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

Technical Memorandum

Task 3: Ground Truthing

Prepared for:

New England Transportation Consortium (NETC)
Project 19-2 Technical Committee

Prepared by:

GZA GeoEnvironmental, Inc.

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OVERVIEW

GZA performed slope stability and erosion modeling under Task 2 of this project. GZA adopted an analytical method similar to the Response Surface method widely adopted by U.S. Army Corps of Engineers (USACE) and FEMA for their coastal storm surge flood studies. GZA used key input parameters (such as surficial geology and topography) that affect slope stability, performed numerical slope stability analysis using representative geotechnical material properties and groundwater conditions, and established an interpolation and extrapolation scheme for scenarios that are not directly modeled. High resolution (3 m x 3 m) digital terrain model (DTM) data was used.

For this "Ground Truthing" task, GZA applied field data and engineering experience from past GZA projects at a number of selected "test sites" to verify and validate the modeled slope stability results. In addition, landslide susceptibility maps produced by Maine Geological Survey (MGS) were compared to our modeled results as part of the verification and validation process.

METHODOLOGY

GZA selected a number of "test sites" based on the following criteria:

- Known past slope failure or stability issues;
- Proximity to water bodies (river or ocean);
- Availability of site-specific subsurface exploration geotechnical information;
- Past project experience combined with local knowledge; and
- Coverage of both soil types, cohesive and granular.

Figure 1 presents a location map of the two towns selected, Auburn and Kennebunk, Maine. Please note that this document uses the same color scale (below) as presented in the Task 2 memorandum.

Map Color [1]Code	Predicted Stability Zone	Relative Hazard Ranking	Estimated Factor of Safety (FoS)	Probability of Instability	Possible Influence of Stabilizing or Destabilizing Factors
	Unstable	Very High (5)	<0.9	90%	Stabilizing factors required to achieve/maintain stability
	Threshold of instability	High (4)	0.9 – 1.1	>50%	
	Nominally stable	Moderate (3)	1.1 – 1.3	10%	Minor destabilizing factors needed to cause failure
	Moderately stable	Low (2)	1.3 – 1.5	--	Moderate destabilizing factors needed to cause failure
	Stable	Very Low (1)	>1.5	--	Significant destabilizing factors needed to cause failure

[1] Very Low = Green in Auburn; Blue in Kennebunk

GROUND TRUTHING RESULTS AND FINDINGS

Auburn, Maine

The City of Auburn was selected due to its proximity to Lake Auburn and Androscoggin River with varying terrain and land cover types. The surficial material type in Auburn is locally referred to as the Presumpscot Deposit. It consists largely of soft clay, classified by GZA as "C1"[2] characterized as having undrained shear strength of 350 psf, with lesser layers of marine deltaic sands and silts. The Presumpscot Deposit is also the source of many if not most Maine landslides. GZA was involved with a previous roadside embankment slope project along Route 136 in 2010. Some natural failures had occurred due to oversteepening of the riverbank adjacent to the roadway. However, the major failure that GZA provided geotechnical services for was triggered by installation of steel sheet piles during proposed reconfiguration of the slope. **Figure 2** presents the predicted slope failure hazard indices along Route 136, adjacent to Androscoggin River. The calculation was based on a LiDAR[3] dataset dated 2009, prior to the major failure incident in Summer 2010. It is clear that the modeled results were able to capture the low factor of safety values at the toe of the slope, which led to predicted high hazard level (red dots). **Figure 3** presents two representative photographs from the site, post-failure and post-construction.

Figure 4 presents high hazard areas along Jordan School Road, largely due to low soil shear strength (soft clay) and steep slopes. GZA confirmed that the predicted instability patterns closely match steeper areas in the shaded topographic relief in the area. These features represent typical steep-sided erosional gullies commonly found cutting into the Presumpscot deposits in Maine. Note that GZA's results may have overestimated the slope instability/landslide hazard due to the overall conservative approach we adopted (e.g., conservative soil strength parameters and the 250K surficial material layer).

Kennebunk, Maine

Kennebunk was selected due to its proximity to Kennebunk River, Mousam River, and the Maine coastline. GZA's local knowledge, past project experiences and availability of MGS previously published landslide susceptibility map are all contributing factors for using this area as the ground truthing sites.

Downtown

Figure 5 presents the calculated hazard index in the downtown area of Kennebunk. The model results highlight unstable areas along Mousam River, typically riverbanks over-steepened by toe erosion and sloughing and slumping of sand and clay deposits. Many developed areas at the tops of slopes are being encroached on by unstable slopes including a residential neighborhood were identified in the results (as noted on the figure). The Route 1 over Mousam River bridge abutment areas were found to be unstable in prior GZA evaluations and were detected in the model due to steep slopes. These slopes are now constructed of engineered riprap material able to withstand the steep slope angles.

[2] Refer to Task 2 Memorandum for soil classifications.
[3] Light Detection and Ranging (LiDAR)

North Street / Reid Lane (near Cape Arundel Golf Course, Kennebunkport)

Figure 6 presents predicted unstable areas concurrent with erosional gullies along North Street (similar to the Auburn site), in an area with known slope "sloughing" issues in the past. Same as other highlighted areas in Kennebunk, the underlying cause is the presence of Presumpscot Deposit (or as previously described) and steep terrain.

Coastal Marsh/Estuary

The modeled results also identified areas where coastal erosion is apparent based on existing topography and slopes such as near the Kennebunk River mouth area (at the confluence with the Atlantic Ocean), as shown in **Figure 7**. The orange/red pixels highlight drainage channels that are actively eroding and forming the gullied terrain previously described. The area known as Great Hill at the oceanfront of the river mouth is highlighted due to the steep slopes adjacent to the water, even though the area is mapped as dense sand/grave/silt glacial till deposits. By observation, this area has been stabilized repeatedly with a combination of riprap and stone-filled gabion mattresses and continues to actively erode and experience surficial sloughing failures. Note that the hazard index model does not directly consider flood effects such as elevated water levels, waves and resultant erosion. FEMA flood hazard zones will be included in the toolkit as a reference layer.

U.S. Route 1/State Route 9 Intersection

Figure 8 presents some apparent instability issues in this area due to manmade structures. For instance, steep embankment along an existing railroad is highlighted as unstable due to its slopes up to 1.5H:1V[4] (67% in slope value) over a mapped cohesive deposit. The surficial material types used in the model do not have the adequate resolution to detect manmade (and typically engineered for stability) embankment fills. The roadside slopes along Route 1 at the railroad crossing are also steep with slopes up to 2H:1V (approximately 50%). This type of embankment and/or manmade slopes is highlighted due to steep terrain (slope values) used as the input parameter. Areas highlighted in orange/red are often associated with the weak cohesive foundation soil type (C1). However, if these embankments were engineered and have been in service for some time, we anticipate that the risks of instability would be low here at the present, if properly maintained and closely monitored. The figure also shows lower risk areas in blue/green colors, most frequently due to lesser slope angles and more competent medium dense granular deposits (G2) as the foundation soils. This area highlights the fact that the soil types and strength parameters play a key role in determining the estimated hazard levels by this analytical model.

Interstate I-95

Similar to the scenarios presented in **Figure 8**, manmade features (including overpass bridge ramps and railroad embankments) stand out as potentially unstable areas based on the modeling results, as shown in **Figure 9**. Granular deposits mostly are mapped as low or very hazard areas.

COMPARISON WITH MGS LANDSLIDE SUSCEPTIBILITY MAP - KENNEBUNK, MAINE

According to Maine Geological Survey[5], "landslides are one of the most common geologic hazards in Maine, causing damage in both rural and urban areas of the state." What many of the documented landslide incidents had in common was that they occurred in areas underlain by a glaciomarine clay and stratified sand deposit called the Presumpscot

[4] H:V stands for the ratio between horizontal distance and vertical height difference.
[5] Landslide Susceptibility Mapping in Maine, Maine Geological Survey, 2010 (available at the Maine Geological Survey Publications site https://digitalmaine.com/mgs_publications/453/)

Formation, and usually occurred in areas with steep slopes. Rainfall is one of the common triggering factors, in combination with poor drainage. The Presumpscot Formation is a widespread blanket of glaciomarine silt, clay, and sand that covers much of coastal Maine and inland lowlands and has proven to be highly susceptible to slope failure. The Maine Geological Survey (MGS) produced a series of Landslide Susceptibility Maps for areas in Maine. The maps focused on areas underlain by glaciomarine deposits, and in particular, the marine clay of the Presumpscot Formation.

MGS use the following two categories of risk factors in the study, including:

- Geomorphic Risk Factors (such as slope, curvature, aspect, and slope height); and
- Soil properties (such as surficial geologic materials).

The map used for NETC 19-2 Task 3 is titled "Landslide Sites and Areas of Landslide Susceptibility, Town of Kennebunk, Maine" dated 2009 (Open File No. 09-28, downloaded in PDF format, included as **Appendix A**). GZA converted this PDF map to a jpeg file and used features such as roads and town lines to georeference the map in GIS so it could be compared to model results. Please note that this series of MGS maps were reviewed as part of Task 1 (Literature Review) and referenced in the Task 1 memorandum.

Figure 10 presents an image where MGS mapping results and NETC 19-2 modeling results are overlaid on top of each other for comparison. Our study results have a focus on existing roadways, whereas MGS results cover the entire land area. There is, overall, agreement between the MGS predictions and NETC 19-2 modeling results, in terms of where high hazard areas are located (darker/warmer colors). It is apparent that the NETC 19-2 modeling results are significantly higher in resolution (green to red scale), compared to the MGS mapped color blocks (yellow to dark brown color scale; refer to **Appendix A** for MGS map legend). The MGS results appear to have predicted more "high hazard" areas than this study. GZA's results seems to match the underlying terrain and manmade features more accurately than MGS land-based mapping results, mostly because of the fine resolution (3-meter by 3-meter) and the use of generalized rotational stability analyses as the basis for the current model.

Figure 11 indicates that the NETC 19-2 modeling results are more capable of detecting more detailed potential failure features in general, even if the terrain is generally very gently sloping in the coastal areas. **Figure 12** seems to indicate that the MGS mapping results are strongly correlated with existing water courses, such that predicted high hazard areas closely follow streams alignments. **Figure 13** confirms the same observations described above. Please note the excellent agreement between the two sets of mapping results in the residential area (**Figure 13**). MGS did not predict small/discrete potential failure locations due to the lower resolution of the input terrain data. The NETC 19-2 modeling results identified various small potentially unstable areas especially along roadways.

Note that the ESRI aerial imagery was used as a background as a visual reference (with the MGS map set to 50% transparency).

ADDITIONAL HAZARD FLAGS

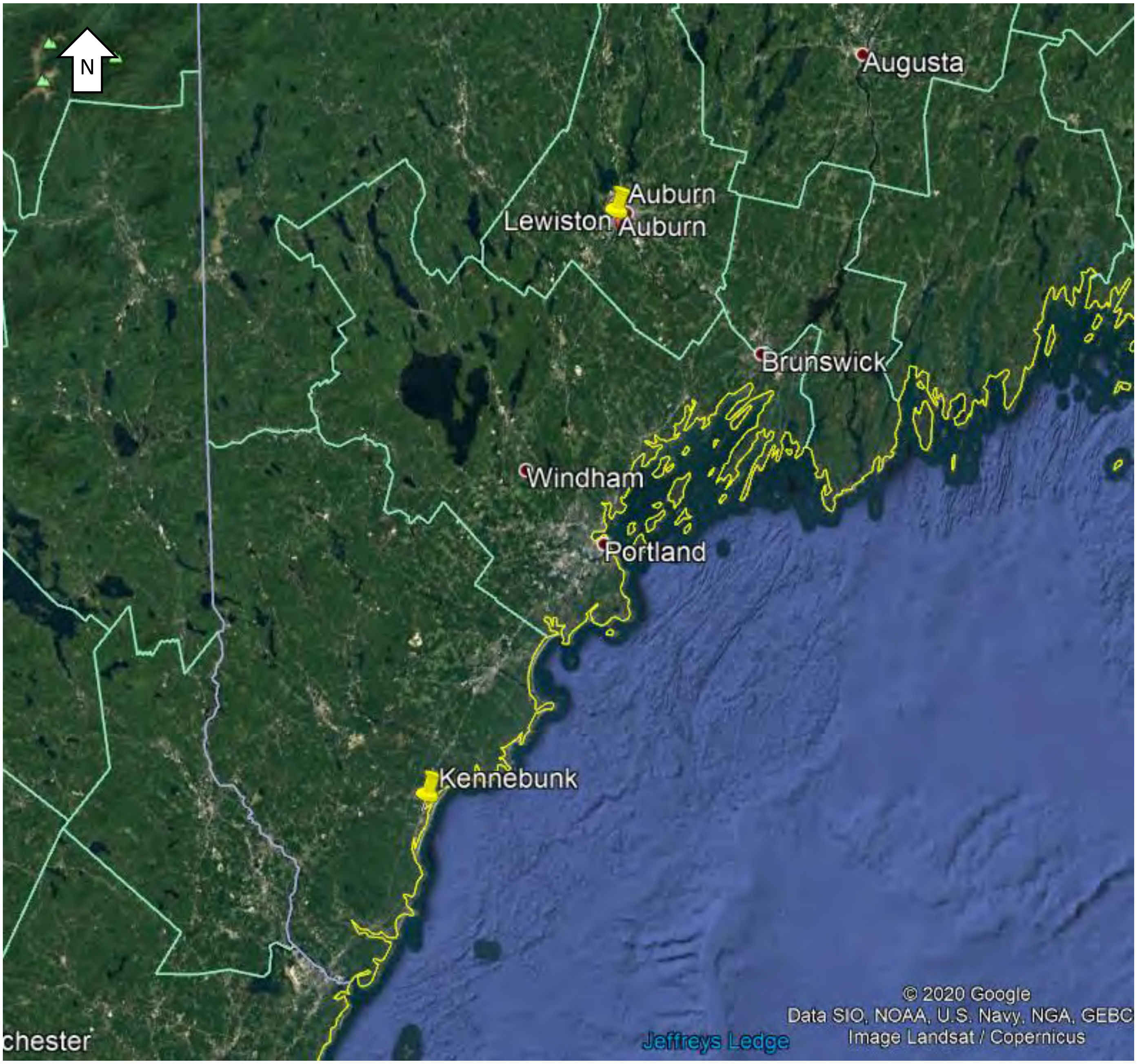
Please note that Figures 11 through 13 presented in the Task 2 memorandum also presented additional layers that highlight erosion risks due to proximity to water body, culverts and FEMA mapped flood zones. Those are not repeated in this document.

SUMMARY/CONCLUSIONS

This memorandum presents GZA's ground truthing methodology and results. GZA selected a few areas in Auburn and Kennebunk, Maine as the ground truthing sites. Key findings include:

- The modeling results were able to identify potential failure or high hazard zones based on the selected input parameters (such as topography and surficial geology). The predicted high hazard areas appear to be accurate, compared to historical failures and/or field observations.
- Steep riverbanks (especially at the toe of slope) are often identified as high hazard areas.
- Steep manmade fill slopes such as bridge abutments and roadway fill embankments are often overly mapped due to weak foundation soils (according to the surficial geological data). When this occurs, the areas are detected as potential unstable areas. In many cases these embankments are engineered using stronger materials than the model detects because the surficial maps in Maine typically don't identify artificial fill and the actual risk of instability is low (i.e., this model produces false positives for certain areas/structures/terrain features).
- Manmade cut slopes adjacent to highways typically consist of the mapped soil type. Consequently, the NETC 19-2 modeling results are expected to be in good agreement there.
- Gullies formed due to long-term "sloughing" (sand / silt / soft cohesive deposits shearing and moving down slope due to changes in moisture and gravity) are apparent from the modeling results.
- The modeling results are also capable of detecting detailed erosion features in flat coastal marsh areas, which conceivably experience regular tidal and/or flood conditions.
- The NETC 19-2 modeling results are in good agreement with the MGS landslide susceptibility mapping results, in terms of overall spatial distribution of the predicted high hazard zones. The results from this study are much finer in resolution and detected more discrete, high hazard areas at various locations, especially along transportation corridors. The MGS results highlight larger areas of landslide susceptibility zones, showing a strong spatial distribution pattern along existing rivers and streams.
- GZA's results are reasonably conservative. For certain areas, the slope instability/landslide hazard may have been overrepresented (i.e., false positives). Our modeling approach adopts conservative assumptions and generic input parameters. We plan to refine the model during the toolkit development phase (Task 4) when feasible.

Figure 1: Location Map of Ground Truthing Sites – Auburn and Kennebunk, ME



Note: Based on Google Earth image.

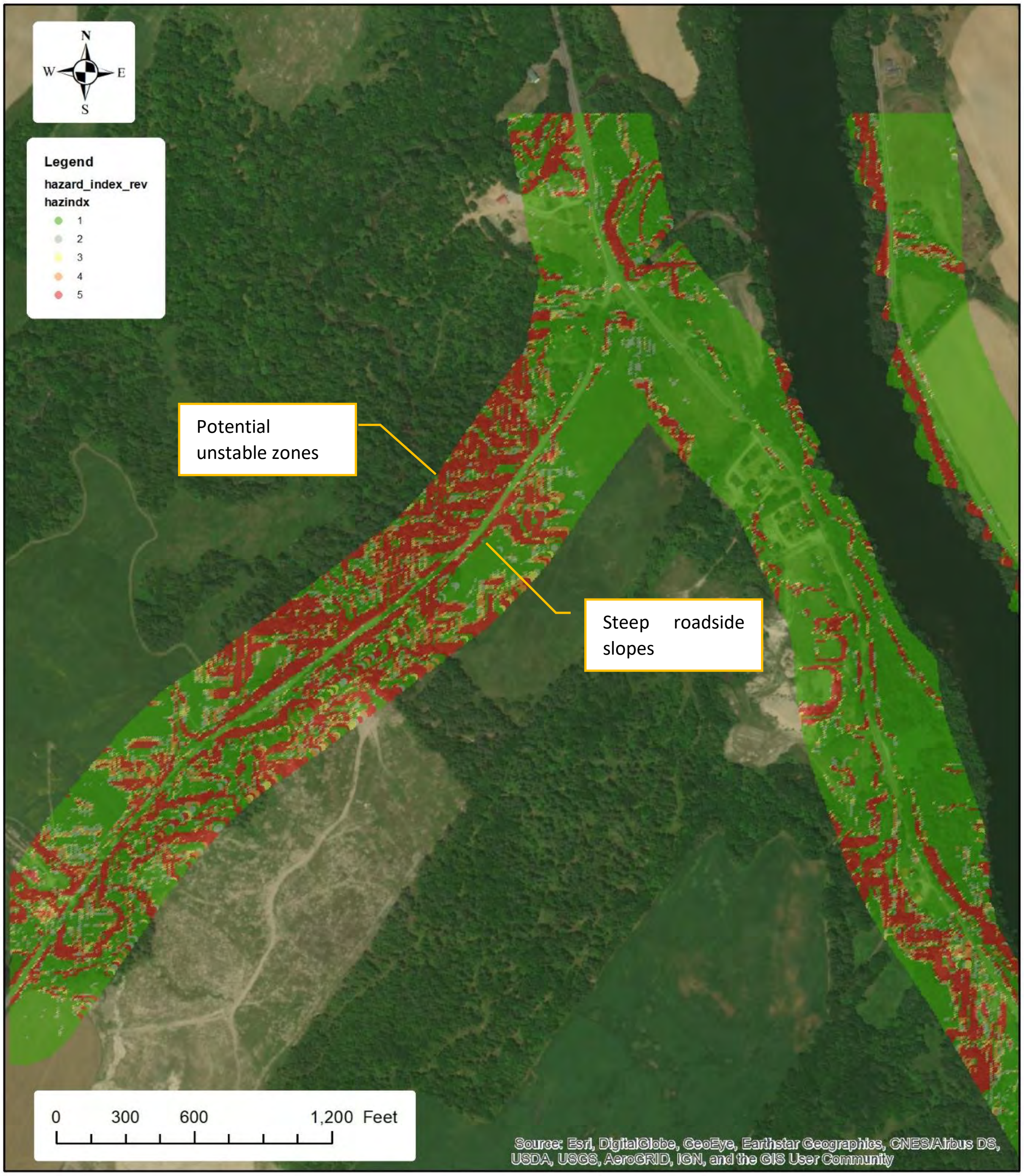
Figure 2: Slope Failure Site at Route 136

Note: Aerial image more recent than 2010; topography LiDAR from 2009. Failure occurred in Summer 2010.

Figure 3: Project Photographs for Route 136 Slope Failure

Note: Top image after failure incident in September 2010; bottom image after construction/remediation completed in December 2010.

Figure 4: Terrain-driven Slope Instability



Note: red indicates low factor of safety values due to steep slopes.

Figure 5: Downtown Kennebunk, Maine

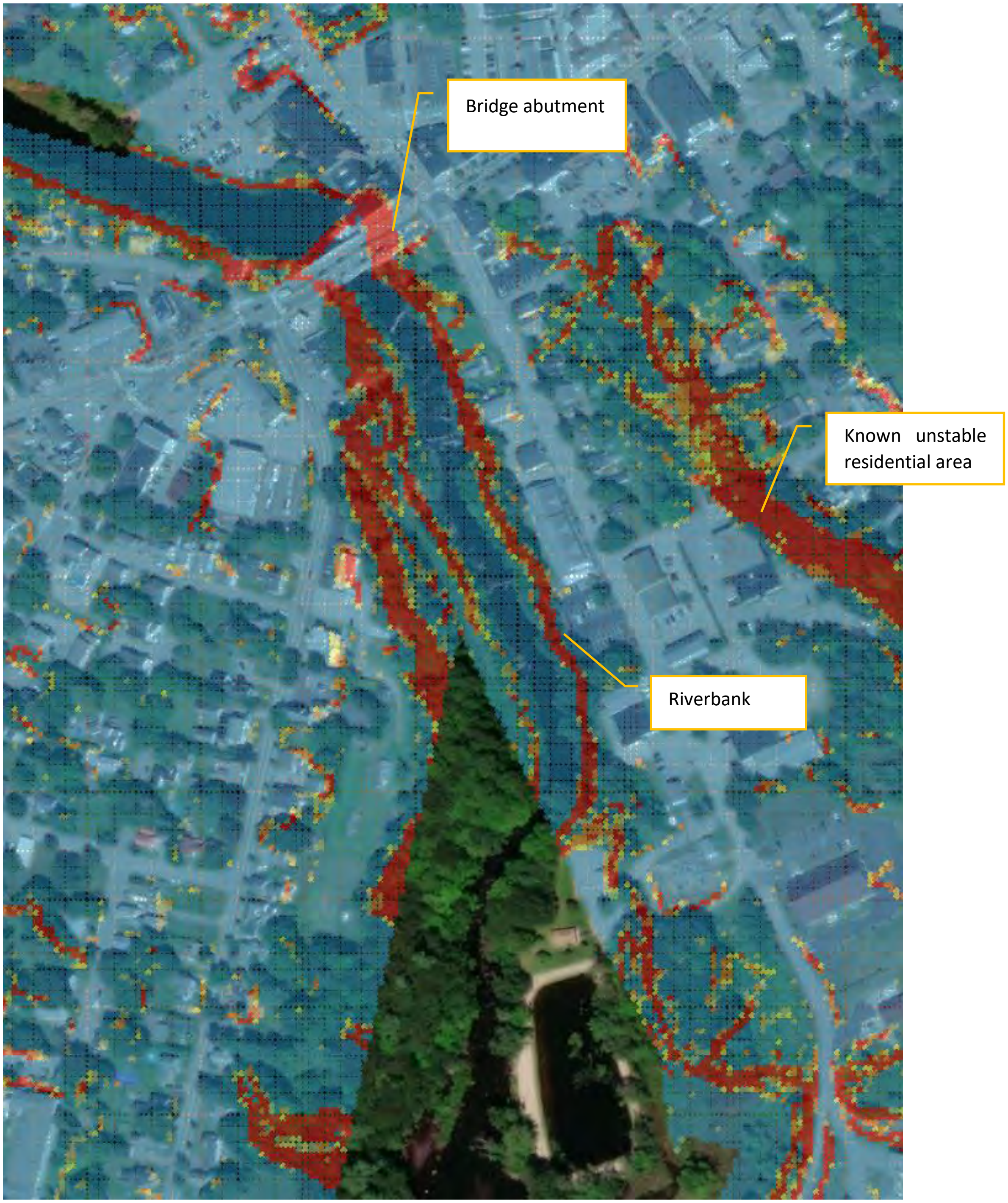


Figure 6: North Street, Kennebunkport, Maine

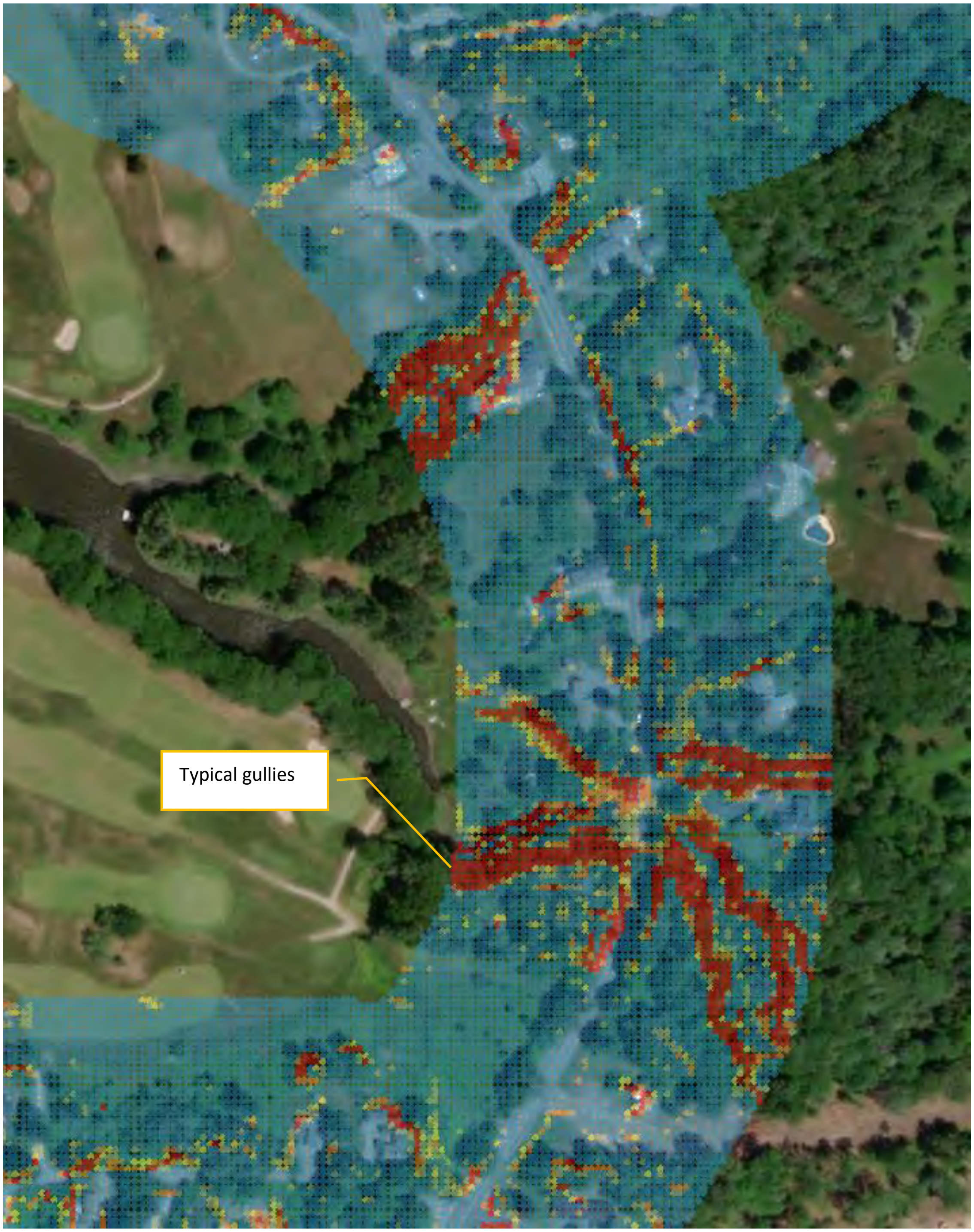
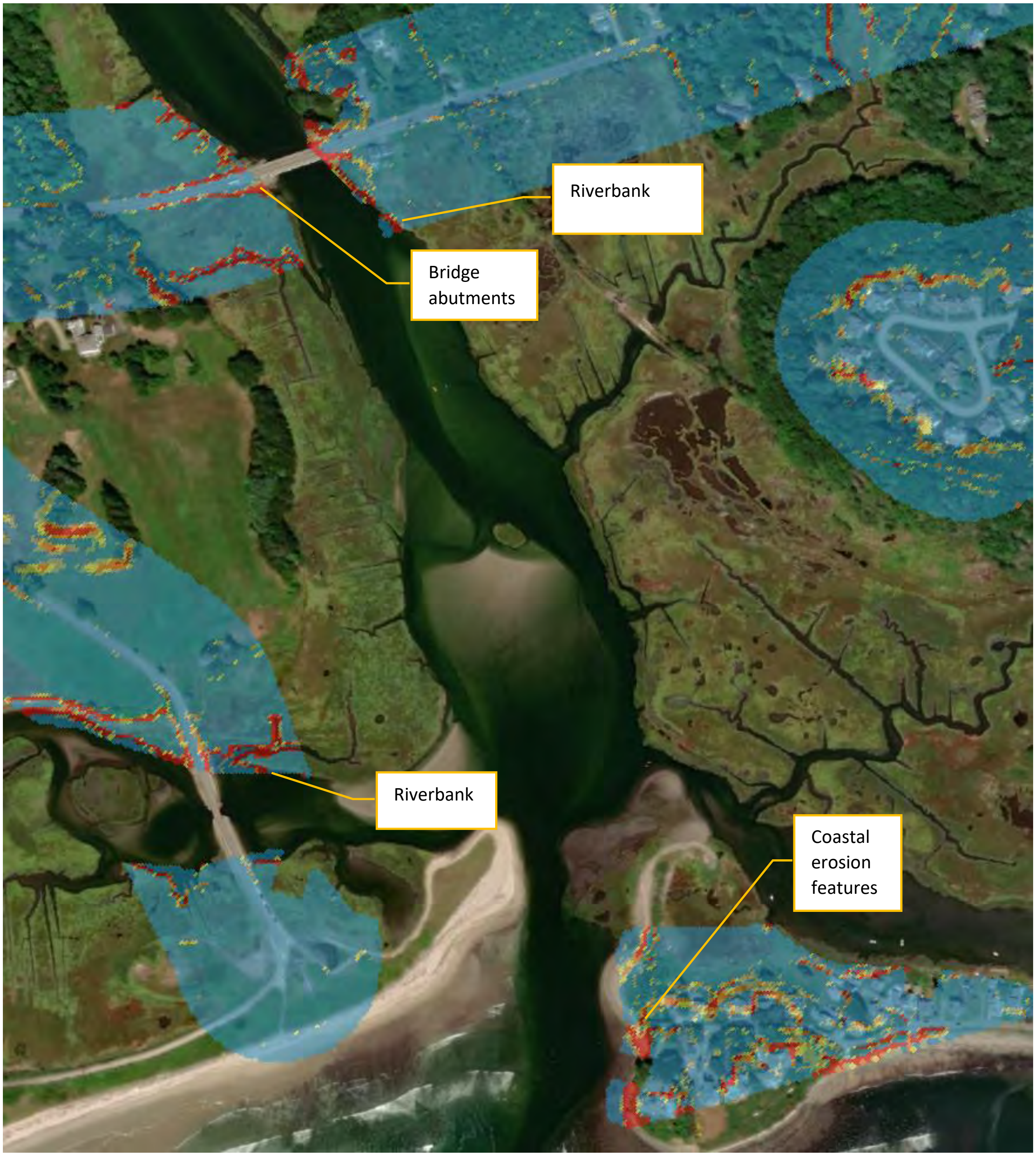
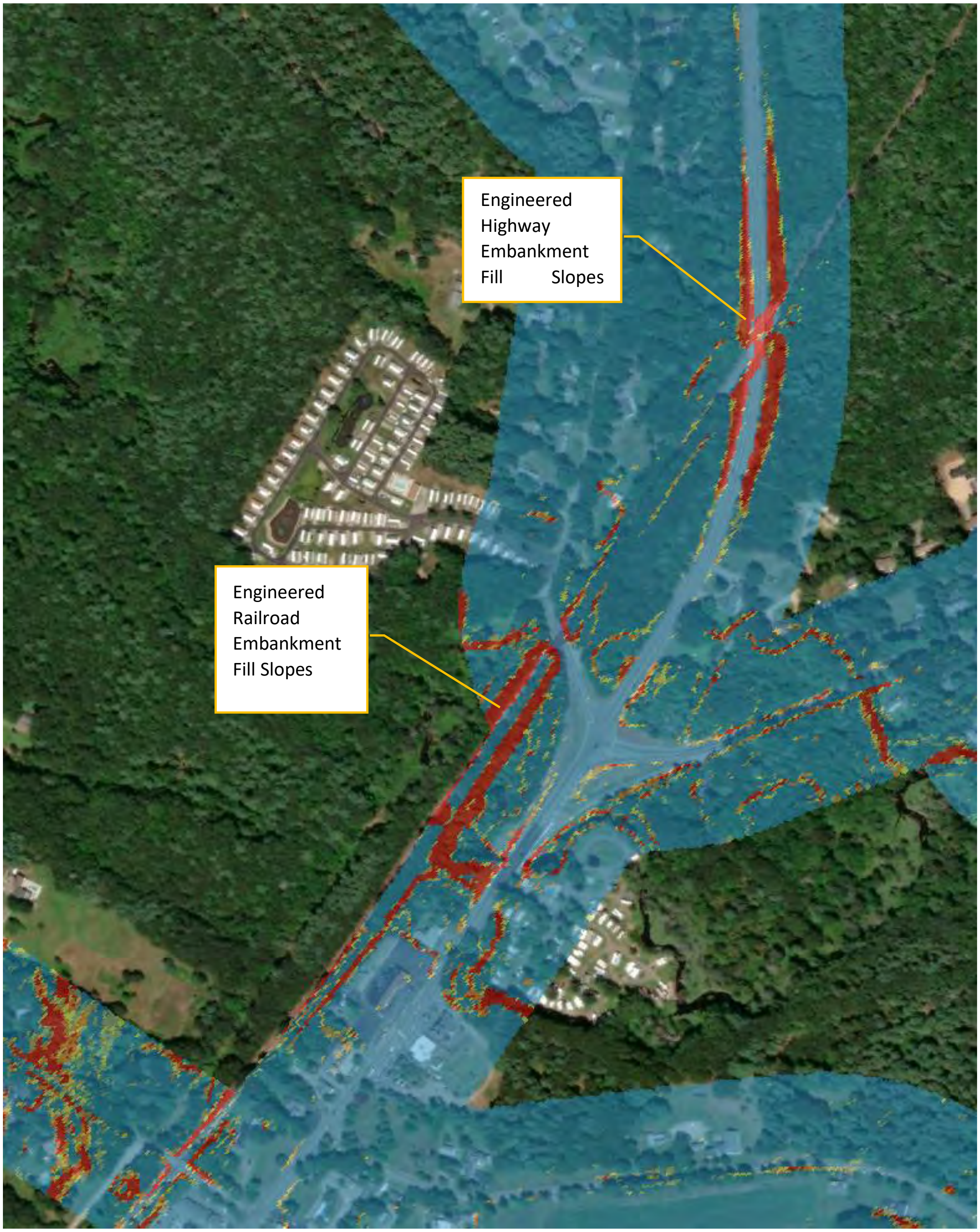


Figure 7: Coastal Erosion and Instability, Kennebunk, Maine



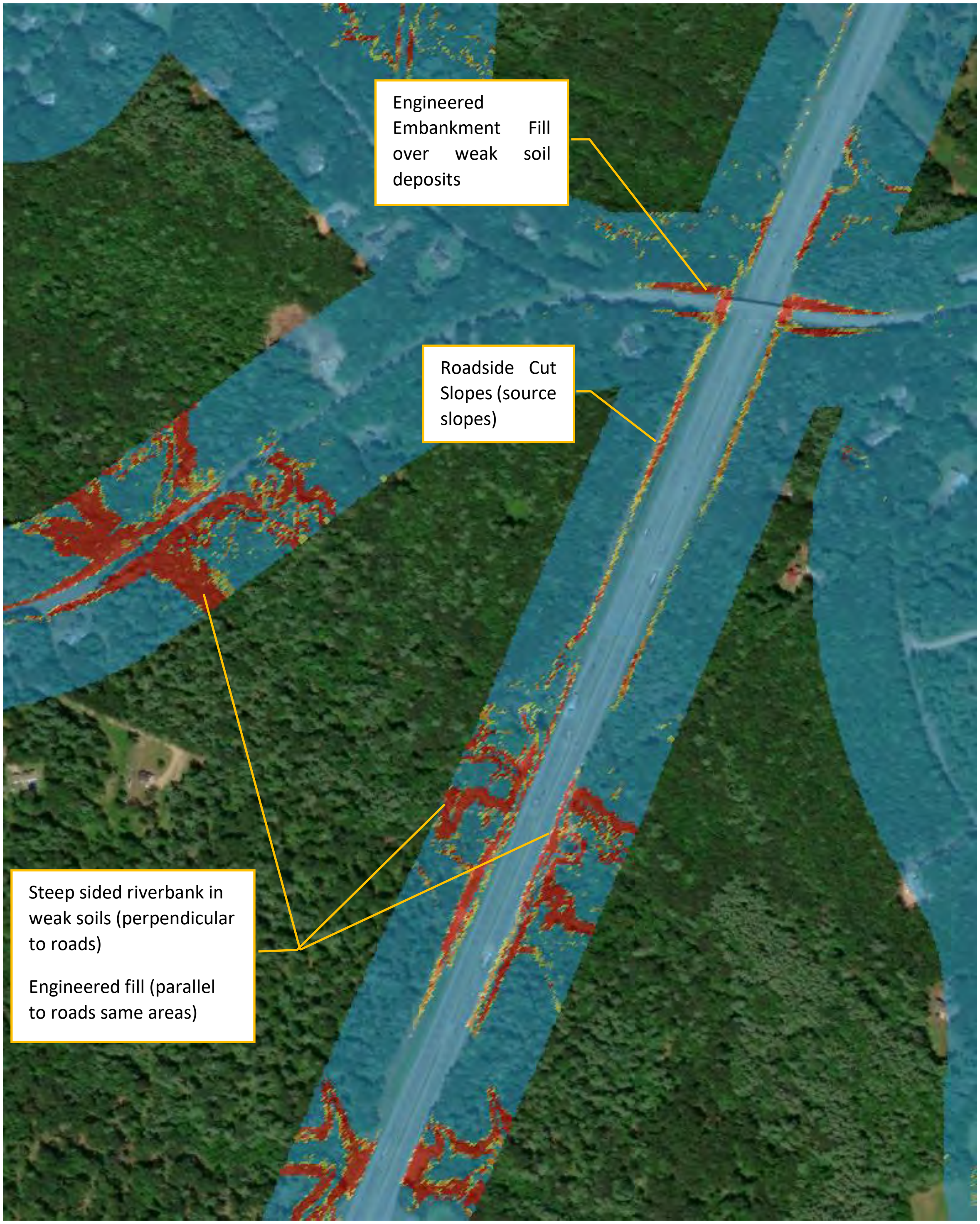
Note: Various erosion / stability issues in a coastal setting.

Figure 8: Route 1, Kennebunk, Maine



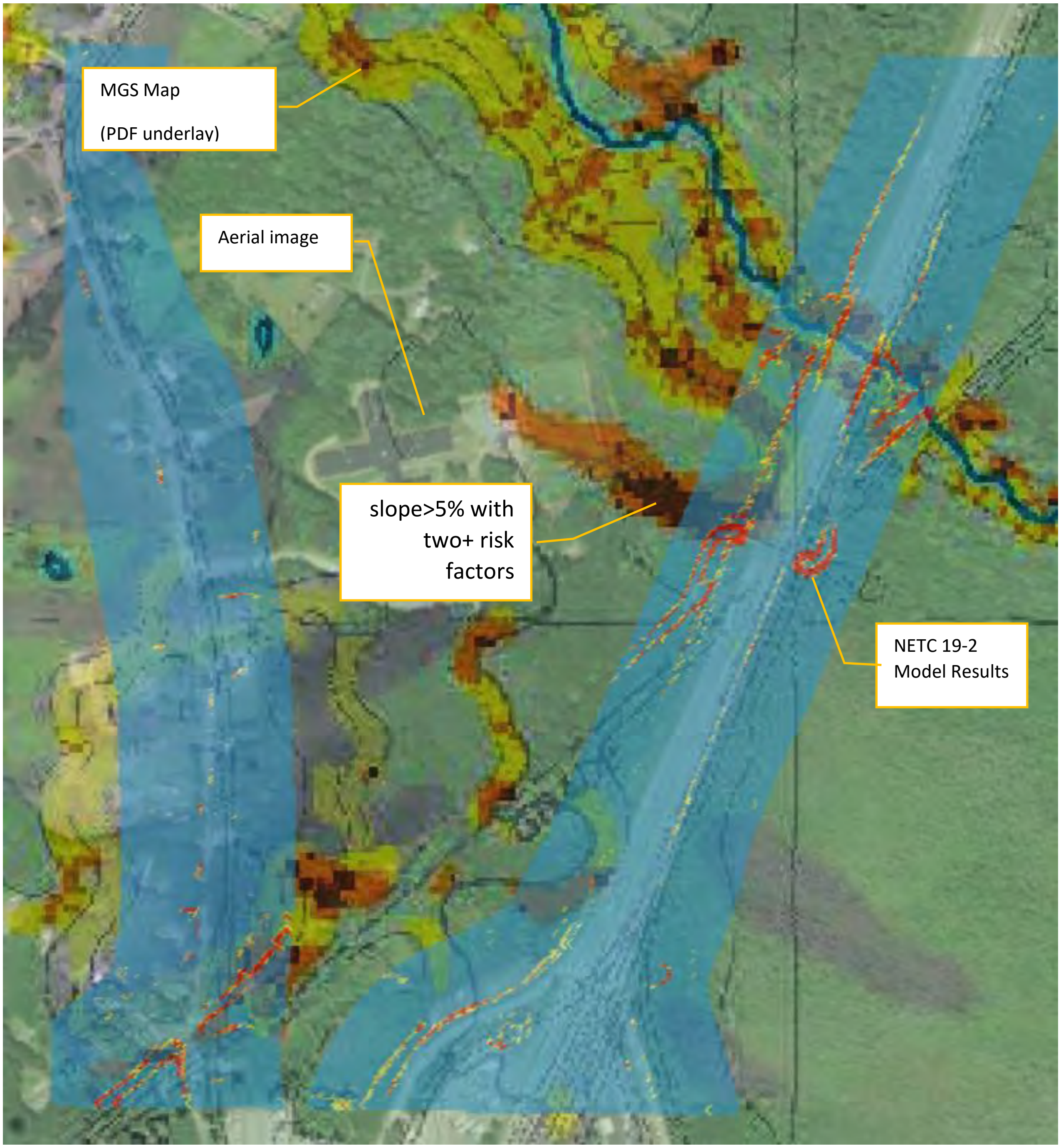
Note: Manmade slopes not part of underlying surficial geology layer used as model input.

Figure 9: Interstate I-95, Kennebunk, Maine



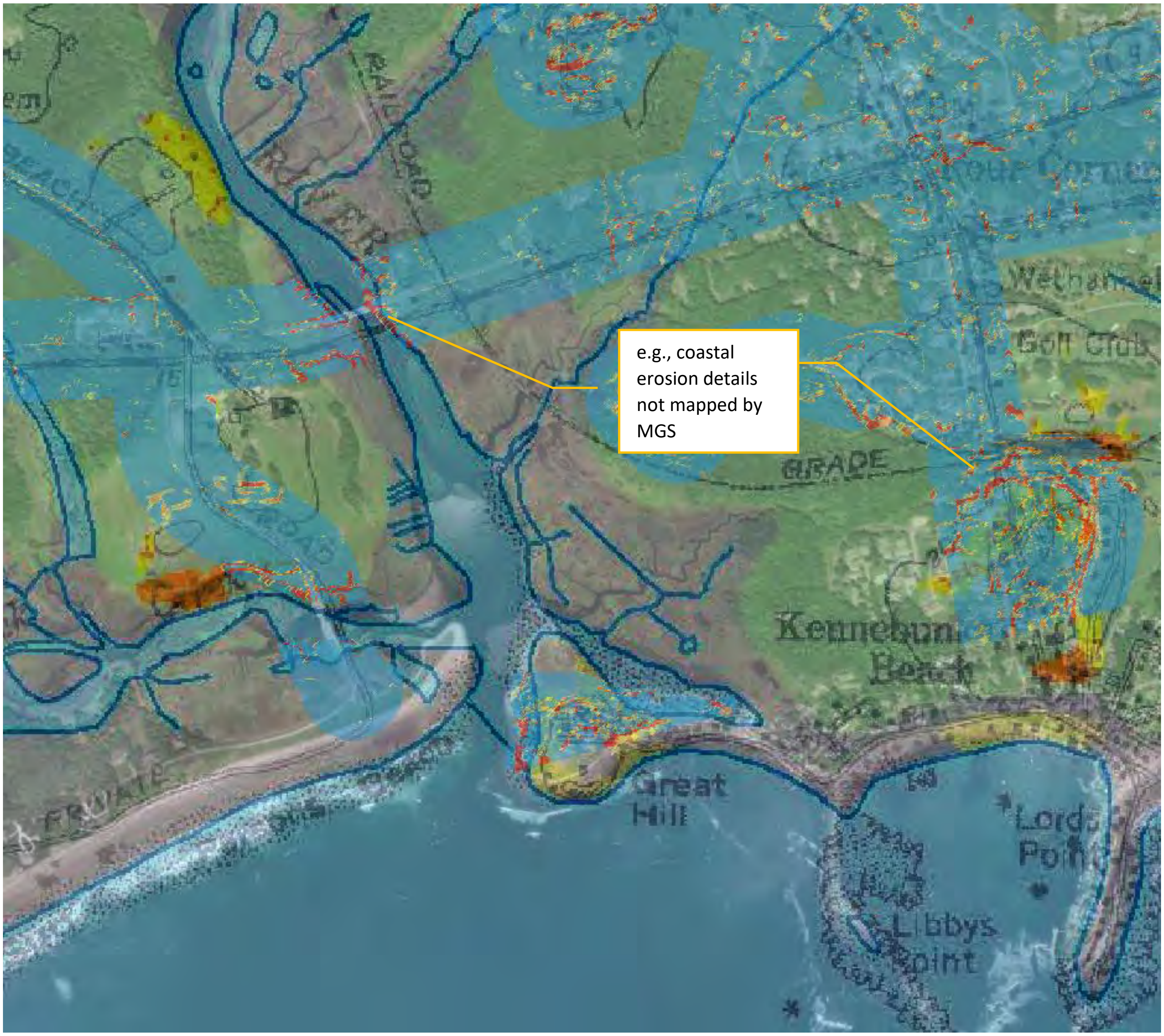
Note: Manmade slopes not part of underlying surficial geology layer used as model input.

Figure 10: Comparison of NETC 19-2 Modeling Results and MGS Landslide Susceptibility Map – I-95



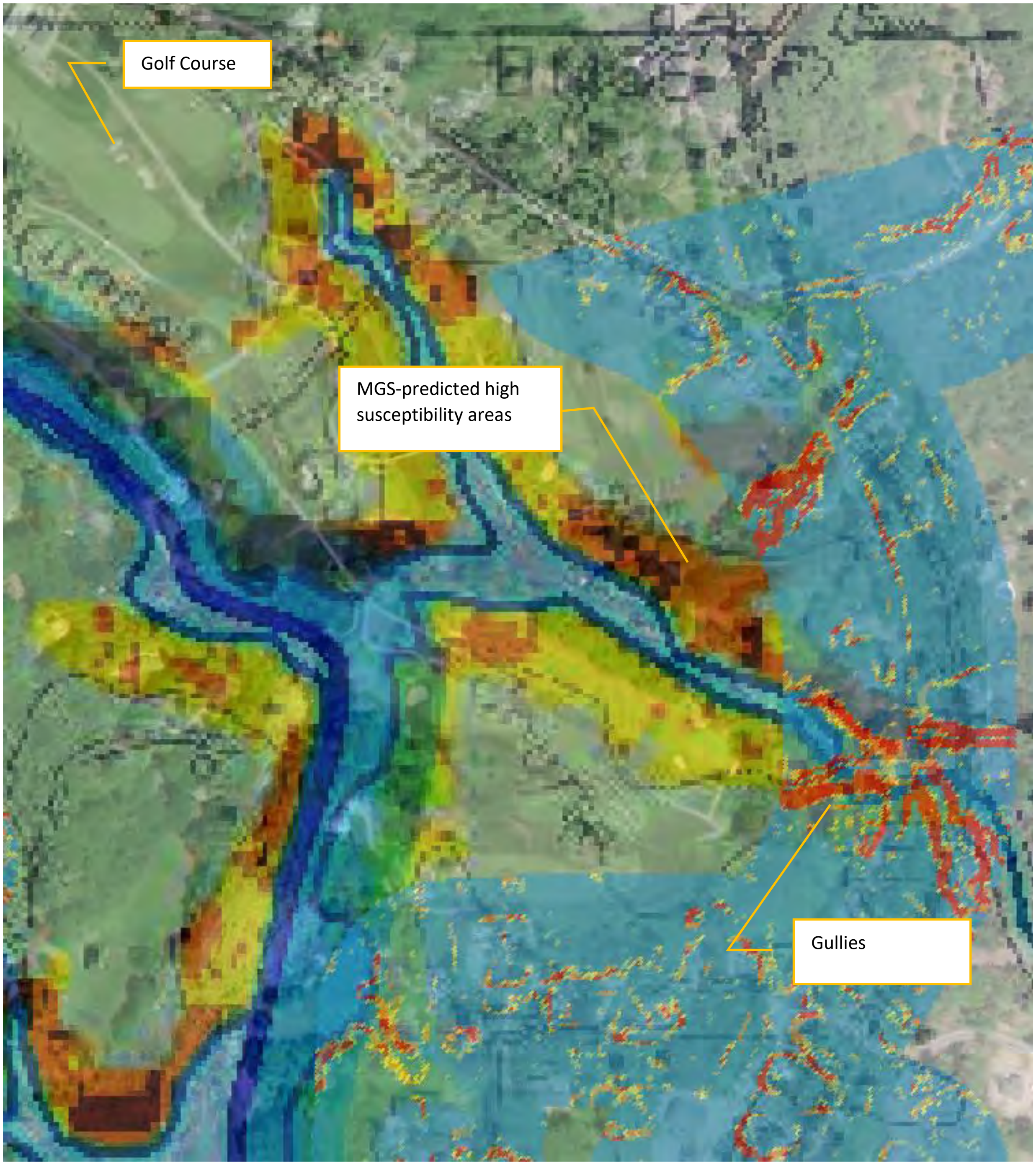
Note: Aerial image and MGS landslide susceptibility map overlaid with NETC 19-2 computed slope stability hazard index. PDF is slightly offset due to projection.

Figure 11: Comparison of NETC 19-2 Modeling Results and MGS Landslide Susceptibility Map – Coast



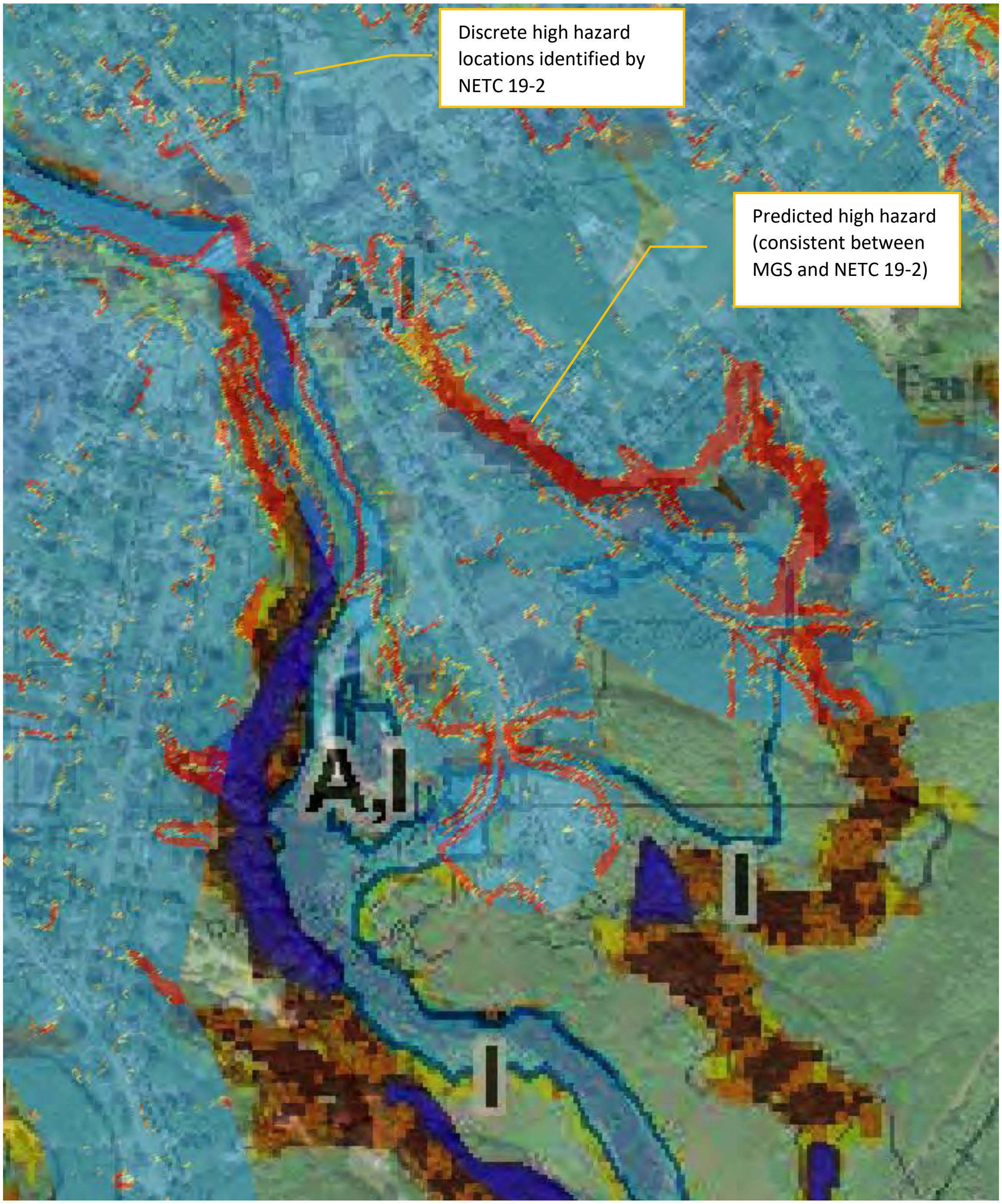
Note: Aerial image and MGS landslide susceptibility map overlaid with GZA computed slope stability hazard index. PDF is slightly offset due to projection.

Figure 12: Comparison of NETC 19-2 Modeling Results and MGS Landslide Susceptibility Map – North Street



Note: Aerial image and MGS landslide susceptibility map overlaid with GZA computed slope stability hazard index. PDF is slightly offset due to projection.

Figure 13: Comparison of NETC 19-2 Modeling Results and MGS Landslide Susceptibility Map – Downtown



Note: Aerial image and MGS landslide susceptibility map overlaid with GZA computed slope stability hazard index. PDF is slightly offset due to projection.

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

LiDAR – Light Detection and Ranging

MGS – Maine Geological Survey

NACCS – North Atlantic Coast Comprehensive Study

NASA – National Aeronautical and Space Administration

NOAA – National Oceanic and Atmospheric Administration

NRCS – Natural Resources Conservation Service

SFHA – Special Flood Hazard Area

USACE – United States Army Corps of Engineers

USDA – United States Department of Agriculture

USGS – Unite States Geological Survey

Appendix A

MGS Landslide Susceptibility Map, Kennebunk, Maine, 2009

Landslide Sites and Areas of Landslide Susceptibility

Town of Kennebunk, Maine

Landslide site mapping by:
Michael E. Foley

Landslide risk factor analysis by:
Michael E. Foley and Marc C. Loiselle

Digital cartography by:
Michael E. Foley
Susan S. Tolman

Robert G. Marvinney
State Geologist

Cartographic design and editing by:
Robert D. Tucker

Funding for the preparation of this map was provided by the Maine Emergency Management Agency.

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Home page: http://www.maine.gov/doc/nrimc/nrimc.htm

Open-File No. 09-28
2009

Landslide susceptibility in fine-grained sediments

Increasing susceptibility

- Slope less than 5 percent.
- Slope equal to or greater than 5 percent.
- Slope equal to or greater than 5 percent and one of the following terrain-related risk factors: slope aspect, curvature, or local relief.
- Slope equal to or greater than 5 percent and two or three of the following terrain-related risk factors: slope aspect, curvature, or local relief.

Landslide susceptibility in other sediments

Increasing susceptibility

- Slope less than 5 percent.
- Slope equal to or greater than 5 percent.

Terrain-Related Risk Factors

Slope: Slope is the primary driving force for landslides and earth movements. Slope is defined as the inclined surface of the land. The steeper the slope, the larger the shear stress produced by the weight of the materials and the more susceptible the slope is to failure. For this map, a slope of 5% or greater is considered a risk factor.

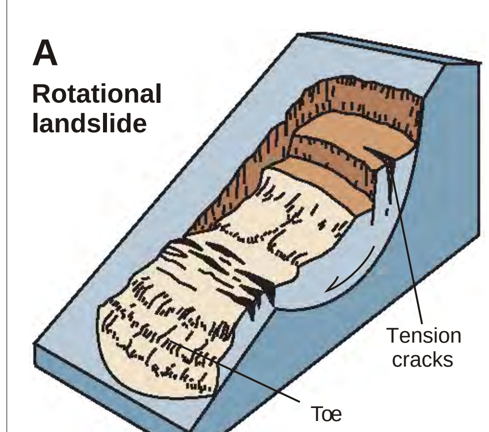
Slope aspect: Slope aspect is the direction toward which the surface of the soil faces. South-facing slopes undergo more extensive freeze/thaw cycles in winter months than slopes with other aspects. Repeated freeze-thaw cycles preferentially reduce the shear strength of the shallow soil material and increase the likelihood of shallow soil slumps. Ultimately, small movements may steepen the slope and lead to larger slope failures. For this map, a slope aspect facing between South 45º East and South 45º W is considered an additional risk factor.

Curvature (concave shape): Hill shape influences landslides by its effects on soil and water distribution. Concave surface topography will tend to concentrate the flow of surface water and ground water, raising ground-water pore pressures and reducing the shear strength of the soil. As a result, concave slopes are more susceptible to failure than straight slopes or convex slopes. For this map, a concave shape is considered an additional risk factor.

Local relief (slope height): As the thickness of the potential landslide block increases, the shear stress on the lower section of the block increases and the block (or slope) is more susceptible to failure. As a consequence, thicker sections of surficial materials will be more susceptible to failure and possibly deeper and larger failures. For this map, local relief greater than 6 meters (approximately 20 feet) is considered an additional risk factor.

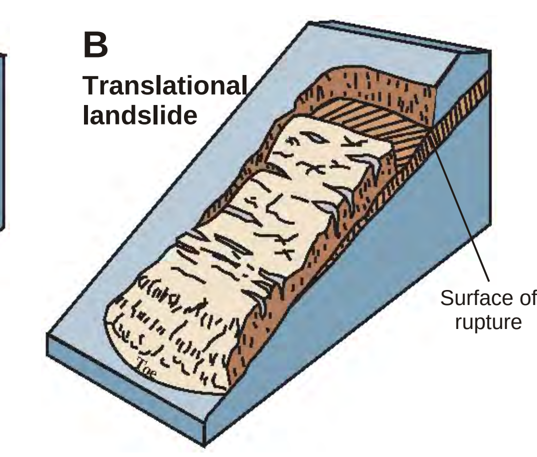
Common Types of Landslides in Maine

A
Rotational landslide



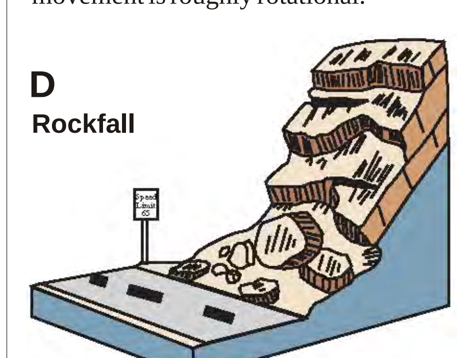
Rotational slide - the surface of rupture is curved concavely upward and the slide movement is roughly rotational.

B
Translational landslide



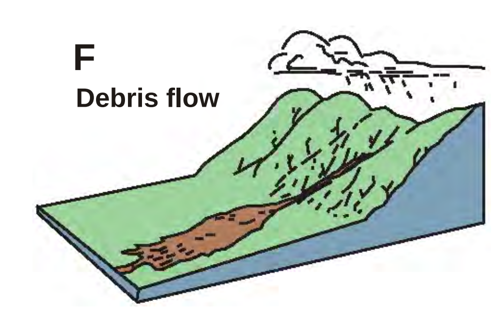
Translational slide - the landslide mass moves along a roughly planar surface with little rotation or backward tilting.

D
Rockfall



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

F
Debris flow

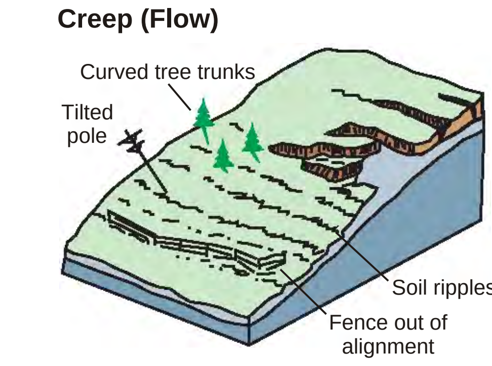


Debris flow - rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope.

H
Earthflow

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

I
Creep (Flow)



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.

Sites of past landslides

The purple area delineates the extent of the landslide and the letter indicates the type of landslide, defined in the diagram entitled *Common Types of Landslides in Maine.* Two or more letters indicate multiple processes were involved at the site or contributed to landslide morphology. Past landslides were mapped from aerial photo interpretation and field investigations in 2008.

Mapped landslides in the town of Kennebunk

This map can be used to identify areas with historical landslide activity and to identify areas that are susceptible to future landslide activity where additional studies should be undertaken before construction or other development is started that could be at risk due to a future landslide.

Ninety-one percent of mapped landslide sites in the town of Kennebunk (19 of 20 features) are located in areas shown as having a slope of 5 percent or more, and 91 percent of the mapped landslide sites are located in areas containing at least one additional geomorphic risk factor.

From this, we conclude that there is a significantly greater risk of a landslide occurring in areas containing one or more of the geomorphic risk factors than in areas that do not contain any of these risk factors.

However, no information is presently available to assess the probability of a landslide occurring within these areas. That is, if a landslide or earth movement does occur, it is very likely to be in the areas containing one or more of the geomorphic risk factors, but it is not possible at this time to predict whether a landslide or earth movement will occur.

Forty percent of the mapped landslide sites in York County are located in the glacial marine Presumpscot Formation which is known for thick sections dominated by marine clay. Eighty-one percent of the mapped landslides show at least some involvement with glacial marine deposits of all types, although other surficial materials (such as till or alluvium) may be present. Less than 14 percent of the mapped landslides involve Holocene alluvial deposits.

Sources of information used to make this map

Terrain-related risk were factors calculated from the National Elevation Dataset 1/3 Arc Second product developed and published by the U.S. Geological Survey. The horizontal resolution of the 1/3 Arc Second dataset is approximately 10 meters. Horizontal accuracy meets the National Map Accuracy Standard for a 1:24,000 scale dataset of ± 40 feet or 12 meters. Absolute vertical accuracy of the elevation data is ±7 meters or approximately ± 21 feet. The shaded relief layer was generated from this dataset, with a sun angle of 45 degrees above the horizon, azimuth of 315 degrees (northwest), and vertical exaggeration of 4.

The distribution of surficial geologic materials was compiled from the Maine Geological Survey surficial geologic maps listed below. The following geologic units were considered to be "fine-grained sediments" for the purpose of this map: Pp, Pm, Pmd, Pmdo, Pmf, Pmn, Pmrs, Pms, and Ha. Where applicable, coastal landslide information was compiled from Maine Geological Survey coastal landslide hazards maps listed below.

Dickson, S. M., 2006, Coastal landslide hazards in the Kennebunkport quadrangle, Maine: Maine Geological Survey, Open-File Map 06-58, scale 1:24000.

Dickson, S. M., 2006, Coastal landslide hazards in the Wells quadrangle, Maine: Maine Geological Survey, Open-File Map 06-56, scale 1:24000.

Neil, C. D., 1999, Surficial geology of the Alfred quadrangle, Maine: Maine Geological Survey, Open-File Map 99-76, scale 1:24,000.

Smith, G. W., 1999, Surficial geology of the Kennebunk quadrangle, Maine: Maine Geological Survey, Open-File Map 99-86, scale 1:24,000.

Smith, G. W., 1999, Surficial geology of the Kennebunkport quadrangle, Maine: Maine Geological Survey, Open-File Map 99-87, scale 1:24,000.

Smith, G. W., 1999, Surficial geology of the Wells quadrangle, Maine: Maine Geological Survey, Open-File Map 99-104, scale 1:24,000.

Limitations of the data

This map may be used to identify areas that are susceptible to landslide activity. Based on the risk factor analysis, ***if*** a landslide or earth movement does occur, it is very likely to be in the areas containing one or more of the geomorphic risk factors shown on this map, but it is not possible at this time to predict ***whether*** a landslide or earth movement will occur.

The landslide site mapping and risk factor analysis were done in 2008. Some mapped landslides may have occurred since the photography and digital elevation model were mapped or generated.

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