Modeling the effects of climate change on cascading natural hazards

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Introduction

Natural hazards threaten lives and impact human infrastructure every year. Climate change can catalyze these events by sequentially perturbing environmental factors that lead to cascading natural hazards. For example, climate-induced drought can enhance wildfires that denude the landscape and increase the risk for landslide activity, particularly after extreme precipitation events. Understanding the link between climate change and cascading natural hazards is critical for both human safety and mitigation efforts, and is the focus of a NASA funded, ESOC-led interdisciplinary research project. Here, we introduce preliminary landslide modeling results from two of our study areas: the Matilija Watershed in Southern California, and the CalWood Fire site ~15 km north of Boulder, CO. We use ***S**tability **IN**dex **MAP**ping* [*Pack et al.*, 1998] implemented through LandLab [*Strauch et al.*, 2018]}, an open-source Earth surface dynamics model [*Hobley et al.*, 2017; *Barnhart et al.*, 2020], to evaluate the probability of landslides in these regions.

Model Overview

Model Inputs
- Digital Elevation Model
- Hydrology
- Land / Vegetation Cover
- Soil Parameters

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Parameters
- Cohesion
- Friction
- Hyd. Conductivity
- Soil Transmissivity
- Surface Slope
- Recharge
- Soil Thickness

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Model Outputs
- Relative Wetness
- Probability of Saturation
- Probability of Failure

Figure 1: Overview of the Landslide Probability model within the LandLab architecture (adapted from Strauch et al, 2018). Parameters are defined by input variables and the assumptions made below.

Model Assumptions

Cohesion Values

Vegetation / Surface Type	Min	Mean	Max
Open Water	0	0	0
Perennial Ice/Snow	0	0	0
Developed Open Space	1.28	1.44	1.68
Developed Low Intensity	1.04	1.17	1.3
Developed Medium Intensity	0.8	0.9	1
Developed High Intensity	0.16	0.18	0.2
Barren Land	0.03	0.1	0.15
Deciduous Forest	5.7	6.2	7
Evergreen Forest	3	10	20
Mixed Forest	4	8	14
Dwarf Scrub	1.2	4	10
Shrub Scrub	1.2	4	10
Grassland Herbaceous	1.6	1.8	2.1
Sedge Herbaceous	1.6	1.8	2.1
Lichens	1	2	3
Moss	3.5	5.25	7
Pasture Hay	1	2	3
Cultivated Crops	1	2	3
Woody Wetlands	0.1	0.2	0.3
Emergent Herbaceous Wetlands	0.1	0.2	0.3

Sediment Type	Min	Mean	Max
Sand	0	0	0
Silt	0	5	10
Clay	10	15	20

Iterations:	3000
Recharge Type:	Log Normal Spatial
Mean:	2.8 mm/d
Std Dev.:	12.5 mm/d

Sediment Type	Friction Angle (degs)
Sand	35
Silt	34
Clay	20

Matilija Watershed, CA

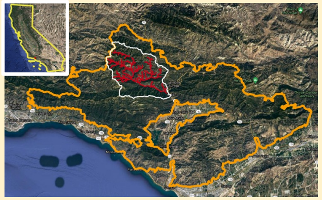

Figure 2: The Dec 2017 Thomas Fire (orange polygon) burned >225,000 acres of Southern California wilderness, including the Matilija Watershed (white polygon). Heavy rains in Jan 2018 led to sediment-rich fluvial events debris flows (red lines). We use Landlab's landslide component to evaluate probability for slope failure.

***Results:** Several areas within the Matilija watershed were unstable prior to the Thomas Fire in Dec 2017. However, the loss of vegetation due to the fire and the expected loss of cohesion from decaying roots has decreased slope stability throughout the watershed. Consequently, nearly the entire region appears highly vulnerable to shallow landslides.*

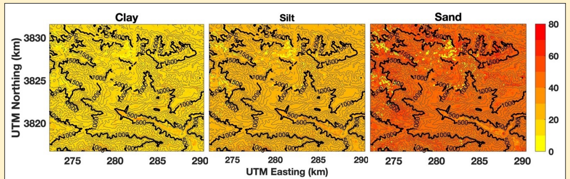

***Figure** 3: Soil Composition in the watershed predicted by POLARIS [Chaney et al, 2016]. The area is predominately underlain by sand (~50%), with some silt (<30%) and minimal clay (<20%).*

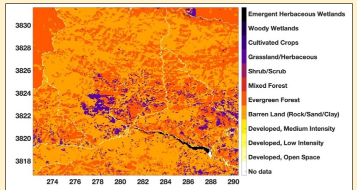

***Figure** 4: Local vegetation as determined from the National Land Cover Database (NLCD)*

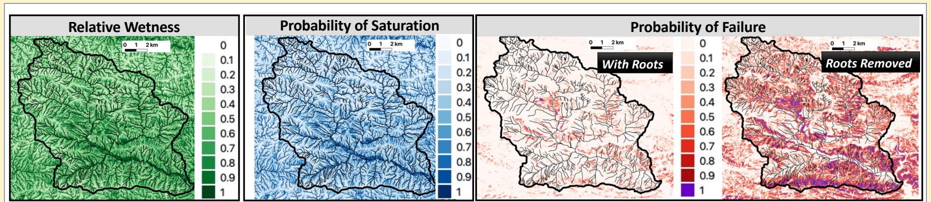

***Figure 5**: Landlab results showing the relative wetness (left), probability of saturation (left-middle) and probability of slope failure (right); two modes of slope failure are shown – with and without root cohesion to simulate the effects of wildfire.*

CalWood Fire Site, CO

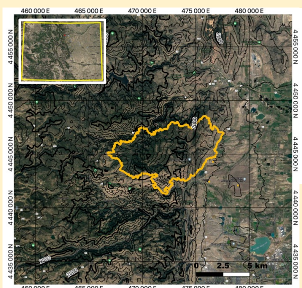

Figure 6: The CalWood fire (orange polygon) north of Boulder, CO burned >10,000 acres between Oct – Nov 2020 We used Landlab's landslide component to evaluate probability for slope failure before and after the fire.

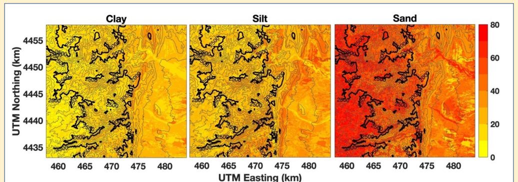

***Figure 7**: POLARIS [Chaney et al, 2016] soil composition is similar to the Matilija site with ~50% sand, ~30% silt and minimal clay (<20%).*

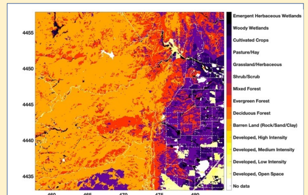

***Figure 8**: Local vegetation from NLCD*

***Results:** Unlike the Matilija site where several areas of moderate instability were made significantly worse by the wildfire, the stability of the Calwood site only marginally decreased after the fire, suggesting that slopes in region will remain stable if/when similar precipitation and recharge values occur here.*

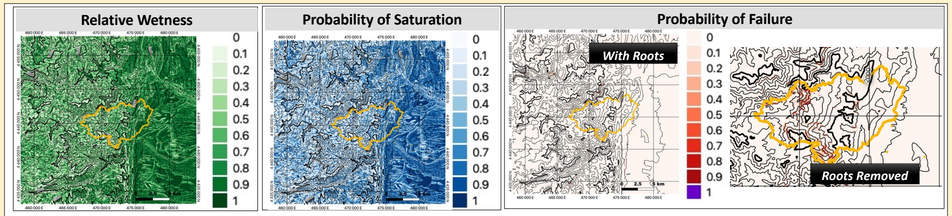

***Figure 9**: Landlab results showing the relative wetness (left), probability of saturation (left-middle) and probability of slope failure (right) with and without root cohesion to simulate the effects of wildfire.*

Next Steps

- Derive a record of slope failures at the Matilija site. How does it compare with predicted values?
- Investigate why the sites exhibit such different responses given the similarities in soil composition.
- Investigate precipitation / recharge threshold values necessary to impose failure at CalWood. Compare with records of precipitation frequency and intensity. What conditions are required to initiate slope failures in the region.
- Expand survey to other recently burned areas in California and Colorado.

Citations

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