

Visual Representation of Landslide Cutback at Deer Run Heights, Jeffersonville, VT Using GIS, Lidar, and Drone Imagery Models

Department of Environmental and Health Sciences
Northern Vermont University at Johnson, VT
December 13, 2018

Written by:
Lillian L. Kolbenson
Senior Thesis and Independent Study

Table of Contents

Abstract	2
Research Objective	2
Introduction	2
Methods	4
<i>Creating GIS Data Points</i>	4
<i>Creating a Presentable GIS Map</i>	5
<i>Creating a 3D Model of a Landscape in Agisoft Photoscan</i>	7
<i>Importing and Using a 3D Model from Agisoft Photoscan into ArcGIS Pro</i>	7
Results	8
<i>Cutback Measurement Data Collection</i>	8
<i>Visualization in a GIS Map</i>	12
<i>Visualization in 3D Models</i>	13
Discussion	14
<i>Data Collection and GIS Map Analysis</i>	14
<i>3D Models of the Landscape Analysis</i>	16
Conclusion	16
Acknowledgments	17
References	18
Appendix	19

Abstract

The landslide located off of Deer Run Heights in Jeffersonville, VT has been continually monitored since the 1999 event. While multiple aspects are being studied, this research project attempts to visualize the data in order to demonstrate the cutback that has occurred since the 1999 event. GIS data is coupled with both the long-term cutback measurements and Lidar, to demonstrate the evolving landscape.

There have not been any large movements noted from these data collected on the landslide site, only gradual changes, however the changes in the ridgeline are proving to be significant overall. Overall, on average this landslide site over the data collection years had a change of 1.48 m, which equates to approximately 0.12 m per year over the 12 years observed at each stake location. However, sectors of the landslide site are more active than others. From the cutback measurements collected and visually speculating the ridgeline, more land will be lost due at this active site.

The GIS maps and video created demonstrate the change overtime visually from the data collected. The 3D model offers exploration and demonstrate of the current state. In future years, these products may be used to compare to changes in this landslide site.

Research Objective

The research objective is to visually demonstrate the cutback at the Deer Run Heights landslide site through maps, video, and 3D models. The results will be shared with the town of Jeffersonville, the Vermont Geological Survey, and displayed on Dr. Leslie Kanat's website regarding landslide research at this area.

Introduction

A major landslide event occurred in 1999 (Vermont Geological Survey, 2018). Figures 1 and 2 show

the location following the landslide event (Vermont Geological Survey, 2018). It left one home overhanging from the ridgeline and threatened other local residences with potential damage



Figure 1. The landslide site showing the debris (Vermont Geological Survey, 2018).



Figure 2. The Jeffersonville landslide site after the event in 1999, showing the overhanging home (Vermont Geological Survey, 2018).

(Vermont Geological Survey, 2018). The state of Vermont claims that the geological factors that caused this event included assorted rock and soil materials, high levels of water in the soil, and erosion due to the river beside this site (Vermont Geological Survey, 2018). These are all conditions that continue to threaten this location and would likely be the cause of future movement. The project that observes this location is supported by the Vermont Emergency

Management Planning. The top of the landslide site can be accessed off of Deer Run Heights. The site is located beside the Brewster River that empties into the Lamoille River. The location neighbors multiple residential homes and overlooks Cambridge Elementary School as well as other residences. Through the state of Vermont, Northern Vermont University has been one of the partners in monitoring this site since the 1999 landslide event. Dr. Kanat has helped facilitate these assessments through multiple methods including using time domain reflectometry to identify fluctuations of strain, soil moisture logging, depth to the water table, and cutback measurements of the ridge.

The estimated size of the 1999 landslide was 27,000 cubic yards (Vermont Geological Survey, 2018). There are fine sands and silt clay layers dispersed through the terrain. Figure 3 shows the soil types found at the landslide site (Natural Resources Conservation Service, 2017).

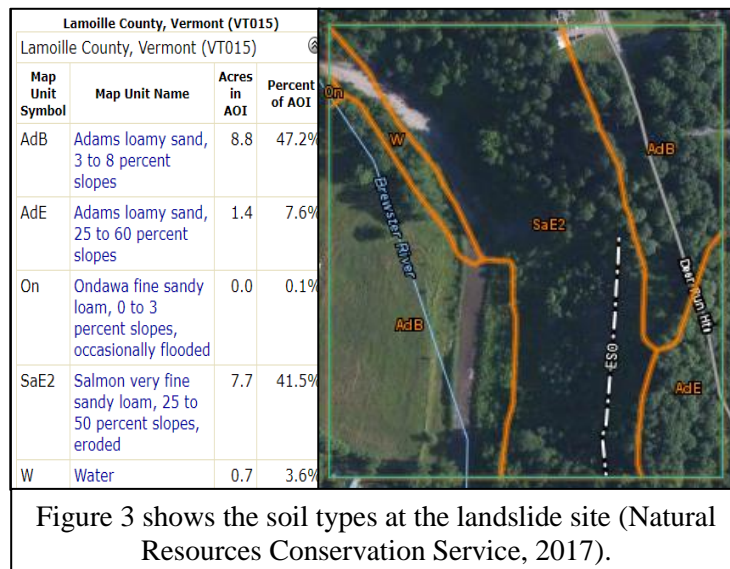


Figure 3 shows the soil types at the landslide site (Natural Resources Conservation Service, 2017).

The cutback measurements, which are the focus of this research, were collected in August 2006, October 2006, April 2007, June 2013, August 2016, and finally September 2018. The slip face has nineteen previously sited locations represented by stakes to help capture the rate of erosion at active areas by the distance from the stakes to the ridgeline. The stakes are located on the Brewster Uplands Community Trust Field. Over the years, the methods of the collection remained the same, although there were varying technicians. I collected the data in Aug. 2016 and Sep. 2018 alongside Dr. Kanat. All the data will be used in Microsoft Excel, and ArcGIS Pro, to demonstrate the changes in the site over the past 12 years. These results will help the state of Vermont, and the local area, recognize the dynamic change in this area and demonstrate the potential of this software in the environmental sciences.

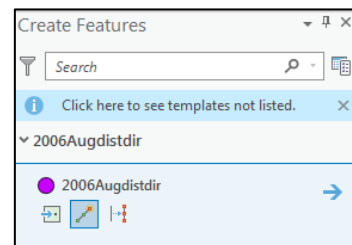
Methods

The first step of this research project began with collecting cutback measurements. At each stake, the distance to the slip face was measured at a central bearing, at +30 degrees, and, at -30 degrees from the central bearing. The GPS coordinates (in NAD83) were taken at each location to be able to locate the stakes more easily in future years. The GPS reading is collected to an error of no more than 6 meters, allowing for technicians to locate them in future years. Due to the exposure and environmental conditions of the area, the wooden stakes or tags at each stake location may be lost and therefore, replacements stakes or a new stake or tag may be added at any location with a new name. All of the data collected is compiled into a field notebook and then added to a Microsoft Excel database including all data from previous years.

Creating GIS Data Points

The data points will be used to help visualize and manipulate the data in ArcGIS Pro.

1. Open ArcGIS Pro and the file that will be used.
2. In order to create new data points, a new feature class must be created. Right-click the database created for the project, and select New. Choose, Create Feature Class, and input a file name and choose the geometric data type for this data. In this case it is points.



3. In the Catalog pane, right-click the new layer and select, Add to Current Map.
4. Click Edit from the ribbon, and choose Create. The Create Feature pane will open on the right by default. Expand the new file and select the Point from Line option, or an applicable selection.

5. Right-click the map and choose Absolute X, Y, Z. Change the coordinate unit to UTM, or other

Absolute X, Y, Z		✕
Grid	18T 672555 4945869	UTM ▾
Z:	0	ft ▾

5. applicable option. Input 18T and the northing and easting as the following image demonstrates, then press Enter.

6. Press the shortcut 'G' on the keyboard. A new dialog box will appear for the Distance and Direction.

Direction and Distance		✕
Horizontal:	244-00-00	NAz ▾
Pitch:	0	dd ▾
Distance:	3.00	m ▾

6. Change the units as needed. In this case, the bearing unit is NAz and the distance is m for meters. Input the values and press Enter to complete this points input values.

7. Open the Attribute Table for the layer by right clicking the new Feature Class layer. Edit the table categories as needed to provide information on the new data points. New categories can be created by right-clicking the layer and selecting Design followed by the Fields category, and finally Add Column.
8. Repeat steps 4, 5, and 6 as needed for the layer and repeat steps 1 through 6 for additional layers.
9. Verify that the points appear as anticipated.
10. Edit the Symbology as desired by selecting the layer needed to manipulate in the Contents pane. Select Appearance from the ribbon, and select Symbology from the Rendering group. For the points, I chose to distinguish between the stakes themselves and the locations where the ridgeline was measured every year with two different shapes for the points. Colors can be changed as well to distinguish between layers.

Creating a Presentable GIS Map

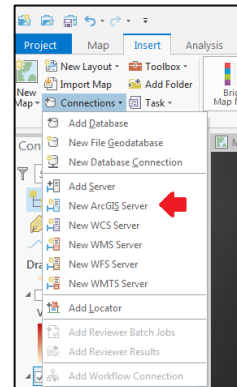
The previously created data points will be placed over Lidar data with added map symbols to visually represent the area.

1. Open ArcGIS Pro and the file that will be used.

2. With the previously created points, the Lidar data will be laid under them to represent the terrain of the study area.

3. Import the Lidar data that will be used.

- a. To access the VCGI database, which has a variety of Lidar data, the Create a Server Connection will be used. Start by selecting Insert from the ribbon. Click the dropdown arrow under Connections in the Project group. Select New ArcGIS Server from the options. The Slope, DEM, and hillshade layers have already been created for usage by VCGI. The server URL for this source is, <http://maps.vcgi.vermont.gov/arcgis>. There is no username or password needed.



4. Using the Clip tool, limit the extent of these rasters to the study area based on a boundary. Repeat as needed for other layers. This will allow tools to run quickly if you manipulate them further, and will better represent the focus area.

5. Change the Symbology of the layers as needed. Select the layer needed to manipulate in the Contents pane, and select Appearance from the ribbon. Select Symbology from the Rendering group. The hillshade can be inverted from the stretched color ramp to demonstrate higher areas in elevation in white and lower elevation in black.

6. Add any addition data layers desired such as roads, water bodies, or residences to the map.

7. The working map can be imported to layout view to add map features. First elect Insert from the ribbon. In the Project group, click New Layout to select a page size for the map.

8. While in the created Layout window, click Insert on the ribbon. Select the drop-down from the Map Frame in the Map Frames group. Select the map you would like to present, by default it is Map1.

9. An image of the created map should appear in the layout view. This can be resized as needed. It will change if the map being shown is manipulated in map view by adding or subtracting layers from view, the zoom factor is changed, or the focus area is moved.

10. Map symbols such as a scale and north arrow can be added from the list of options within the Map Surrounds Group that can be located in the Insert tab on the ribbon.

Creating a 3D Model of a Landscape in Agisoft Photoscan

After flying the drone and capturing images of the landscape, the outputs can be used to create 3D models in order to enhance visualization of this area. Additionally, in future years, this model can be compared to changes in the landscape.

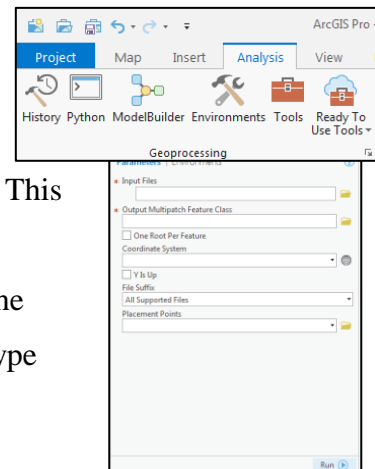
In the process of creating 3D models, there was reference to an undergraduate student's tutorial at Northern Vermont University, Agisoft Photoscan tutorial that focused on building digital models from imagery. There were some adjustments made to the tutorial to tailor it to creating a 3D model for landscapes rather than objects. These changes will be mentioned and distinguished.

In the workflow of inserting photos, no changes were made to the original tutorial. The process of creating a mask was disregarded due to the difference in purpose of capturing an entire landscape. Instead, after the photos were in the file, the workflow began with Align Photos, retaining the same parameters outlined in the tutorial. After the processing had completed, a dense cloud was created. There was no boundary box to resize until after this step. The quality of the dense cloud varied between each of the attempts for the 3D model. The quality was reduced in an attempt to reduce the file size and increase the probability for exporting in more file types. When creating a mesh, this same methodology changed based upon the amount of images in each of the trials. The face count had been run on high and medium to limit the amount of faces produced, which if high was selected, often produced over one million faces in the program. The process of building a texture retained the recommendation of the tutorial throughout the trials.

Importing and Using a 3D Model from Agisoft Photoscan into ArcGIS Pro

The importing of the previously created 3D model into ArcGIS Pro will allow for manipulation of the output.

1. Import the 3D file into ArcGIS Pro. On the ribbon, select Analysis, and in the Geoprocessing group select Tools. The Geoprocessing pane will open on the right side of the program by default. In the Toolboxes, open the drop-down for 3D Analyst Tools. In the From File subcategory, select Import 3D Files. This will open a new dialog box.
2. In the Parameters for the tool, in the Input Files, browse to the previously created 3D model file. This can include the file type COLLADA. This file type is one that can be exported from



Agisoft Photoscan that is a 3D file format for interactive applications and capable of being imported into GIS software's. This file type is also referred to as .dae.

3. The Output Multipatch Feature Class will default to the folder created for this project. All of the other inputs are optional and are not needed for importing. Note, if it is a large file size, the processing will take a few minutes.

Results

Cutback Measurement Data Collection

The changes in the location of the ridgeline at this landslide site are obvious. The most

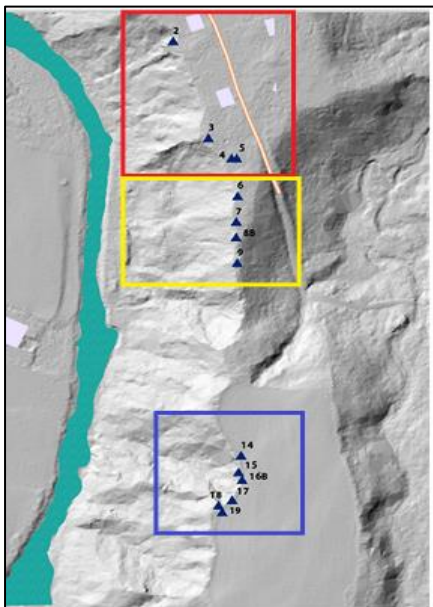


Figure 4. An overview of the study area with stakes identified and regions including the northern (red), central (yellow), and southern (blue) regions.

recent data collected provided the most accurate GPS coordinates, and since the stakes have stayed stationary since they were first placed, the previous GPS coordinates were updated to the 2018 values. Stake 1 had data collected twice in 2006, and once in 2007. The collected GPS values for the location placed the stake below the landslide site beside the Brewster River. For this reason, the stake and all of its data has been disregarded from this study. Stakes 2, 6, and 16 had updates over the years of data collection relating to tags or stakes. The physical stake from 2 was lost, however replacement stakes and new tags were added and renamed to distinguish them. Additionally, due to the erosion beside this stake, there was a distance and bearing collected for the northern and western direction. Therefore, in 2016 and 2018 there are two data collections for this stake that were distinguished with 2 north (2N) and 2 west (2W.) Stake 6 lost its tag between the 2013 and 2016 collection years and

was replaced with a new one in order to more easily identify it. The stake's name was changed from 6 to 6B. Stake 16 also lost its tag preceding the 2018 collection date and was replaced with a new tag, changing the stake name to 16B.

The stakes can be broken into three categories representing the areas of movement. Figure 4 outlines these regions. The northern region includes stakes 2W and 2N, 3, 4, and 5. The central region includes stakes 6, 7, 8, and 9. The southern region includes stakes 13, 14, 15, 16B, 17, 18, and 19. Stakes 11 and 12 follow a different landslide and were chosen to not be included in this research project. The complete database for these measurements made this landslide site can be found as the appendix, DRHKolbenson.xlsx.

The northern area is represented in Figure 5, demonstrating the change in ridgeline. The distance, between stake 2 and from the ridgeline started at 4.80 m (Aug. 2006), to 4.13 m (Oct. 2006), and finally to 4.67 m (Apr. 2007). After the drop to 4.67 m from the ridge (Apr. 2007), it again went up to 5.5 m (Jun. 2013). The bearings were consistent for these points at 260 degrees. Since these points do not gradually recede, and in fact demonstrate the ridge line gaining ground, there was likely error in the collection of the data in Oct. 2006 and again in Jun. 2013. In Aug. 2016 the new tag was added. The ridgeline at 2N was 3.75 m away, and 2W was 3.25 m. When it was measured in Sep. 2018, 2N was 4.78 m away, 2W was 3.25 m away. Both bearings varied by 2 degrees between these years. This slight variation could be to blame for the slight variability in distance in 2N between the two years. Stakes 2N and 2W do not have significant change over the two-year collection period.

The distance from the Stake 3 to the ridgeline measured at its greatest distance of 6.23 m (Aug. 2006), at the next collection date it was 6.18 m (Oct. 2006), but increased by 0.02 m to 6.20 m (Apr. 2007). It can be speculated that potential reading errors occurred since the central bearing measured remained the same for each collection time. In 2016, the stake measured to be 5.67 m from the ridgeline at an angle of 230 degrees, but in 2018 measured 6.00 m at an angle of 242 degrees.

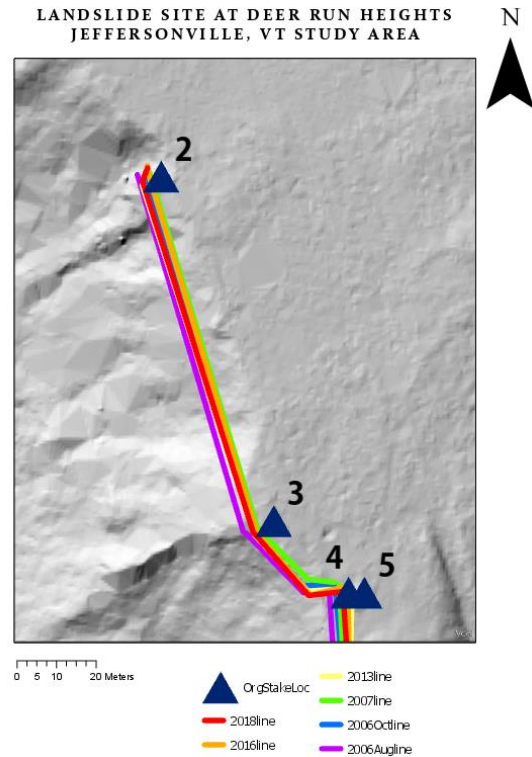


Figure 5. The northern region of the landslide site over the course of the collection dates.

Stake 4 originally measured at 11.28 m (Aug. 2006) before dropping slightly to 1.27 m (Oct. 2006), and again to 11.17 m (Apr. 2007), down to 9.98 m (Aug. 2016), and to 10.55m (Sep. 2018). Potentially, there may have been an error in the 2016 collection date. The bearing was 270 degrees taken in 2006 and 2007 but dropped to 262 degrees in 2018. Disregarding that year, there was a change of 0.73 m over the 12-year period.

Stake 5 had the greatest distance from the ridgeline in the first year of the collection at 7.48 m (Aug. 2006), it dropped to 7.30 m (Oct. 2006), to 7.18 m (Apr. 2007), but there was no collection date in 2013 (Jun. 2013), in the nine years the distance dropped to 4.43 m (Aug. 2016), and most recently measured at 5.87

m (Sep. 2018). While the Aug. 2016 data seems to be an outlier, there is a general trend of decreasing distance and changed by 1.61 m. This demonstrates a drastic change over a 12-year collection period.

The central region includes 6, 7, 8B, and 9 and are represented in Figure 6. Stake 6 had a distance initially of 4.93 m (Aug. 2006), dropping to 4.87 m (Oct. 2006), to 4.80 m (Apr. 2007), to 4.57 m (Jun. 2013), to 4.34 m (Aug. 2016), and finally to 4.02 m (Sep. 2018). This stake does not demonstrate to have a significant error. There was a change of 0.91 m over the 12 years.

Stake 7 showed the greatest loss of material of 6.14 m (Aug. 2006), to 4.87 m (Oct. 2006), to 6.02 m (Apr. 2007), down to 5.50 (Jun. 2013), to 5.27 m (Aug. 2016), and finally 5.18 m (Sep. 2018). The bearing remained the same in 2006 and 2007, however, it dropped to 270 degrees in 2013, to 272 degrees in 2016, and dropped more significantly in 2018 to 260 degrees. This may be the reason for the inconsistent trend in distance during 2006 and 2007. For this reason, the Oct. 2006 data can be disregarded. However, this stake had a change of 0.96 m from Aug. 2006 to Sep. 2018.

Stake 8 had a distance that was collected from 2006 to 2013, however, it was considered lost in 2016 and a new stake thereafter referred to as 8B was created in replacement. Initially, the distance was 6.40 m (Aug. 2006), to 5.98 m (Oct. 2006), down to 5.10 m (Apr. 2007). The

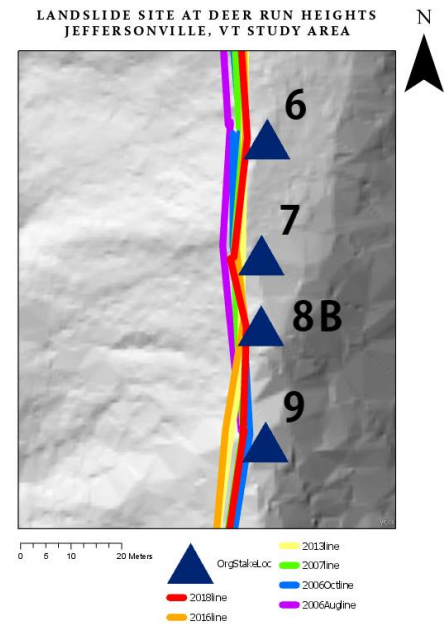


Figure 6. The change in the ridgeline in the central region.

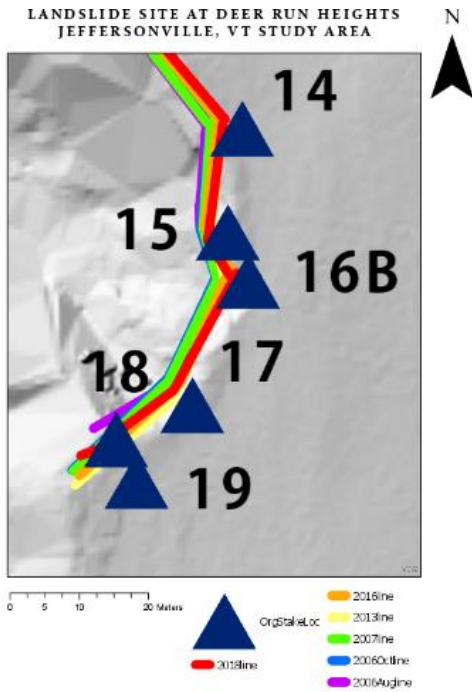


Figure 7. The change in the ridgeline in the southern region.

bearing of this stake was 285 degrees consistently. There was a consistent downtrend, with a difference of 1.30 m. Stake 8B's distance started at 4.07 m (Jun. 2013), to 3.90 m (Aug. 2016), and down to 2.97 m (Sep. 2018). There was a change of 1.1 m over the five years. This stake location demonstrated a significant change in distance from the face of the landslide.

Stake 9 had a distance was collected every year, with the greatest distance in the first two years of 4.77 m (Aug. 2006), to 4.78 m (Oct. 2006), down to 4.57 m (Apr. 2007) and remained at this distance the next data collection (Apr. 2013), to 4.21 m (Aug. 2016), and finally to 4.17 m (Sep. 2018). It showed a change of 0.60 m over the 12 years. There is a demonstration of erosion of the landslide in this area.

The southern region includes stakes 13, 14, 15, 16B, 17, and 18 and is demonstrated in Figure 7. This region is separated from the central region by approximately 10 m because the area between does not indicate a reason for concern in terms of loss of land. The distance from this stake to the ridgeline was initially 3.58 m (Aug. 2006) and down to 3.53 m (Apr. 2007). These were the only collection periods of this location. It demonstrated a change of 0.05 m in the one-year period. The location could not be located in the following years.

The original collected distance of stake 14 was 3.67 m (Aug. 2006), and dropped to 3.60 m (Apr. 2007), to 3.33 m (Jun. 2013), to 3.90 m (Jun 2013), down to 3.83 m (Jun. 2016), and finally to 3.62 m (Sep. 2018). There was variation in the bearings that potentially caused the inconsistent trend. However, comparing 2013 through 2018 there was a loss of land of 0.28 m.

The collected distances of stake 15 likely had errors in the first two years of collection. It started at 3.61 m (Aug. 2006), and went up to 3.67 m (Apr. 2007), but dropped to 3.33 m (Jun. 2013), to 3.12 m (Jun. 2016), and finally 2.93 m (Sep. 2018). There was variability in the final collection year in bearing. Consistently the bearing was 272 degrees and dropped to 236 degrees. Ignoring the 2007 outlier, overall there was a change in the distance by 0.68 m.

The distance from stake 16 initially was 3.60 m (Aug. 2006), dropped to 3.46 m (Apr. 2007), and to 1.76 m (Jun. 2016). There was a change in the distance of 1.84 m. However, a new stake, stake 16B, was created in Sep. 2018 at a distance of 1.82 m. The original stake 16 was consumed by erosion. There was some variability between the two stakes of approximately 10 degrees to the ridgeline. Despite these potential errors, there was an overall change in distance of 1.78 m.

Stake 17, in the first two years, Aug. 2006 and Apr. 2007 had a bearing of 313 degrees and dropped from 3.54 m to 3.30 m. The following collection year, the bearing decreased to 308 degrees and jumped up to 3.37 m (Jun. 2013). The next year it dropped again to 2.99 m at a bearing of 319 (Jun. 2016), but again changed to 3.08 m with a bearing of 300 degrees in the 2018 data. In the year 2013, there were likely data collection issues, similarly to 2018 since the other years followed a constant drop otherwise. There was a change of 0.46 m between the Aug. 2006 and Sep. 2018 data collection values.

Stake 18 had collection periods in Aug. 2006, Apr. 2007, and Sep. 2018. The first year there was a bearing of 194 degrees, and a distance of 3.08 m. The bearing remained the same and dropped significantly to 1.75 m in Apr. 2007. The most recent year had quite a different bearing of 152 degrees, but there was a great drop in distance to 0.88 m. There was a decrease of 0.87 m between the earliest collected year and the most recently collected year.

Stake 19 only had two collection periods because the stake was placed at this location in Jun. 2016. In this year there was a bearing of 292 degrees, with a large distance of 8.68 m, but in Sep. 2018, the bearing remained the same and the distance only dropped by 0.01 m.

Visualization in a GIS Map

In regards to the GIS map, the lines connecting the data points, or stakes, in the GIS layers were linear. This does not demonstrate the locations of the ridgeline due to the lack of a linear landscape. The lines created help to demonstrate the change over time and give a general visualization of the landscape. The only exception to this development of the map is the line connecting the central to the southern region. Since there are no stakes located there, due to the ridgeline being inactive, a curved line was created in the GIS maps that attempts to follow contour lines.

Visualization in 3D Models



Figure 8. The first attempt with all of the images collected from the drone flight shown in Agisoft Photoscan at 30 degrees.

In total, the drone flight produced 1,067 images. There were also an additional 228 images captured on a cell phone of some of the areas that were under tree cover to test if using a cell phone to capture images had the potential to produce models as well. The first attempt at the 3D model from all of the drone images produced a model, however, the size of this model due to the number of faces and file size did not permit exporting in any capacity. The model was also not able to be resized to help limit the output additionally. A PDF and COLLADA file exports were attempted but the files were too large for success. Figure 8 captures this model in Agisoft Photoscan.

In order to resolve this issue, the model was attempted again but limiting the total images to only 602 images respectfully. Additionally, the number of faces were limited throughout the process in an attempt to increase the speed of the steps and limit the completed file size. The quality was altered from high to low in the processes build a dense cloud, build a mesh, and build a texture. The change was so dramatic from the previous that the face count changed from 12 million to 1.4 million in the process build a mesh. This 3D model resulted in an overall image missing aspects and quite patchy in coverage. For this reason, no exportation was attempted.

There are mainly two visible sectors of the landslide site from the drone images, the northern, and the southern. All

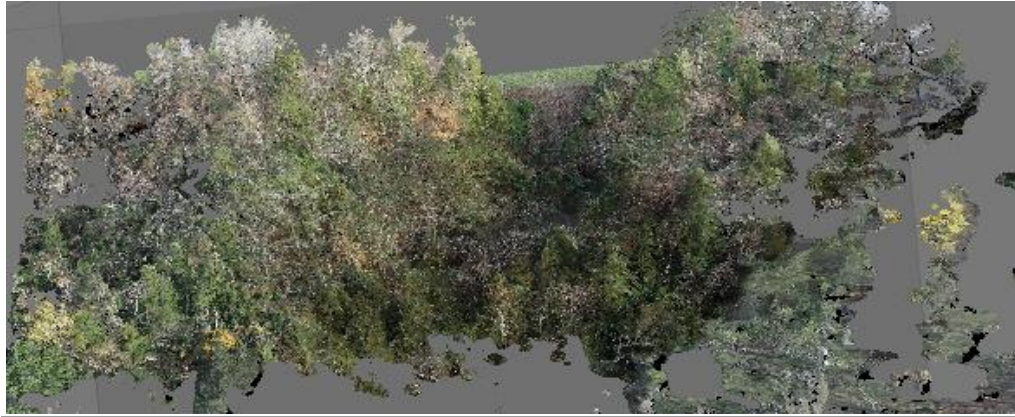


Figure 9. The southern sector of the landslide site from compressed images.

of the photos were hand selected once more by limiting the count overall, but this time was separated into the two different sectors. The northern sector had a total of 233 images. The southern sector had a total of 121 images. Each side had a model run which was completed much faster than the previous attempts, however, the software was unable to align the images. Therefore, this resulted in a similar patchy coverage as before.

Finally, the total limited images from the second attempt of 602 total images file sizes were made smaller through the process of batch compressing images in Adobe Photoshop but approximately half of their original size in order to increase the overall speed of the program and produce a smaller file size. In this attempt, during the Build a Mesh process, the high-quality option had 3.4 million faces versus the second attempt with uncompressed images that had over 12 million faces. The processes still took significant hours to produce each stage of the model. Due to the significance of the southern sector this processing limited the focus to that area. Figure 9 demonstrates the final output of the southern section of the model with compressed images that was exported a PDF file.

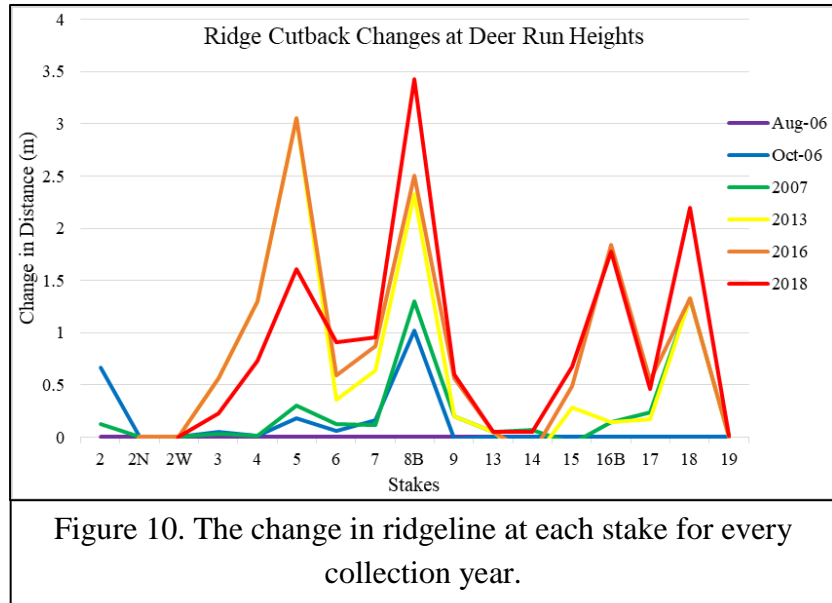
Discussion

Data Collection and GIS Map Analysis

The greatest changes, based on stake location, of the ridgeline over the study area occurred at 8B, 16B and 18. Stake 8B showed a change of 3.43 m. Despite this, the other stakes in the central region were no as extreme comparatively, stake 6 had a change of 0.91 m, stake 7 had a change of 0.96 m, and stake 9 had a change of 0.61 m. The southern region including the

stakes 16B and 18 is quite active. In this area the smallest changes in the ridgeline this area was around stakes 13 and 14.

The northern region had an average change of 1.34 m, the central region had an average difference of 0.23 m, and the southern region had an average change of



0.81 m. The entire study area had an average ridgeline change of 1.21 m. On average, this site had a change of 1.48 m, which equates to approximately 0.12 m per year over the 12 years observed. Figure 10 compares all of the stakes change collectively. Years that did not have data collections were assigned the previous collection years' value for the portrayal in the graph only. Stake 8B appears to have the most change in ridgeline distance based on the graph.

The cutback measurements made at the stakes that were created as data points in ArcGIS Pro and captured in a video by using OBS Studio. The video is a .vpj file that will be placed on The Drone Project page on Dr. Kanat's webpage (<http://kanat.jsc.vsc.edu/drone/>), in addition to my personal website (<http://kanat.jsc.vsc.edu/student/kolbenson>).

In addition to the collected measurements, assessments to material movement were speculated. Stakes 2, 3, 4, 5, 6, 7, 11, 14, 15, 16B, and 17 all had notable overhang throughout the collection years or demonstrated an active area, accounting for almost all of the stakes. The most significant assessments of loss of material visually seen were made at stakes 6, 7, and 14. Stake 6's ridgeline was falling and could easily break apart with minimal weight. Stake 7 had overhang and began to slough off at +30 degrees from the central bearing. Stake 14 had approximately 20 cm of overhang.

3D Models of the Landscape Analysis

Initially, to capture the whole study area, all of the images, taken with the drone were used in the first trial of creating a 3D model. This model captured a lot of the area and the surrounding vicinity. There were 1,064 images included in this attempt. The resulting file size ended up being extremely large. There were over a million faces produced from the model. The exported file to .pdf was not viewable due to the size of the file. The second attempt had almost half of the images from the previous, attempting to specifically limit and cut any potentially redundant photos aggressively. There were only 602 images included. However, this also proved to not be effective in terms of the time demands. Finally, once the images were compressed, the results were more easily produced and provided a much smaller file size.

Due to the amount and file size of the images collected by the drone, it proved to be difficult in smoothly creating a 3D model in Agisoft Photoscan. The results did allow for a model that is viewable in the program of the collective landslide at the total image capacity. Additionally, this attempt helped in explaining the program at a greater degree and increased the overall understanding of problem-solving in regards to this software.

Once the images were compressed using Adobe Photoshop, the results were produced much more quickly and were able to be exported. This allowed for greater analysis and demonstration of the models created from the landslide site. The 3D models exported formats will lead to greater visualization of this landslide site, and understanding in order to make overall assessments and compare to future years' cutback changes of the ridgelines.

Conclusion

Based on the cutback measurements collected and visually speculating the ridgeline, more land will continue to be lost due to the active site. A large event of rainwater, or seismic activity would likely be to blame for another landslide event which can be presumed due to the initial cause of the landslide. The results would greatly affect the homes that still remain off of Deer Run Heights at the top of the ridgeline, in addition to the school, residences, and businesses found below the site. The great movement of soil, rocks, and many trees on the ridgeline may cause significant damage.

There have not been any large movements noted from these data collected on the landslide site, only gradual changes, however the changes in the ridgeline are proving to be

significant overall. It is known from previous research at this site that the area is susceptible to changes in water levels that is likely one of the main causes of for the differences in ridgelines accounted for at the stakes in addition to the receptive rock and soil composition. The GIS maps and video demonstrate the change overtime. The 3D model offers multiple formats and focus areas of the landslide site to explore and demonstrate the current state. In future years, this same model can be compared to future measurements and potentially updated 3D models. Similarly, the GIS maps can be used to compare future measurements and new data points can be added to the software. The potential for damage on the local community reiterates the importance of continued surveillance of this area.

Acknowledgments

I thank Dr. Leslie Kanat for his guidance in the data collection, creating the visual representation of the findings, and in developing this senior thesis as a whole. Additionally, I thank the student technicians over the previous collection years that helped to allow this thesis to occur from the data collection. I thank Northern Vermont University for supplying the necessary equipment and software for the aspects of this research. I thank the property owners for the use of their land within the study area.

References

Brouillette, Mike (March, 2017). "The Vermont Lidar Program: Using VCGI's NEW Lidar Services in ArcGIS: Hill Shade and Digital Elevation Model." VCGI. Slides 1-28.

Ferullo, Robert (2018). "Building Digital Models from Imagery: Agisoft Photoscan Tutorial." Pages 1-13.

Kanat, Leslie. (2018). "Deer Run Heights Landslide." Northern Vermont University. Retrieved 17 Oct 2018 from,
<http://kanat.jsc.vsc.edu/drh/default.htm>

Natural Resources Conservation Service (2017). "Web Soil Survey: Deer Run Heights Jeffersonville, VT." United States Department of Agriculture. Retrieved 17 Oct 2018 from,
<https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>

Vermont Geological Survey (2018). "Jeffersonville Landslide." Department of Environmental Conservation: Agency of Natural Resources. Retrieved 17 Oct. 2018 from,
<https://dec.vermont.gov/geological-survey/vermont-geology/jefflandslide>

Appendix

File Directory

The digital submissions of the senior thesis may be found on my personal website (<http://kanat.jsc.vsc.edu/student/kolbenson>) and in the student research lab drive at Northern Vermont University at Johnson in the directory, E://Kolbenson/FinalDocumentsandFiles. This folder will contain the following submissions,

- KolbensonDRHOverview.pdf
 - This file is the exported 3D model of the entire Deer Run Heights landslide site with compressed images.
- KolbensonDRHSouthernSect.pdf
 - This file is the exported 3D model of the southern section of the landslide site, representing one of the most active ridgelines of the study area.
- KolbensonSeniorThesisDRH.docx
 - This is the compiled paper of this senior thesis document as a Microsoft Word document file.
- KolbensonSeniorThesisDRH.pdf
 - This file is the compiled paper of this senior thesis document as a PDF file.
- DRHKolbensonforGIS1.xlsx
 - The Microsoft Excel database for all of the years of collected data of the ridgeline. There is also visual speculation of the area for loss of material and change in this file as well.
- KolbensonDRH.aprx
 - This ArcGIS Project File contains all of the essential outputs from the processes run to create the data points and maps for this project.
- VideoStakes2.mov
 - This is a video file of the GIS Maps created from the stakes.

Additionally, all of this information can be located on the previously mentioned website.

