INTRODUCTION
Jones Creek Watershed
The Jones Creek watershed is a small mountain basin located west of Acme in Whatcom County, WA (Figure 1). The lower portion of the watershed is underlain by the Cretaceous-aged Darrington phyllite, a mechanically weak rock that is prone to developing unstable soils (Jakob et al., 2004). There are four major active landslide bodies in the phyllite, including the Cutblock, Darrington, Straight, and South slides (Figure 1). All of the landslide bodies except the Cutblock have approximately two million years since the stream channel. Shallow mass wasting events on the landslide during periods of intense precipitation can lead to debris flows that threaten Acme residents. Here we discuss the application of the DHSVM as a useful tool for identifying specific areas in the Jones Creek watershed that are susceptible to mass wasting during extreme precipitation events.

Soil Type (STATSGO database)
Develop the grid
\( \theta = \text{angle of internal friction} \)
\( T = \text{Temperature (C)} \)

Probability Thresholds
Mass wasting is simulated for 87 historical storms of a variety of magnitudes and durations. Each storm is plotted according to precipitation duration (hours) and intensity (centimeters per hour) and coded according to the failure probability at the top of each mapped landslide. Probability thresholds are then interpreted from cumulative 10 percent intervals (Figure 6). Storms with failure probability between 40 and 70 percent plot empirically and can be subdivided into shorter time scale. Superimposed thresholds for shorter storms compared with Godd (2004) intensity-duration threshold for the Seattle area, which has an exceedance probability of 42 percent (Figure 4). For longer storms, the Godd (2004) threshold predicts greater failure probability.

METHODS
Model Setup

We obtained hourly meteorological data from the nearby Abbotsford A-station, British Columbia, Canada, which is located approximately 30 miles north of the study area. The station was selected for its long historical record of data. Meteorological model inputs include the following parameters:

- Temperature (C)
- Wind Speed (m/s)
- Relative Humidity (%)
- Longwave Radiation (W/m²)
- Shortwave Radiation (W/m²)
- Precipitation (mm)

Physical model inputs include a stream network and the following 30-meter resolution GIS data sets (Figure 3):

- Digital Elevation Model (Puget Sound LiDAR Consortium)
- Soil Type (STATSGO database)
- Landcover (NOAA, Figure 3)

The infinite slope factor of safety (FS) equation describes planar failure in shallow soils (Figure 4). The equation is commonly used in modeling applications because it is computationally efficient and the variables are readily available from literature or field measurements. The equation is based on the concept that failures are hydrologically triggered when water table fluctuations cause local pore pressures to reduce soil shear strength below the imposed stresses (Oyen and Lettenmaier, 2004; Hammond et al., 1992). The equation is solved cell by cell over a ten-meter DEM:

\[
FS = \frac{1 + \theta}{\gamma} \left( \frac{C}{D} \right) - \frac{1}{1 - \theta} \left( \frac{C}{D} \right) - \frac{1}{\gamma} \left( \frac{C}{D} \right)\left( \frac{C}{D} \right)
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DHSVM uses a stochastic probabilistic approach to model slope instability. The advantage of this approach is that it is possible to quantify some of the uncertainty and variability associated with the parameters that govern slope instability (Hammond et al., 1992). Values for soil cohesion, root cohesion, angle of internal friction, and vegetation surcharge are chosen at random from probability distributions defined by the specific soil and vegetation type at each cell (Figure 5). We use literature values and distributions. Although values for soil cohesion and angle of internal friction are usually chosen from normal distributions, we use uniform distributions for those parameters to reflect the notionally high degree of mechanical variability in active landslides.

Mechanical Parameters

- \( \theta \): angle of ground surface
- \( D \): total soil thickness (m)
- \( C \): soil cohesion (kPa)
- \( q_v \): vegetation surcharge (kPa)

RESULTS

DISCUSSION

The relationship between failure probability, basin saturation, and antecedent precipitation is erratic between 40 and 70 percent probability for both the South and Straight landslides. This could represent a transitional zone where small changes in soil saturation cause minor fluctuations around a factor of safety of one, and therefore significant variability in failure probability. Assuming the parameters that control failure probability have been adequately characterized, the forty percent failure probability thresholds can be thought of as a major break above which failures are quite likely. An abrupt change in stochastic failure probability beyond a certain soil saturation level can be indicative of a real failure probability threshold, even if the actual exceedance probability differs from the modeled probability (Bert et al., 2012).

Stochastic Modeling with the Infinite Slope Equation

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