Spatial modeling of landslide susceptibility: An open-source web-based approach using interactive R Shiny

Dr. Peter V. Gorsevski
peterg@bgsu.edu

http://geogis.bgsu.edu/

Indirect Impact form Landslides

Grande Ronde River, WA

Impacts from Landslides

Research Article

Spatial Prediction of Landslide Hazard Using Logistic Regression and ROC Analysis

Pece V Gorsevski Paul E Gessler

Available online at www.sciencedirect.com
ScienceDirect
Geomorphology 80 (2006) 178 – 198
GEOMORPHOLOGY
www.elsevier.com/locate/geomorph

Spatially and temporally distributed modeling of landslide susceptibility

Pece V. Gorsevski [a,*], Paul E. Gessler [a], Jan Boll [b], William J. Elliot [c], Randy B. Foltz [c]

J Geograph Syst (2003) 5:223–251
DOI: 10.1007/s10109-003-0113-0
Journal of Geographical Systems

Integrating a fuzzy *k*-means classification and a Bayesian approach for spatial prediction of landslide hazard

Pece V. Gorsevski[1], Paul E. Gessler[1], Piotr Jankowski[2]

[1] Department of Forest Resources, College of Natural Resources, University of Idaho, Moscow, ID 83843, USA (e-mail: peceg@uidaho.edu, paulg@uidaho.edu)
[2] Department of Geography, San Diego State University, San Diego, CA 92182, USA (piotr@typhoon.sdsu.edu)

Received: 9 March 2003/Accepted: 11 July 2003

Abstract. A robust method for spatial prediction of landslide hazard in roaded and roadless areas of forest is described. The method is based on assigning digital terrain attributes into continuous landform classes. The

Spatial Prediction of Landslide Hazard Using Fuzzy *k*-means and Dempster-Shafer Theory

Pece V. Gorsevski
Department of Forest Resources
University of Idaho

Piotr Jankowski
Department of Geography
San Diego State University

Control and Cybernetics
vol. **35** (2006) No. 1

An heuristic approach for mapping landslide hazard by integrating fuzzy logic with analytic hierarchy process

by
Pece V. Gorsevski[1], Piotr Jankowski[2] and Paul E. Gessler[1]
[1] Department of Forest Resources, College of Natural Resources

Available online at www.sciencedirect.com
ScienceDirect
Computers, Environment and Urban Systems 32 (2008) 53–65
Computers, Environment and Urban Systems
www.elsevier.com/locate/compenvurbsys

Discerning landslide susceptibility using rough sets

Pece V. Gorsevski [a,*], Piotr Jankowski [b]
[a] School of Earth, Environment & Society, Bowling Green State University, Bowling Green, OH 43403, USA
[b] Department of Geography, San Diego State University, San Diego, CA 92182, USA

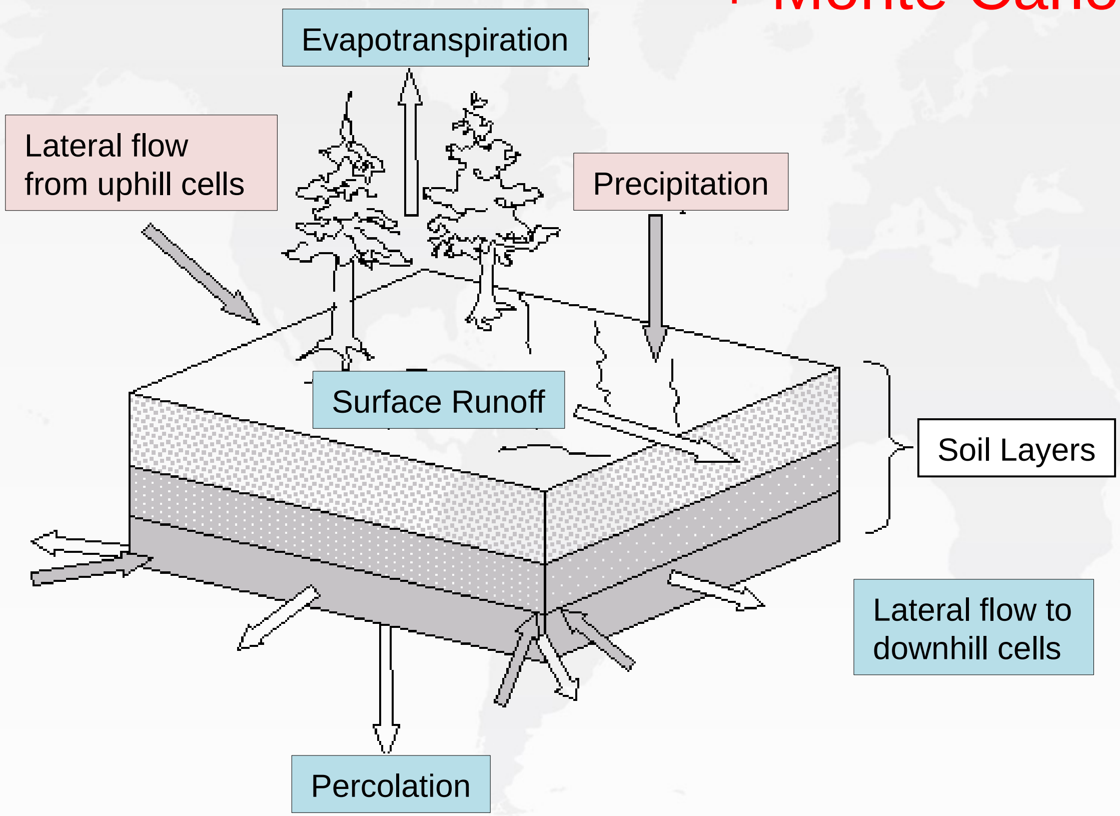
Computers & Geosciences 36 (2010) 1005–1020
Contents lists available at ScienceDirect
Computers & Geosciences
journal homepage: www.elsevier.com/locate/cageo

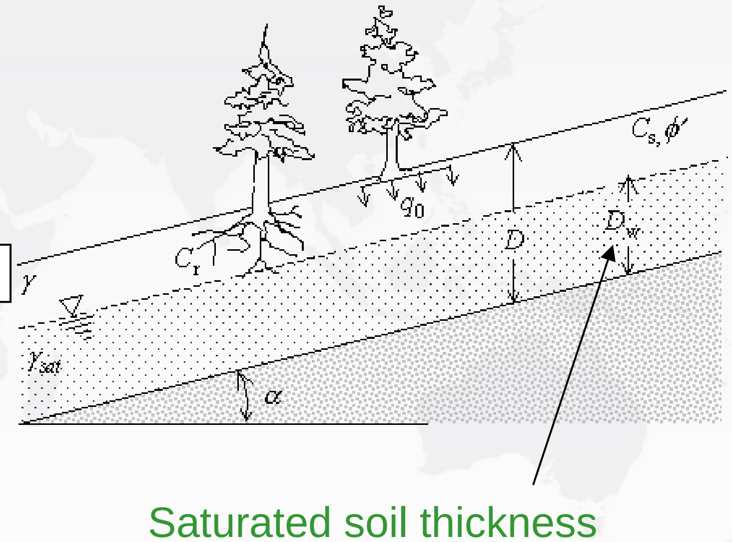
An optimized solution of multi-criteria evaluation analysis of landslide susceptibility using fuzzy sets and Kalman filter

Pece V. Gorsevski [a,*], Piotr Jankowski [b,1]
[a] School of Earth, Environment & Society, Bowling Green State University, Bowling Green, OH 43403, USA
[b] Department of Geography, San Diego State University, San Diego, CA 92182, USA

Spatio-Temporal Modeling

Soil Moisture Routing (SMR) model + Infinite Slope Equation + Monte Carlo





$$D_i \frac{d\theta_i}{dt} = P(t)_i - ET(t)_i + \sum Q_{in.i} - \sum Q_{out.i} - L_i - R_i$$

Daily water balance

$$\sum \frac{\text{Resisting forces (shear strength)}}{\text{Driving forces (shear stress)}}$$

Gorsevski et al. 2006 [Geomorphology]

Environmental Modelling and Software 161 (2023) 105632

Contents lists available at ScienceDirect

Environmental Modelling and Software

journal homepage: www.elsevier.com/locate/envsoft

A free web-based approach for rainfall-induced landslide susceptibility modeling: Case study of Clearwater National Forest, Idaho, USA

Pece V. Gorsevski

School of Earth, Environment & Society, Bowling Green State University, Bowling Green, OH, 43403, USA

A R T I C L E I N F O

Handling Editor: Daniel P Ames

Keywords:
SHALSTAB
Landslide susceptibility
Shiny
Slope stability
Web-based modeling

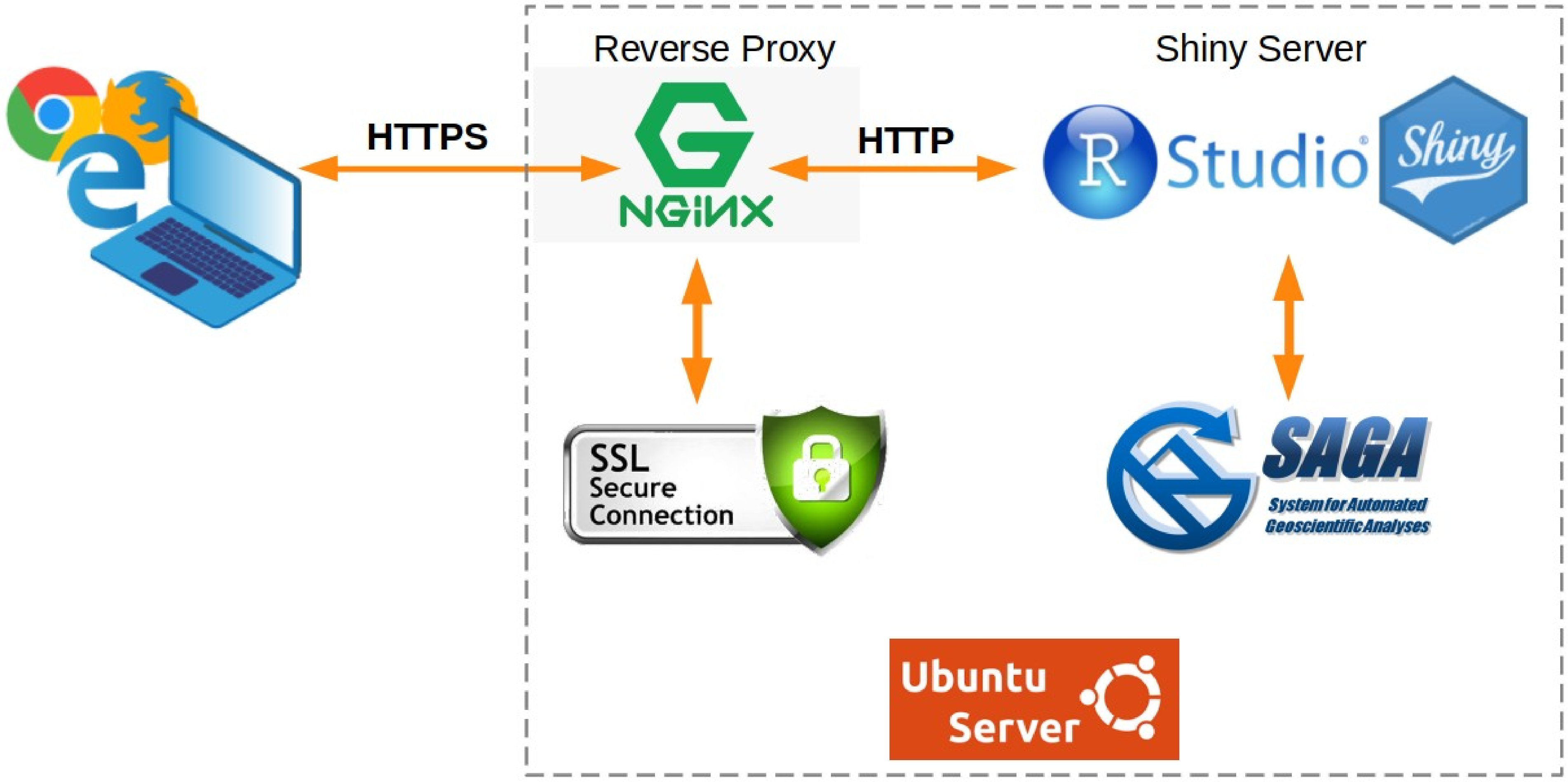
A B S T R A C T

This study presents an interactive web-based approach for modeling rainfall-induced landslide susceptibility using Free Open Source Software (FOSS). The design is based on the R statistical framework and Shiny package coupled with the shallow slope stability model (SHALSTAB) from SAGA GIS. The easy-to-use real-time application extends the potential of current modeling efforts to non-expert R and GIS users and can also be used in an educational context for classroom teaching activity and enabling research-informed learning. The parsimonious approach (i.e. few parameter inputs) is accomplished in two sequential steps including modeling and validation by the use of site-specific datasets. The approach was tested in a case study on the Clearwater National Forest and the results from the validation showed an overall accuracy of 0.894, kappa of 0.789 and AUC from ROC curve was 0.715. The modeled landslide potential may be used as a decision-support tool for local planning.

1. Introduction

Rainfall-induced shallow landslides are the most common gravitational mass movements caused under conditions of transient infiltration into initially unsaturated soils (Baum et al., 2010; Lehmann et al., 2013). The intense or prolonged rainfall is usually the main triggering mechanism that weakens the soil shear strength by increasing soil water content and pore water pressure. The assessment of rainfall-induced landslide susceptibility at local and regional scales which is necessary knowledge derived from past failures can be used for predicting future failure conditions. However, scenarios that cause landslide failure are altered and changing due to climatic effects and need to be addressed by using physical laws (Hürlimann et al., 2022). At present, altered situations are addressed by widespread deployment of artificial intelligence techniques which accelerate discovery of physical laws and governing processes that influence instability factors. Despite all of that, the existing physically-based models are still an important asset for landslide modeling and understanding new conditions as a result of envi-

System architecture of the web-based system



Shallow slope stability model (SHALSTAB)

SHALSTAB is a ***deterministic model*** that calculates the critical ***shallow groundwater recharge conditions*** (mm/day) that can destabilize a slope.

The model couples ***cohesionless infinite plane slope stability*** model and ***steady-state shallow subsurface flow*** (i.e., hydrological model).

Infinite slope model is the ratio of resisting (shear strength) to driving forces (shear stress))

The ***hydrological model calculates the spatial patterns of soil saturation*** (i.e., wetness) using upslope contributing areas, soil transmissivity and local slope with a presumption that the flow infiltrates to a lower conductivity layer and follows topographically determined flow paths.

Hydrological Model Wetness

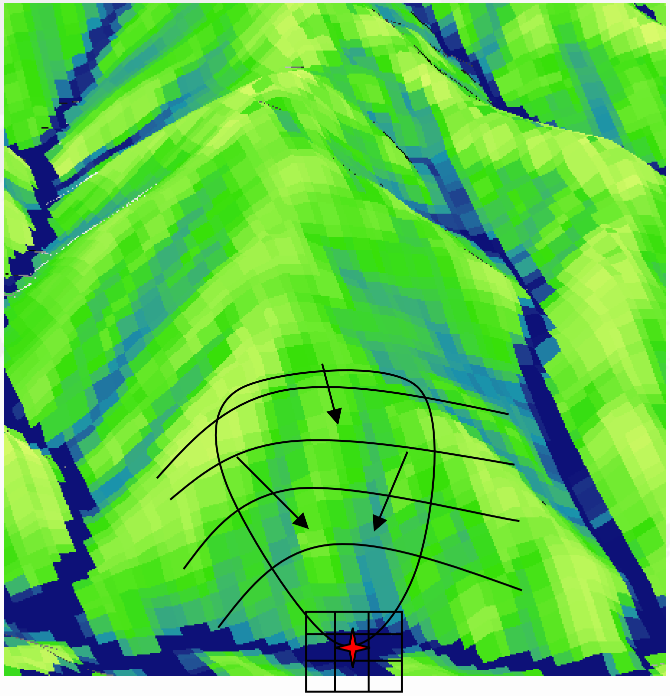
Wetness Index represents the spatial distribution of ***water flow across a given area*** in order ***to predict zones of saturation***

$$CTI = \ln(A_s / \tan \beta)$$

where:

A_s is the specific catchment area (is large typically in converging segments of landscapes)

β is the local slope angle (is small at base of concave slopes where slope gradient is reduced)



(Speight, 1974; Bevan & Kirkby, 1979; Moore et al. 1991; 1993)

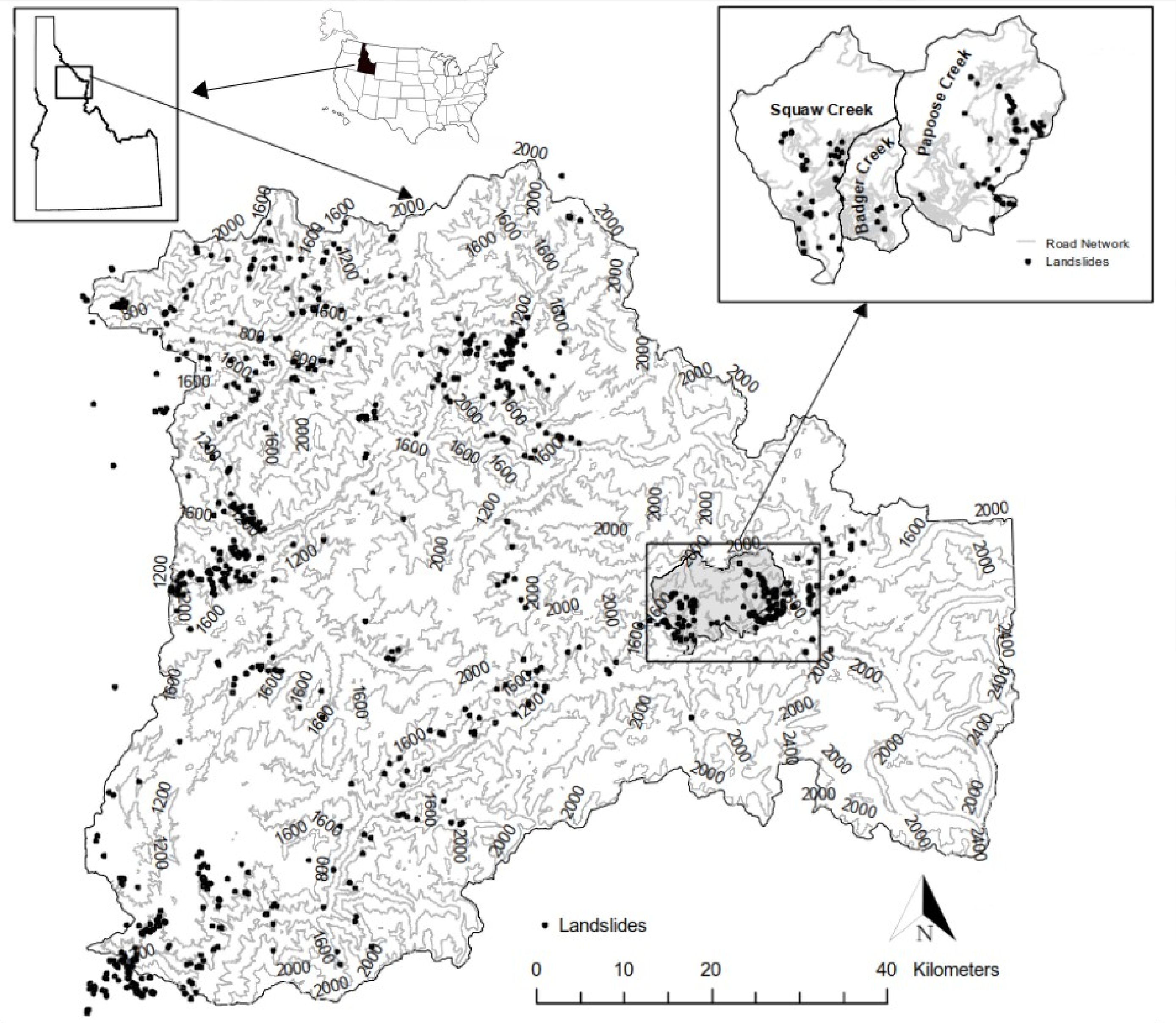
SHALSTAB

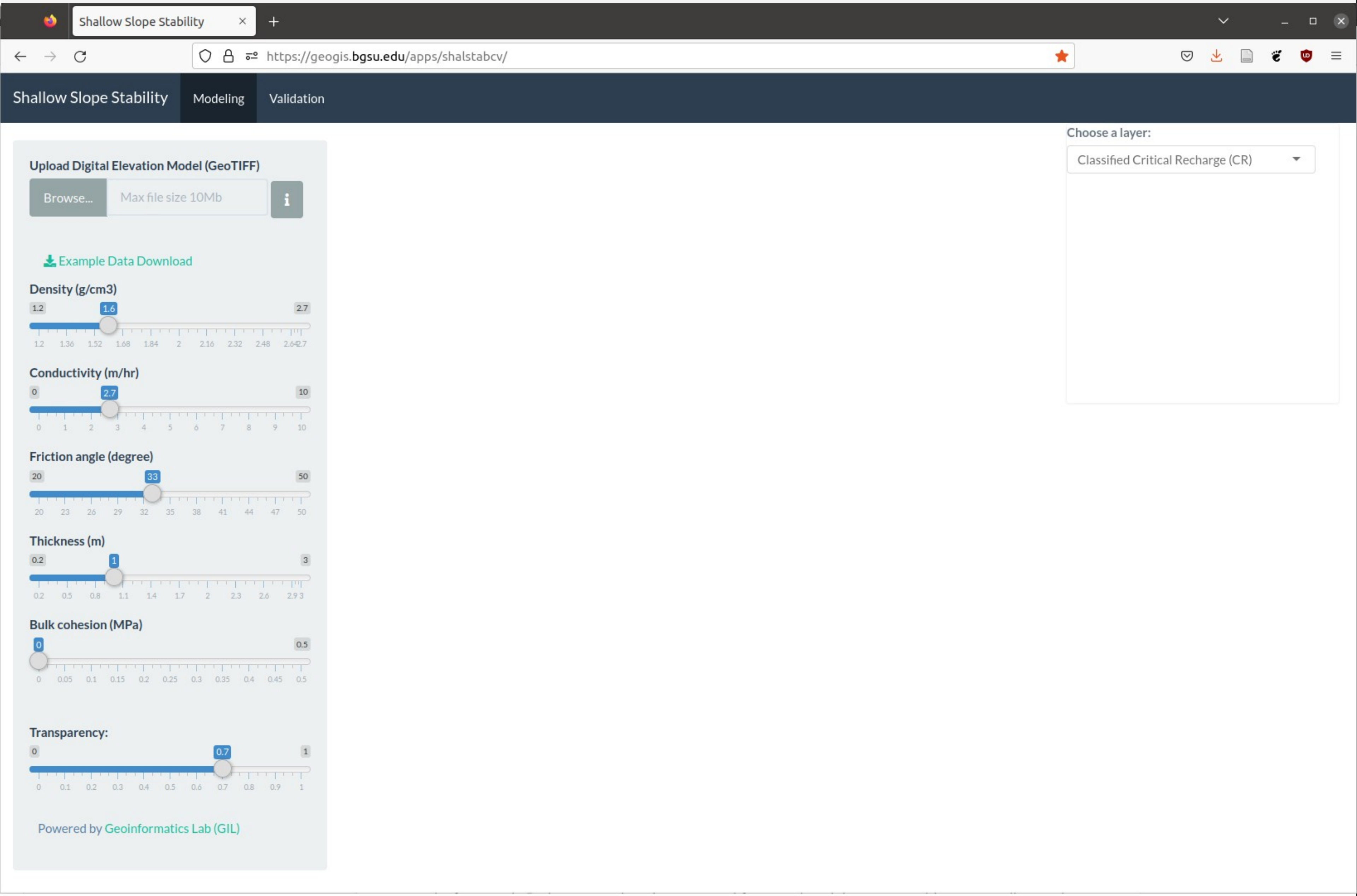
The ***critical steady-state rainfall (Q)*** that is predicted to cause instability at each grid cell is solved by the following equation:

$$Qc = T\sin\theta / (a / b)[\rho s / \rho w\ (1 - \tan\theta / \tan\varphi)]$$

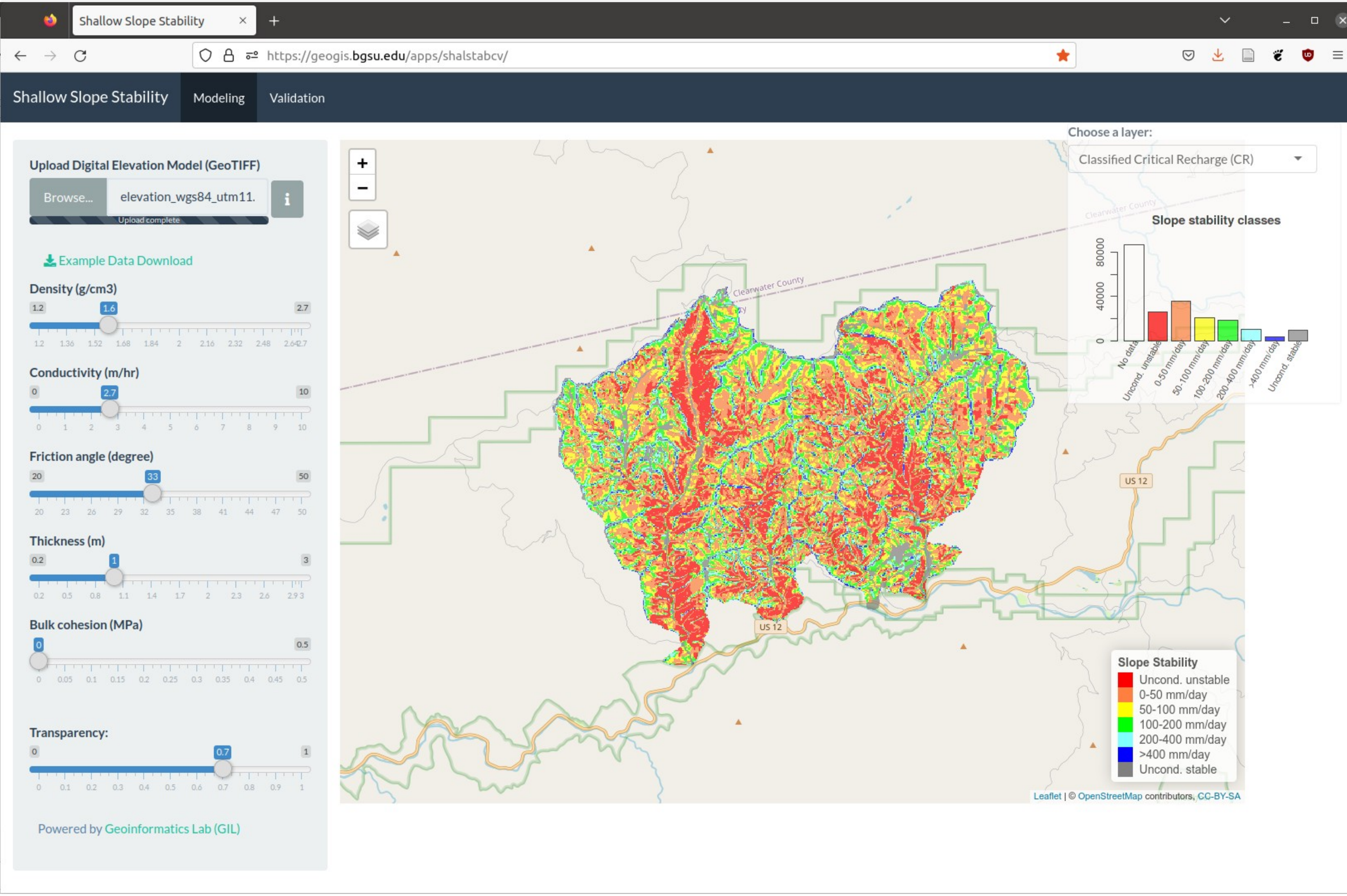
where topographic terms from the DEM include drainage area that contributes subsurface flow ***a***, the outflow boundary length (i.e. cell width) ***b***, and the local slope of the ground surface or angle which is assumed to be parallel to the failure plan ***θ***. The rest of the parameters include the saturated *bulk density of the soil* ***ρs***, the *water bulk density* is ***ρw***, the *angle of internal friction* ***φ***, and the *soil transmissivity* ***T***, which is given by the product of the soil thickness and water level above the failure plane.

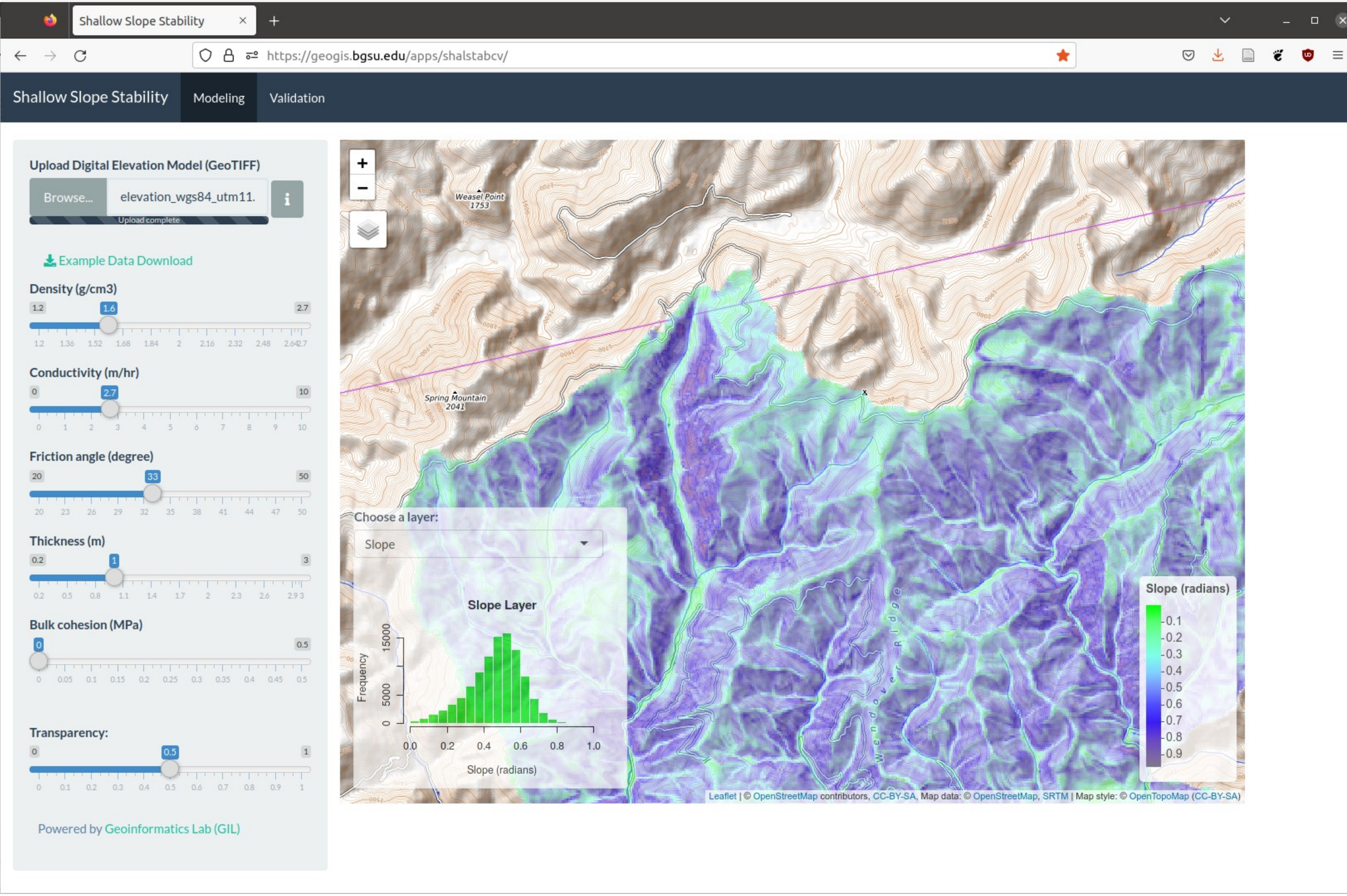
Clearwater National Forest



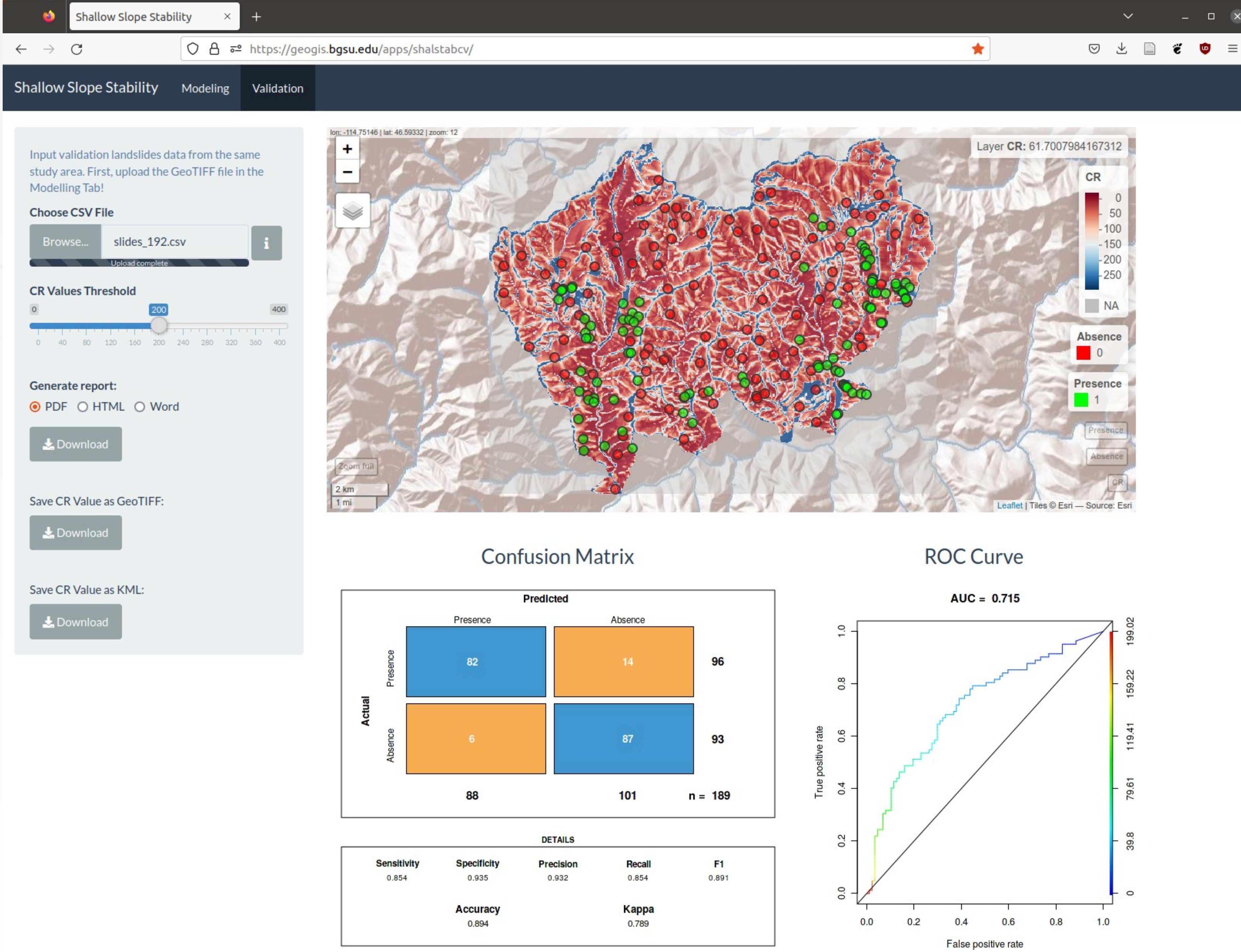


https://geogis.bgsu.edu/apps/shalstabcv/


Shallow Slope Stability
https://geogis.bgsu.edu/apps/shalstabcv/
Shallow Slope Stability
Modeling
Validation
Upload Digital Elevation Model (GeoTIFF)
Browse...
elevation_wgs84_utm11.
Upload complete
Example Data Download
Density (g/cm3)
Conductivity (m/hr)
Friction angle (degree)
Thickness (m)
Bulk cohesion (MPa)
Transparency:
Powered by Geoinformatics Lab (GIL)
Choose a layer:
Classified Critical Recharge (CR)
Slope stability classes
No data
Uncond. unstable
0-50 mm/day
50-100 mm/day
100-200 mm/day
200-400 mm/day
>400 mm/day
Uncond. stable
Clearwater County
US 12
Slope Stability
Uncond. unstable
0-50 mm/day
50-100 mm/day
100-200 mm/day
200-400 mm/day
>400 mm/day
Uncond. stable
Leaflet | © OpenStreetMap contributors, CC-BY-SA



Shallow Slope Stability
https://geogis.bgsu.edu/apps/shalstabcv/
Shallow Slope Stability
Modeling
Validation
Upload Digital Elevation Model (GeoTIFF)
Browse...
elevation_wgs84_utm11.
Upload complete
Example Data Download
Density (g/cm3)
1.2
1.6
2.7
Conductivity (m/hr)
0
2.7
10
Friction angle (degree)
20
33
50
Thickness (m)
0.2
1
3
Bulk cohesion (MPa)
0
0.5
Transparency:
0
0.5
1
Powered by Geoinformatics Lab (GIL)
Weasel Point
1753
Spring Mountain
2041
Choose a layer:
Slope
Slope Layer
Frequency
Slope (radians)
Slope (radians)
Leaflet | © OpenStreetMap contributors, CC-BY-SA, Map data: © OpenStreetMap, SRTM | Map style: © OpenTopoMap (CC-BY-SA)


Shallow Slope Stability
https://geogis.bgsu.edu/apps/shalstabcv/
Shallow Slope Stability
Modeling
Validation
Input validation landslides data from the same study area. First, upload the GeoTIFF file in the Modelling Tab!
Choose CSV File
Browse...
slides_192.csv
Upload complete
CR Values Threshold
0
200
400
0 40 80 120 160 200 240 280 320 360 400
Generate report:
PDF
HTML
Word
Download
Save CR Value as GeoTIFF:
Download
Save CR Value as KML:
Download
lon: -114.75146 | lat: 46.59332 | zoom: 12
Layer CR: 61.7007984167312
CR
0
50
100
150
200
250
NA
Absence
0
Presence
1
Presence
Absence
CR
Zoom full
2 km
1 mi
Leaflet | Tiles © Esri — Source: Esri
Confusion Matrix
Predicted
Presence
Absence
Actual
Presence
Absence
82
14
96
6
87
93
88
101
n = 189
DETAILS
Sensitivity 0.854
Specificity 0.935
Precision 0.932
Recall 0.854
F1 0.891
Accuracy 0.894
Kappa 0.789
ROC Curve
AUC = 0.715
True positive rate
False positive rate
0.0 0.2 0.4 0.6 0.8 1.0
199.02
159.22
119.41
79.61
39.8
0

Landslide Susceptibility Report

17 March, 2021

Slope Stability Report

SHALSTAB (Shallow Slope Stability) computes grid cell critical shallow groundwater recharge values (CR in mm/day) as a measure for relative shallow slope stability, utilizing a simple model that combines a steady-state hydrologic model (a topographic wetness index) to predict groundwater pressures with an infinite slope stability model.

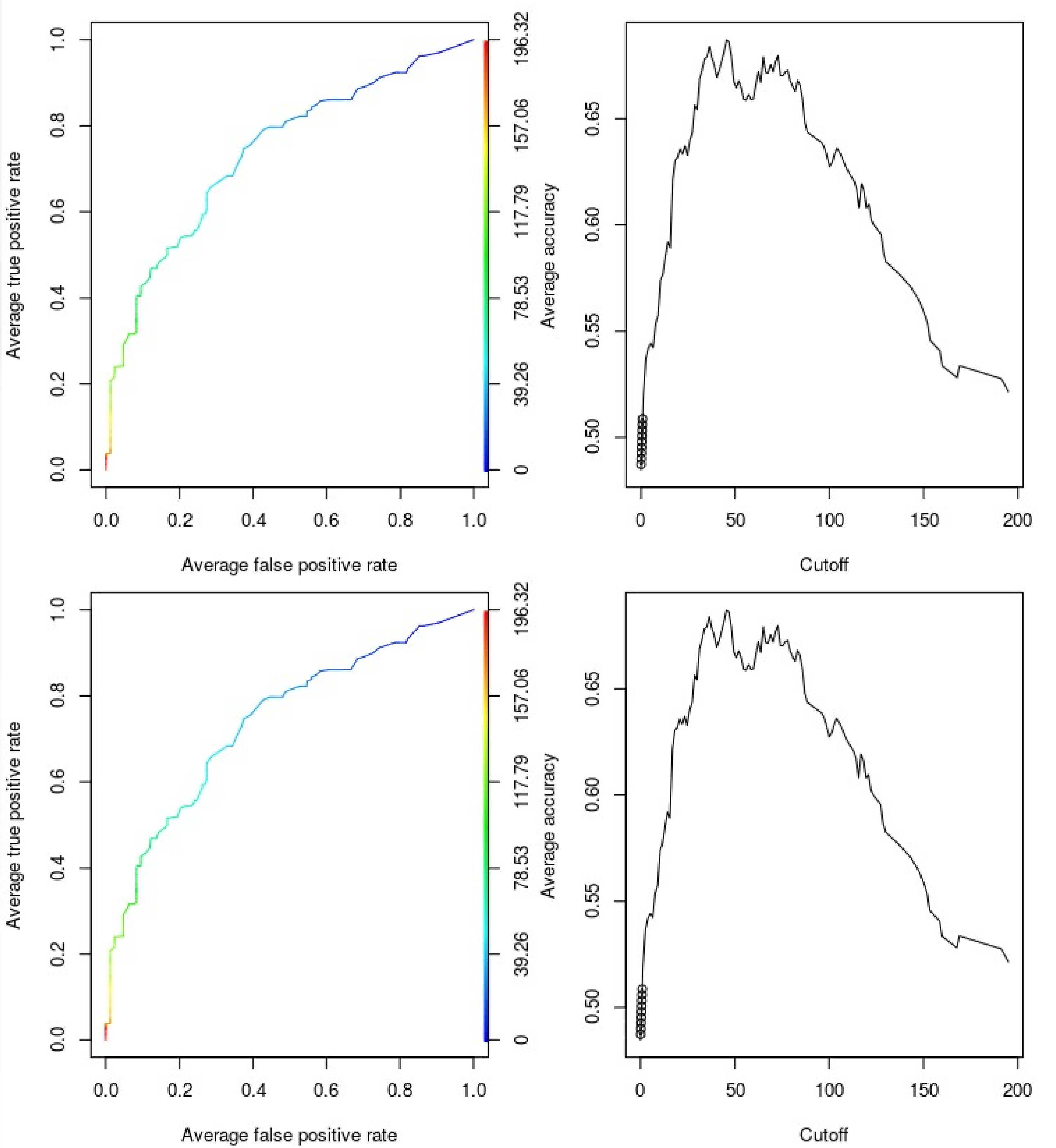
Reference: *Montgomery D. R., Dietrich, W. E. (1994) A physically based model for the topographic control on shallow landsliding. Water Resources Research, 30, 1153-1171*

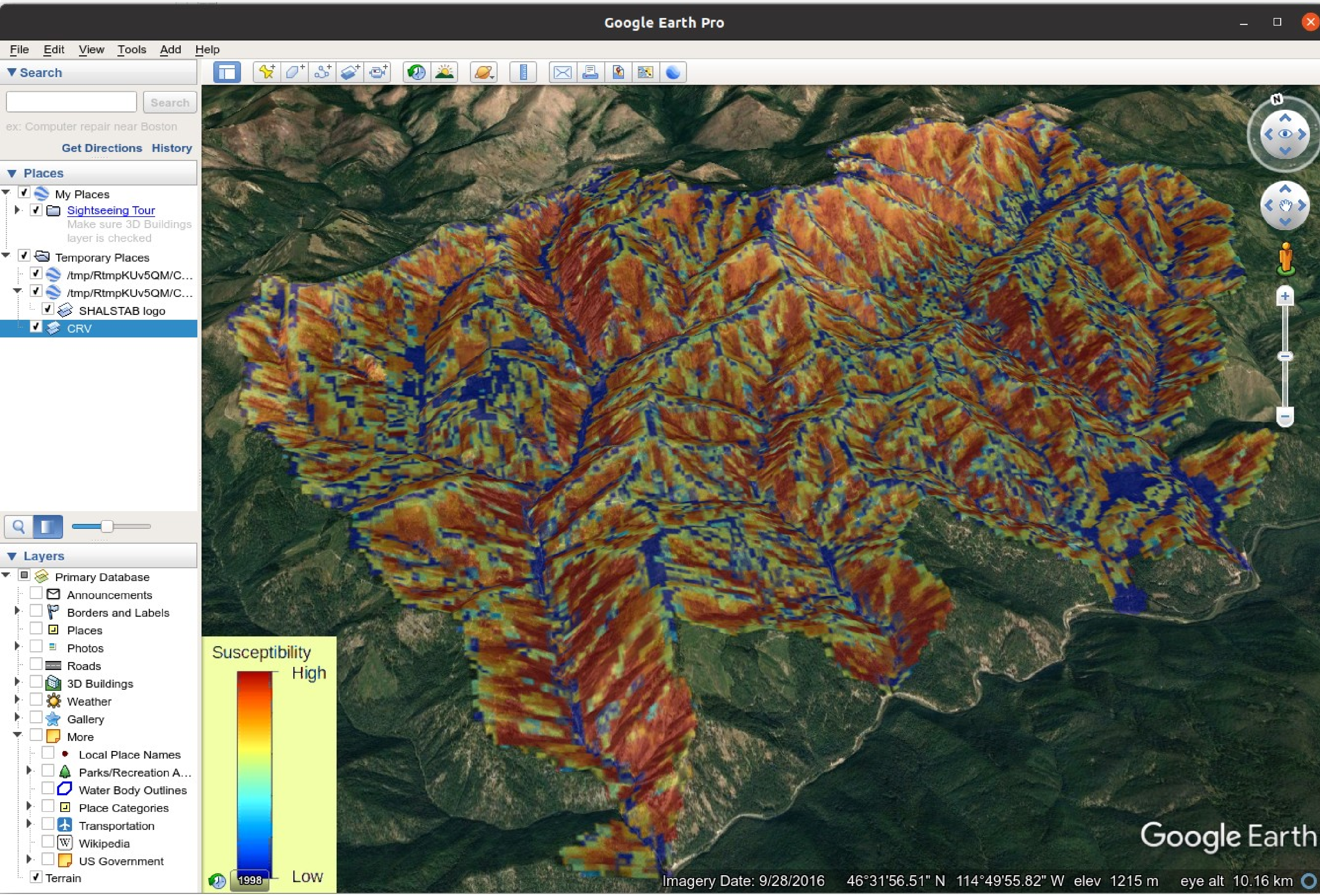
SHALSTAB Input Parameters

Material Density (g/cm3): 1.6
Hydraulic Conductivity (m/hr): 2.7
Material Friction Angle (degree): 33
Material Thickness (m): 1
Bulk Cohesion (MPa): 0

Model Inputs & Outputs Information

```
## class      : RasterStack
## dimensions : 415 , 509 , 211235 , 4 (nrow, ncol, ncell, nlayers)
## resolution : 30.0001082515009 , 30.0001082515007 (x, y)
## extent     : 659695.21 , 674965.27 , 5151023.6 , 5163473.64 (xmin, xmax, ymin,
## crs        : +proj=utm +zone=11 +datum=WGS84 +units=m +no_defs +ellps=WGS84 +t
```


Average true positive rate
Average false positive rate
Average accuracy
0.0
0.2
0.4
0.6
0.8
1.0
0
39.26
78.53
117.79
157.06
196.32
Cutoff
0.50
0.55
0.60
0.65
0
50
100
150
200


Google Earth Pro
File Edit View Tools Add Help
Search
Search
ex: Computer repair near Boston
Get Directions History
Places
My Places
Sightseeing Tour
Make sure 3D Buildings layer is checked
Temporary Places
/tmp/RtmpKUv5QM/C...
/tmp/RtmpKUv5QM/C...
SHALSTAB logo
CRV
Layers
Primary Database
Announcements
Borders and Labels
Places
Photos
Roads
3D Buildings
Weather
Gallery
More
Local Place Names
Parks/Recreation A...
Water Body Outlines
Place Categories
Transportation
Wikipedia
US Government
Terrain
Susceptibility
High
Low
1998
Google Earth
Imagery Date: 9/28/2016 46°31'56.51" N 114°49'55.82" W elev 1215 m eye alt 10.16 km

Conclusions

The presented web-based framework extends the capabilities of existing spatial models for landslide susceptibility for ***non-R*** and ***non-GIS users*** and can also be used in an ***educational context for classroom teaching activity***.

By lowering technical hurdles of this web-based approach, ***powerful functions are made accessible to a wider user community.***

The work sheds light on an ***interactive modeling*** and ***visualization*** that can facilitate decision-making by ***local planners*** who are often required to alter the level of risk which depends on different circumstances.

The case study demonstration showed an produced an ***overall accuracy of 0.894***, ***kappa of 0.789*** and ***0.715 (AUC)***.

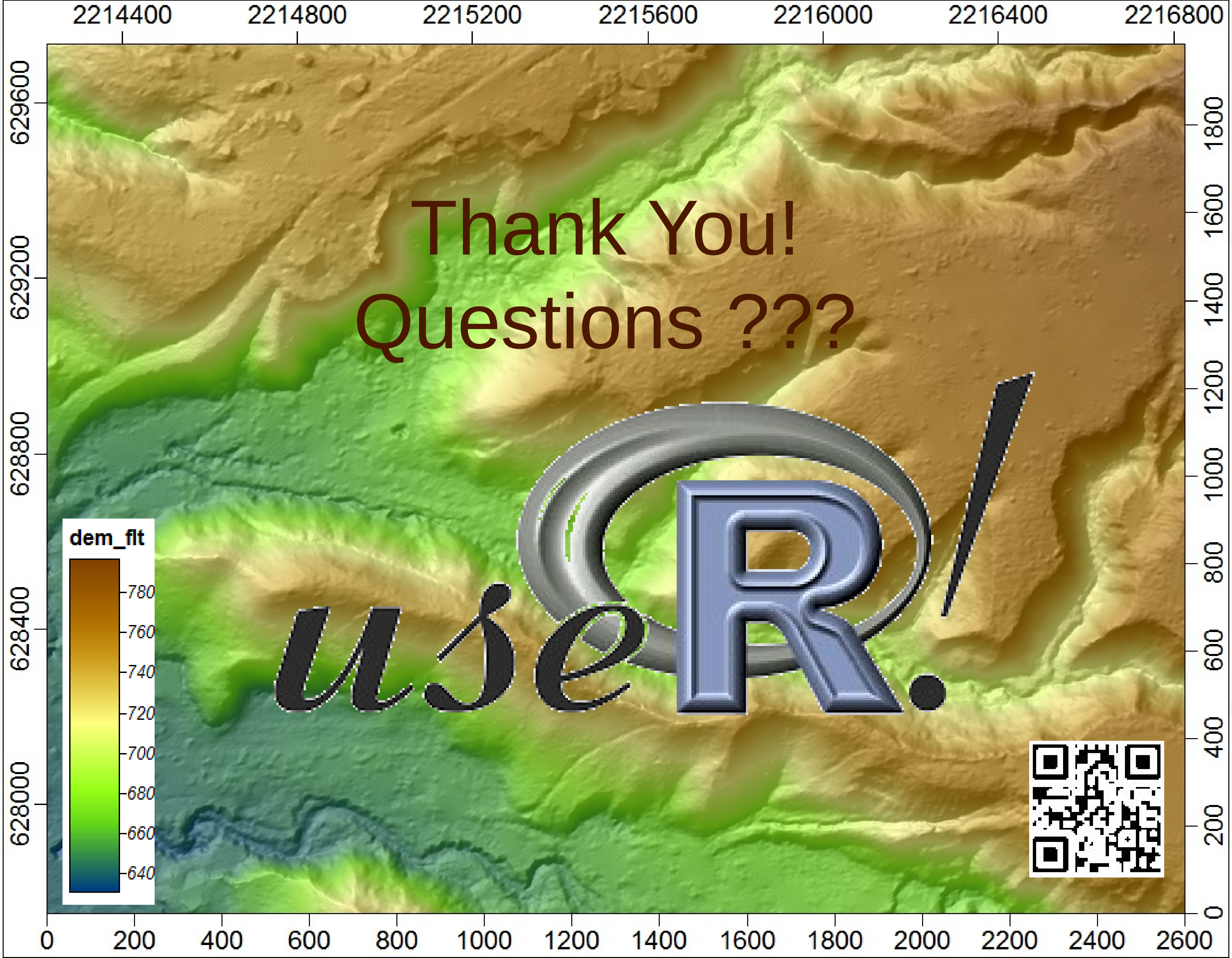
Future Work

Integration with other modules such as the ***Stability Index Mapping (SINMAP)*** which is a ***stochastic and distributed model*** (i.e., requires the maximum and minimum input parameter values)

Providing tools for ***interactive downloads*** and ***preprocessing of DEM*** datasets, adding flexibility to spatial services

Landslide Inventory and ***access to standardized landslide datasets***.

Enabling ***real-time group-based spatial decision support systems*** (SDSS) as a collaborative framework for landslide susceptibility.


Thank You!
Questions ???
useR!
dem_flt
780
760
740
720
700
680
660
640
2214400 2214800 2215200 2215600 2216000 2216400 2216800
629600 629200 628800 628400 628000
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600
0 200 400 600 800 1000 1200 1400 1600 1800