Various “triggers” can initiate landslides. This exercise investigates how rainfall amounts, rates and durations influence the initiation and likelihood of debris flows in the La Honda, California region.

This region is in the central Santa Cruz Mountains on the western US coast (see attached figure). The underlying rocks are sedimentary, with some interspersed volcanics, and the mountains rise gradually from the sea to heights of approximately 1,000 m, 10 to 15 km inland. The mountains have not been glaciated, and thus a thick cover of soil and vegetation is present over most of the area. Most of the annual precipitation (>85%) falls as rain from November to March. A geologist at the US Geological Survey collected the given data set, based on observations from 1975 to 1984.

Each data row corresponds to a particular storm over the dates given. The storms have been grouped into three sets (Group 1, 2 and 3). The occurrence (or lack thereof) of debris flows is noted in the last data column, which gives the number of debris flows that were observed in the 10 km² study area. Bear in mind that the study area was fixed, therefore slope and hillside material types were not variables being evaluated. Most of the debris flows observed (74 out of 110 total) occurred during a single storm (Storm #5). However, there are some generalizations that can be made about what kinds of conditions tend to produce debris flows. Group 1 storms produced debris flows, whereas storms in Groups 2 and 3 did not. Group 2 data all have pre-storm seasonal rainfall that is below a threshold of 28 cm, whereas Group 1 and 3 both have pre-storm seasonal rainfall above the 28 cm threshold.

Your exercise is to answer some questions by evaluating this data set. The underlying goal is to discern what the best predictors of debris flows might be in terms of rainfall information. This information could be used in a debris flow warning system. You can make millions!!!!

The hardest part of this exercise is to rearrange the spreadsheet data sets into configurations that allow you to graph the variables you might want to evaluate. You will need to work in Excel, cut and pasting data, and you may want to work with several “worksheets” to keep things from getting too messy. You will turn in all graphs used to answer the questions below.

1. Let's start with some simple questions: a) How does pre-storm rainfall (the amount that fell in the rainy-season months just prior to each storm), vary among the groups? b) How does pre-storm rainfall influence debris flow onset? c) How important do you think pre-storm rainfall is in predicting debris flows?

2. a) How does total rainfall per given storm vary among the groups? b) How does max. rainfall rate (intensity) in each storm vary among the groups? c) How important do you think rainfall intensity and total rainfall are in predicting debris flows?

3. a) For Group 1 storms that caused debris flows, how does total rainfall, and max rainfall rate compare with numbers of debris flows caused by the storms? b) Make a graph of each of these comparisons. Excluding the storm on Jan 3-5, 1982 that caused the
largest number of flows, which of these factors (total rainfall or max rainfall rate) exhibits the stronger relationship with numbers of debris flows?

4. Compare the total rainfall and maximum intensities of Group 1 storms with those of Group 3 storms. This requires making a graph. Are there clear thresholds in total rainfall or maximum intensities that dictate whether debris flows will occur?

5. Why do you think the intense storm on 23-24 December did not trigger any debris flows? Consider pre-storm rainfall, total rainfall and max rainfall intensity. Does this shed light on lack of debris flows from Group 2 storms in general?

6. Consider the interplay between rainfall intensities (e.g., 0.25 cm/hr, 0.5 cm/hr, etc.) and the durations (in hours) of rainfall at those intensities. Make an x-y plot to compare the intensities (y-axis) and durations (x-axis) of Group 1 and Group 3 storms (that initiated or did not initiate debris flows, respectively). This will require some cutting and pasting as well as data rearranging. Your ultimate goal is to have a column of intensity versus a column of duration for Groups 1 and 3. Having done this, inspect the graph

   a) Is there an obvious threshold of rain duration for given intensities that must be exceeded to produce debris flows in the study area? b) How would you expect these quantities to interact to produce debris flows? c) Print out your graph, and sketch in a line delineating the boundary between debris flow storms (group 1) and non-debris flow storms (group 3). d) For what intensities is this threshold better defined, vs. poorly defined (make some kind of distinction in the threshold line thickness or color and use a legend)? e) How might that play into hazard prediction? f) Come up with a way to fit a mathematical threshold curve to your data. What type of relationship best describes this threshold? g) Do you think this mathematical relationship will work at predicting landslides elsewhere? Why, or why not? h) Plot your derived mathematical relationship on a plot of intensity versus duration for Group 2 data. Group 2 data represent all of those values from storms that occurred before a prior seasonal rainfall threshold of 28 cm had been achieved. What does this relationship tell you about your calculated threshold? i) A recent published threshold relationship for coastal British Columbia landslides has the relationship:

   \[ I = 14.82 \times D^{0.39} \]

   Where \( I \) is intensity in (mm/hr NOT cm/hr) and \( D \) is the duration in hours. The values of 14.82 and -0.39 are empirically-derived coefficients and define the intercept and slope of the relationship in log-log space. The authors of this study speculate that their threshold relationship is valid for many areas affected by rain induced landslides. Plot this threshold relationship on the graph of your data – does the B.C. relationship work in La Honda? Explain your answer. j) How could your mathematical expression for landslide threshold be used for mitigation purposes?
Figure 1. Location of study area near La Honda, in central Santa Cruz Mountains of the San Francisco Bay region, California.