: "included angle" between aspect of slope and aspect of the nearest roadway segment greater than +/- 22.5 degrees (index value = 1)
6	Surficial Materials	Generalized soil classification per 1:250,000-scale Maine Geological Survey surficial geology map symbols and local knowledge about the relationship between surficial geology and soils' geotechnical properties. Material ID – Material Type 101 - Loose Granular Soil 102 - Medium Dense Granular Soil 103 - Dense Granular Soil 201 - Soft Cohesive Soil 202 - Medium Stiff Cohesive Soil 203 - Stiff Cohesive Soil 300 - Rock

Layer ID	Layer Name	Layer Description
7	Factor of Safety	Factor of safety (FoS) based on numerical slope stability modeling results (GeoStudio SLOPE/W) with slope (in percent), specified soil type and associated geotechnical properties. - Not available (-9,999) - Unstable (0 – 0.9) - Threshold of instability (0.9 – 1.1) - Nominally Stable (1.1 – 1.3) - Moderately Stable (1.3 – 1.5) - Stable (> 1.5)
8	Hazard Index	The hazard index values have a one-to-one relationship with the computed FoS. - Very Low Hazard (1) for FoS >= 1.5 - Low Hazard (2) for 1.3 <= FoS <1.5 - Moderate Hazard (3) for 1.1 <= FoS < 1.3 - High Hazard (4) for 0.9 <= FoS < 1.1 - Very High Hazard (5) for FoS < 0.9
9	Culvert Hazard Index	Culvert hazard index based on roadway priority rating (1 through 6) and descriptive culvert conditions (critical, poor, fair, and good) per Maine DOT's cross culverts data layer. - High hazard (roadway priority 1 or 2 combined with culvert conditions of "critical" or "poor") - Medium hazard (all the combinations in between) - Low hazard (roadway priority 3 through 6 combined with culvert condition of "good")

Thank You

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