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

Technical Memorandum

Task 2: Modeling

Prepared for:

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

Prepared by:

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OVERVIEW

Following a comprehensive review of existing literature, available source data, and analytical methods, GZA started to develop our own approach to identify critical parameters, perform analyses, and generate model outputs of soil slope stability and potential erosion areas.

GZA developed model applications to evaluate and screen for erosion and slope stability zones along roadway corridors that have the potential to impact roadways. We understand the predominant characteristics that impact roadway failure include, but are not limited to:

- Surficial geology (i.e., geologic formation and soil material/geotechnical properties);
- Topography; and
- Flood/water-related failure mechanisms such as surface erosion (e.g., overtopping and wave impact), internal erosion (e.g., underseepage and piping); material softening by saturation; pavement failure (seepage and wave loads and flotation); and culvert failure or overtopping.

METHODOLOGY

Under Task 2, GZA considered the following aspects / input parameters:

- Geostatistical analysis of topography, National Elevation Dataset published by U.S. Geological Survey (USGS);
- Geospatial analytics such as roadway segmenting, orientation, site condition and/or proximity queries (MaineDOT roadway inventory);
- Large culverts (MaineDOT);
- Maine Geological Survey (MGS) 1:250,000 (250k) surficial geological data;
- USGS national hydrography dataset (NHD) with streams and surface water bodies;
- Land cover dataset published by Natural Resources and Conservation Service (NRCS); and
- Flood hazard mapping data published by Federal Emergency Management Agency (FEMA).

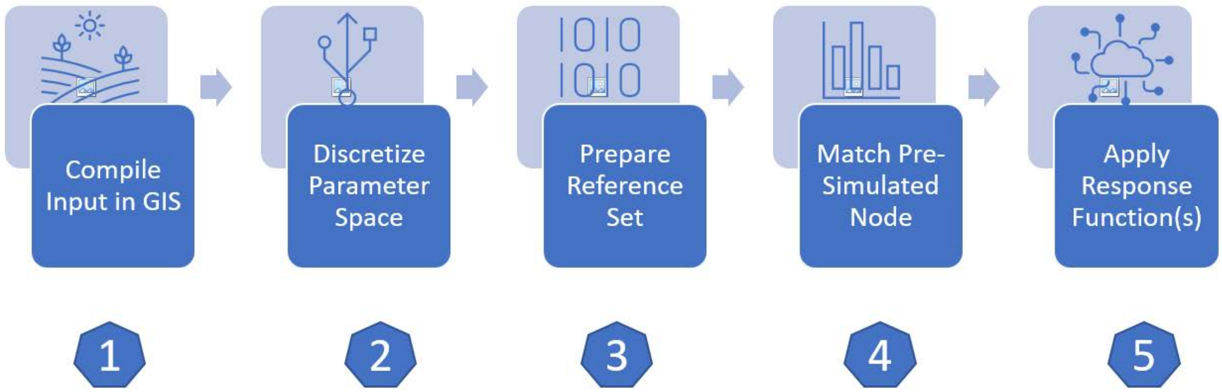
Figure 1 presents a simple schematic of the road-side slopes for this study. We grouped slopes into two main categories: source slopes and support slopes, which are defined by their relative elevation to the nearest roadway segment.

GZA adopted an analytical concept "analogous" to the Response Surface method widely adopted by U.S. Army Corps of Engineers (USACE) and FEMA for their coastal storm surge flood studies (Resio et al., 2009[1], USACE, 2015[2]). GZA's work flow included the following steps, as graphically summarized in the chart below:

- Select key input parameters that affect slope stability;
- Discretize parameter space per surficial geological information;
- Assemble a base parameter combination set for numerical simulations;
- Perform numerical slope stability analysis using simplified geotechnical material properties;
- Include varying groundwater conditions; and

[1] Resio, D.T., J. Irish, and M. Cialone, "A surge response function approach to coastal hazard assessment – part 1: basic concepts", Natural Hazards, 2009. 51:163–182. DOI 10.1007/s11069-009-9379-y
[2] North Atlantic Coast Comprehensive Study (NACCS) Coastal Storm Hazards from Virginia to Maine, ERDC/CHL TR-15-5, November 2015.

- Establish an interpolation and extrapolation scheme for scenarios that are not directly modeled.



Complex geometry such as slope length, slope surface curvature and toe undercutting were considered as additional risk contributing factors and were simulated as part of the sensitivity analysis. External loading, such as surcharge from traffic, was not included but can be incorporated at a later stage.

NUMERICAL SLOPE STABILITY ANALYSIS

GZA used SLOPE/W (submodule of GeoStudio v.2018), a widely used commercial slope stability software program for analyzing soil slopes. SLOPE/W can effectively analyze both simple and complex problems for a variety of slip surface shapes, pore-water pressure conditions, soil properties, and loading conditions. **Figure 2** presents a simple schematic of the geometry modeled in SLOPE/W. GZA used the Morgenstern-Price (M-P) method with half-Sine side function (SLOPE/W default). The M-P method, similar to the Spencer method, uses mathematically more rigorous formulations than the earlier Bishop's method, which include all interslice forces and satisfy all equation of statics (**Figure 3**).

GZA carefully examined the surficial geological data available from Maine Geological Survey (MGS)/USGS and selected the 250k unified state-wide layer as input. The material geological descriptions are presented in **Table 1**. GZA classified the soils into three main categories:

- granular soils with frictional angle (ϕ) as the soil strength parameter;
- cohesive soils with undrained shear strength (s_u) as the soil strength parameter;
- rock – weathered or intact bedrock (not modeled at this stage).

For each soil type (granular or cohesive), GZA divided them into three subgroups, with simplified, representative soil strength properties based on engineering judgment and local knowledge, as presented in **Table 2**. For example, G1, a granular soil with the lowest frictional angle, represents silty sandy materials with relatively low density, whereas G3, with the highest frictional angle, represents gravelly materials or dense sandy soils, such as glacial till. Fine-grained glaciomarine deposits were largely classified as C1, a cohesive soil with very low shear strength (or cohesion value).

Two groundwater conditions (as shown in **Figure 2**) were assumed to represent:

- relatively dry condition with a groundwater table approximately 10 feet below ground surface; and
- relatively wet condition with a groundwater table approximately 3 feet at crest of the slope and exiting the ground surface at the slope toe.

Dry and wet groundwater conditions can be a result of various factors such as precipitation, material types, slope aspect and curvature, local hydrologic setting and seasonal variations. Simulated SLOPE/W results are summarized in **Table 3**. Critical Factor of Safety (FoS) values from the critical slip surface are presented in the table, which are the slip surface that produce the minimum FoS value of all the slip surfaces analyzed by the program in each simulation. In general, a shallower groundwater table tends to lower the FoS in granular soil slopes, whereas the difference is less noticeable in cohesive soils. FoS values are positively correlated with increasing soil strength parameters (**Table 3**). Please note that the predicted FoS values appear to be conservative, when compared to a rule-of-thumb number that a Geotechnical engineer may use. Contributing factors to the overall conservative FoS results include:

- Large size of the slope modeled: the slope is 100 feet long in horizontal distance, which leads to a tall slope when the slope angle is large;
- Deep seated slip surfaces: critical slip surfaces appeared to be deeper than commonly observed, partially due to the size of the slope modeled;
- High groundwater: the slope is essentially saturated in the model, which increases instability for granular soils;
- Stabilizing factors not considered such as suction (i.e., negative pore pressure) in fine-grained materials;

Figure 4 presents an example SLOPE/W geometry used for this study. GZA selected a slope size of 100 feet in horizontal distance from crest to toe. A separate sensitivity analysis indicates that shorter slopes tend to produce larger FoS values with the same input parameters. Therefore, using 100-foot wide slopes in modeling is judged conservative for this study. **Figure 5** presents the SLOPE/W simulation results for the granular soils and **Figure 6** presents the results for the cohesive soils. These curves can be viewed as discrete slices from a 4-dimensional (response) surface, with the response being the factor of safety and the variables being the slope angle, material type and ground conditions. **Figure 7** presents interpolated and extrapolated results for next steps to estimate a FoS value for each grid cell based on its slope in percent (%) up to 120% (steeper slopes will be defaulted to this value). Natural soil slopes, regardless of material types or geometry, becomes inherently unstable when the slope exceeds 100% (i.e., 1-to-1 slope), consistent with our modeling results and general knowledge. Additional material types and/or parameters can be incorporated in the model when needed, under the modular structure of the overall approach. The curves in **Figure 7** are smooth, consistent with the modeled results.

Please note that multi-layered geometry is beyond the scope of this screening level analysis. Stratigraphy should be considered for site-specific slope stability studies and engineering design.

Preliminarily, GZA proposed to use the following slope stability risk index system based on calculated FoS values:

FoS	Risk Designation	Color Coding		Remarks
>= 1.5	Very Low	Deep Green		Significant destabilizing factors needed to initiate failure
1.3 – 1.5	Low	Green		Moderate destabilizing factors needed to initiate failure
1.1 – 1.3	Moderate	Yellow		Minor destabilizing factors needed to initiate failure
0.9 – 1.1	High	Orange		Stabilizing factors required to prevent failure
< 0.9	Very High	Red		Significant stabilizing factors required to prevent failure

The "Remarks" column was added to highlight possible influence of stabilizing or destabilizing factors. **Appendix A** presents output views of the SLOPE/W-calculated slip surfaces and factors of safety for various scenarios.

GIS MAPPING OF SLOPE STABILITY AND EROSION RISK INDEX

GZA assembled the following list of fields to determine the risk indices for roadway-impacting slopes:

- Easting (X) and Northing (Y) in UTM 19N coordinate system;
- Grid cell elevation, slope, aspect and curvature;
- MGS 250k surficial material type;
- NRCS land cover type;
- Roadway surface elevation and roadway segment aspect;
- Distances from grid cell to the nearest roadway segment, hydrographic feature and culvert; and
- FEMA special flood hazard area designations (flood zones and BFE if available);

Computations were performed using Python scripts and output results are directly linked and processed in GZA's GeoTool (ESRI ArcGIS web mapping application[3]) and can be displayed as various map layers/attributes.

Selected preliminary output generated in ESRI's ArcMap (v.10.5.10) is shown in **Figure 8**. The hazard presented is generally driven by slope instability. The selected test area is along Route 136 (near Androscoggin River), Auburn, ME. Five hundred (500) feet each side of the road was used as the spatial filter for potential road impact screening zone for slope and erosion hazards. Note that the calculated hazard index value increases with the estimated hazard level. **Figure 9** presents selected key parameters for two representative locations (as shown in **Figure 8**). Pt 1 is located near the bottom of the embankment slope next to the Androscoggin River, with a slope of 117%, which means the natural slope at the toe exceeds one horizontal to one vertical. Pt 2 is located on the other side of the road on a relatively flat parcel, with a gentle slope of 3%. The soil type was the same for both, classified as "201", the weakest cohesive material in this study. The computed factors of safety for slope stability are 0.1 and 2.6 for Pt1 and Pt2, respectively. The Hazard Index for Pt 1 and Pt2 was calculated to be 5 and 1, respectively. As a result, the map in **Figure 8** shows a strip of red color along the river bank and large patches of green color on the other side of the road. **Figure 10** presents a close-up view of a pre-existing gully-like feature, where the predicted hazard indices are fairly high. In addition, red shading along the support slopes west of the road also indicates some potential slope instability issues in this area.

Figure 11 presents the areas (in red) that are within 50 feet of hydrographic features such as streams and other surface water bodies. **Figure 12** presents the areas (in magenta) that are within 100 feet of existing culverts. There is some overlapping information between the two plots. It also appears that the existing culvert layer only contains culverts along Route 136 for this example study area.

FEMA flood zone, proximity to water (hydrographic features such as stream or pond), and proximity to culvert are presented as individual layers as Boolean numbers. GZA proposes to use 50 feet or 100 feet for flagging due to proximity to these types of features. These layers will be presented in the GIS toolkit.

[3] Transferrable to other external sites when needed, e.g., MaineDOT's server.

SUMMARY

GZA's general modeling approach and selected preliminary results of the modeling task are summarized in this document. GZA categorized slopes using key input parameters and used SLOPE/W to quantify soil slope stability risk levels based on factors of safety numerically. The computed factor of safety results are overall conservative due to the simplified approach, assumptions, and conservative input parameters adopted. They are probably lower bound values. We understand that the objective of this study is to identify high hazard/risk slope-failure prone areas and GZA's results will serve as a basis for a high-level hazard screening tool. The presented FoS results are not intended to be adopted for direct use for any specific site. The results should be viewed as approximate accurate to the order of magnitude Other risk factors such as flood and wave impacts are adopted as qualitative flags. The web-based viewer (i.e., the toolkit) will be interactive and allow users to selectively display various results regarding slope stability and erosion for a given/selected area or point of interest. Spatial filters and other numerical filters can be incorporated in the toolkit to enhance clarity and focus for the information being presented to the users.

Table 1: GZA Classification for 1:250,000-Scale Surficial Geology Maps

Symbol	Geologic Unit	Materials	Topography	Origin	GZA Classification
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.	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.	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.	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.	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.	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.	C2

Symbol	Geologic Unit	Materials	Topography	Origin	GZA Classification
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.	C1
ms	Glaciomarine deposits (coarse-grained facies)	Sand, gravel, and minor amounts of silt.	Flat to moderately sloping. Steeper on ice-contact slopes and delta fronts. May be kettled where deposited over stagnant ice blocks.	Deposited where glacial meltwater streams and currents entered the sea. Includes glaciomarine deltas, subaqueous kames and fans (subaqueous outwash), and outwash that prograded into shallow marine waters and locally covered earlier glaciomarine silt and clay deposits.	G2
go	Glacial outwash deposits	Sand and gravel.	Flat to gently sloping. Steeper on ice-contact slopes and delta fronts. May be kettled where deposited over stagnant ice blocks.	Deposited by meltwater streams in front of the receding late Wisconsinan ice margin. Includes non-marine outwash plains, deltas, and fans.	G2
g	Ice-contact glaciofluvial deposits (exclusive of eskers)	Sand, gravel, and silt.	Flat-topped kame terraces and deltas which are locally kettled and bounded by steep sides, or hummocky terrain with numerous kames and kettles.	Deposited by meltwater streams adjacent to stagnant glacial ice.	G2

Symbol	Geologic Unit	Materials	Topography	Origin	GZA Classification
ge	Eskers	Gravel and sand. May include minor amounts of till. Portions of many eskers below the marine limit are partly or entirely buried by glaciomarine deposits.	Individual or multiple ridges. Complex eskers may have anastomosing patterns and be gradational with other types of ice-contact deposits.	Chiefly deposited by meltwater streams flowing in tunnels within or beneath the late Wisconsinan ice sheet. Map unit also includes small undifferentiated areas of units "g" and "go".	G3
sm	Stagnation moraine	Mostly till, but also includes variable percentages of undifferentiated sand and gravel.	Undulating topography with local hummocks and ridges.	Deposited during the dissipation of stagnant glacial ice.	G3
em	End moraines	Till or sand and gravel. May be very bouldery. Commonly interbedded with or overlain by glaciomarine sediments in areas that experienced late-glacial marine submergence. Only the largest end moraines and some dense clusters of smaller ones are shown here as a separate unit (em). Elsewhere, short lines mark the crests of moraine ridges, which are locally so numerous that only selected individuals are represented.	Ridges. Commonly arcuate, discontinuous, and in groups. May be multi-crested and hummocky. Size range: 1-30 m high, 5-200 m wide, and 30 m to over 10 km long.	Deposited in the marginal zone of the late Wisconsinan ice sheet, by glacial ice and/or meltwater flowing out of the ice.	G3
rm	Ribbed moraine	Till is the principal constituent, but stratified sediments are present in some of the deposits.	Numerous hummocks and short sub-parallel ridges which typically occur in lake basins and other lowland areas.	Origin uncertain. Deposited either at the margin of or beneath the late Wisconsinan ice sheet.	G3

Symbol	Geologic Unit	Materials	Topography	Origin	GZA Classification
t	Till	Heterogeneous mixture of sand, silt, clay, and stones. May include many boulders. Generally massive, but in many places contains beds and lenses of variably washed and stratified sediments.	Generally a blanket deposit that conforms to the underlying bedrock topography. Also forms drumlins and other glacially streamlined hills.	Deposited directly by glacial ice.	G3
n/a	Thin drift	Area of many bedrock outcrops and/or thin surficial deposits (generally less than 3 m thick). The type of surficial material is known or inferred.	Topography of these areas reflects the configuration of the bedrock surface and ranges from smooth undulating hills to knobby terrain and high mountains.	Commonly the result of non-deposition of glacial sediments, but the surficial materials in some coastal areas have been largely removed by marine erosion in late-glacial time.	G3
n/a	Thin drift, undifferentiated	Area of many bedrock outcrops and/or near-surface bedrock where the surficial materials have not been mapped.	Same as other thin-drift areas.	Same as other thin-drift areas.	G2
rk	Bedrock	Area of extensive bedrock outcrop, or where the bedrock has only a thin cover of soil and vegetation. Surficial deposits are essentially absent. Particularly common on the ridge crests and steeper slopes of mountainous areas.	Hilly to mountainous terrain.	Same as the thin-drift areas.	R

Notes:

1. Source table downloaded from https://www.maine.gov/dacf/mgs/pubs/mapuse/series/surf-250/surf-exp.htm.
2. G denotes granular soil; C denotes cohesive soil; and R denotes rock.
3. Numeric values 1 through 3 denote increasing density and/or shear strength.

Table 2: Summary of Material Properties for SLOPE/W Runs

	Granular Soil			**Cohesive Soil**			**Rock**
Parameter	G1	G2	G3	C1	C2	C3	R
Material Code in GIS *	101	102	103	201	202	203	300
Unit Weight (pcf)	118	125	135	120	120	120	150 - 170
Friction Angle (°)	28	32	38	0	0	0	--
Undrained Shear Strength (psf)	0	0	0	350	750	1,250	--

Note: * code (integer) assigned by GZA for identification purposes during computations. No computation performed for rock at this stage.

Table 3: Summary of SLOPE/W-calculated Factors of Safety

Row ID	Soil Type	Key Parameter	Slope (H:V)	Slope (%)	FoS (wet)	FoS (dry)
1	G1	ϕ = 28°	6:1	17%	1.85	3.07
2			4:1	25%	1.23	2.05
3			3:1	33%	0.90	1.53
4			2:1	50%	0.53	0.96
5			1.5:1	67%	0.33	0.66
6			1:1	100%	0.10	0.34
7	G2	ϕ = 32°	6:1	17%	2.28	3.69
8			4:1	25%	1.52	2.48
9			3:1	33%	1.11	1.85
10			2:1	50%	0.66	1.16
11			1.5:1	67%	0.42	0.80
12			1:1	100%	0.12	0.43
13	G3	ϕ = 38°	6:1	17%	3.00	4.60
14			4:1	25%	2.00	3.13
15			3:1	33%	1.48	2.33
16			2:1	50%	0.89	1.47
17			1.5:1	67%	0.58	1.02
18			1:1	100%	0.21	0.55
19	C1	Su = 350 psf	6:1	17%	1.09	1.09
20			4:1	25%	0.72	0.72
21			3:1	33%	0.53	0.53
22			2:1	50%	0.34	0.34
23			1.5:1	67%	0.22	0.22
24			1:1	100%	0.10	0.14
25	C2	Su = 750 psf	6:1	17%	2.34	2.33
26			4:1	25%	1.64	1.64
27			3:1	33%	1.15	1.15
28			2:1	50%	0.72	0.72
29			1.5:1	67%	0.48	0.49
30			1:1	100%	0.13	0.23
31	C3	Su = 1,250 psf	6:1	17%	3.89	3.89
32			4:1	25%	2.58	2.57
33			3:1	33%	1.92	1.91
34			2:1	50%	1.21	1.20
35			1.5:1	67%	0.83	0.82
36			1:1	100%	0.49	0.49
37	R	Rock	----- Not modeled -----			

Notes:

1. Table 3 lists the factor safety value of the "critical slip surface", i.e., the one with the lowest FoS value among all slip surfaces evaluated by the program.
2. Red indicates FoS value less than 1.0 (i.e., instability).
3. "wet" denotes the shallow groundwater table case and "dry" denotes the 10-foot deep groundwater table case (Figure 2).

Figure 1: Schematic of Road-side Slopes

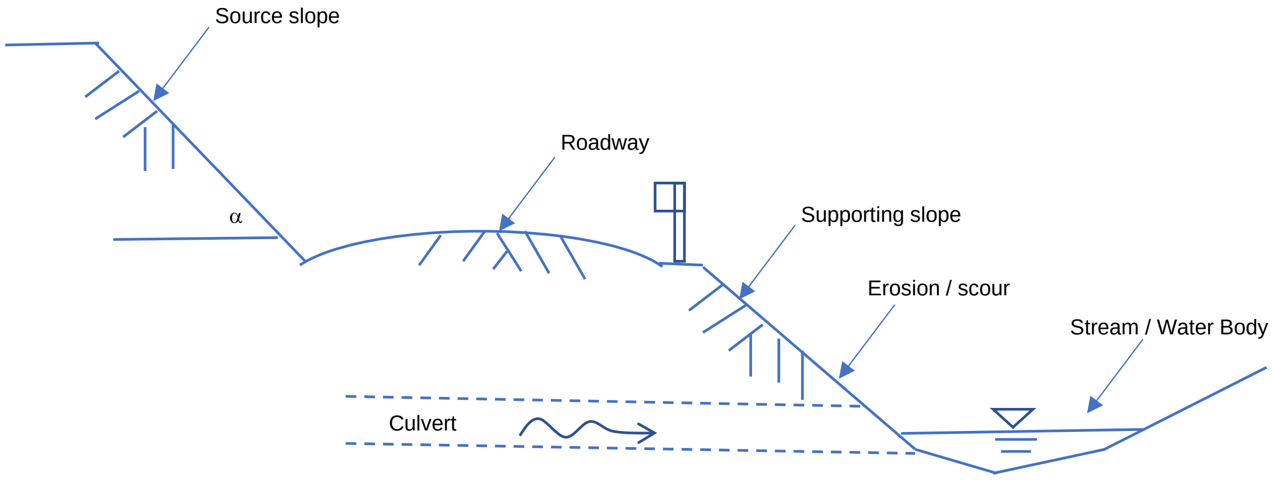


Figure 2: Schematic of SLOPE/W Model

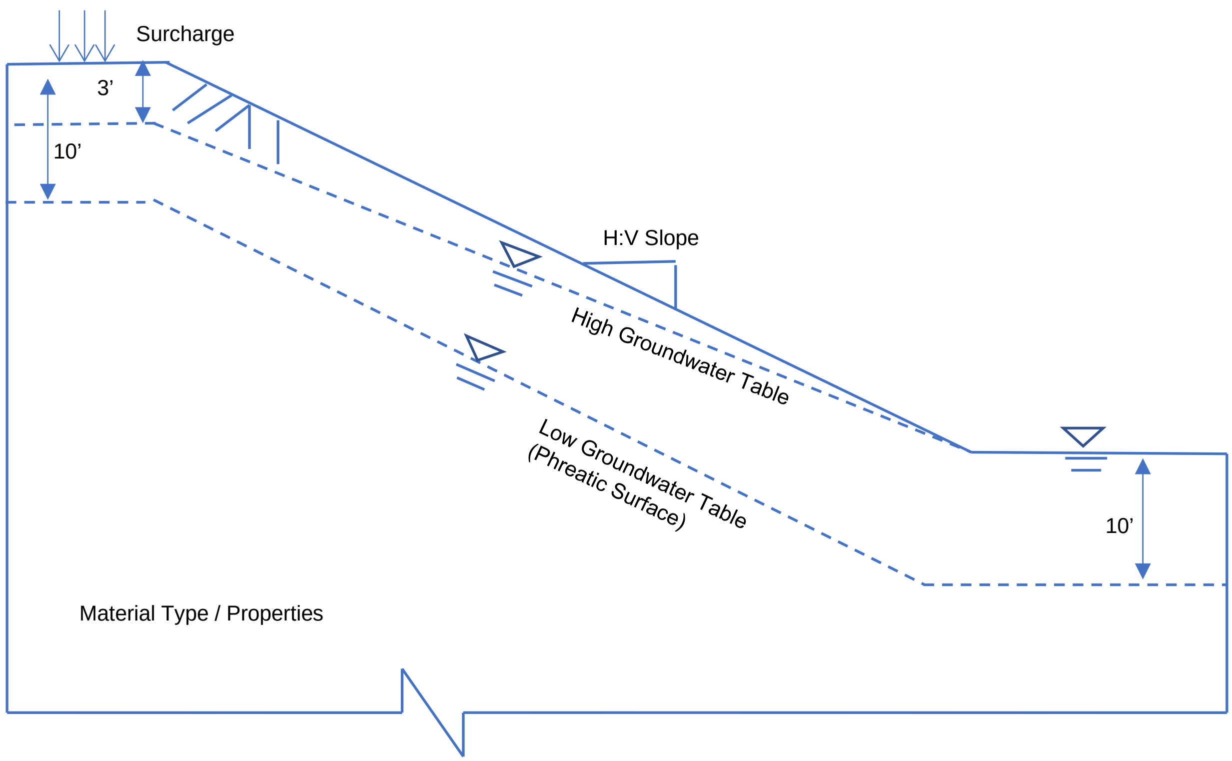
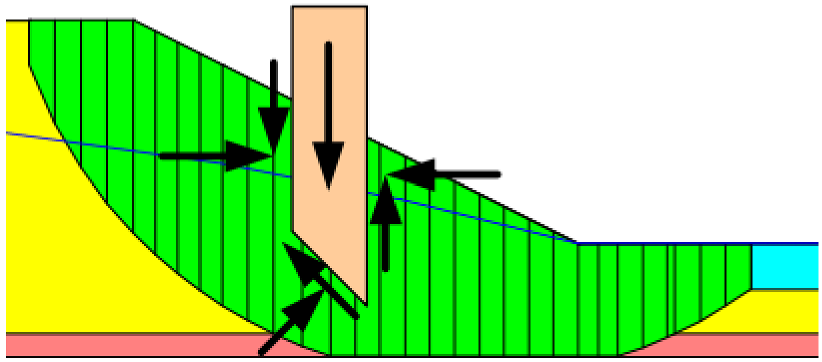
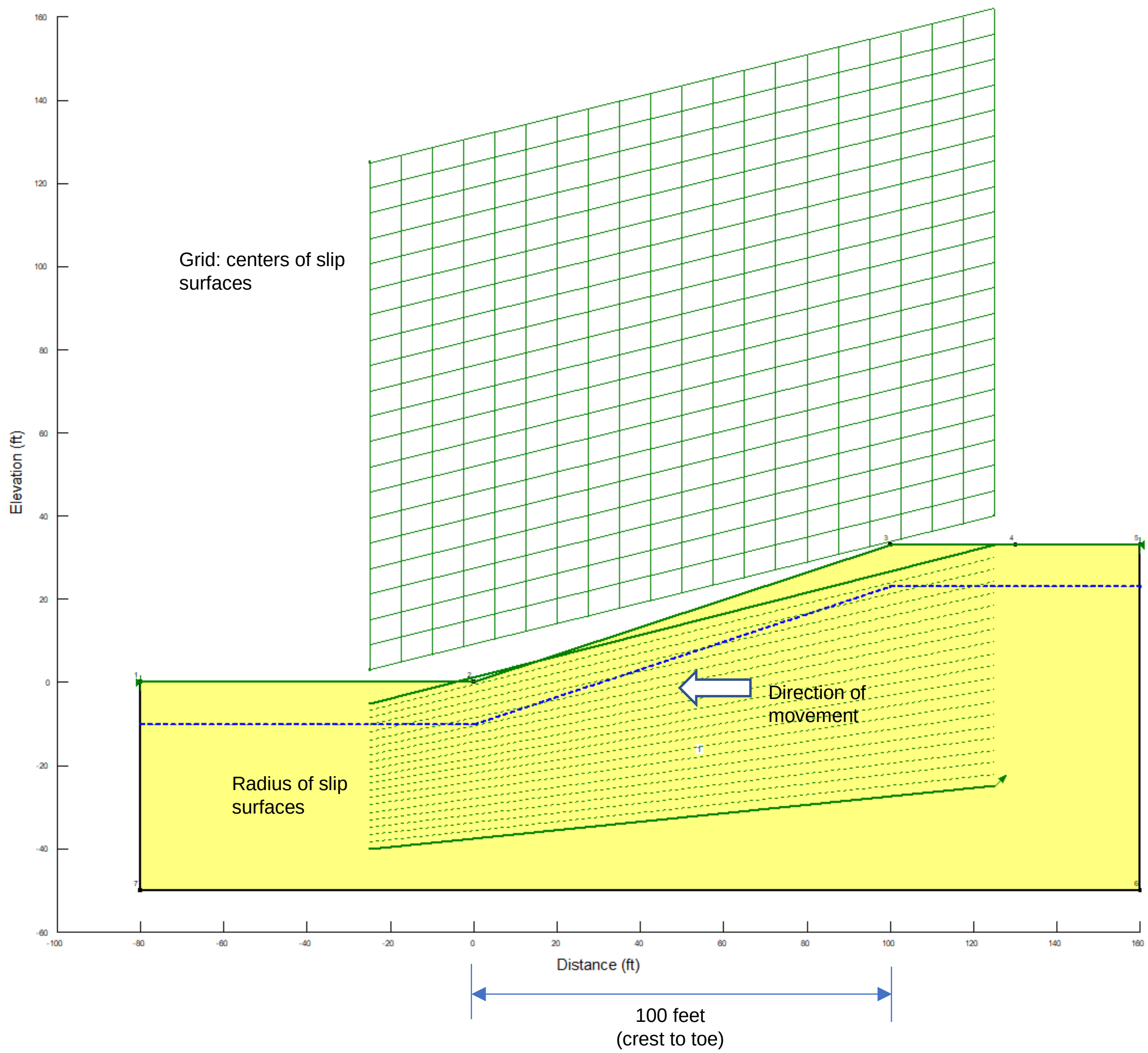


Figure 3: Schematic of Slice Discretization and Slice Forces in SLOPE/W



Source: Figure 2-1 of SLOPE/W Manual "Stability Modeling w/ SLOPE/W - An Engineering Methodology" GEO-SLOPE International, Ltd., November 2012 Edition.

Figure 4: SLOPE/W Model – Example



Note: Example shows a 3H:1V slope with one uniform material. Grid and radius method used for Grid and radius for circular slip surfaces.

Figure 5: SLOPE/W-calculated Factors of Safety – Granular Soils

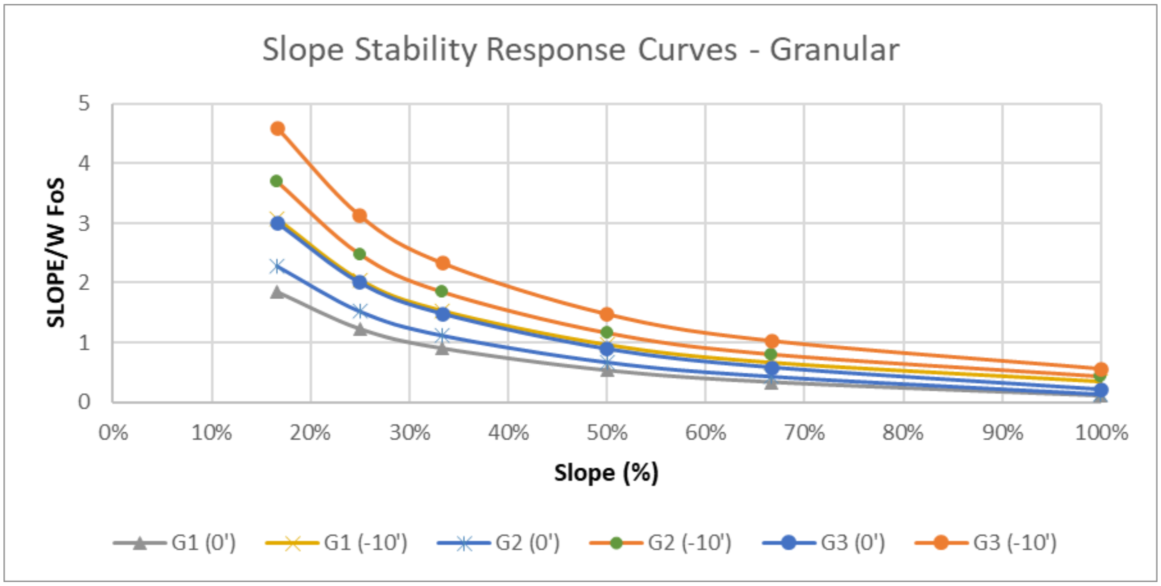


Figure 6: SLOPE/W-calculated Factors of Safety – Cohesive Soils

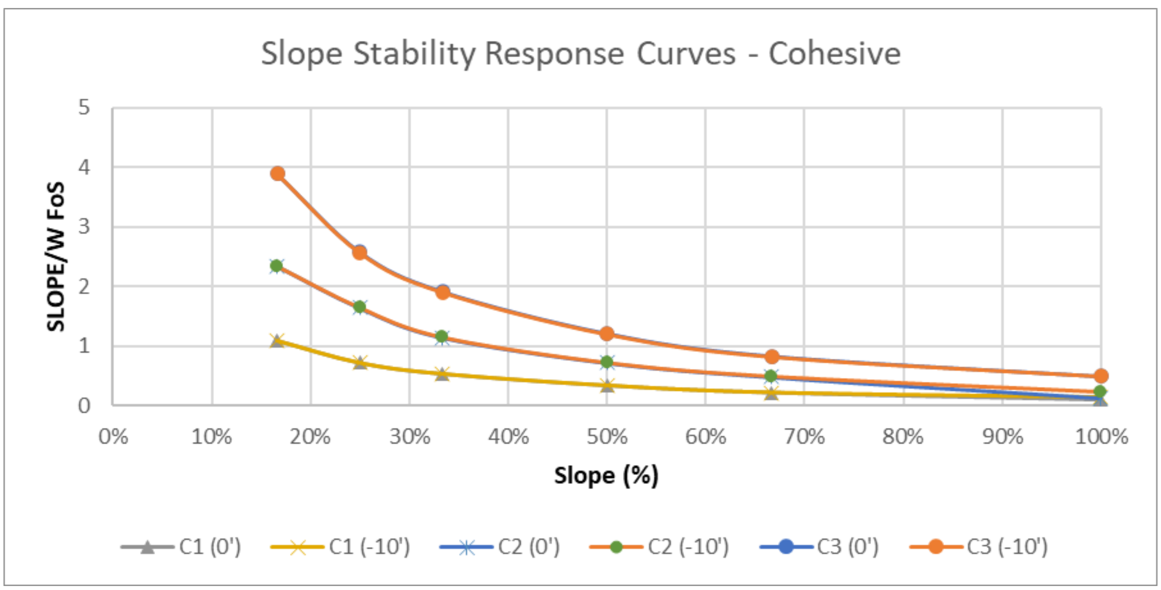
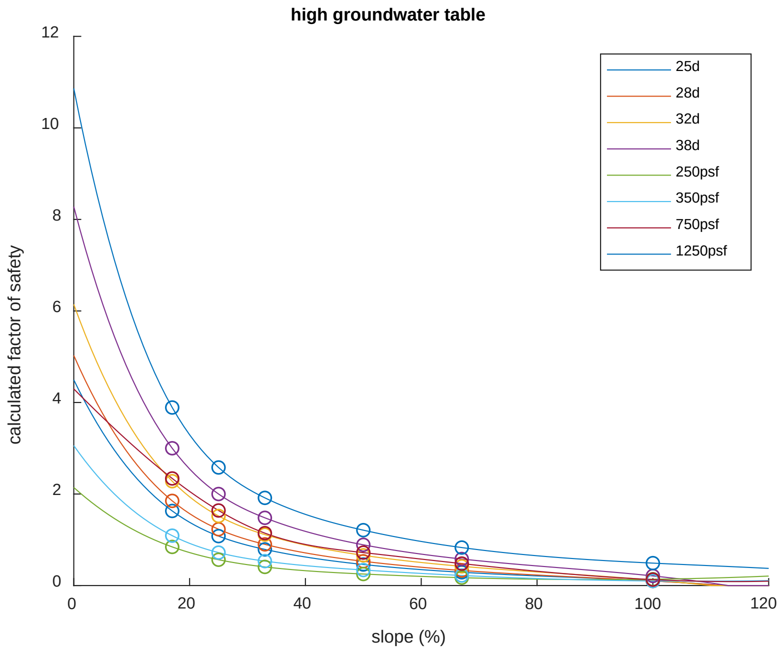
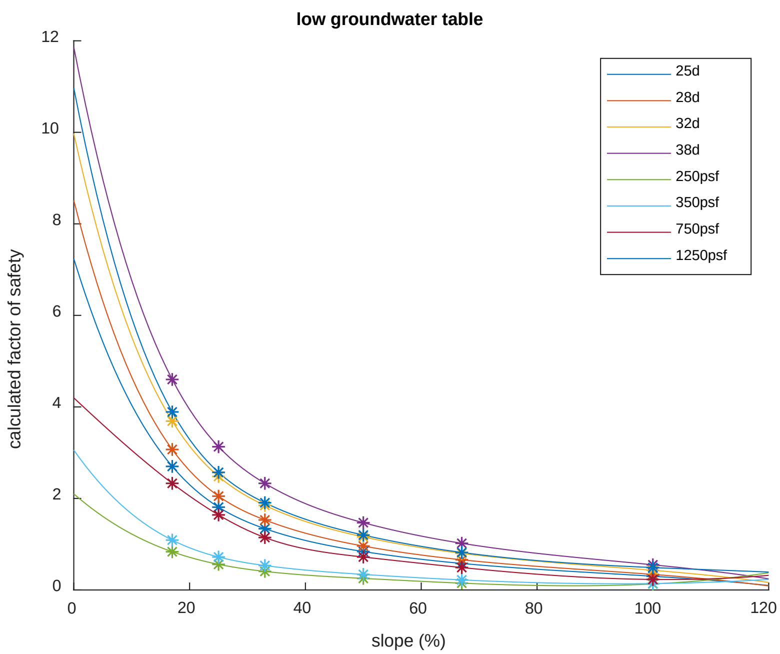


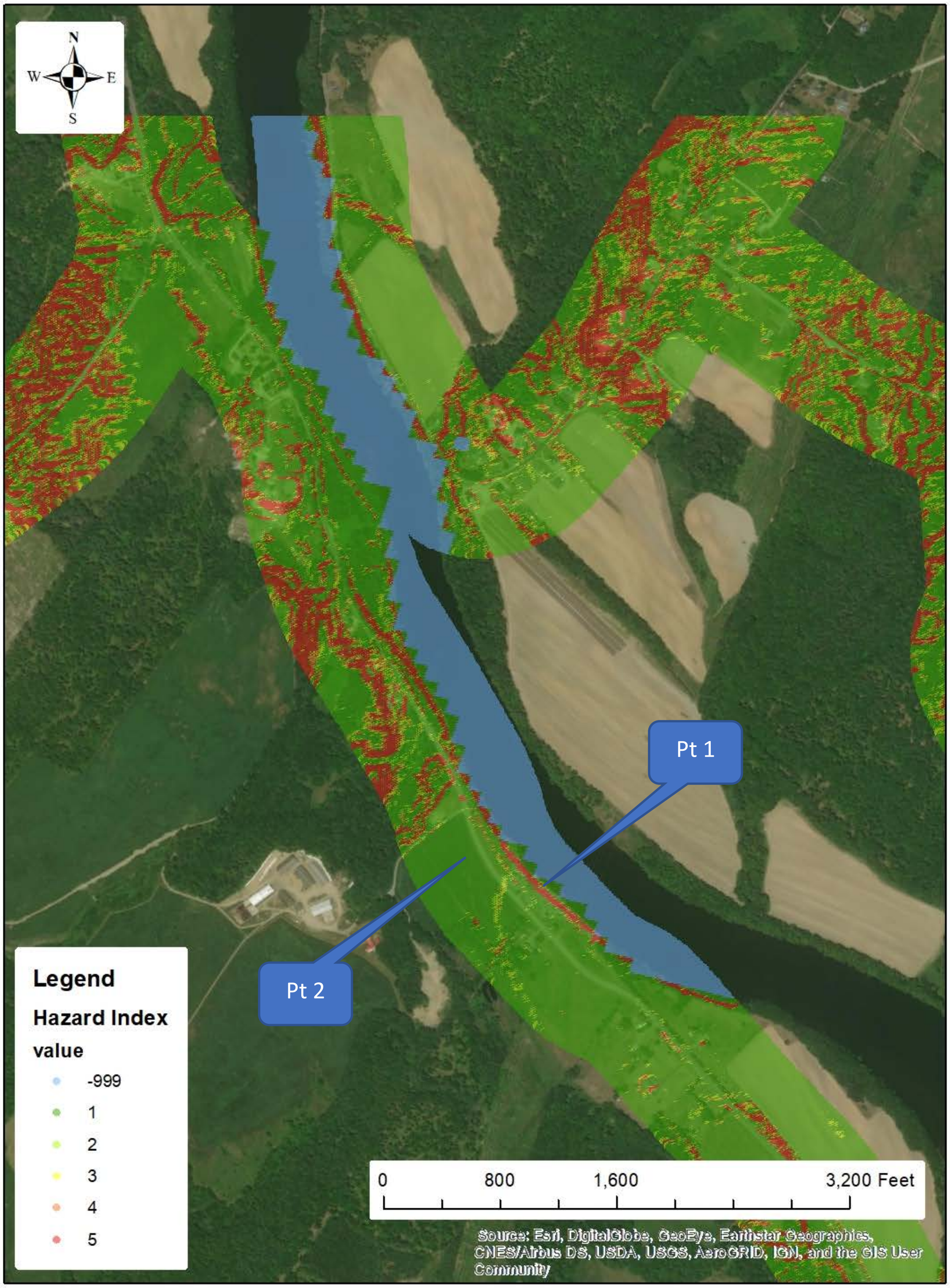
Figure 7: Interpolated FoS Values – Various Scenarios





Note: Open circle or asterisk denotes SLOPE/W calculated values for both high and low groundwater conditions; curve denotes MATLAB spline-interpolated values at 1% intervals.

Figure 8: Example Slope Stability Hazard Index Map, Route 136, Auburn, ME



Note: Index values of 4 and 5 indicate marginal stability and instability per GZA's modeling results. "-999" deontes area covered by water. Key parameters for Point locations Pt1 and Pt2 shown in Figure 9.

Figure 9: Key Parameters for Points Pt1 and Pt2

a) Pt 1

Location: 405,559.415 4,875,111.025

Field	Value
FID	201682
Shape	Point ZM
F__ID	543366
x	405551
y	4875119
z	34
lc	21
mat	201
slp	117
fos	0.1
asprel	1
slptype	0
risk	5
flag	1

b) Pt 2

Location: 405,454.398 4,875,153.032

Field	Value
FID	198390
Shape	Point ZM
F__ID	528631
x	405444
y	4875162
z	38
lc	81
mat	201
slp	3
fos	2.56
asprel	1
slptype	1
risk	1
flag	0

Figure 10: Example Close-up View of Computed Hazard Index Map

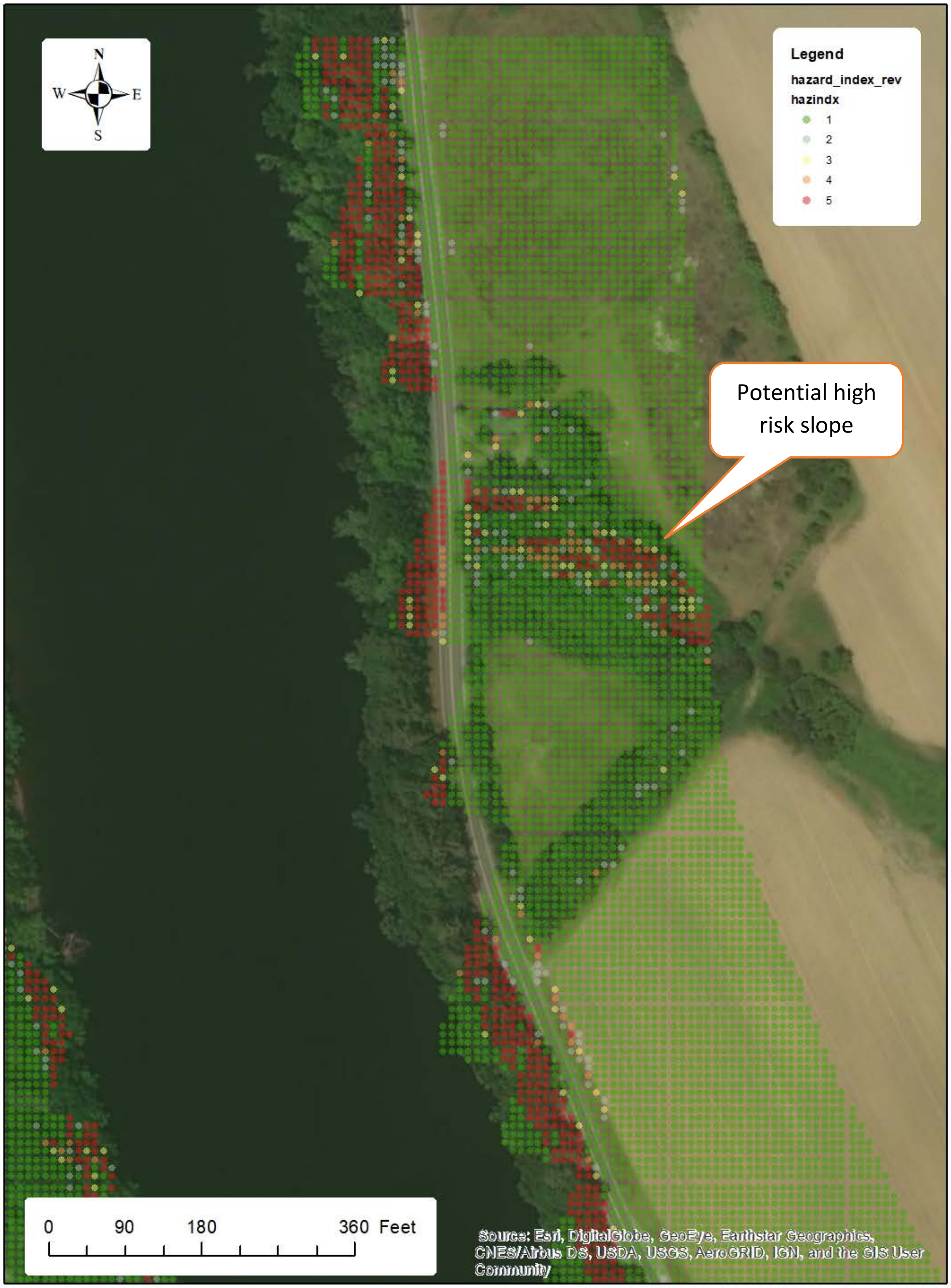


Figure 11: Example Proximity Flag to Hydrographic Features

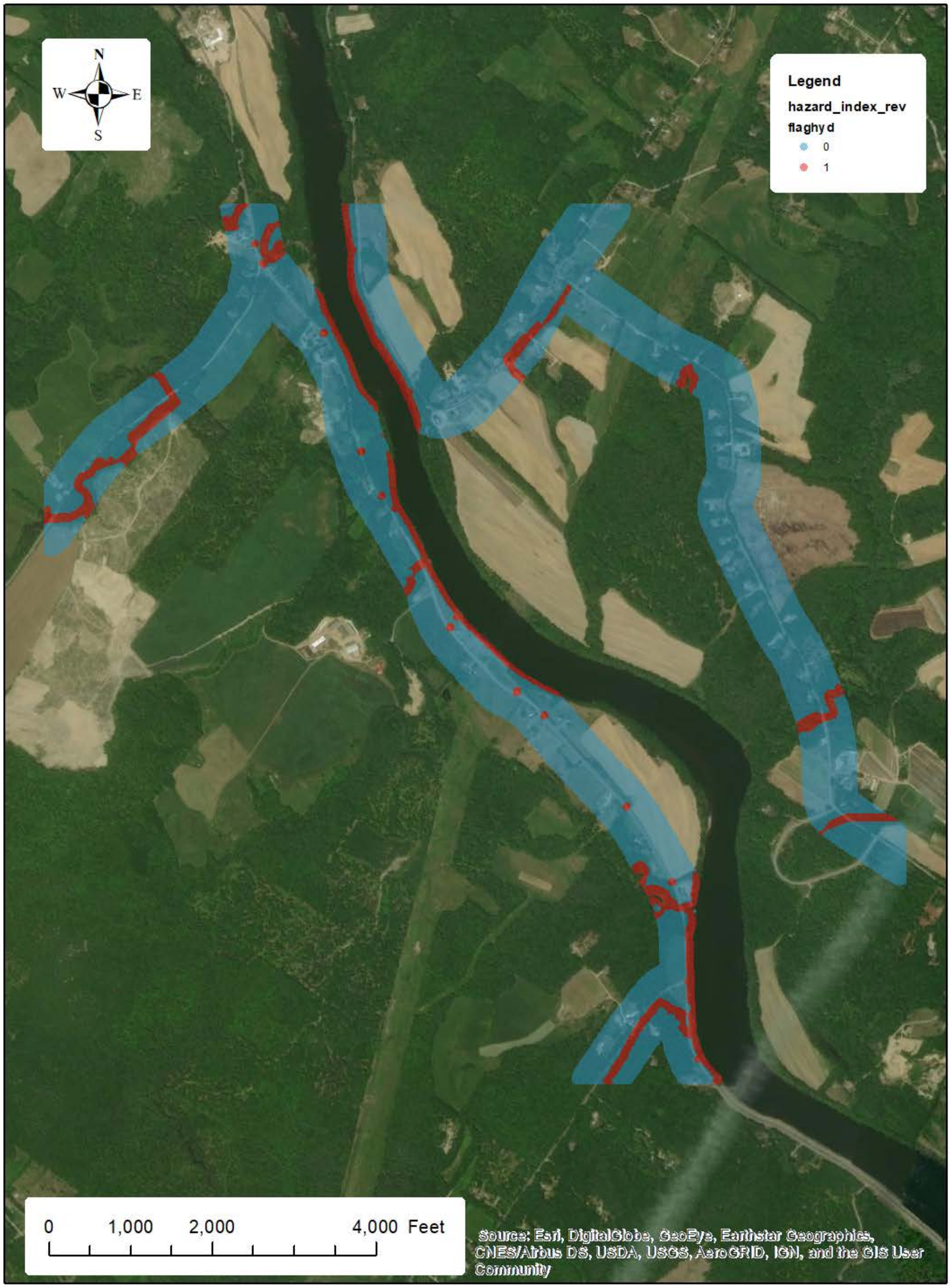


Figure 12: Example Proximity Flag to Culverts

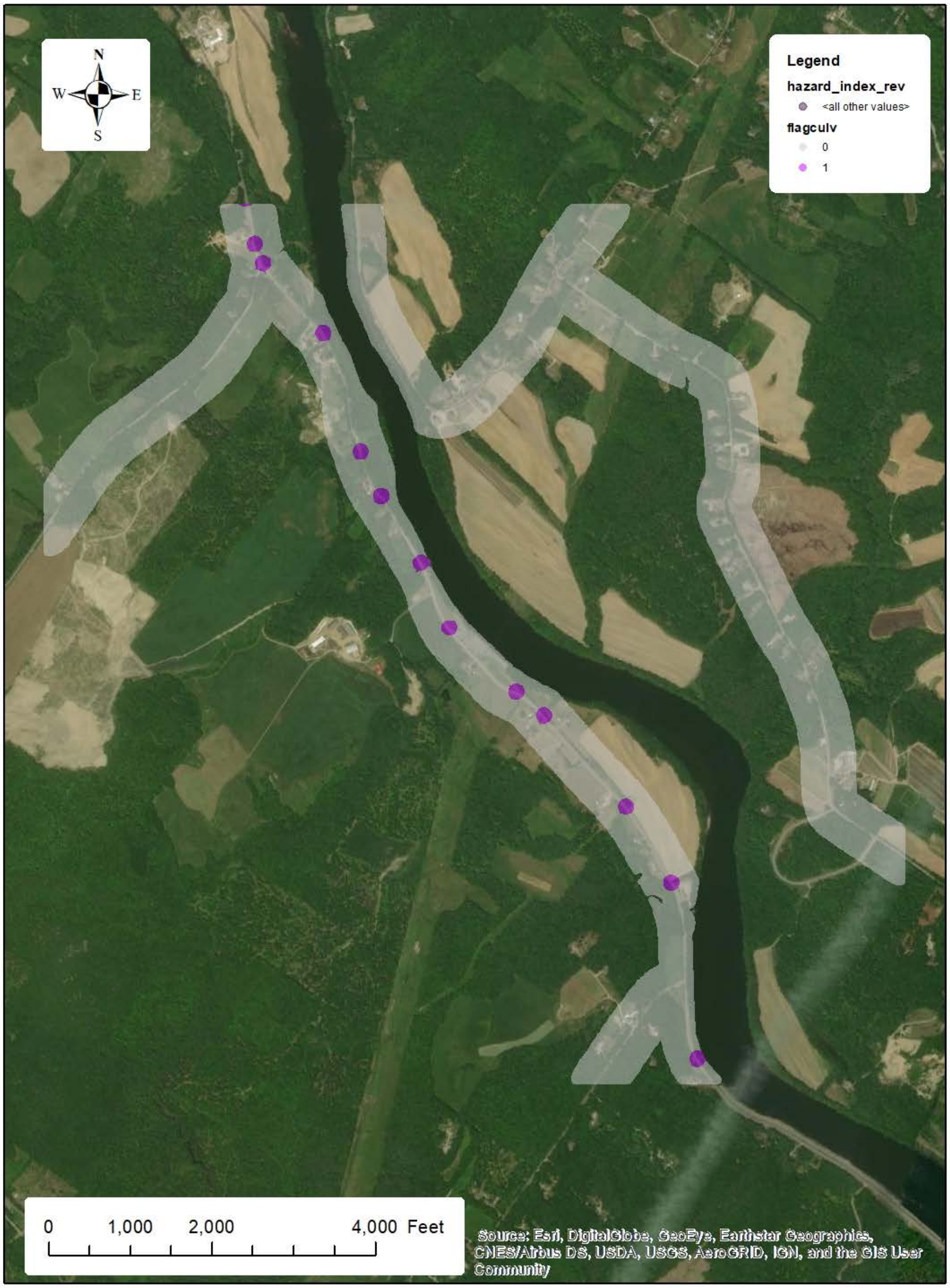
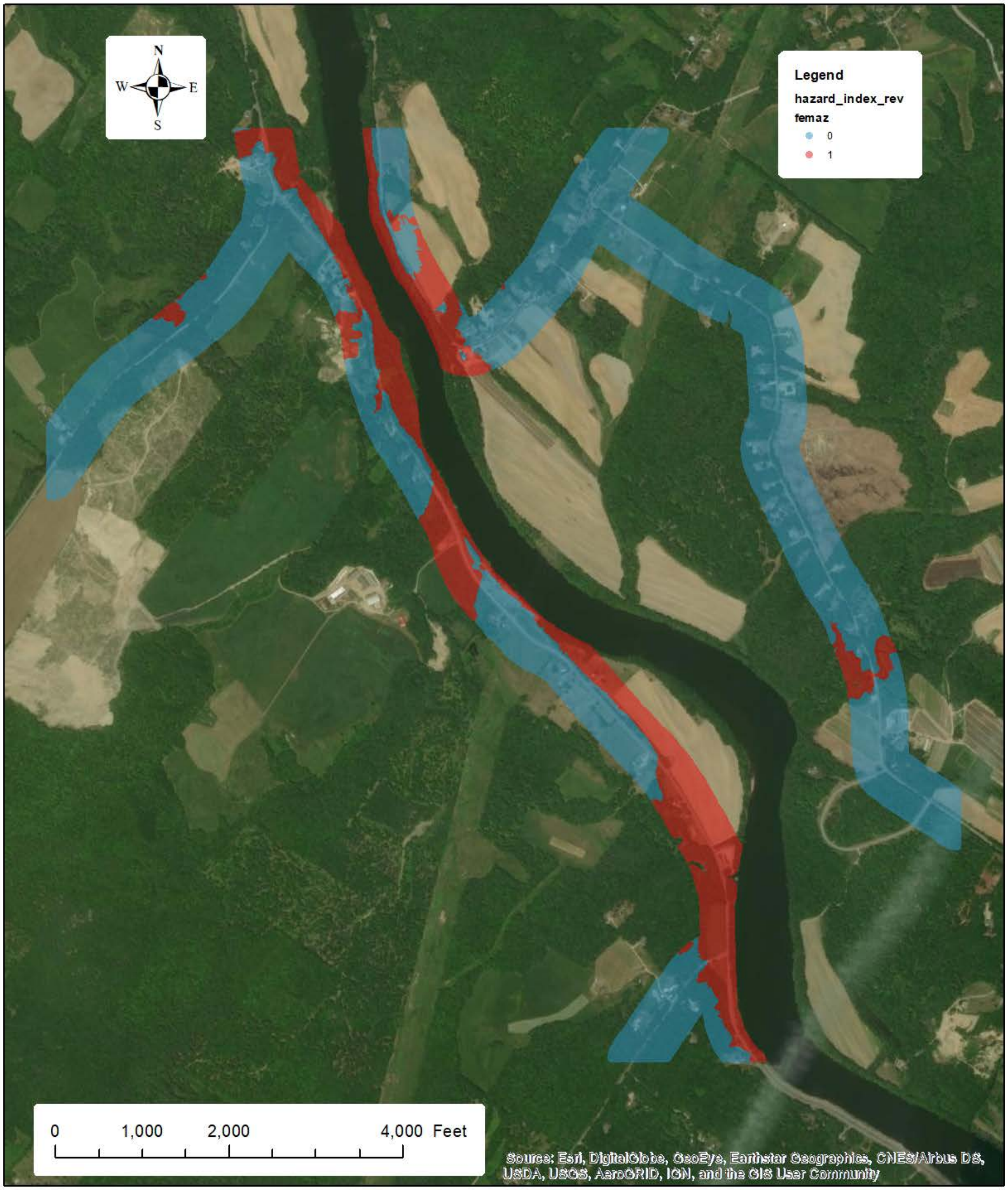


Figure 13: FEMA Special Flood Hazard Area



Note: "1" denotes Zone A/AE (1-percent annual chance floodplain); "0" denotes Zone X (outside 1-percent annual chance floodplain).

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

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

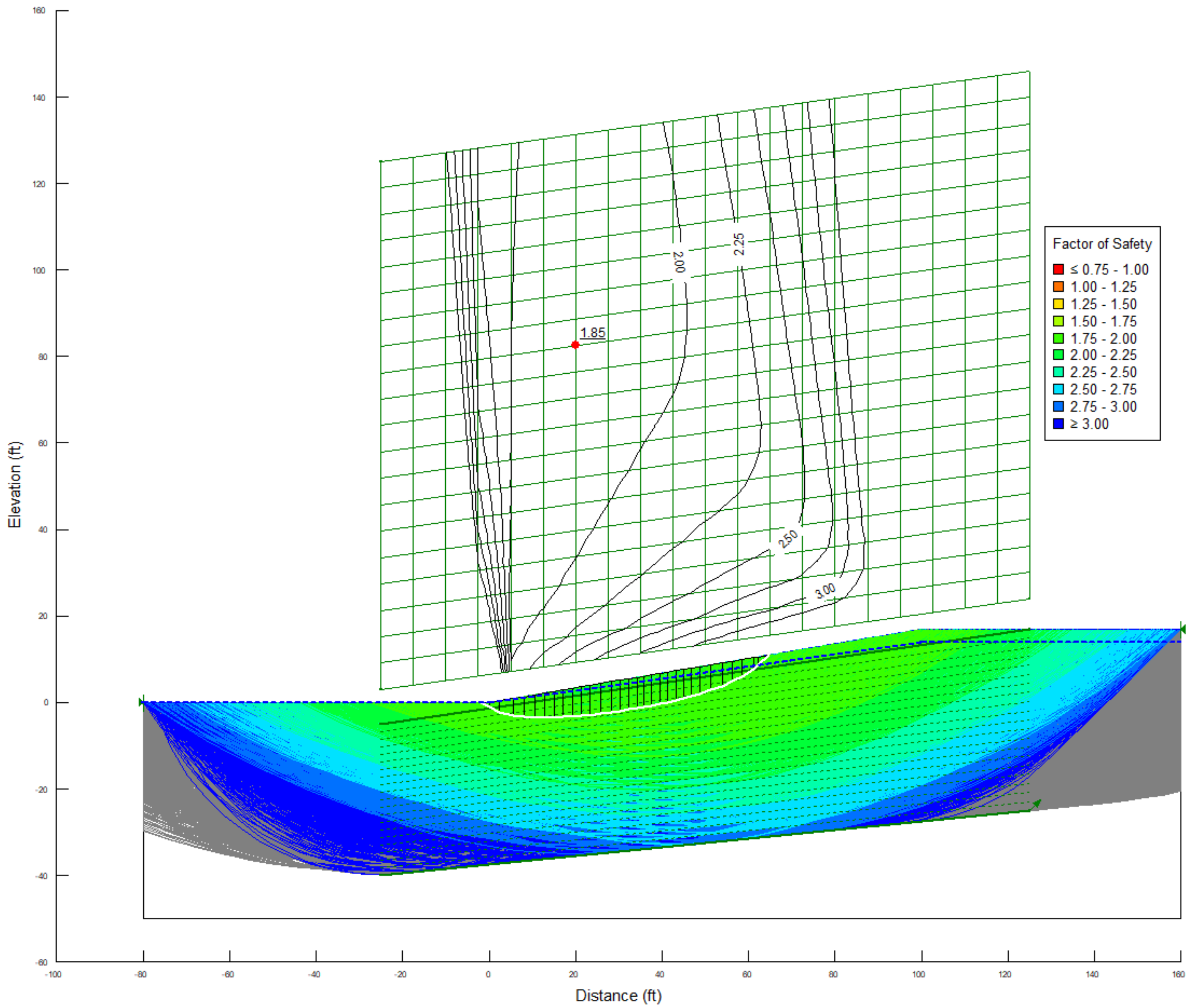
USDA – United States Department of Agriculture

USGS – Unite States Geological Survey

APPENDIX A

Selected Output Plots of SLOPE/W Simulations

Figure A-1: SLOPE/W-Calculated Factor of Safety Results – Loose Sand (G1) on 6:1 Slope



Notes (applicable to all figures in Appendix A):

1. White denotes critical slip surface.
2. Red dot denotes critical factor of safety (i.e., minimum value).
3. Blue-dash line denotes groundwater table (i.e., phreatic line).

Figure A-2: SLOPE/W-Calculated Factor of Safety Results – Soft Clay (C1) on 6:1 Slope

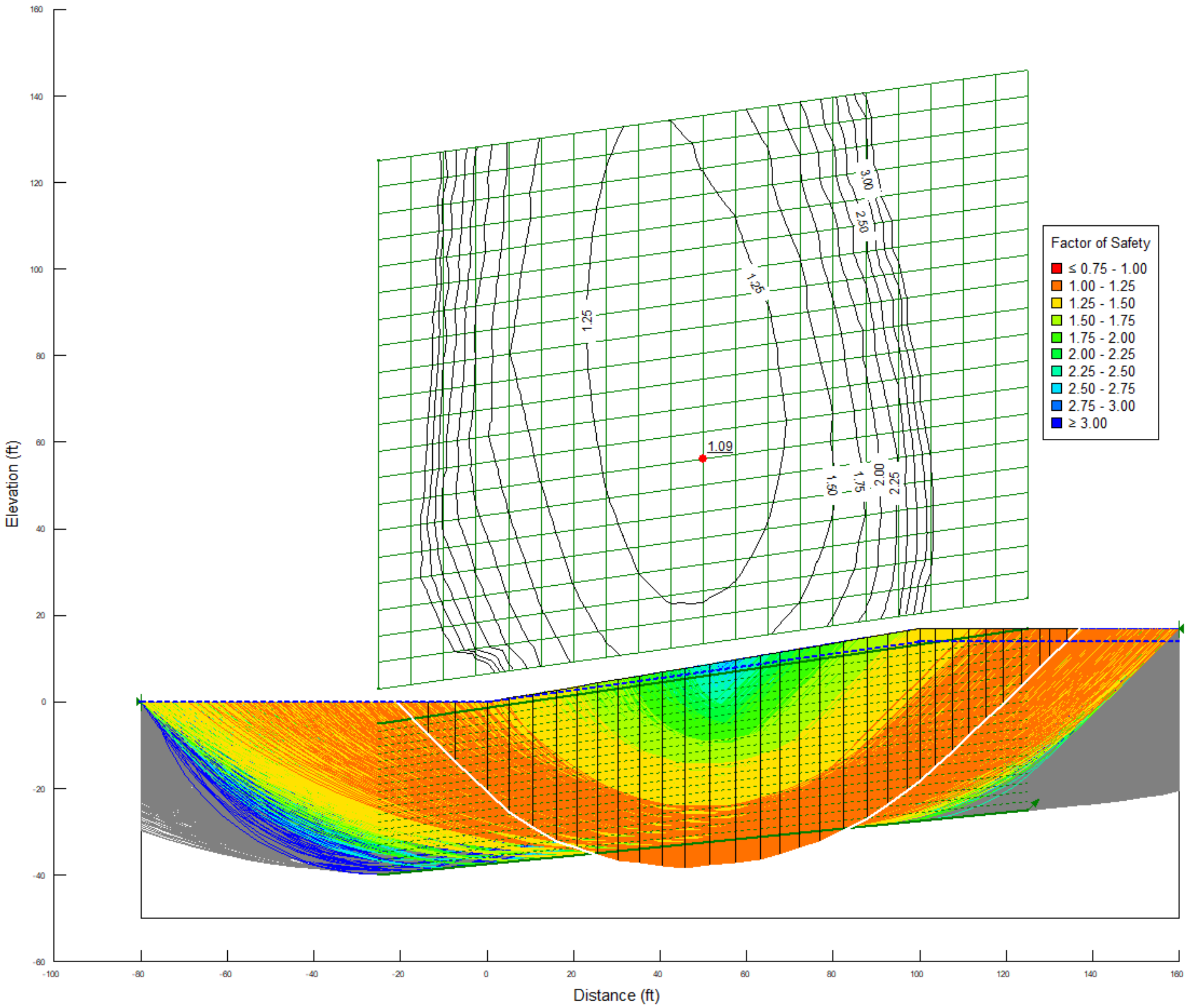


Figure A-3: SLOPE/W-Calculated Factor of Safety Results – Loose Sand (G1) on 4:1 Slope

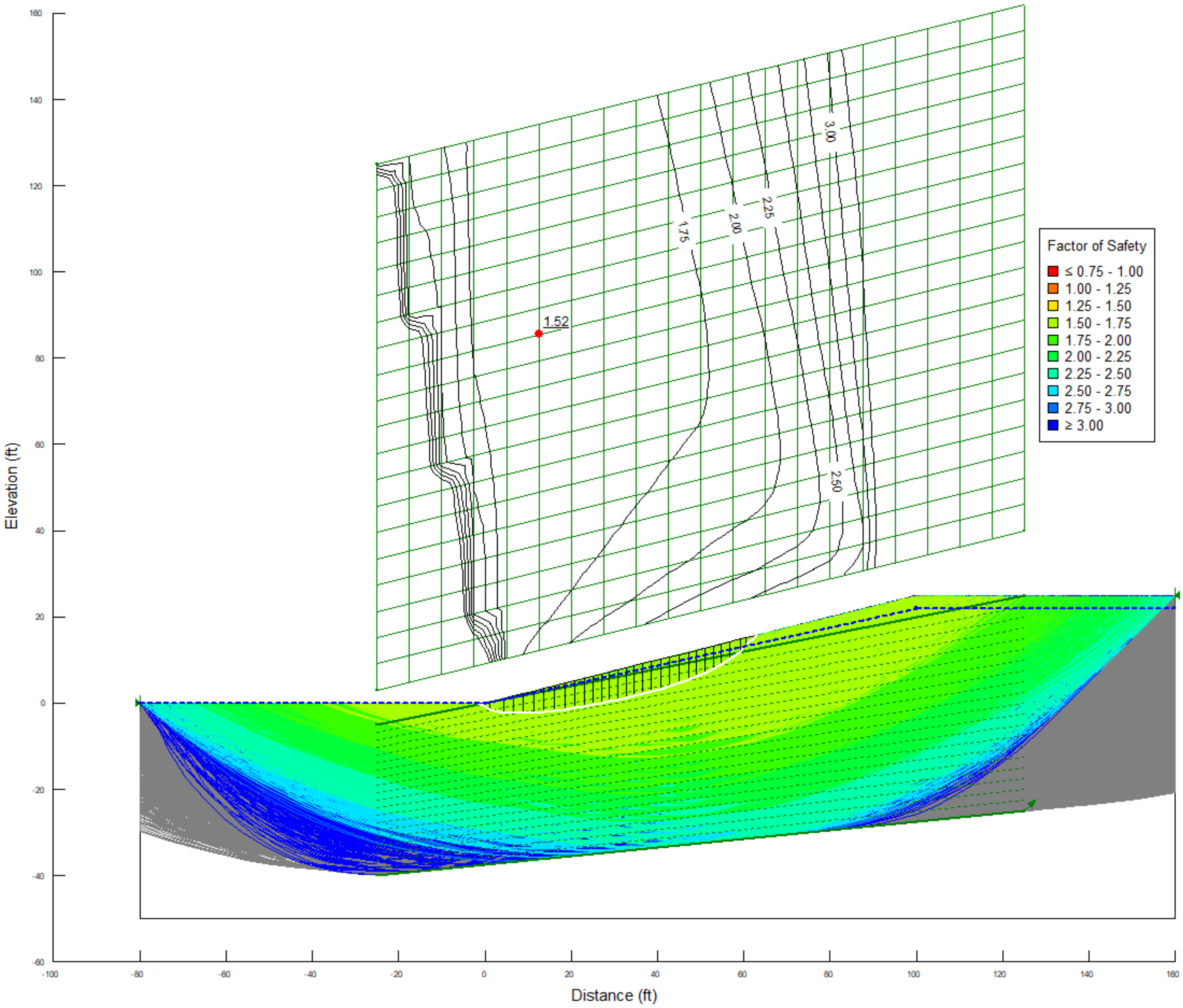


Figure A-4: SLOPE/W-Calculated Factor of Safety Results – Soft Clay (C1) on 4:1 Slope

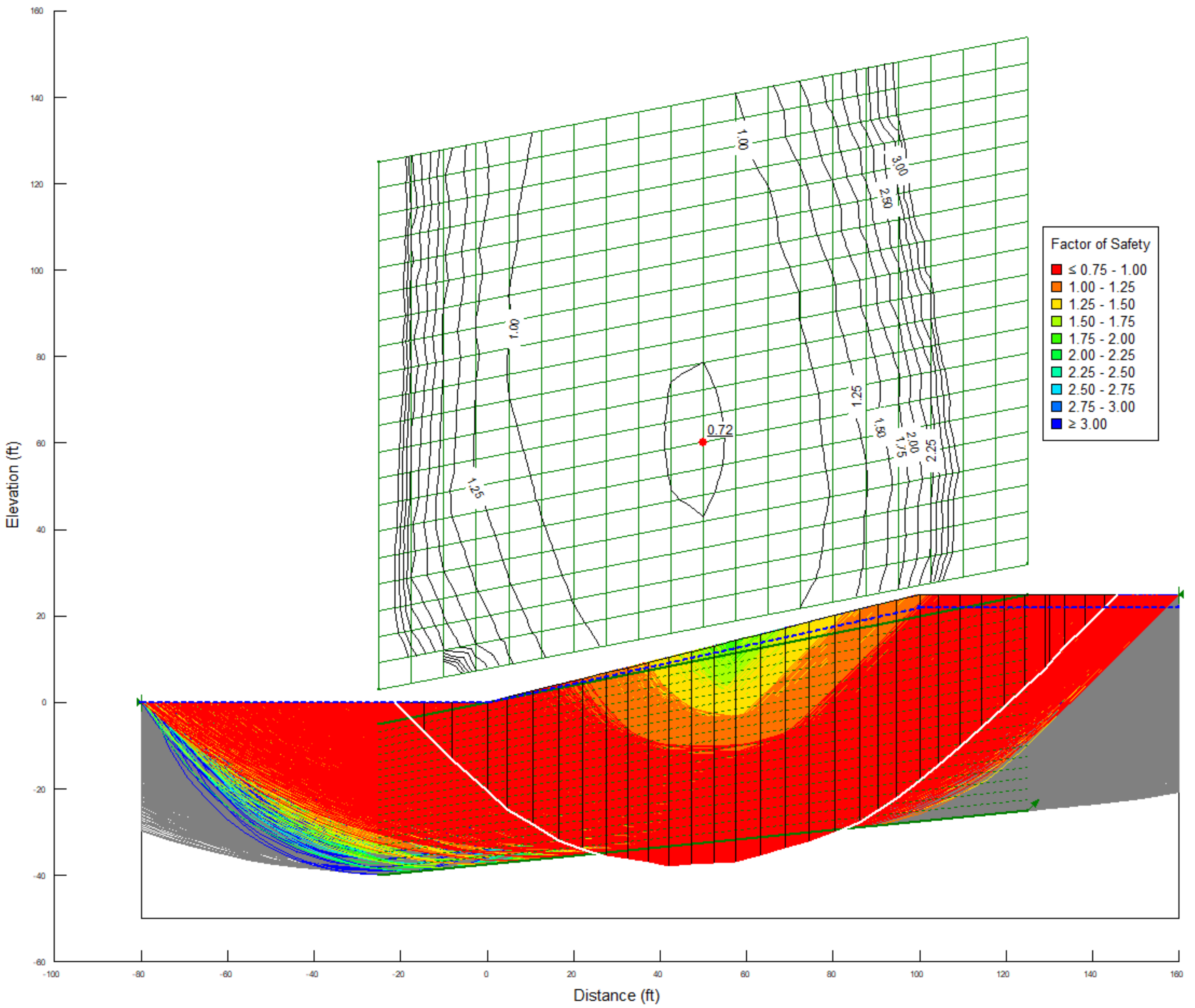


Figure A-5: SLOPE/W-Calculated Factor of Safety Results – Loose Sand (G1) on 3:1 Slope

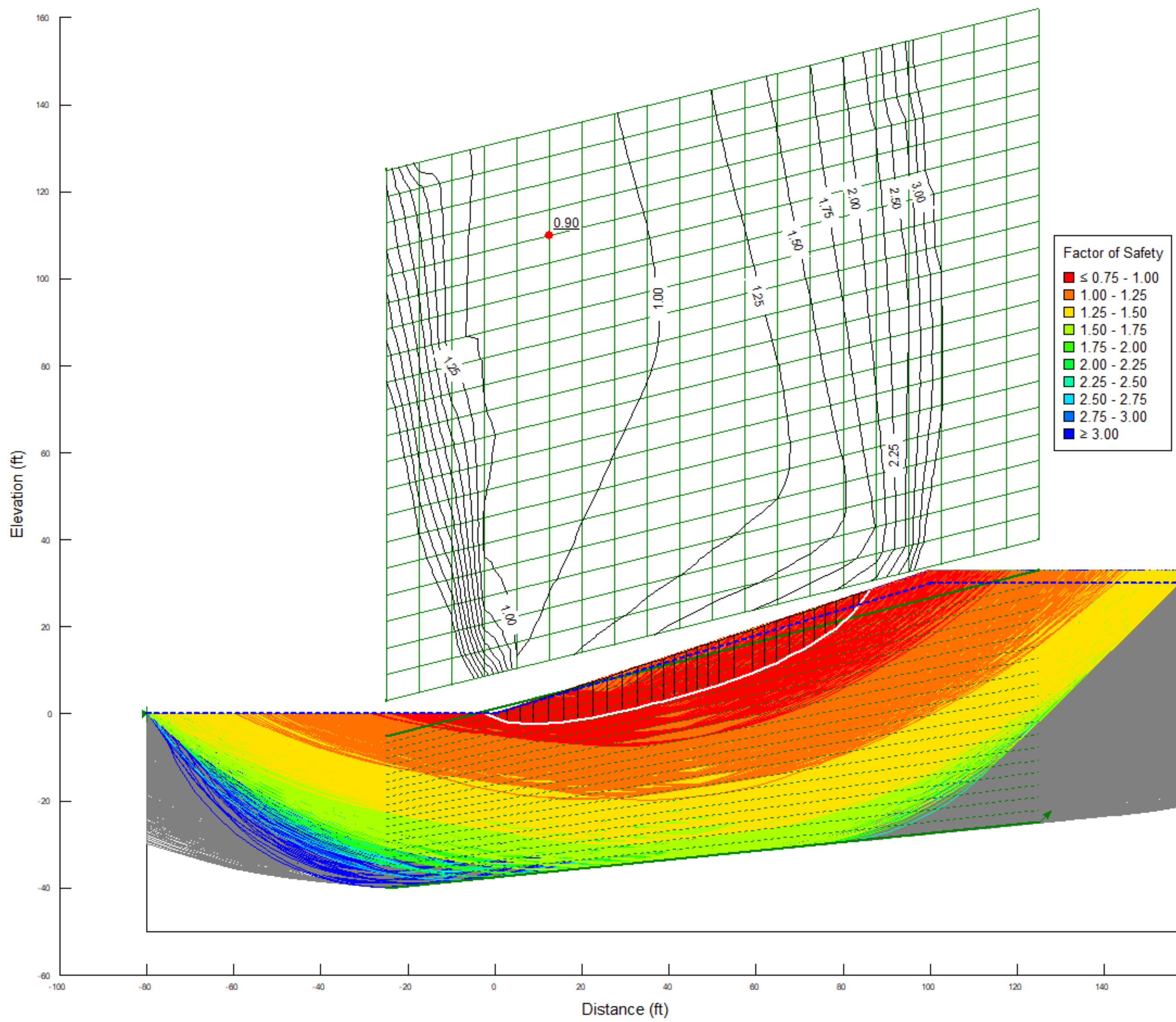


Figure A-6: SLOPE/W-Calculated Factor of Safety Results – Medium Dense Sand (G1) on 3:1 Slope

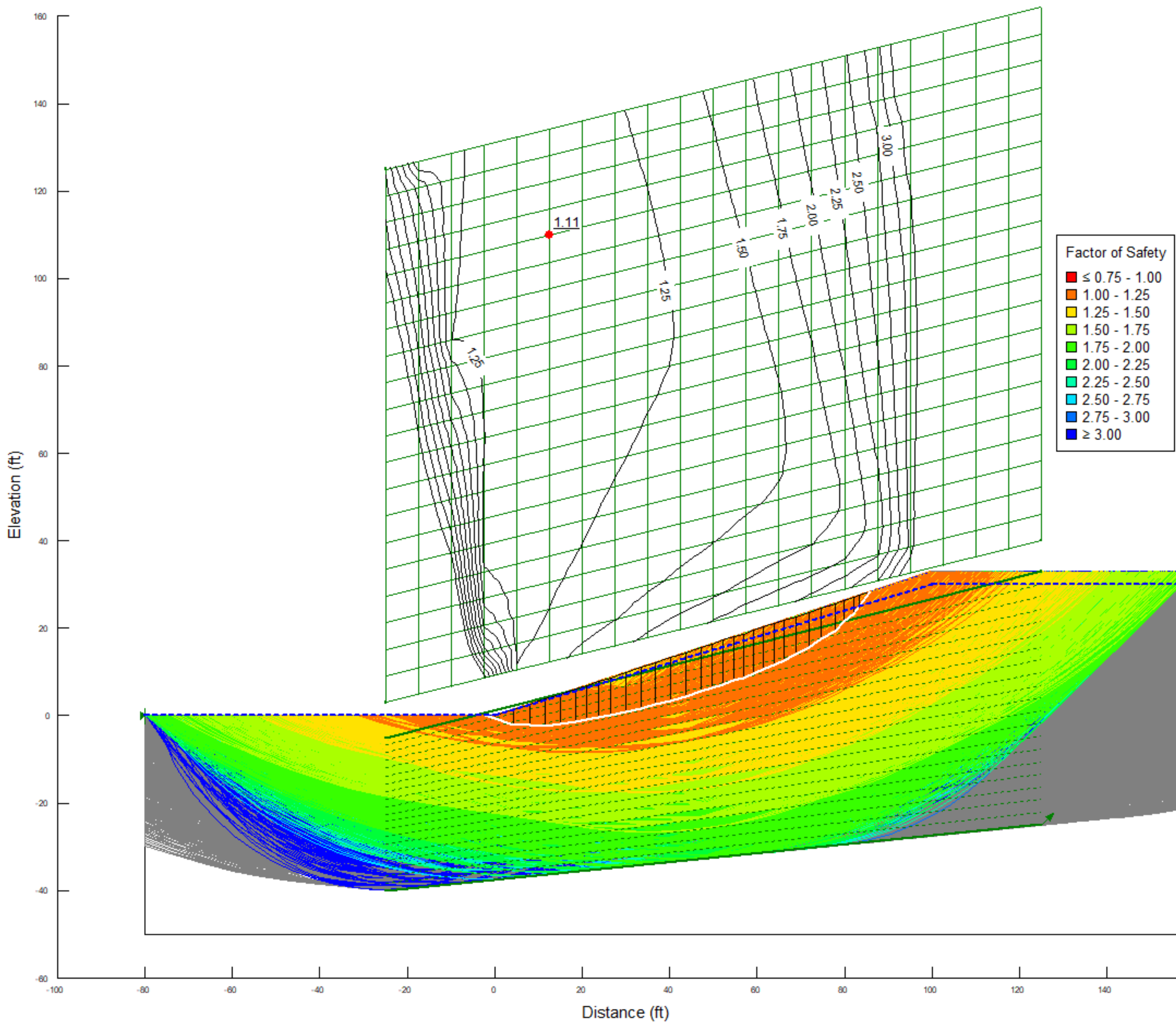


Figure A-7: SLOPE/W-Calculated Factor of Safety Results – Dense Sand (G3) on 3:1 Slope

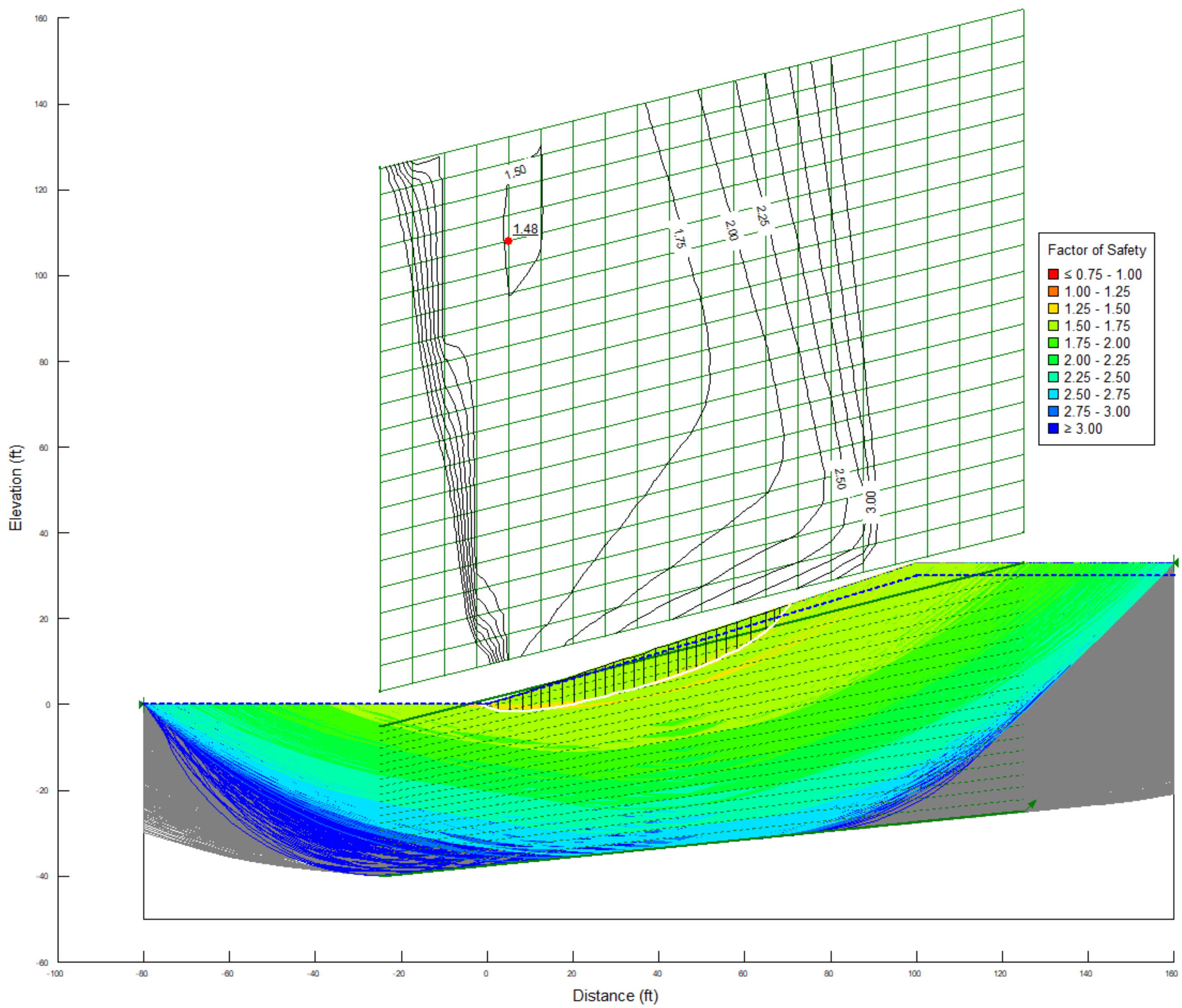


Figure A-8: SLOPE/W-Calculated Factor of Safety Results – Medium Stiff Clay (C2) on 3:1 Slope

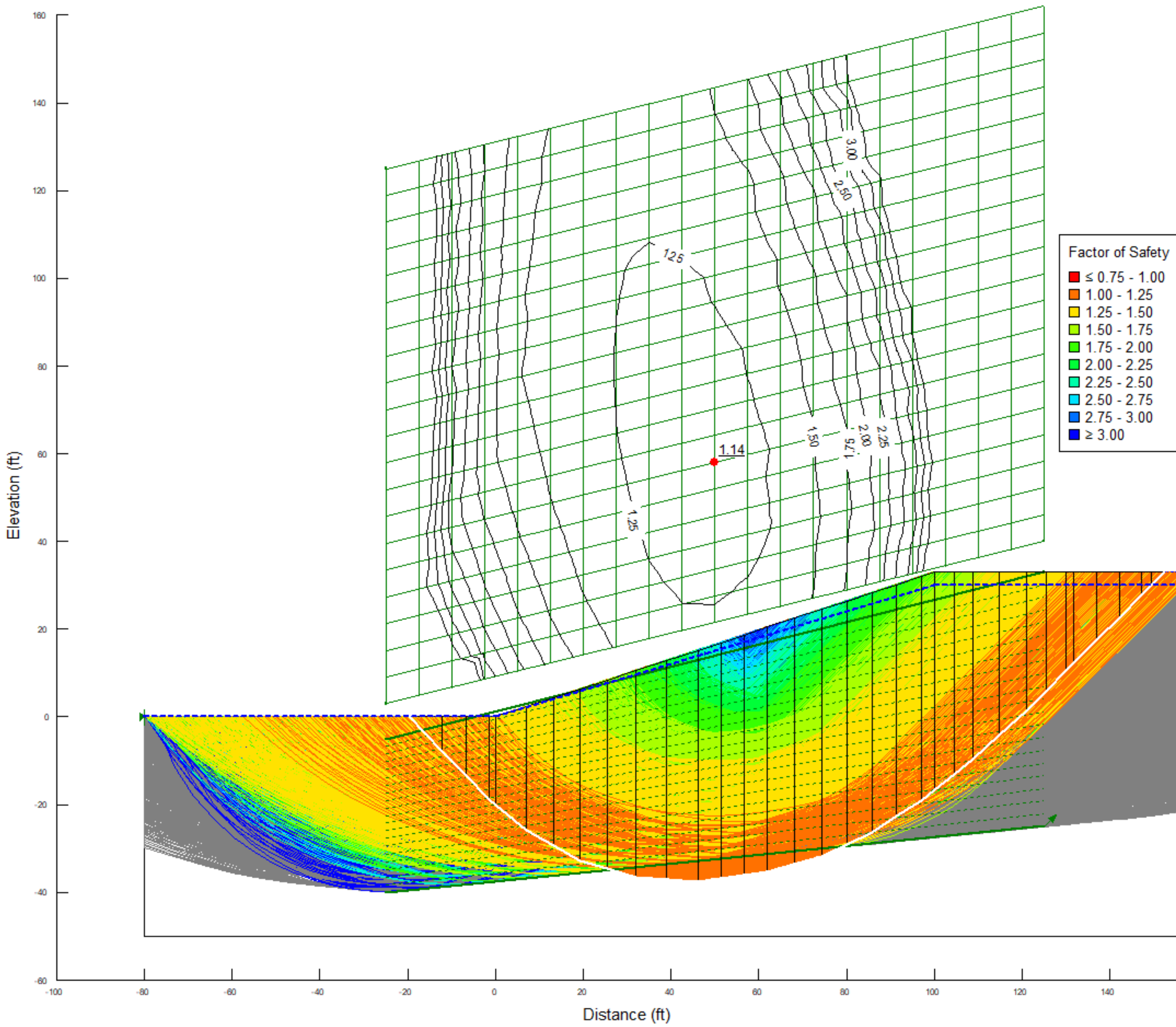


Figure A-9: SLOPE/W-Calculated Factor of Safety Results – Medium Dense Sand (G2) on 2:1 Slope

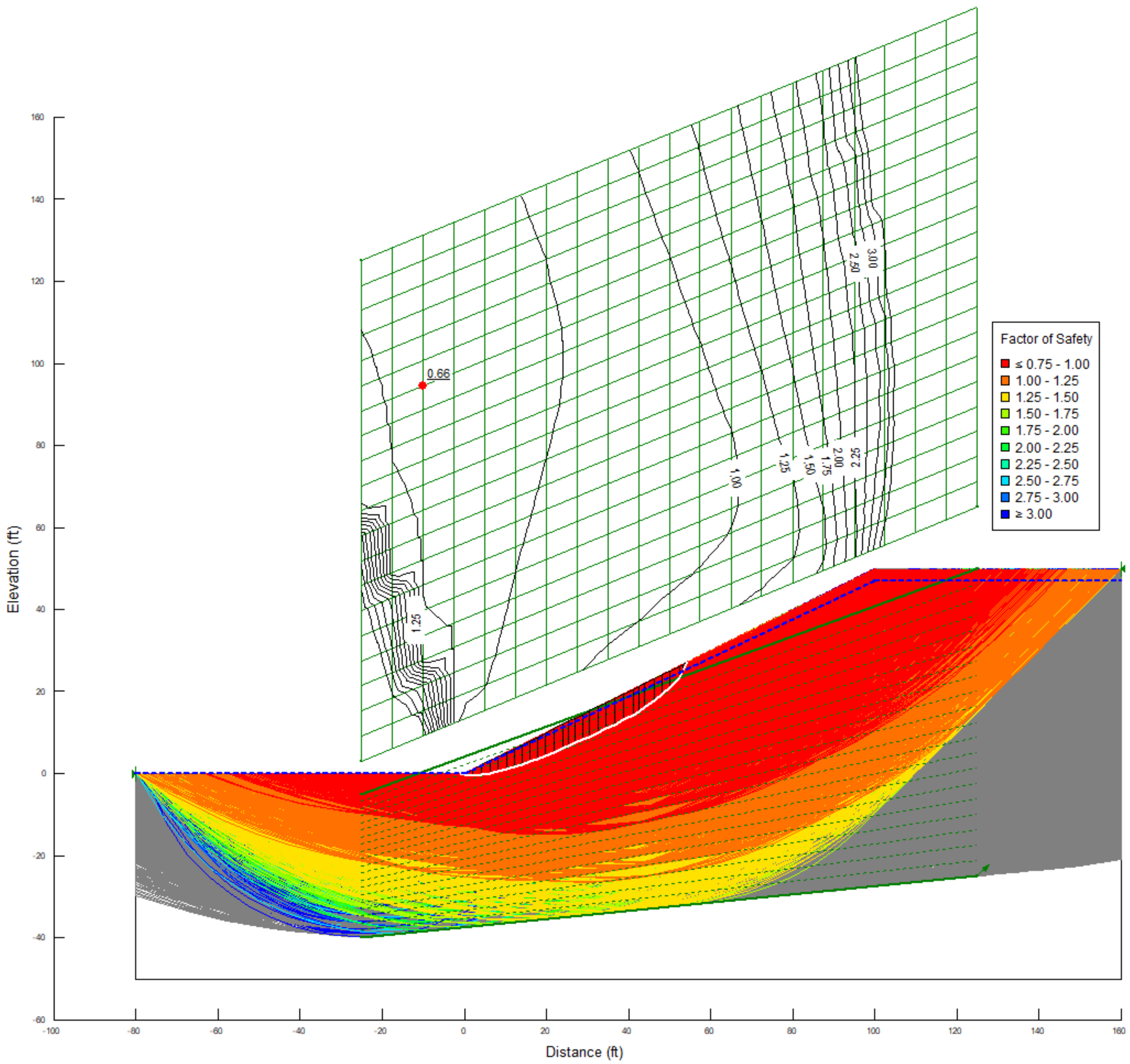


Figure A-10: SLOPE/W-Calculated Factor of Safety Results – Dense Sand (G3) on 2:1 Slope

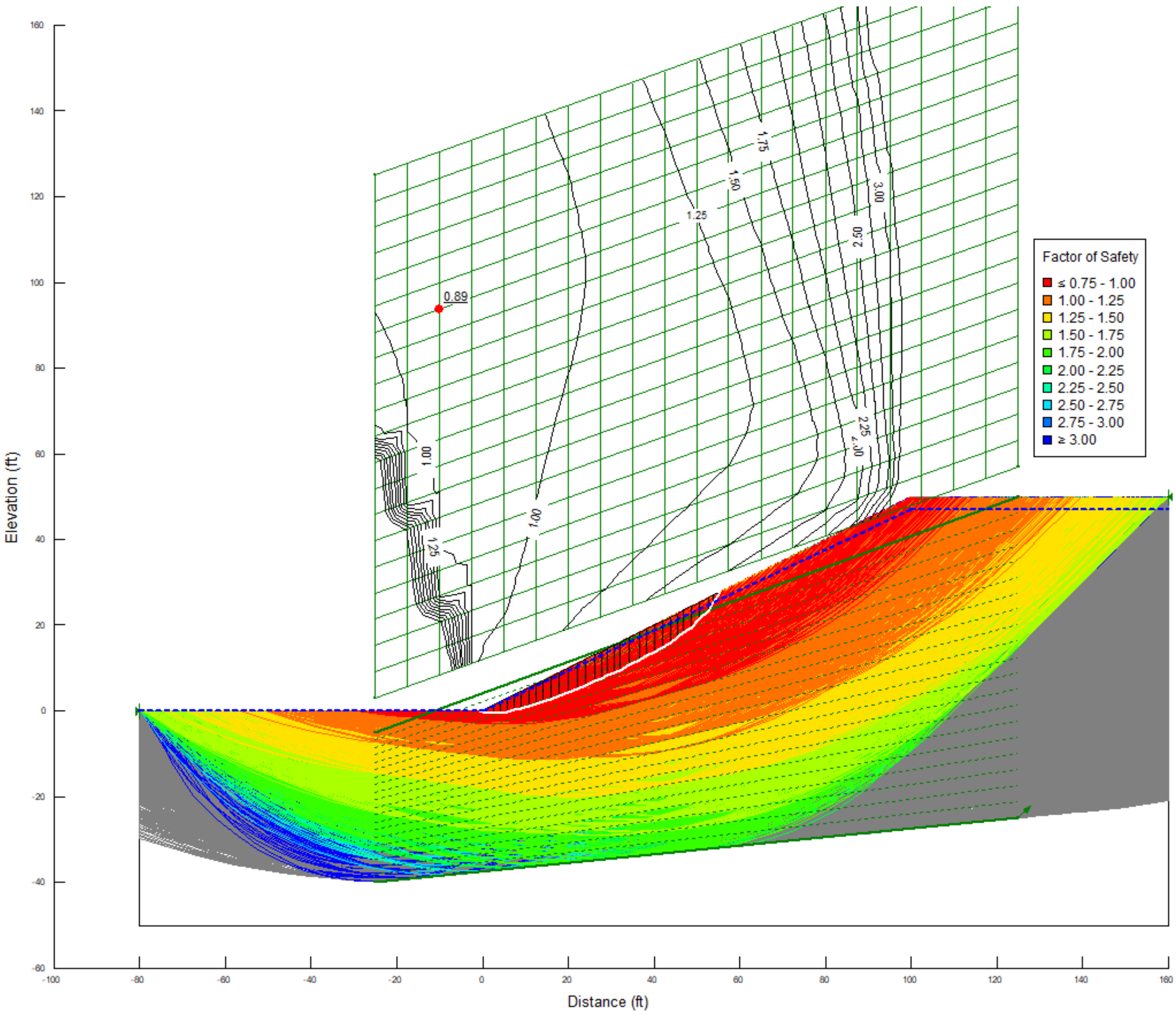


Figure A-11: SLOPE/W-Calculated Factor of Safety Results – Medium Stiff Clay (C2) on 2:1 Slope

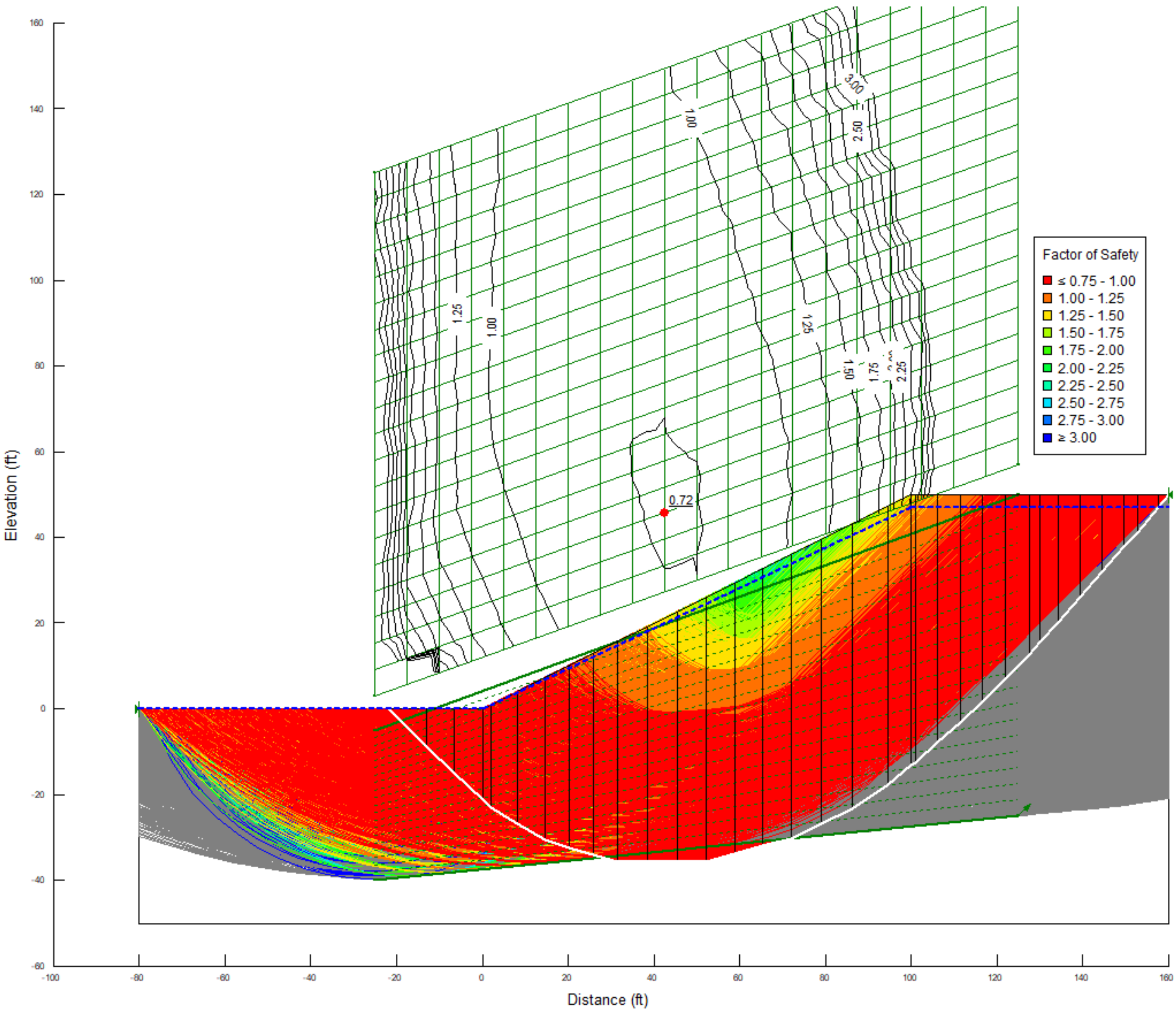


Figure A-12: SLOPE/W-Calculated Factor of Safety Results – Medium Dense Sand (G2) on 1.5:1 Slope

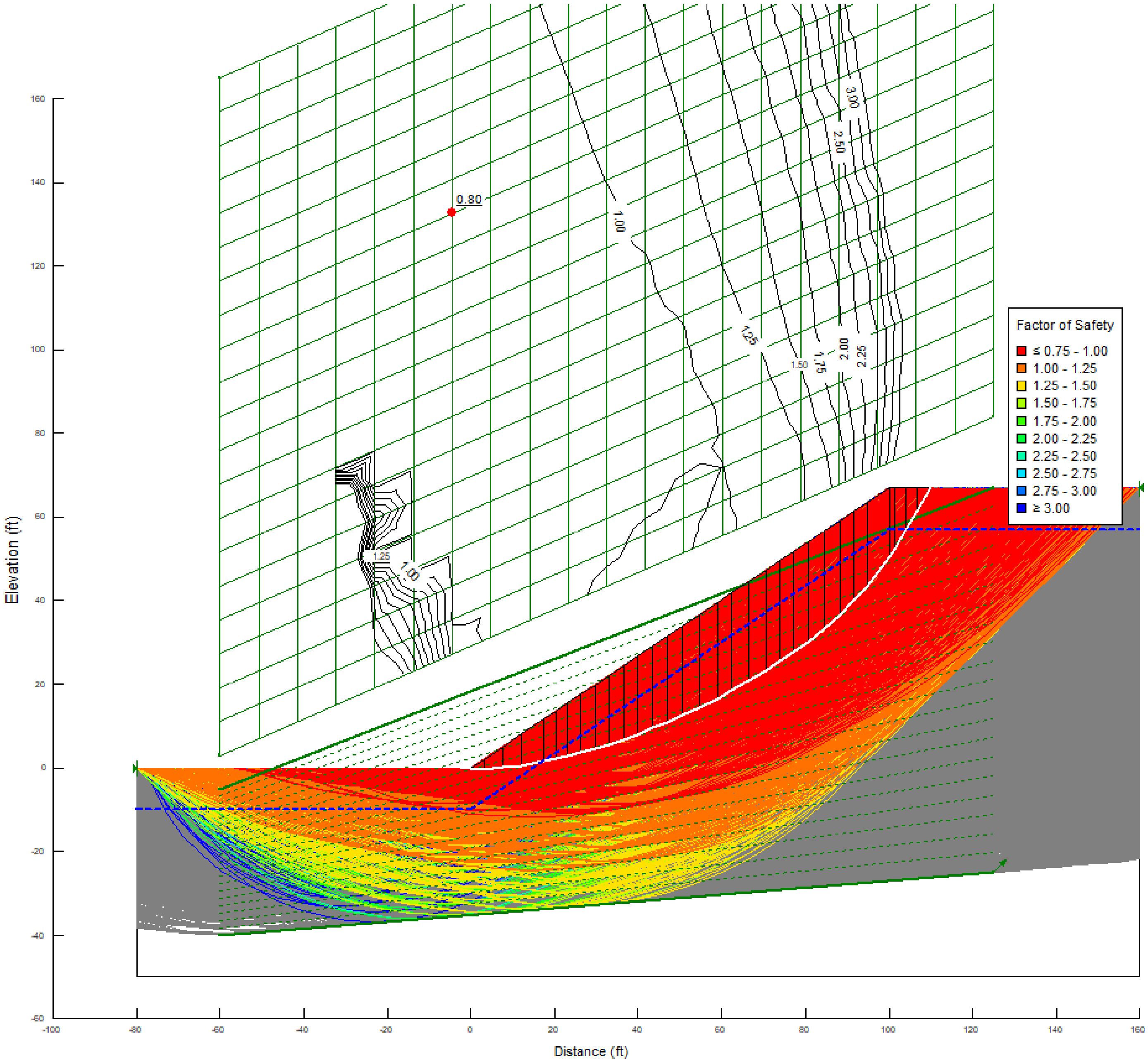


Figure A-13: SLOPE/W-Calculated Factor of Safety Results – Dense Sand (G3) on 1.5:1 Slope

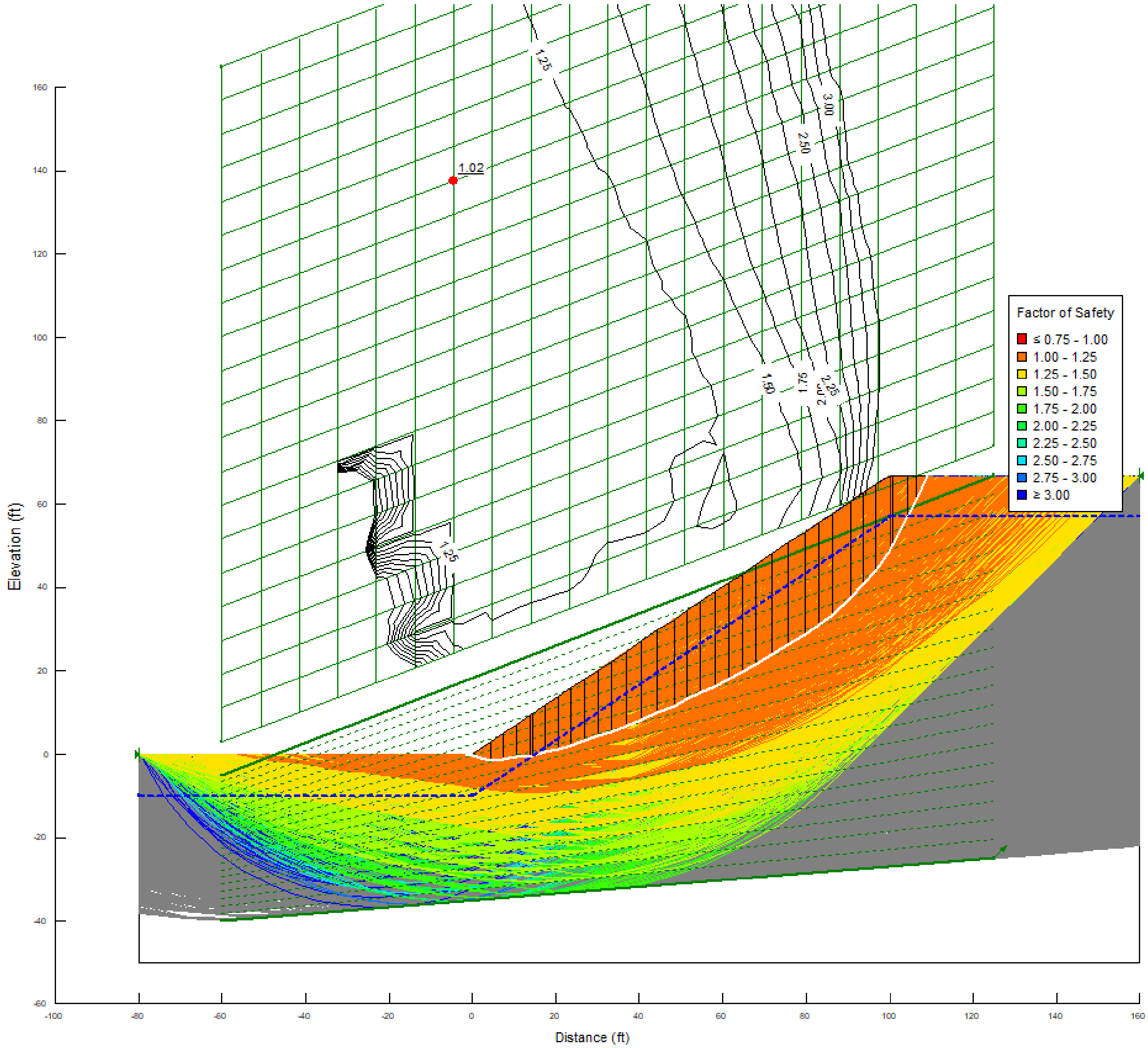


Figure A-14: SLOPE/W-Calculated Factor of Safety Results – Stiff Clay (C3) on 1:1 Slope