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Using Raster GIS Analysis To Determine Slope Stability

1 Introduction:

Slope failure can bring about the destruction of property and lives. In urban areas, an estimation of slope stability is conducted by ground surveys, which are time consuming and costly. With the use of geographic information systems analysis, an estimate of the probability of slope failure can be derived for a larger area in a shorter amount of time, provided that enough data exists to assess the geographic area in question.

This project does not attempt to accurately identify areas that are likely to have slope failure. It is meant to demonstrate and explore the capability of GIS utilities. Within the City of Prince George, the topography is relatively flat; however, near the city center is a massive hill (Connaught Hill) that is a remnant of the last glaciation to occur in this area. As this hill has somewhat steep slopes and is located directly beside urban areas, it seemed a good study area for the purposes of this project.

The principle behind this project is that given a range of raster variables that describe a geographic area in terms of slope stability, a favorability analysis can be performed to find areas with a high probability of slope failure provided a training area is given where slope failure has occurred. That is to say that if an area where slope failure has occurred is described (at a previous period) by certain values within a range of variables, then by correlation other areas that had those same values within the same range of variables will possibly experience slope failure as well.

The source data for this project include a digital contour file, a cadastral city land title map, a city roads coverage, a Landsat image and a 1 metre orthophoto image. Given this data, the following slope stability related raster variables will be derived: slope, a normalized difference vegetation index, and a flow accumulation index. A training area will be arbitrarily determined along an area where slope failure has occurred. Given this data it will be determined which areas of Connaught Hill are likely to fail, within a given probability. As mentioned previously, it is the purpose of this paper to examine the potential use of GIS analysis for this problem, not to accurately get a probability of failure. Due to the nature of the arbitrarily assigned training area, the supposition for probability to fail is best defined as follows; given that the area described by the assigned training area will experience slope failure in a given geological event (an earthquake for example), which areas of Connaught Hill will also experience slope failure.

2 Data Processing:

**The majority of the project was completed with PCIWorks, some elements of MicroStation, ESRI Arc*

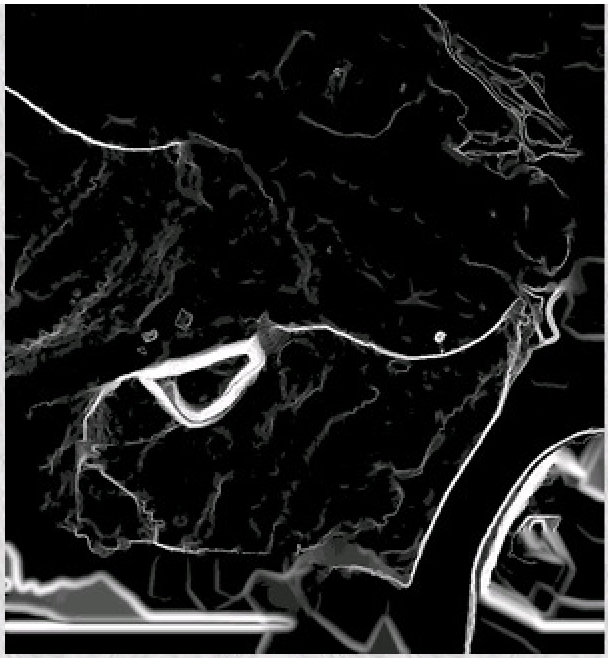
*Products, and Alchemy were also used.**
Click on an image for full view

2.1 Variable Development:

2.1.1 Slope:

Before a slope channel can be created a digital elevation model was needed. As the finest resolution raster data set available was one metre (the orthophoto), it seems apparent the resolution of the DEM should be one metre as well, especially considering the DEM is based on contours with a one metre step size. Therefore the DEM was built into a pix file already containing the orthophoto. The DEM was built using the contours and also using roads as hard breaklines, all with the routine vdemint. Once the DEM was completed, a slope was derived using the routine slp.

Shown Below:
One Metre Orthophoto (Far Left)
DEM With False Building Elevations (Middle) - Building Elevations are Modelled to Create 3D "Feel" for the Prince George Scene (Shown Later)
Slope (Far Right)

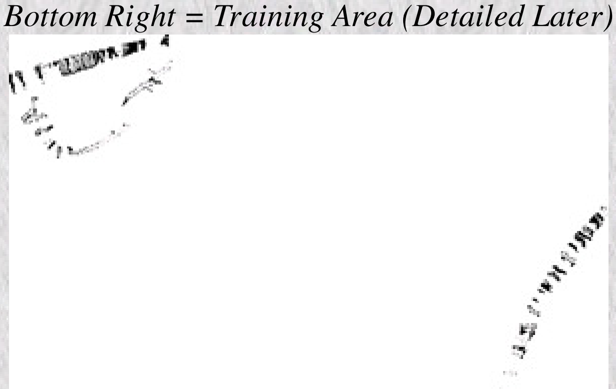



2.1.2 Flow Accumulation:

Flow accumulation is the measure of pixels that flow into each pixel. As watercourses generally form in a landscape, so does this channel generate probable watercourses, given elevation values. Flow accumulation can be derived simply from a DEM. The routine used to generate flow accumulation in PCIWorks is dwcon, which firsts computes a depressionless DEM, and from that a flow direction, and from that a flow accumulation, and finally a delta value channel. The only channel that is needed for this project is the flow accumulation channel.

Due to the poor contrast on the flatter areas within the DEM, much of the resulting flow accumulation was of little value. However, the areas with high elevational transition had a good flow accumulation map and therefore the bad aspects of the image were segmented out. Slope failures do not occur in linear lines less than a metre wide. As the flow accumulation channel displayed sinuous or linear features it was determined an average filter would be used to smooth the data, a 9X9 grid was used to maximize smoothing without losing original values. The resulting modified flow accumulation was much more adaptable to classification.

Flow Accumulation (Segmented and Average Filtered)
Top Left = Connaught Hill
Bottom Right = Training Area (Detailed Later)



2.1.3 NDVI:

The source data for this project include a Landsat image from 1992. From this image, a measure of the red wavelengths and near infrared wavelengths can be used to generate a normalized difference vegetation index. However, a Landsat image has pixels that are 30m across, this particular image had been resampled to 25m pixels, which is a much coarser resolution that the orthophoto resolution. Therefore the Landsat data could be fused with the orthophoto to create higher resolution. Red wavelengths correspond directly with an orthophoto intensity image because an orthophoto is a measure of visible light and does not incorporate near infrared wavelengths. Therefore it made little sense to fuse both bands of Landsat data with the orthophoto. The NDVI was then created and scaled using the modeling formula given in the documentation in the appendix.

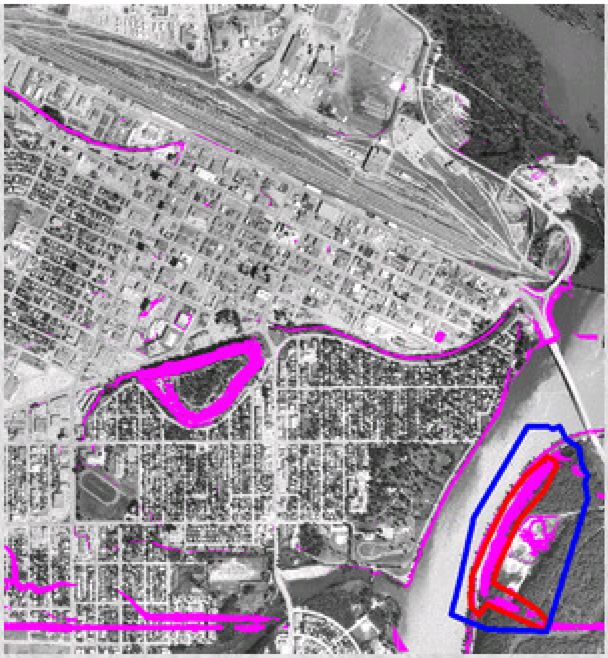
Normalized Difference Vegetation Index

2.2 Classification and Spatial Integration:

Classifications were then run on the three different input channels. According to PCIWork's documentation, favorability analysis performs better if the input classifications do not have a wide range of classes. Therefore the three channels were classified using eight classes. The slope and NDVI got the best results from the k-means classification, while the flow accumulation classification was far superior using the fuzzy k-means method.

To perform favorability analysis two training areas, or bitmap masks, have to be created. The first identifies the area surveyed for whatever the favorability analysis is to predict. The second identifies the area within the survey where the incident in question has occurred. These were determined arbitrarily as this type of survey is beyond the scope of this project. An area alongside the east bank of the Fraser River shortly after its confluence with the Nechako River was used. Along this bank there are many portions where slope failure has already occurred so it was felt this area was a good approximation.

Overview Image: Orthophoto with Training Areas and Output Vectors
Red Vector (Smaller Vector in Bottom Right) =Area of Occurence
Blue Vector (Larger Vector on Bottom Right) = Area of Survey
Pink Bitplane (Bitplane throughout Image) = Area of Probable Occurence



Favorability analysis in PCIWorks first requires the input classifications to be grouped together. The routine that performs this calculates a probable weight factor for each input classification, basically it determines which classifications best describe the bitmap masks and assigns a weight factor. The weight factors were as follows:

1. Normalized Difference Vegetation Index = 0.43
2. Slope = 0.69
3. Flow Accumulation = 0.32

It then outputs a channel called the unicon channel which is called up by the routine to perform the actual analysis. The actual analysis has many different algorithms that can be used to do the analysis, all of the algorithms were executed and it was determined that the 'Fuzzy Gamma' method yielded the best results with an r squared value of 0.950.

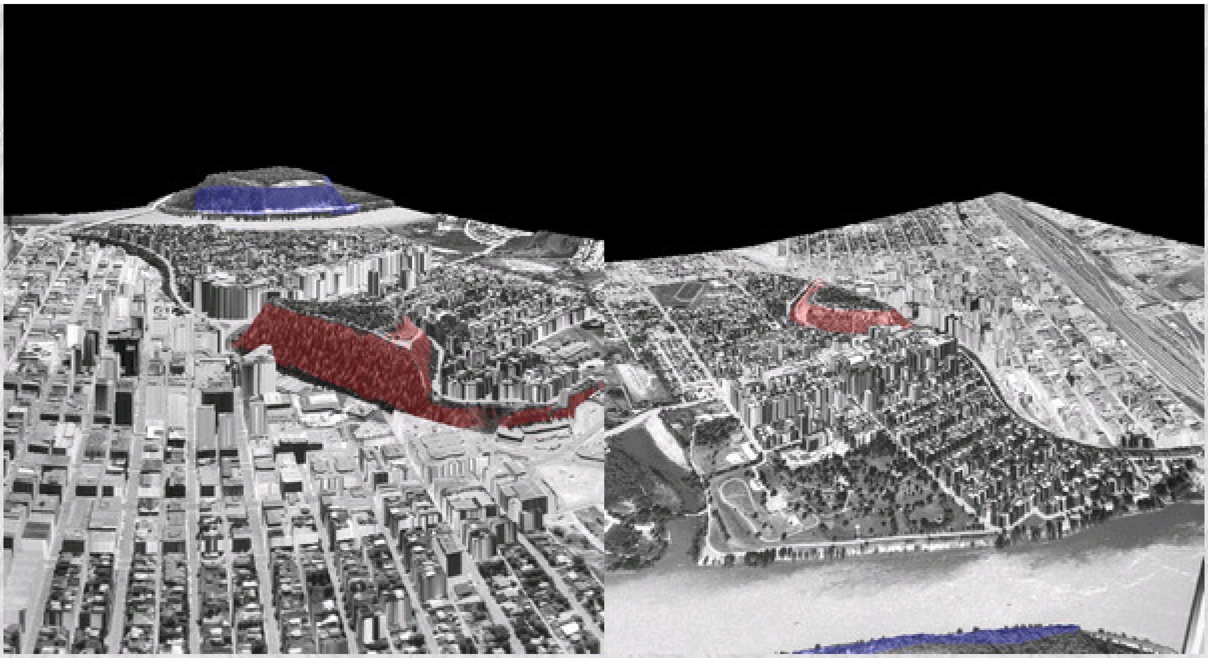
This creates an output eight bit channel which is scaled to indicate probability, that is to say a value of two hundred indicates an extremely likely probability, while a value of ten would be extremely unlikely. This image was thresholded keeping any value 96 percent or higher likely to fail, or any value within a digital number range of 245-255. The areas that do not incorporate Connaught Hill were then segmented out.

2.3 Output:

To display the resulting data best it was desired to model the probable slope failure bitmap mask into the high resolution orthophoto by adding a scaling value to any area described by the bitmap mask. If the resulting orthophoto is then shown in red along with the original orthophoto in blue and green, then those areas with probable slope failure will appear with red tints. The training area where it was arbitrarily decided that slope failure had occurred was modeled in the same way and will be shown with blue tints.

Connaught Hill is centrally located around the downtown area of Prince George. Slope Failure in this area would be catastrophic. To indicate the importance of this, the digital elevation model was altered to include 'pseudo' building heights using the cadastral city lot information. The modified orthophoto scheme was then draped overtop in a 3D perspective to create the two main output images.

3D Scenes of Prince George With Slope Failure Area Tinting
SE Aspect on Left, NW Aspect on Right
Tinting in Center = Connaught Hill
Tinting in Top (Left Image), Tinting in Bottom (Right Image) = Simulated Known Slope Failure Occurence



3 Discussion:

3.1 Limitations:

The final output in no way shows an area that is actually likely to experience slope failure. It shows those areas likely to fail given the set of rather presumptuous assumptions. These assumptions include:

1. Data derived from a low quality DEM (flat area built from contours) will not alter the final favorability analysis because those areas of high rates of elevation change will be higher quality.
2. That the 'pseudo' surveyed areas along with the areas of actual occurrence are accurately estimated.
3. That slope failure can be accurately estimated from only flow accumulation, slope, and NDVI data.

However, it was not the intent of the report to describe the actual area of probable slope failure, but to identify the feasibility of using favorability analysis in PCIWorks to estimate areas of probable slope failure. If some of the assumptions were removed and other data sets were added to the methodology (soil type, parent material, etc), it seems likely that an accurate estimate could be done. At the very least, the program is capable of performing this type of analysis.

3.2 Results:

The results of this analysis were not particularly encouraging. Due to the high importance of slope relative to the other inputs and the estimated bitmap mask of areas of known occurrence, the entire area of Connaught Hill was identified as likely to fail. While this may make sense according to the computers algorithm methods, it is clearly apparent looking at Connaught Hill that this is unlikely. Therefore the fault lies in the input data. With a more topographically varied area, and an actual survey, it would be possible to do this analysis with much more meaningful results.

4 Summary:

This report shows that the possibility exists to accurately assess the possibility of slope failure for broad geographic regions in a relatively short amount of time. The ranges of possibilities for this type of analysis are vast. City planners can identify areas that should have retaining walls and such built on them. Rather than use subjective variables (i.e. slopes greater than x percent), forest practices could incorporate this type of study to look at a wide range of factors to determine if a slope is unstable.

Other methods could be used to do similar types of analysis. Skiing enthusiasts could benefit from areas of high avalanche probability given variables such as slope, aspect, and volume. There are many such examples of the benefits of this type of analysis.

For a complete step by step data processing breakdown see: Documentation (Word Document)