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# Landslide Computer Modeling Potential

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The Payette National Forest selected the Stability Index Mapping (SINMAP) model for use in identifying landslide prone areas. The USDA Forest Service publication, *Roads Analysis: Informing Decisions About Managing the National Forest Transportation System*, mentions SINMAP as a tool for analyzing the potential for shallow landsliding, the most dominant form of soil mass movement and sediment delivery for Payette National Forest lands. The SINMAP model is an ArcView extension that computes and maps a slope stability index based primarily on digital elevation data in the Geographic Information System (GIS). Landslide data collected in West Central Idaho from the 1997 New Year's Day storm event is being used to calibrate the input parameters of the SINMAP model.

## Background

Identifying landslide-prone areas is a recent requirement for land management activities for most western national forests. Recent management direction on landslides and landslide-prone areas is included in PACFISH, USDA Forest Service 1994; INFISH, USDA Forest Service 1995; Chinook Salmon Biological Opinion, USDI National Marine Fisheries Service 1995; Steelhead Biological Opinion, USDI National Marine Fisheries Service 1998; and Bull Trout Biological Opinion, USDI Fish and Wildlife Service 1998. Additional emphasis on proper watershed health, together with restoration management, sustainable forest ecosystem management, and forest roads, is identified in the USDA Forest Service's Natural Resource Agenda for the 21<sup>st</sup> Century, USDA, 1998.

Program and project level analysis to determine potential landslide-prone areas requires a consistent, science-based process that is both adaptable to local conditions and reproducible over large geographic areas, which requires a foundation in a GIS environment. Ground slope and contributing drainage-area data from a GIS digital elevation model (DEM) is also important. The SINMAP model, which runs as a spatial analyst extension on the PC version of ArcView, met these needs (Pack et al 1998). SINMAP, which is available on the Internet, was developed in British Columbia with the support of the Canadian government. SINMAP has its theoretical basis in the infinite slope stability model with wetness obtained from a topographically based steady state of hydrology. These components are combined with an accounting for parameter uncertainty to define the stability index (SI). The model uses landslide initiation points in GIS to calibrate input parameters to the model.

## Study Area

The 1997 New Year's Day storm in West Central Idaho caused numerous landslides. Landslides and flooding closed many roads, isolating rural communities until emergency road repairs were made. The small community of Lower Banks was abandoned due to the threat of future landslides.

The Payette National Forest also had numerous landslides resulting from the 1997 New Year's Day storm on basalt lands (where information on landslides was lacking). The forest conducted an aerial photo inventory supplemented with ground sampling in areas with a high occurrence of landslides on primarily basalt geologies, mapped the initiation points of the landslides, and put the data into the GIS. In an inventory area of 294 square miles, 483 landslides were identified. Typically, the area has mixed conifer forests on the north and east aspects with scattered timber intermixed with brush and grasslands on the south and west aspects at elevations of 3,500 to 6,000 feet. Below 3,500 feet elevation, the south and west aspects are typically grass and low brush with scattered timber and brush on the north and east aspects. The inventoried area was 60 percent forested and 40 percent nonforested. The typical area soils were classified as colluvial soil composed of angular rock fragments, silts, sands, and clays 2 to 6 feet deep.



Figure 1. Medium-sized landslide in brush on basalt soils.

Only 15 percent of the landslides inventoried appeared to be influenced by management activities such as roading and timber harvest. Eighty-five percent of the landslides occurred in brush and grass vegetation areas, while only 15 percent occurred in timber. North aspects had a much lower occurrence of landslides (7.5 percent) compared to south (26.3 percent), east (26.7 percent), and west (39.5 percent) aspects.

Landslides appeared to be influenced by the bedding planes of the basalt flows, often occurring along bands that paralleled the planes. Landslide occurrence also corresponded to the dip slope of the basalt bedding planes. The contact zone between the “upper” and “lower” basalt had a higher occurrence of landslides. Steep slopes (60 percent average ground slope), with a concave shape where water tends to collect, typically spawned more landslides.

## Testing

Armed with our landslide data in GIS, we tested the SINMAP model at Boise State University with the assistance of the Rocky Mountain Research Station in Boise, ID. The SINMAP modeling is based on DEM data and landslide initiation points. The model generates and maps stability indexes for the pixels in the DEM. Pixel sizes used in DEMs vary. We used a 30-meter DEM, which means that each pixel represents 30 meters on the ground. Landslide initiation points are used to calibrate the model interactively with the computer screen. We omitted road-related and stream-cut landslides from the calibration process. They fail to fit the criteria of the infinite slope stability equation, because their geometry has been altered. In addition, the 30-meter pixel size cannot accurately represent ground slopes on fills, cuts, and slopes directly adjacent to streams because the slope changes occur in areas less than 30 square meters.

Table 1 shows the results the modeling yielded after calibration for the Upper Weiser River drainage.

Table 1—Upper Weiser River SINMAP Statistics.

Stability Class	Stable	Moderately Stable	Quasi-Stable	Lower Threshold	Upper Threshold	Defended	Total
Region 1							
Area (km <sup>2</sup> )	76.9	26.2	29.4	30.8	3.0	0	166.3
Percent of Region	46.2	15.7	17.7	18.5	1.8	0	100
Number of Landslides	3	2	2	66	31	2	106
Percent of Slides	2.8	1.9	1.9	62.3	29.2	1.9	100
Landslide (Number/km <sup>2</sup> )	0	0.1	0.1	2.1	10.5	41.9	0.6

The input parameters were:

T/R—250 to 1,500

C'—0.05 to 0.15

Phi—34 to 43

The term T/R is the ratio of transmissivity to the effective recharge rate of the storm being modeled or the slope distance required for soil saturation on a straight slope. The term C' is a dimensionless cohesion, a combination of root and soil cohesion divided by soil depth. Phi is the internal angle of friction of the soil. The SINMAP model uses uniform probability distributions of the input parameters with lower and upper limits. This approach reflects the uncertainty associated with estimating parameters in terrain stability mapping (Hammond et al 1992).

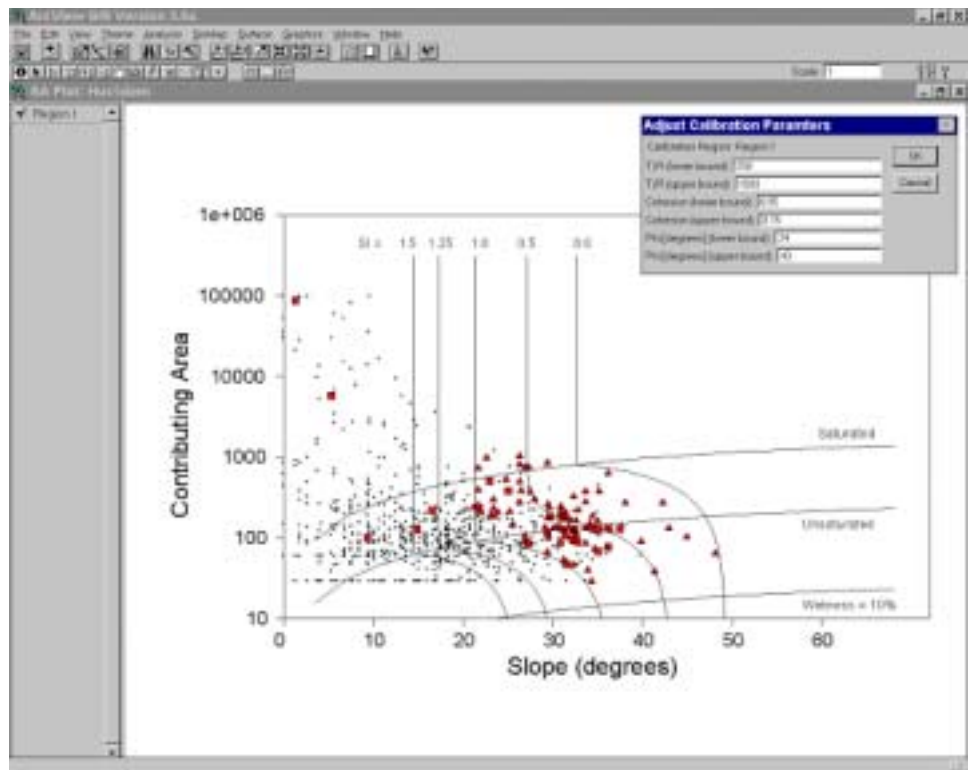


Figure 2. Upper Weiser River slope-area plot.

The slope area (SA) plot shows the relationship between contributing areas and ground slope (Tarboton 1997). The geometric points (little squares or triangles) represent landslide locations. The single points represent a random selection of points within the calibration region. The slope and contributing areas are generated from the DEM. The vertically oriented curves are the breaks between stability index areas.

- Points to the left of the SI line of 1.5 are in the stable region.
- Points between 1.5 and 1.25 SI lines fall into the moderately stable region.
- Points between the 1.25 line and the 1.0 line fall in the quasi-stable region.
- Points between the 1.0 and the 0.5 line fall into the lower threshold region.
- Points between the 0.5 and the 0.0 line fall into the upper threshold region.
- Points to the right of the 0.0 line fall into the defended region.

The location of the 1.0 SI line is controlled by the lower bounds of the C' and Phi parameters. The location of the 0.0 SI line is controlled by the upper bounds of the C' and Phi parameters. The area between the 0.0 SI line and the 1.0 SI line represents the uncertainty associated with the parameters.

The horizontally oriented lines represent the wetness that is controlled by the T/R calibration parameter. All points above the upper line are saturated. The position of the upper line is controlled by the upper bounds of the T/R ratio. The position of the middle line is controlled by the lower bounds of the

T/R ratio. Points between the upper and middle lines fall into the possible saturated area that represents the uncertainty associated with the T/R ratio. Points that fall below the middle line are unsaturated. The bottom line represents 10 percent wetness.

Calibrating the input parameters to the landslide points involves shifting the lines of the SA plot to fit the landslide occurrence by changing the upper and lower boundaries of the input parameters. A stability index of 1.0 may be thought of as a factor of safety. Very few landslides should occur to the left of the 1.0 line since the factor of safety is  $>1.0$ . These landslides can be identified on the stability index map from the SA plot using the (REX) tool in the SINMAP program. The REX tool is a Golden Retriever icon on the tool bar that enables the user to click on a landslide on the SA plot and find the same landslide point spatially on the stability index map. Landslides that had a  $SI > 1.0$  were checked for slope and were found to be near stream bottoms where the 30-meter grid averaged the slope on both sides of the stream, resulting in erroneous slope readings when compared to the inventoried slope of the landslides.

Table 1 shows the results of the calibrated model. The stable regions with a  $SI > 1.0$  have very low landslide densities. Landslides in that region (left of the 1.0 line) were attributed to the 30-meter DEM being unable to accurately show abrupt slope changes that are found in drainage bottoms. The lower and upper threshold regions show an increasing density of landslides with decreases of SI values  $< 1.0$ .

The initial SINMAP tests were done with a single calibration region. The model allows up to 10 calibration regions based on logical areas designated in GIS. For the Upper Weiser River area, we did further analysis using three calibration regions based on geology; "Upper Basalt," "Lower Basalt," and a 150-meter band around the contact zone.

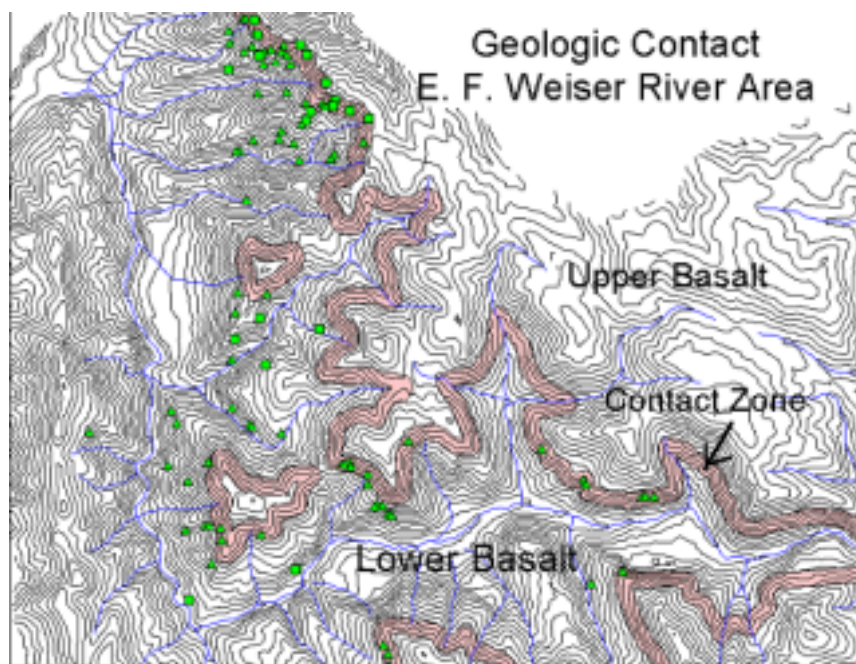


Figure 3. Contour map of the Upper Weiser River area showing geology and landslide locations.

Table 2 displays the landslide statistics for multicalibration regions.

Table 2. Upper Weiser Multicalibration Region Landslide Statistics

Geology	Area (km <sup>2</sup> )	Percent of Area	Number of Landslides	Percent of Landslides	Landslide Density (per km <sup>2</sup> )
Upper Basalt	37.2	52.1	1	1.0	0.03
Contact Zone	6.5	9.1	43	42.2	6.62
Lower Basalt	27.7	38.8	58	56.8	2.09

The SI values generated by SINMAP enable the user to reclassify the stability regions using spatial analysis. To simplify the results, we grouped the SI values into three zones of potential slope stability hazards: SI values > 1 were classified as having low to zero stability hazards; SI values between 1.0 and 0.7 were classified as having low to moderate stability hazards; and SI values < 0.7 were classified as having moderate to high stability hazards. The data in table 3 is based on this stability index grouping and displays the existing landslide densities in all three calibration regions combined in the analysis.

Table 3. Upper Weiser River SINMAP Reclassification Results

Landslide Potential	Area (km <sup>2</sup> )	Number of Landslides	Landslide Density (number/km <sup>2</sup> )
Moderate to High	3.7	53	14.3
Low to Moderate	11.4	42	3.7
None to Low	56.3	7	0.1

The three landslide potential categories generated a map (figure 4). Field crews were sent to verify or “ground truth” proposed timber harvest units and proposed road locations by using the map. The field verification for classifying landslide-prone areas was based on the following criteria:

1. Evidence of past landslides;
2. Soil characteristics for soil depth, rock fragments, and texture;
3. Ground slope;
4. Contributing drainage area and evidence of water; and
5. Vegetative rooting strength.

Feedback from the field crews was positive. Some landslides missed in the photo inventory were found, and all fell within areas mapped as moderate-to-high potential. Areas classified on the ground as landslide prone also fell within areas mapped as having a moderate-to-high potential.

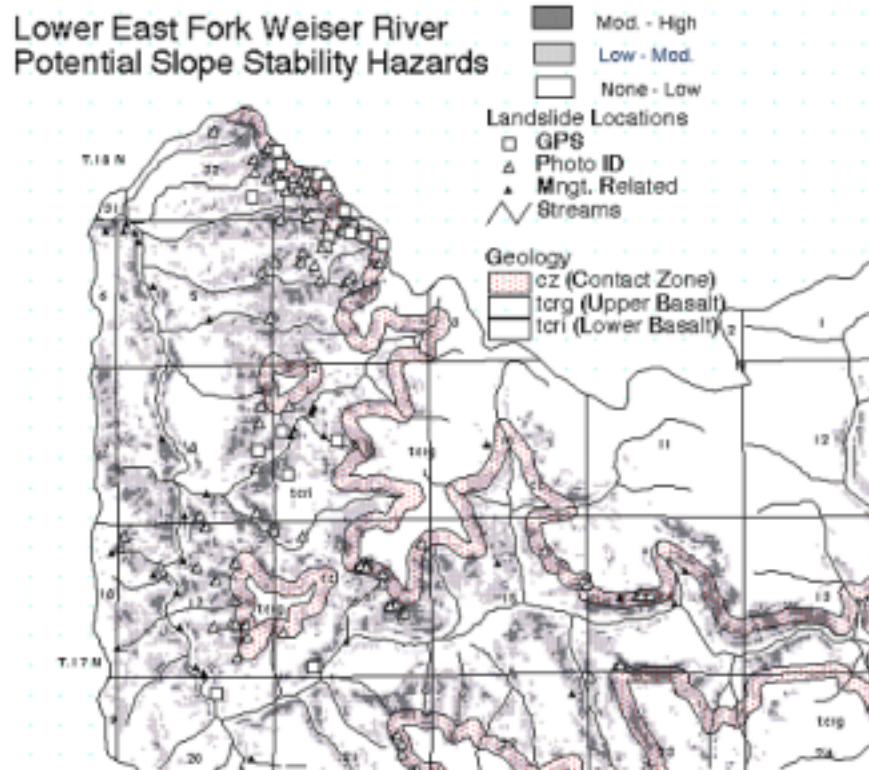


Figure 4. Map of Upper Weiser River area showing landslide potential categories

## Conclusion

Since our initial testing of the SINMAP model, we have used the modeling procedure at various scales, including determining landslide hazards on 7.2 million acres in the Boise, Payette, and Sawtooth National Forests in support of a Forest Plan Revision. Additional analysis at the project level with SINMAP has been done on granitic, metamorphic, and basalt geologies. Calibration parameters varied by geology but were found to be transferable on similar geologic landforms using the same storm event. We have found the model relatively easy to use and flexible for a variety of situations.

Using the SINMAP model successfully requires accurate DEMs and a landslide inventory with accurate landslide initiation points in GIS. A detailed landslide inventory helps the modeler understand the processes that have effects on landslide potential. The detailed inventory helps the modeler adjust calibration parameters and develop calibration regions. The inventory is also valuable for field verification. Although SINMAP uses state-of-the-art GIS modeling techniques, computer modeling does not replace on-the-ground field investigation.

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