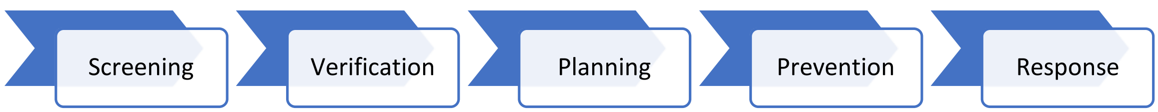
CONTENTS

PROJECT OBJECTIVE

Soil erosion and landslides are a major concern for New England state Departments of Transportation (DOT), roadway planners, and designers, impacting the cost to maintain transportation networks and other critical infrastructure. Effective screening tools used for modeling, monitoring, and forecasting erosion can aid in assessing erosion (washout) and landslide susceptibility, which is critical for regional operations and planning.

GZA is developing a screening-level tool to identify roadways vulnerable to erosion and landslides. The work is being performed in collaboration with the New England Transportation Consortium (NETC). The project objective is to develop a multi-scale, multi-season land-based erosion and landslide modeling and monitoring toolkit for infrastructure management for all the New England states (including Maine, New Hampshire, Vermont, Massachusetts, Rhode Island and Connecticut).

The model and toolkit development will support a process of:



LITERATURE REVIEW

A first step in the development of the model and toolkit is a literature review to collect and complies available information regarding: 1) slope instability susceptibility; and 2) modeling capabilities suitable for the New England region, including means and methods used by others.

Previous studies from New England and other parts of the country were identified, summarized, and cataloged. We also identified information and causative factors that appear to be relevant for this project. GZA focused on studies that appeared to have application to the New England states (i.e., studies done in areas with similar geography, landscapes and climate), and that were conducted by government agencies such as state departments of transportation (DOT), the US Geologic Survey (USGS) and U.S. Army Corps of Engineers (USACE).

We also identified studies that used a GIS-based approach for spatial hazard analysis for slope stability (landslide and/or erosion). We also researched available datasets that could be used for the toolkit development.

Tables 1 through **3** (below) summarizes GZA's key references and findings. Three major categories of literature sources were identified and reviewed:

- Slope stability design standards and guidance documents (**Table 1**);
- GIS-based modeling publications on approaches and case studies for slope stability, landslide and/or erosion (**Table 2)**; and
- Available datasets including GIS format and other traditional datasets (**Table 3**).

A summary of each reference is provided in the tables. Key findings of the overall Literature Search are summarized below:

- At the national level, U.S. Geological Survey has compiled a landslide inventory and made it available through an ESRI web-based interactive map product (USGS, 2019).
- Three New England states have landslide inventory or geodatabase. There is existing state-wide landslide inventory in the States of Maine, being presented and accessible as a web-based GIS portal. Data is compiled and managed by the Maine Geological Survey (MGS, 2020). The Vermont Geological Survey compiled a preliminary landslide inventory based on historical landslide locations, accessible via a web-based online portal (VGS, 2019). New Hampshire Geological Survey (NHGS) has also compiled a landslide geodatabase (currently not available online for public access; information provided by NHDOT).
- State-wide Landslide Hazard Mapping was developed by University of Massachusetts (UMass) in 2013 (UMass, 2013). The underlying computing engine, SINMAP, is a deterministic model for Stability Index Mapping, which was used to identify areas that may be prone to shallow, translational landslides, assuming an infinite slope geometry. Certain parameters within the model can be assigned with uniform probability distributions, to account for uncertainty and allow model calibration.
- There are a number of research or mapping projects in the New England area focusing on landslides susceptibility based on a set of input parameters such as terrain information, groundwater conditions, land cover type and precipitation (e.g., Tufts, 2013; VGS, 2012). These studies are often for a specific area with unique site characteristics and the results were developed with specific objectives. For example, the Tufts 2013 study was to assess risk imposed by slope failure on transportation network.
- Most of these studies largely rely on GIS spatial datasets such as digital elevation/terrain model (DEM/DTM), surficial geology and land cover data, with the transportation network included as shapefiles.
- Most studies apply decision-based deterministic models to analyze and compute key risk factors such as factor of safety for slope stability, using simplified physics-based methods (e.g., USGS, 2001; NCGS, 2011; Barr, 2017).
- Some studies use a collation of risk factors to determine composite susceptibility factors (MGS, 2009a and MGS, 2009b).
- Final mapping products are often presented spatially in terms of categorized risk/susceptibility levels, typically using a risk factor approach.
- Currently no online GIS portal (in the New England state or at the national level) provides interactive slope stability assessment based on user input. Nor does any site or product provide real-time predictions.
- There is no state-wide or regional erosion/landslide GIS mapping application dedicated to the transportation system in New England, which was also confirmed by the survey results (Section 3.0).
- USGS 3D provides a nation-wide repository of topographic data and some related layers developed using spatial analytics (e.g., slope).
- Most of the existing applications utilize Esri GIS web mapping platforms.

References presented in Table 2 mostly rely on deterministic approaches to calculate and/or quantify landslide and erosion susceptibility/vulnerability. We also reviewed published references using heuristic or probabilistic/statistical approaches (see

Additional References at the end of this document). Previous research demonstrated that it is possible to improve landslide prediction accuracy by using regression and machine learning models with refined input data. We will likely explore and potentially incorporate some of the applicable approaches (heuristic and/or statistical) when developing the toolkit for this project.

Table 1: Summary of Literature Search on Design Guidance Documents

Category	Content Summary	Reference
Guidance Document	This circular outlines the key elements of a comprehensive and effective national strategy for reducing losses from landslides nationwide and provides an assessment of the status, needs, and associated costs of this strategy. The framework envisions a society that is fully aware of landslide hazards and routinely takes action to reduce both the risks and costs associated with those hazards. The strategy envisions bringing together relevant scientific, engineering, construction, planning, and policy capabilities of the Nation to eliminate losses from landslides and other ground-failure hazards nationwide.	USGS, 2003. Circular 1244 "National Landslide Hazards Mitigation Strategy— A Framework for Loss Reduction".
Guidance Document	This handbook gives a brief overview of precautions and actions that can be adopted to at least ensure an individual's immediate safety. We strongly suggest that, where possible, the assistance of professional engineers/geologists or those experienced in the successful mitigation of unstable slopes be consulted before actions are taken. This handbook helps home-owners, community and emergency managers, and decisionmakers to take the positive step of encouraging awareness of available options and recourse in regard to landslide hazard.	USGS, 2008. Circular 1325 "The Landslide Handbook— A Guide to Understanding Landslides".
Design Guide	Slope Stability – Engineer Manual provides guidance for analyzing the static stability of slopes of earth and rock-fill dams, slopes of other types of embankments, excavated slopes, and natural slopes in soil and soft rock. The criteria in this EM are to be used with methods of stability analysis that satisfy all conditions of equilibrium.	USACE Engineering and Design EM 1110-2-1920, October 2003.
Design Guide	New England State DOT Highway Design Manuals/Standards	CTDOT, MaineDOT, MassDOT, RIDOT, NHDOT, and VTrans; dates vary.

Table 2: Summary of Literature Search on Examples and Modeling Approaches

Category	Content Summary	Reference
Example	This online ESRI web-based interactive map provides landslide sites at the national scale. The database provides centralized access to information about landslide occurrence and a starting point for the public, land managers, emergency planners and researchers interested in landslide hazards.	USGS, 2019. U.S. Landslide Inventory
Example	The Story Map is a website dedicated for providing information on historical landslides, causes of landslides in Maine, and other related information on landslides in Maine.	MGS, 2020. Landslides in Maine – An Introductory Guide.
Example	Vermont Landslides Inventory compiles various datasets including existing county-wide landslide inventories, Vermont Geological Survey surficial geologic maps and publications, and sites from Vermont Agency of Natural Resources Stream Geomorphic Assessment.	State of Vermont, 2020. "Vermont Open Geodata Portal"
Modeling Approach	This is the companion document for the story map (above). The purpose of this guide is to provide introductory information about the types of mass wasting that may occur in Maine and their causative factors.	MGS, 2020. "Maine Landslide Guide" by L. J. Spigel, Open file No. 20-9, March 2020
Modeling Approach	This map product presents landslide susceptibility/vulnerability based on terrain information, such as slope, curvature (shape) and local relief (slope height), and surficial material type (e.g., fine grained versus coarse grained soils).	MGS, 2009a. "Landslide Sites and Areas of Landslide Susceptibility, Town of Kennebunk, Maine", by Maine Geological Survey, Open File No. 09-28. MGS, 2009b. "Landslide Sites and Areas of Landslide Susceptibility, Town of Kittery, Maine", by Maine Geological Survey, Open File No. 09-30.
Modeling Approach	The New Hampshire Department of Transportation (NHDOT) now incorporates 380 rock cuts and four different Rock Fall Hazard Rating Systems, through Rock Cut Hazard Survey since 1975. This research project was initiated to investigate combining new rock cut data with pre-existing data into a Geographical Information System (GIS). Rock cut point features were collected for every rock cut with a Global Positioning System (GPS) and were added as a data layer on top of existing data coverage available through the Department's GIS server. A relational database was developed which would store all the rock cut data and be linked to the GIS through a structured query language (SQL) connect statement.	NHDOT, 2002. "GIS and the New Hampshire Rock Cut Management System" Final Report, New Hampshire DOT Research Record.

Category	Content Summary	Reference
	Collected data included rock cut structural data, photographs, and two-dimensional profiles.	
Modeling Approach	This study developed and tested a protocol to map potential hazard areas to advance the state of landslide mapping and landslide hazard assessment in Vermont. Used seven site areas in an attempt to represent conditions throughout Vermont. As a bare-earth lidar digital elevation model (DEM) was envisioned as being a key part of any resulting protocol (and the distribution of lidar data in Vermont was more limited when this study was conceived) the study sites are mostly within Chittenden County. Other considerations in site area selection included map coverage, geology, elevation, types of terrain, urban disturbance, and types of landslides expected. Fourteen potential parameters were considered as to their effect on landslide hazard, including: location with respect to the marine limit of the Champlain Sea, aspect, distance to stream, elevation, hydrologic group, NDVI, profile curvature, roughness, slope angle, slope height, soil type, stream power index, surficial geology, and topographic wetness index.	Vermont Geological Survey, 2012. "Protocol for Identification of Areas Sensitive to Landslide Hazards in Vermont" prepared by Clift and Springton, University of Norwich.
Modeling Approach	The purpose of this project is to prepare an updated map of potential landslide hazards for the Commonwealth of Massachusetts. The intent is to provide the public, local government and local and state emergency management agencies with a map showing the location of areas where slope movements have occurred or may possibly occur in the future under the right conditions of prolonged antecedent moisture and high intensity rainfall. The information is useful for planning upgrades and improvements to culverts and drainage along roadways in the future. In additional to printable maps, data are also available as ESRI ArcGIS data files.	MEMA, 2013. "Slope Stability Map of Massachusetts" by UMass Geosciences.
Modeling Approach	This study is to develop an assessment of the risk posed to transportation networks in southern New Hampshire by slope failure, including parameters to assess slope failure risk; GIS raster calculations to assess slope failure risk for the area of interests, GIS raster calculations to assess slope failure hazard risk in regards to the transportation networks in the area of interest. Parameters include slope of the land surface; surficial geology characteristics, soil drainage and land cover.	Tufts, 2013. "Slope Failure Hazard Risk Assessment – An Analysis of the Hazard Risk Posed by Slope Failure to Transportation Networks in Southern New Hampshire" by Tufts University.
Modeling Approach	Washington Department of Natural Resource GIS Open Data – Slope Stability – provides a predictive data layer of shallow-rapid slope stability using one or more calibrated GIS-based models and covers all forested watersheds of western Washington State, to be a screening tool for determining shallow-rapid landslide potential. It is intended to be used for pre-classification screening of forest	Washington DOT, 2018. "Washington Department of Natural Resource GIS Open Data – Slope Stability"

Category	Content Summary	Reference
	practices applications and screening for slope stability concerns on managed timberlands. This data layer is derived from calibrated algorithms (models) that use DEMs to generate slope and curvature information.	
Modeling Approach	The intent is to provide the public, local government, and local and state emergency agencies with a description and location of areas where slope movements have occurred, or are likely to occur, and the general areas at risk from these slope movements. The map was produced using SINMAP (Stability Index MAPping) software, an ArcViewTM 3.x extension developed by Pack and others (1998) for use in a GIS. SINMAP then assigns a stability index based on computed factors of safety. The six stability zones are assigned relative hazard rankings (high, moderate, and low) based on the calculated stability index ranges and known slope movement occurrences. Model input parameters include upper and lower bounded values for recharge to the shallow groundwater system, soil transmissivity (soil permeability or hydraulic conductivity multiplied by soil thickness), and other soil properties (i.e., unit weight, thickness, effective internal friction angle, and effective cohesion). To account for the variability and uncertainty inherent within the natural system, SINMAP randomly samples the bounded input parameter values using a uniform probability distribution.	NCGS, 2011. “Stability Index Map of Henderson County, North Carolina for Shallow Translational Slope Movement Susceptibility during a 5-inch Recharge Event” by North Carolina Geological Survey.
Modeling Approach	This paper evaluated and compared the approaches of SINMAP, LISA, and Iverson’s (2000) transient response model for slope stability analysis by applying each model to a historical landslide incident in Madison County, Virginia. Of these three stability models, Iverson’s model would be the preferred method of the three models to evaluate landslide hazards on a regional scale in areas prone to rain-induced landslides as it considers both the transient and spatial response of pore pressure in its calculation of slope stability. The stability calculation used in SINMAP and LISA is similar and utilizes probability distribution functions for certain parameters. SINMAP only considers soil cohesion, internal friction angle and rainfall-rate distributions. LISA allows the use of distributed data for all parameters.	USGS, 2001. “A Comparative Analysis of Hazard Models for Predicting Debris Flows in Madison County, Virginia”, by Meghan M. Morrissey, Gerald F. Wieczorek, and Benjamin A. Morgan, Open-File Report 01-0067, 2001.
Model	Landslide responses to rainfall involve transient processes with different intrinsic timescales. A new model of these transient processes links slope failure and landslide motion to groundwater pressure heads that change in response to rainfall. This paper tries to examine relationships between these timescales to develop a mathematical model that uses reduced forms of Richards equation to evaluate effects of rainfall infiltration on landslide occurrence, timing, depth, and acceleration in diverse	Iverson, 2000. “Landslide Triggering by Infiltration”, R. M. Iverson, Water Resources Research, Vol. 36, No. 7, 1897-1910, July 2000

Category	Content Summary	Reference
	situations. The model adds realism to current models that predict landsliding as a function of steady state hydrology with a minimum of added data requirements. The model also provides information for assessing rates of postfailure landslide motion, thereby refining hazard forecasts. The model neglects important factors such as soil strength evolution (contractile strain weakening, dilatant strain hardening, and fabric development). It also neglects mechanical effects of three-dimensional landslide geometries.	
Model	SINMAP 2.0 (Stability Index MAPping) is an ArcGIS (9+) plug-in that implements the computation and mapping of a slope stability index based upon geographic information, primarily digital elevation data. SINMAP assumes an infinite plane slope stability model with wetness (pore pressures) obtained from a topographically based steady state model of hydrology. Digital elevation model (DEM) methods are used to obtain the necessary input information (slope and specific catchment area). Parameters are allowed to be uncertain following uniform distributions between specified limits. These may be adjusted (and calibrated) for geographic "calibration regions" based upon soil, vegetation or geologic data. The methodology includes an interactive visual calibration that adjusts parameters while referring to observed landslides. The calibration involves adjustment of parameters so that the stability map "captures" a high proportion of observed landslides in regions with low stability index, while minimizing the extent of low stability regions and consequent alienation of terrain to regions where landslides have not been observed. This calibration is done while simultaneously referring to the stability index map, a specific catchment area and slope plot (of landslide and non landslide points) where lines distinguish the zones categorized into the different stability classes and a table giving summary statistics. SINMAP is grid based, requiring ArcGIS version 9.0 or higher.	Pack et al., 2005. SINMAP User's Manual "SINMAP 2, A Stability Index Approach to Terrain Stability Hazard Mapping", R.T. Pack, D.G., Tarboton, C.N. Goodwin and A. Prasad (Utah State University).
Modeling Approach	Slope stability studies in the USDA Forest Service in accordance with a three-level concept: • Leve 1 – generally for watershed analysis, ecosystem management support, etc.; • Level 2 – intermediate level for evaluation of slope stability along road corridors and other routes; • Leve 3 – detailed (site-specific) level for design of stabilization measures. Use XSTABL interactive program for soil and Federal Highway Administration's rock slope stability analysis method for rock slopes.	USDA, 1994. "Slope Stability Reference Guide for national Forests in the United States".
Modeling Approach	Physics-based combined with GIS-based approach for slope failure modeling; identified the following major causative factors: slope angle, soil type and geology; vegetation; land use and drainage density; antecedent precipitation/soil moisture; rainfall intensity	Barr, 2017. "Slope-Failure Risk Analysis Mapping | Pilot Project" for Minnesota's Local

Category	Content Summary	Reference
	and duration. Infinite slope approach used for simplicity for application in conjunction with GIS source data.	Road Research Board (LRRB) in 2017.
Modeling Approach	Developed a GIS-based computer program (in ESRI's ArcGIS platform) for spatial infinite slope landslide hazard analysis, based on calculated factors of safety. Used an underlying probabilistic infinite slope analysis model which processes normally-distributed soil properties.	J. Sanders, 2017. "Developing a GIS Tool for Infinite Slope Stability Analysis (GIS-TISSA), Michigan Technological University MS Thesis.
Modeling Approach	Presented a landslides case study in Nepal. Developed a GIS tool which is able to calculate safety factor of the slopes within ArcGIS. Input included soil test data, geological distribution, hydrological information and topographical information with automated algorithm to estimate realistic slope instability coefficient. Prepared roadside maintenance priority map.	Bhattarai, et al. "Quantitative Slope Stability Mapping With ArcGIS: Prioritize Highway Maintenance", ESRI User Conference.
Modeling Approach	Developed and tested a GIS-based 3-D slope stability model in terms of computing time and model results. The model was developed as a C- and Python-based raster module of the open source software GRASS GIS and considers the 3-D geometry of the sliding surface. The model is able to calculate factor of safety and probability of slope failure for a number of randomly selected potential slip surfaces, ellipsoidal or truncated in shape. This is a deterministic-probabilistic model.	Mergili et al., 2014. "A strategy for GIS-based 3-D slope stability modelling over large areas", Geoscientific Model Development conference proceedings.
Modeling Approach	Presented an early warning system developed for Maryland, using a GIS database and a collective overlay of maps that highlight highway slopes susceptible to soil slides or slope failures in advance through spatial and statistical analysis. Considered six major factors, including event precipitation, geological formation, land cover, slope history, slope angle, and elevation. Precipitation and poor surface or subsurface drainage conditions are principal factors causing slope failures.	Ramandathan, et al., 2015. "Development of a GIS-based failure investigation system for highway soil slopes", Frontiers of Earth Science.

Table 3: Summary of Available GIS Data Inventory

Category	Content Summary	Reference / Source
Inventory	Landslide Hazards Program: - Debris flow hazards; - U.S. Landslide Inventory – web-based interactive map with landslide data. The searchable map includes contributions from many local, state, and federal agencies and provides links to the original digital inventory files for further information. - Earthquake-triggered ground failure	USGS landslide hazards
Inventory	Maine Landslide – landslide inventory	Maine Geological Survey
Inventory	New Hampshire Landslide Geodatabase	New Hampshire Geological Survey
Inventory	Vermont Landslides Inventory	State of Vermont, 2020. "Vermont Open Geodata Portal" with downloadable attribute data
Source Data	National Flood Hazard Layer	FEMA "Flood Insurance Rate Maps", date varies.
Source Data	National 3D Elevation Program	3DEP Data
Source Data	State-wide DOT Roadway Inventory (Maine, NH, VT, MA, RI and CT)	Available online (mostly through state GIS office); date varies;
Source Data	State-wide LiDAR (Maine, NH, VT, MA, RI and CT)	Available online (mostly through state GIS office); date varies;
Source Data	National precipitation frequency data	National Oceanic and Atmospheric Administration (NOAA) Atlas 14
Source Data	National soil information database	SSURGO data provided/served by the USDA-NRCS: 1. Vermont Center for Geographic Information (VCGI) 2. USDA / NRCS
Source Data	Global Landslide Catalog including (point data, polygons and csv files associated with the map data)	NASA provides collated downloadable data
Source Data	Connecticut Erosion Susceptibility	Connecticut Department of Energy and Environmental Protection

Note: Table 3 lists key datasets that the model development likely requires. Additional data source will be identified and obtained during the modeling development process.

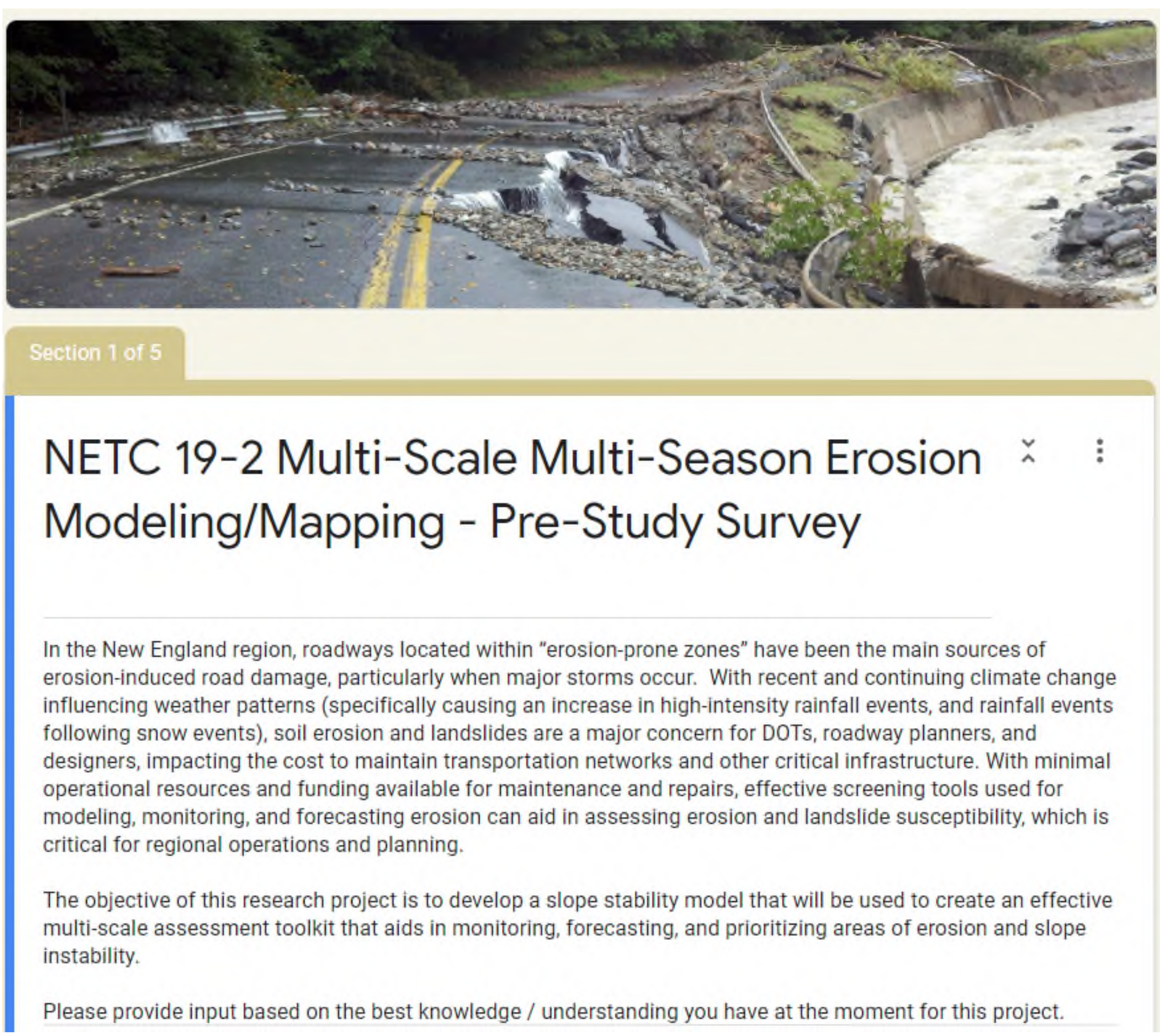
PRE-STUDY SURVEY

GZA collated a list of contacts with the help of the NETC 19-2 committee, including New England state's DOTs and other state agencies. We developed a list of questions, which were provided to the project technical committee for approval prior to the solicitation of responses. Once the list of questions was approved the internet-based survey was developed in Google Forms and was available online during the Task 1 phase of this project in May 2020.

The primary goal of the survey was to identify the current GIS practice, GIS modeling capability, toolkit expectation and available datasets within the State DOTs and GIS offices in New England. The survey consisted four sections:

- Needs assessment;
- Model use and expectations;
- Policies and procedures (related to GIS); and
- Available datasets

The online survey was distributed to the New England state transportation agencies (CT, MA, ME, NH, RI, VT) in May 2020 for responses. Objective of the survey was stated at the beginning of the questionnaire (below).



Section 1 of 5

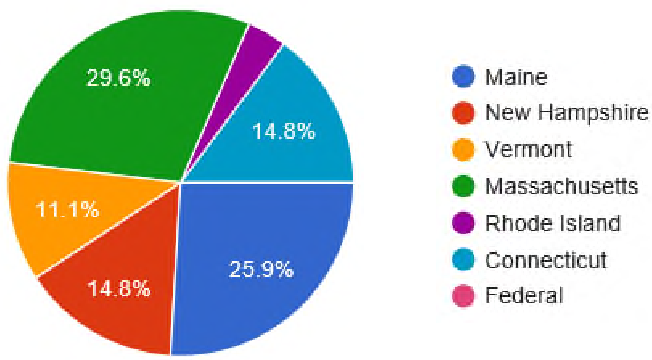
NETC 19-2 Multi-Scale Multi-Season Erosion Modeling/Mapping - Pre-Study Survey

In the New England region, roadways located within "erosion-prone zones" have been the main sources of erosion-induced road damage, 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 DOTs, roadway planners, and designers, impacting the cost to maintain 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.

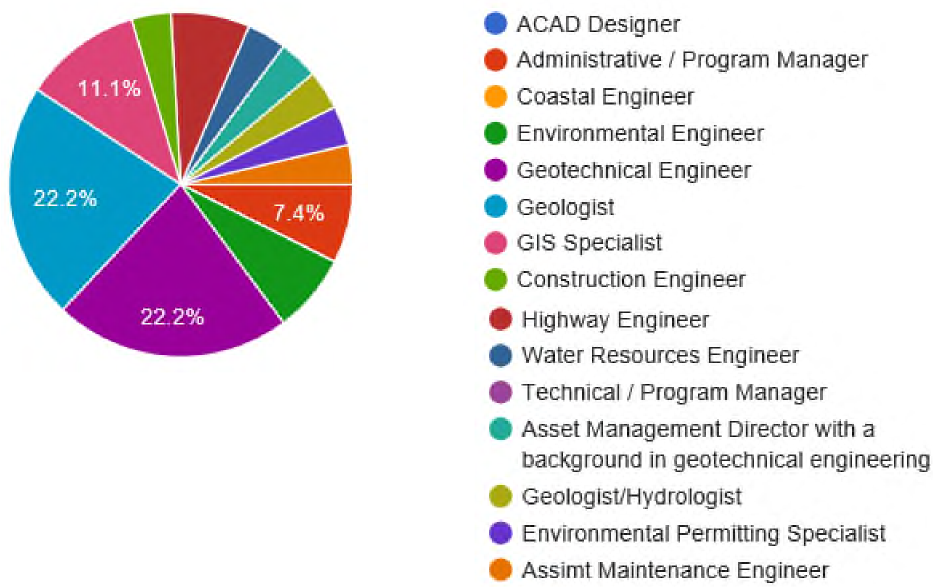
The objective of this research project is to develop a slope stability model that will be used to create an effective multi-scale assessment toolkit that aids in monitoring, forecasting, and prioritizing areas of erosion and slope instability.

Please provide input based on the best knowledge / understanding you have at the moment for this project.

A total of 27 responses were received. All six New England states responded to the survey (below), with particularly good turnouts in Maine and Massachusetts. No federal agency participated in the survey.



The respondents appear to come from a wide variety of practices, as shown in the chart below.



Key findings from the survey are summarized below:

- Respondents of this survey cover a wide range of technical backgrounds, including geology, geotechnical, hydrology, CAD, GIS and management. Approximately 80% are engineers, scientists and geologists.
- All the respondents (except for one) are from three state offices/departments, namely, DOT, Geological Survey and State GIS.
- Majority of the participants indicate that their work requires the use of GIS and they are familiar with online applications and/or desktop GIS.
- There is a strong preference for using GIS-based technology within the New England state DOTs and ESRI (ArcGIS and ArcMap) appears to be the predominant software package used by the state government agencies.
- Microsoft Office Suite and AutoDesk are also widely used for daily job functions.
- Google products are being widely used, in particular Google Earth/Google Earth Pro.

- Sharepoint, FTP and MS Teams are widely used for data sharing. One respondent indicated that only secure
- Mobile electronic devices are widely used for field data collection, in addition to the traditional hand-written method.
- Two thirds of the respondents think that this toolkit will be useful.
- Most respondents agreed that we need to collaborate with state GIS, state Geological Survey, USGS and USACE. Half of the responses also indicate that some collaboration is needed with National Park Services and Federal Highway Administration.
- The proposed toolkit is expected to be used for emergency response, engineering, maintenance and planning.
- Expectant users largely prefer electronic format of maps that can customized via a web-based portal. Paper format is still being used but not preferred or required. Approximately half of the respondents indicate that smaller sizes (11”x17” and below) of maps are more likely being used and the other half would like to have the option available for large prints (36”x24” and above) as well.
- More than half of the respondents expect to use the toolkit both on computer and mobile device. None expects to use the toolkit solely on a mobile device.
- Required dataset as input for the toolkit are topography, surficial geology, groundwater conditions/soil moisture, precipitation, hydrologic information and existing roadway structures (bridges and culverts), per survey responses.
- Respondents provided names and/or hyperlinks to datasets that may be used for the toolkit development including asset database and transportation feature classes.
- Less than 50% of the respondents have knowledge on policy and/or procedure related to GIS standard and protocols existent within each state. This could be due to the fact that most participants are not from the state GIS.
- Most of the respondents are aware that there is some sort of online GIS mapping application developed by their states but there is no application dedicated to erosion and landslide monitoring and modeling.

The full survey output is included as **Appendix A**.

CONCLUSIONS

The results of both the literature review and project survey indicate that a web-based viewer and a heuristic/deterministic model for slope stability and erosion has been the dominant approach used by others. The models developed by others predominantly analyzed topography as the primary variable, with additional variables of surface cover, geology and precipitation-driven change to soil moisture.

ACRONYMS

DEM - Digital elevation model

DTM - Digital terrain model

DOT – Department of Transportation

FEMA – Federal Emergency Management Agency

GIS – Geographic Information System

FIRM – Flood Insurance Rate Map

MGS – Maine Geological Survey

NASA – National Aeronautical and Space Administration

NOAA – National Oceanic and Atmospheric Administration

NRCS – Natural Resources Conservation Service

USACE – United States Army Corps of Engineers

USDA – United States Department of Agriculture

USGS – Unite States Geological Survey

ADDITIONAL REFERENCES

Huang et al., 2020. "Comparisons of heuristic, general statistical and machine learning models for landslide susceptibility prediction and mapping", CATENA (Elsevier), Vol 191. https://doi.org/10.1016/j.catena.2020.104580

Mergili et al., 2019. "Combining release and runout in statistical landslide susceptibility modeling", Landslides 16:2151-2165. DOI 10.1007/s10346-019-01222-7

Ozioko and Igwe, 2020. "GIS-based landslide susceptibility mapping using heuristic and bivariate statistical methods for Iva Valley and environs Southeast Nigeria", Environmental Monitoring and Assessment, 192 (119).

Ruff and Czurda, 2008. "Landslide susceptibility analysis with a heuristic approach in the Eastern Alps (Vorarlberg, Austria), Geomorphology 94(3): 314-324.

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APPENDIX A

PRE-STUDY SURVEY RESULTS