A NEW METHOD FOR DETERMINATION OF MOST LIKELY INITIATION POINTS AND EVALUATION OF DIGITAL TERRAIN MODEL SCALE IN TERRAIN STABILITY MAPPING

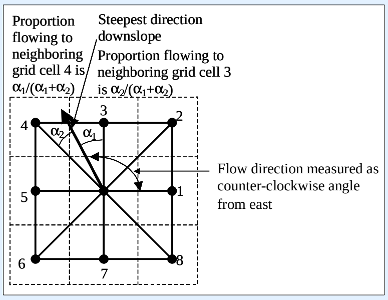
Paolo Tarolli[1] and David G. Tarboton[2]

[1]University of Padova, Land and Agroforest Environments Department, Padova, ITALY (paolo.tarolli@unipd.it)
[2]Utah State University, Civil & Environmental Engineering Department, Logan, UT (dtarb@cc.usu.edu)

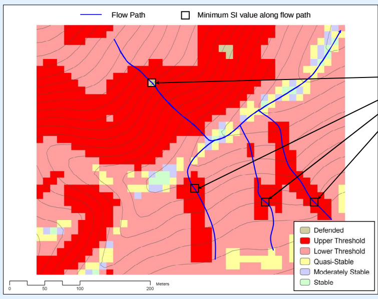
ABSTRACT

Physically-based models have been used previously to model and map the spatial distribution of shallow debris slides, and areas of potential instability. Here we use the SINMAP stability index (SI) defined as the probability that the factor of safety is greater than 1. We introduce a new approach for determining the **Most Likely Initiation Point (MLIP)** by identifying the grid cell with critical (lowest) stability index on each downslope path from ridge to valley. Only potential initiation points less than a threshold are considered to avoid identification of stable locations on downslope paths that do not contain any unstable locations. Mapped or observed landslides are often used to evaluate the effectiveness of model derived terrain stability maps. The accuracy of models depends on the quality of input variables, in particular the digital terrain model (DTM) from which many of the input variables for terrain stability models are derived. In this paper we use airborne laser altimetry (LIDAR) derived elevation data for testing the effect of different DTM grid cell size resolution on the modeling of shallow landslides in a small basin located in the Northeastern Region of Italy. Physically based models quantify the potential instability at each location. Because in our study area the mapped landslides included landslide runout zones we found that the direct comparison of SI within and outside of mapped landslides was not effective. However when MLIP was used we found appreciable differences between the density of MLIP points within and outside mapped landslides with ratios as large as three or more, demonstrating the utility of MLIP for evaluating terrain stability maps.

THEORY OF MLIP

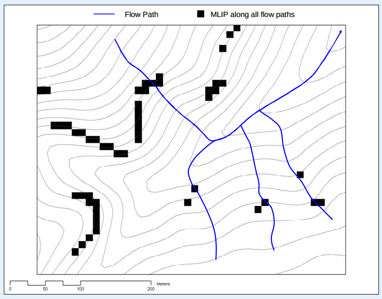


D∞ Algorithm, Tarboton (1997)



SINMAP SI Map

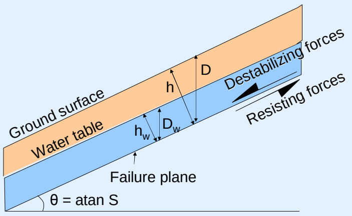
Points with minimum value of SI along flow path



MLIP for all flow paths

TERRAIN STABILITY MODEL

The MLIP method is based on the D∞ algorithm (Tarboton, 1997) for the representation and calculation of flow direction and on the stability index (SI) from the SINMAP model. The stability index (SI) is defined as the probability that a location is stable (FS > 1) assuming uniform probability distributions of the uncertain geophysical parameters (Pack et al., 1998).



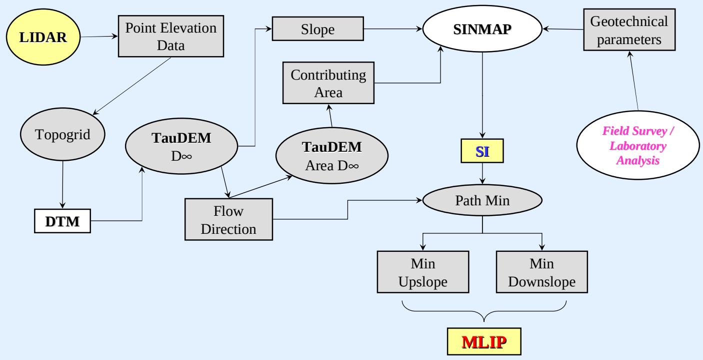
$$\text{Factor of safety, } FS = \frac{\text{Resistive forces}}{\text{Destabilizing forces}}$$

$$FS = \frac{C + \cos\theta\left[1 - \min\left(\frac{R}{T}\frac{a}{\sin\theta}, 1\right) r\right]\tan\phi}{\sin\theta}$$

$C = (C_r + C_s)/(h \rho_s g)$ $r = \rho_w/\rho_s$
T = soil transmissivity (m²/hr)
R = steady state recharge (m/hr)

SINMAP, SI = probability (FS>1)

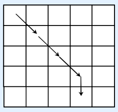
MLIP MODEL



ALGORITHM FOR CALCULATION MLIP

MINIMUM DOWNSLOPE FUNCTION

0.8	0.5	0.7	0.4	0.8
0.7	0.7	0.3	0.3	0.1
0.9	0.8	0.1	0.2	0.4
0.5	0.4	0.2	0.5	0.8
0.3	0.4	0.7	0.8	0.9

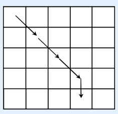


0.1				
	0.1			
		0.1		
			0.5	
			0.8	

Grid cell with lowest value at or downslope of each grid cell

MINIMUM UPSLOPE FUNCTION

0.8	0.5	0.7	0.4	0.8
0.7	0.7	0.3	0.3	0.1
0.9	0.8	0.1	0.2	0.4
0.5	0.4	0.2	0.5	0.8
0.3	0.4	0.7	0.8	0.9



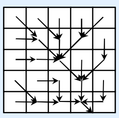
0.8				
	0.7			
		0.1		
			0.1	
			0.1	

Grid cell with lowest value at or upslope of each grid cell

SI

0.8	0.5	0.7	0.4	0.8
0.7	0.7	0.3	0.3	0.1
0.9	0.8	0.1	0.2	0.4
0.5	0.4	0.2	0.5	0.8
0.3	0.4	0.7	0.8	0.9

\+



Flow Direction

min SI downslope

0.1	0.1	0.1	0.1	0.1
0.1	0.1	0.1	0.1	0.1
0.1	0.1	0.1	0.2	0.4
0.4	0.2	0.2	0.5	0.8
0.3	0.4	0.7	0.8	0.8

0.8	0.5	0.7	0.4	0.8
0.7	0.7	0.5	0.3	0.1
0.9	0.8	0.1	0.2	0.1
0.5	0.4	0.2	0.1	0.8
0.3	0.3	0.2	0.1	0.8

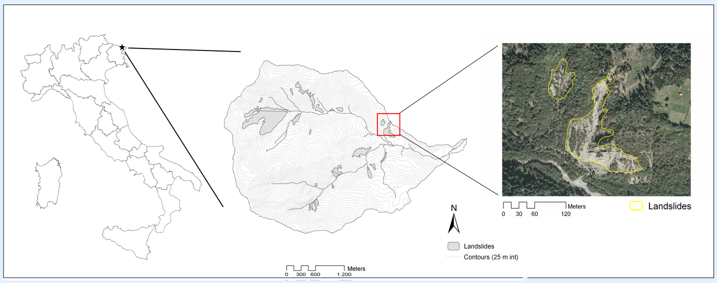
min SI upslope

				0.1
		0.1	0.2	
		0.2		
0.3				

MLIP

Most Likely Initiation Points (MLIP) are where $SI_{ups} = SI_{down} = SI < \text{threshold}$

STUDY AREA



Catchment area (km²)	10.7	Mean slope gradient (°)	33
Average elevation (m.a.s.l.)	1244	Maximum slope gradient (°)	77
Minimum elevation (m.a.s.l.)	470	Mean annual precipitation (mm)	2200
Maximum elevation (m.a.s.l.)	2075	Area of Landslides (km²)	0.5 (4.7% of basin)

METHODOLOGY

(i) Digital Terrain Model (DTM) computed from LIDAR points at multiple resolutions: 50m, 20m, 10m, 5m, and 2m.

(ii) Terrain stability index, SI, computed for each resolution DTM from SINMAP using default parameters

(iii) MLIP grids evaluated for each DTM resolution SI grid for a range of threshold SI values.

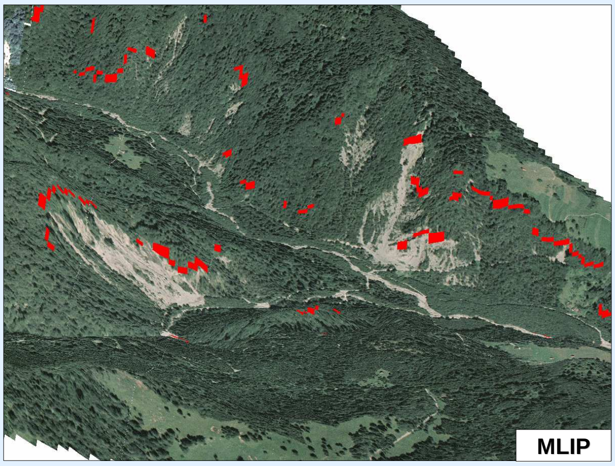
(iv) A range of thresholds applied to SI grid for each DTM resolution to categorize terrain instability.

The quality of the SI map is evaluated by comparing the density of MLIP points within and outside observed landslide area

$$\text{Density Ratio} = \frac{(P_{lds} / \text{lanslide area})}{(P_{bas} / \text{basin area})}$$

P_{lds}, and P_{bas} are the number of cells within the landslide area and within the basin as a whole, mapped by the approach. When used with SI these are grid cells less than a SI threshold. When used with MLIP these are grid cells identified by the MLIP upslope and downslope criteria and less than a SI threshold. Threshold ranges are given at the left of the table below.

RESULTS

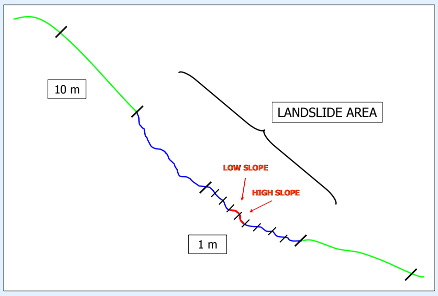


DENSITY RATIO

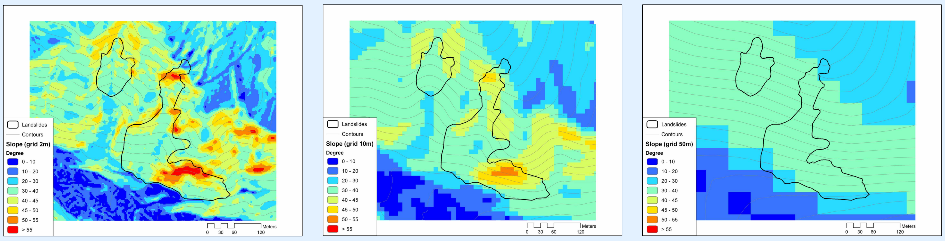
Grid resolution (m)	50	20	10	5	2
MLIP SI 0-0.2	5.23	1.83	**3.81**	2.97	2.57
MLIP SI 0-0.5	3.19	1.91	**3.66**	2.93	2.57
MLIP SI 0-1	1.53	1.42	**3.53**	2.91	2.57
MLIP SI 0-infinite	1.46	1.38	**3.51**	2.91	2.56

Grid resolution (m)	50	20	10	5	2
SI 0-0.2	3.41	2.47	2.61	2.35	2.34
SI 0-0.5	2.25	2.27	2.23	2.24	2.17
SI 0-1	1.33	1.27	1.29	1.29	1.31
SI 0-infinite	1	1	1	1	1

SLOPE "SCALE EFFECT" PROBLEM



Computed slope is more variable with higher values for a smaller DTM grid resolution.



CONCLUSIONS

A. THE **MOST LIKELY INITIATION POINT** (MLIP) METHOD IS SUGGESTED AS A NEW WAY TO EVALUATE TERRAIN STABILITY MODELS WHEN MAPPED LANDSLIDE AREA INCLUDES RUNOUT ZONES

B. THE HIGHER DENSITY RATIO FOR THE MLIP APPROACH THAN FROM CATEGORIES DEVELOPED FROM THE SI GRID ALONE, VALIDATES THE POTENTIAL OF THE MLIP METHOD

C. A DTM RESOLUTION OF 10m GIVES THE HIGHEST MLIP DENSITY RATIOS SUGGESTING THAT FOR THIS DATA THE 10m RESOLUION IS OPTIMAL. (THE ONE EXCEPTION FOR A 50m DTM IS SPURIOUS DUE TO SMALL NUMBER OF PIXELS)

D. THE MLIP APPROACH PROVED USEFUL FOR EVALUATING THE QUALITY OF A SI MAP WHERE MAPPED LANDSLIDES INCLUDED RUNOUT ZONES AND PROVED USEFUL FOR TESTING THE PERFORMANCE OF SI DERIVED FROM DIFFERENT RESOLUTION DTMs

FUTURE WORK

A. MAP LANDSLIDE RUNOUT AREA FROM MLIP TRIGGER POINTS

B. INVESTIGATE "SCALE EFFECT" WITH INCREASING RESOLUTION OF DTM

C. TEST THE MLIP APPROACH WITH OTHER TERRAIN STABILTY MODELS LIKE SHALSTAB (Montgomery and Dietrich, 1994) AND QUASI DYNAMIC (Borga et al., 2002).

D. ANALYZE EFFECTS OF A VERY HIGH RESOLUTION DTM OBTAINED BY LIDAR SURVEY IN A REGION WITHOUT HIGH TREE FOREST

References

Borga, M., Dalla Fontana, G., and Cazorzi, F., 2002b: Analysis of topographic and climatic control on rainfall-triggered shallow landsliding using a quasi-dynamic wetness index. J. Hydrol., 268 (1-4), 56-71.

Montgomery, D.R., and Dietrich, W.E., 1994. A physically based model for the topographic control on shallow landsliding. Water Resour. Res., 30(4), 1153-1171.

Pack, R., et al., 1998. The SINMAP Approach to Terrain Stability Mapping. Submitted to 8th Congress of the International Association of Engineering Geology, Vancouver, British Columbia, Canada.

Tarboton, D.G., 1997. A new method for the determination of flow directions and upslope areas in grid digital elevation models. Water Resour. Res. 33, 309–319.

Acknowledgements

The authors are grateful to "Servizio Territorio Montano e Manutenzioni" (Direzione Centrale Risorse Agricole, Naturali, Forestali e Montagna) of Friuli Venezia Giulia Region for the collaboration in field surveys and furniture of lidar, and aerial photographs database.

This work has benefit from discussion with Kiran Chinnayakanahalli.

We thank Michela Dini and Luca Bincoletto that provided critical support during field work and data collect.

Tarolli also acknowledges the contribute of Giancarlo Dalla Fontana and Marco Borga during the prework discussion, and the support of Ing. Aldo Gini Foundation on the scholarship period at Utah State University .