# Landslides – Infinite Slope Factor-of-Safety Model

## Abstract

This activity is designed to expose students to one of the classic equations used by geologist and engineers to investigate and understand the stability of a hillslope, especially as it relates to soil moisture. Students will learn the infinite slope stability model for estimating the “Factor of Safety” for slope stability. They will also experiment with changing the parameters of the model to explore a sensitivity analysis. Sediment transport in streams begins with upland slope erosion. Episodic erosion in the form of landslides contribute the bulk of sediment carried by streams, which affects fluvial geomorphology and flood patterns. Soil moisture driven by precipitation and snowmelt is a primary trigger of many landslides and changing climate is projected to alter the frequency and magnitude of these triggers. The exercises focus on connecting the dots in the hydroclimatic influence on hillslope and fluvial processes. Using hydrologic model results for recharge, students will explore hillslope landslide probabilities and changes in these probabilities with changing climate. The model is applied to a high elevation natural area in Washington, but is applicable to other areas where steep slopes and high precipitation contribute to landslide hazards.

## Intended Audience

This unit is intended for upper level undergraduate and graduate students in hydrology, environmental engineering/sciences, and geology/earth sciences.

## Conceptual Learning Outcomes

1. Students learn what factors contribute to hillslope stability and instability.
2. Students will discover how sensitive stability is to different factors.
3. Students will learn how spatially variable site characteristics influence stability.
4. Students will explore the stability consequences of factors affected by changes in climate.

## Practical learning Outcomes

1. MS Excel and spreadsheet-based calculation and visualization of a simple model
2. Accessing data online to better grasp place-based data and available tools
3. Prediction and estimation of the effects of varying a key model parameter on model results
4. Use of parameter distributions and Monte Carlo simulations to capture uncertainty and identify a spatially-distributed probabilistic landslide hazard

## Reference Videos and Documents

1. When Nature Strikes - Landslides

<https://www.youtube.com/watch?feature=player_embedded&v=dj44dpr8oHs>

About a 5-minute video on landslides in Washington, specifically at Oso and near Mount Rainier.

1. USGS (2004) Landslide types and processes: Fact Sheet 2004-3027. <http://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html>
2. The Water Cycle and Climate Change

<http://earthobservatory.nasa.gov/Features/Water/page3.php>

Provides global maps of changes in precipitation intensity, stream runoff, and drought

1. Basic information on factor of safety: <https://en.wikipedia.org/wiki/Factor_of_safety>

## Instructions

This activity has been designed as three exercises. Each of the exercises has a series of questions for the students to answer that will help them understand the relevance of the exercise. The first exercise has the student use Excel to understand and explore the factor of safety equation, including impacts from modifying the factors within the equation. The second exercise works on the students graphing ability and provides a visual way of seeing how factor of safety changes given relative wetness and slope. The final exercise exposes the students to real world data and the earth surface modeling using Landlab. Data and use of Landlab is provided on the web through HydroShare – an internet resource designed for sharing, acquiring, and collaborating with hydrological data. After going through the reference video and documents above, step through these exercises for a broad introduction to hillslope stability and what drives the changes we see and experience in the landscape around us.

## Steps within this Unit

1. **Using Excel to understand Factor-of-safety equation**
2. Open up the Excel *FS\_Exercise.xls* file.
3. There are 3 parts to this spreadsheet: 1) the factor of safety (FS) equation and its parameters, 2) the calculation section, and 3) visualizing results and study questions.
4. Review the equation, its general meaning, and the makeup of *resisting* and *destabilizing* forces. Go over each of the parameters of the equation. Review the units of the parameters.
5. In Part 2, example values of parameters (low, middle, high) are provided. Formulas that calculate the two elements (A and B) of the FS equation are provided. Click on the boxes, look at the formulas within, and try to match the formula to the equation in Part 1.
6. Perform your own calculation by entering in values in the blue boxes and watch the “Your Results” change.
7. Perform sensitivity test by keeping all the parameters the same and adjusting only one, such as slope angle or cohesion. Some parameters have a lot of influence of the FS compared to others. This is a sensitivity analysis.
8. Part 3 provides a graph where you can see where their results plot compared to the 3 examples. Are they above or below FS=1?
9. Address the following questions in your exercise:
10. What does it mean when FS = 1?
11. What are the units of FS? (*Hint: Cancel out the units*)
12. What happens to the first element (A) of the FS equation when cohesion is 0?
13. What is FS when slope is 0? (*Hint: can you divide by 0?)*
14. What is FS when soil depth is great (like 30 m) and soil is saturated? Why do you think that is?
15. Why do you think the example with the highest value of cohesion resulted in a FS < 1?
16. What parts of this equation are likely to be influenced by climate? How does this depend on where you are and what time of year?
17. **INSTRUCTOR**: To unprotect the spreadsheet for making amendments/edits, click the *review* tab, *change* group, and *unprotect sheet*. A password may be required, which is “unprotect”.
18. **Creating a graph in Excel to understand relationship between slope and factor-of-safety when conditions are wet or dry**

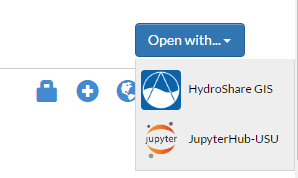
In this exercise, you will create a graph of the factor-of-safety (y-axis) and slope (x-axis) for two different soil wetness conditions: Rw = 1 (saturated soil) and Rw = 0.1 (dry conditions). Set the Rw=1. Record the FS value as you change the slope in increments of 5 degrees (from 0 to 45 degrees) in the table below. Repeat this, but set the Rw=0.1. On graph paper or in Excel, plot the FS vs Slope for each of the Rw conditions (2 columns below). Address the following questions:

1. How does the factor of safety change as slope increases?
2. Is the relationship between slope and FS linear (straight line) or not?
3. For the same slope, which Rw line has the higher FS? Explain why this is the case.

|  |  |  |
| --- | --- | --- |
| Slope | Factor of Safety when  Rw = 1 | Factor of Safety when  Rw = 0.1 |
| 0 |  |  |
| 5 |  |  |
| 10 |  |  |
| 15 |  |  |
| 20 |  |  |
| 25 |  |  |
| 30 |  |  |
| 35 |  |  |
| 40 |  |  |
| 45 |  |  |

1. **Using “Landlab” to explore a model of landslide probability in a real-world setting**

In this exercise, you will apply the infinite slope stability model in a real world setting. The location is Thunder Creek watershed in North Cascades National Park Complex in Washington. This is a steep environment with glaciers at the mountain tops and relatively large landslides in the past. You will be acquiring data and accessing “Landlab” landslide component from HydroShare ([https://www.HydroShare.org](https://www.hydroshare.org)). Landlab is a Python-based landscape modeling environment and the landslide component is one of many components available for users to access and link together to build their own landscape model. For more information about Landlab, see <http://landlab.github.io/#/>.

1. Access the data of Thunder Creek watershed and the Jupyter Notebook tutorial via HydroShare
2. Go to [www.HydroShare.org](http://www.hydroshare.org/) and click on 'Sign up now' Blue Button
3. Create an account if you don’t have one. After filling out “Sign Up” profile information (can edit at a later date), verify and activate account from your email (sent by HydroShare).
4. Go back to HydroShare and Sign In with you user name (email) and password.
5. Click on ‘Discover’ tab at top.
6. In Search window, type: “Thunder Creek Landlab Landslide Example”. Select this resource.
7. Read the *Abstract* about this data and exercise.
8. Scroll down to see the ‘Content’ and the data used in the ‘landslide’ component and the Jupyter Notebook that accesses the tutorial “landslide\_driver.ipynb” that will ‘drive’ the component.
9. To run this tutorial within HydroShare, once you’ve navigated to the “Thunder Creek Landlab Landslide Example”, click on the 'Open With…' blue button and select 'JupyterHub-USU'.   
     
   EXTRA - For instructions on how to run an interactive iPython notebook, click here: <https://github.com/landlab/tutorials/blob/master/README.md> and links within.  
   For more Landlab tutorials, click here: <https://github.com/landlab/landlab/wiki/Tutorials>
10. To access the tutorial notebook, execute the “Import the Required Libraries” (might need to scroll down) by clicking once in the shaded code box with **In [ ]:** in front and then typing “shift-enter” (both keys at the same time). A \* will appear in the [ ] when this code box is running.
11. You will likely need to enter your HydroShare Password again in box provided. This should end with a green text saying “Successfully established a connection with HydroShare” and a 1 in the [1].
12. Also execute the “Get the HydroShare Resource Content” code box. This accesses the “landslide\_driver.ipynb” tutorial. If you’ve run this tutorial before, it will ask if you want to overwrite you previous work, type ‘y’ for yes.
13. A list of the content of this resource is provided and it also finds the notebook we want. Click on the “landslide\_driver.ipynb” notebook in blue text at the bottom.
14. Now you are inside the landslide tutorial. Congratulations! Read the introduction and begin executing the code boxes one-by-one using “shift-enter”. Also read the before and after text boxes to understand what you’re executing. Some might take a few seconds or even minute to run given the size of the datasets.
15. You can also try some of you own code by selecting the + in the menu bar at top, which adds a new code cell. Try doing this and type in the box “print ‘hello world’” (not the “). Then “shift-enter”. See your output!
16. To run this tutorial on your own machine,
    1. To download all the data, click on the button ‘Download All Content as Zipped Bagit Archive’
    2. To use this tutorial, you should have Landlab installed and up-to-date on your computer. To install Landlab, please follow the instructions: [https://landlab.github.io/#/#install](https://landlab.github.io/#install). This will require you to have a preassembled Python distribution (like Anaconda) on your machine and it is up to date (see the install link above).
    3. Open the “landslide\_driver.ipynb” Jupyter Notebook from within the location where you archived the data.
    4. Run through the tutorial by reading the introduction and begin executing the code pieces using “shift-enter” one by one.

## Assessment

**Study Questions**

* 1. What hillslope factor-of-safety value would you consider building a house on? When would you avoid building?
  2. Does geology play a role in the factor-of-safety value? How?
  3. Would it be wise to clear trees on a hillslope with an estimated factor-of-safety value of 1? What parameters within the equation do trees affect?
  4. Does the factor-of-safety value provide information about how large a landslide might be or how far it might travel?
  5. In what situations would the infinite slope factor-of-safety approach not be appropriate?
  6. Where might you expect a hillslope to be stable and where would it be unstable? Does the Landlab landslide component example (exercise C) shed any light on this question?
  7. How would assess stability in urban areas? What conditions are different there?