Correlating Precipitation to Changes in Groundwater and Stream Depth to evaluate Slope Instability at Deer Run Heights in Jeffersonville, Vermont, 2011

Figure 1. Deer Run Heights, Site of Past Landslide Event (Nichols, n.d)

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January 2, 2012

Abstract

Located in the Village of Jeffersonville, Vermont is Deer Run Heights, a ridge known to produce past landslide events, where there is an ongoing comprehensive geotechnical study of the area. Data from this study was collected to help determine the relationship between local precipitation, ground and stream water flows with slope instability. Onset data loggers and a rain gauge were used to monitor changes in water levels and the amount of local precipitation for just over three months. Although some correlations can be seen, there is still a great deal of collaborative work needed in the future to determine these relationships.

Hypothesis

Local precipitation patterns will result in changes to groundwater levels as well as stream flow around Deer Run Heights, which will be visible in the measurement of monitoring wells and a rain gauge. Precipitation increases runoff in the upper stream, which in turn increases groundwater levels in the monitoring wells (along with direct deposition), and is associated with an increase in discharge in the Brewster River and an increase in erosion and undercutting along the base of the ridge. The resulting slope instability is the product of the driving forces being greater than the resisting forces.

Introduction and Significance

Located in the Village of Jeffersonville, is Deer Run Heights (DRH), a ridge known to produce past landslide events. The most recent major event occurred in 1999, along with several smaller events in 2006, 2008 (Beckler et.al 2009), and 2011. The event in 1999 was the result of three slides that occurred on a steep bluff along the east side of the Brewster River, which displaced 27,000 cubic meters of material into and over the river into the village. A residence sitting at the top of the ridge was severely damaged and had to be removed (Beckler et. al 2009). The event of 2006 was noted by the Farrera's, owners of a residence that is situated just north of the 1999 event location; who came home to find an unusual amount of sunlight in their home, the result of a smaller slide that occurred earlier that day (Beckler et. al 2009). The 2006 event, although much smaller posed a significant concern because it occurred above Cambridge Elementary School as well as many commercial and residential properties (Beckler et. al 2009).

If an event similar in magnitude as the 1999 slide occurred at the location of the 2008 slide, the village below, including the elementary school could be in serious jeopardy (Banks 2009).

Dr. Leslie Kanat of Johnson State College and Dr. George Springston of Norwich University, along with their environmental science students, and in cooperation with the Vermont Geological Society have initiated an ongoing detailed geological assessment of Deer Run Heights and surrounding areas (Beckler et. al 2009). One aspect of this assessment is to study the correlation of local precipitation to changes in groundwater levels and stream flow around Deer Run Heights to provide a better understanding of how water may influence slope failure. This, along with other information will allow for better understanding and prediction of a future landslide event along the ridge.

Area of Study

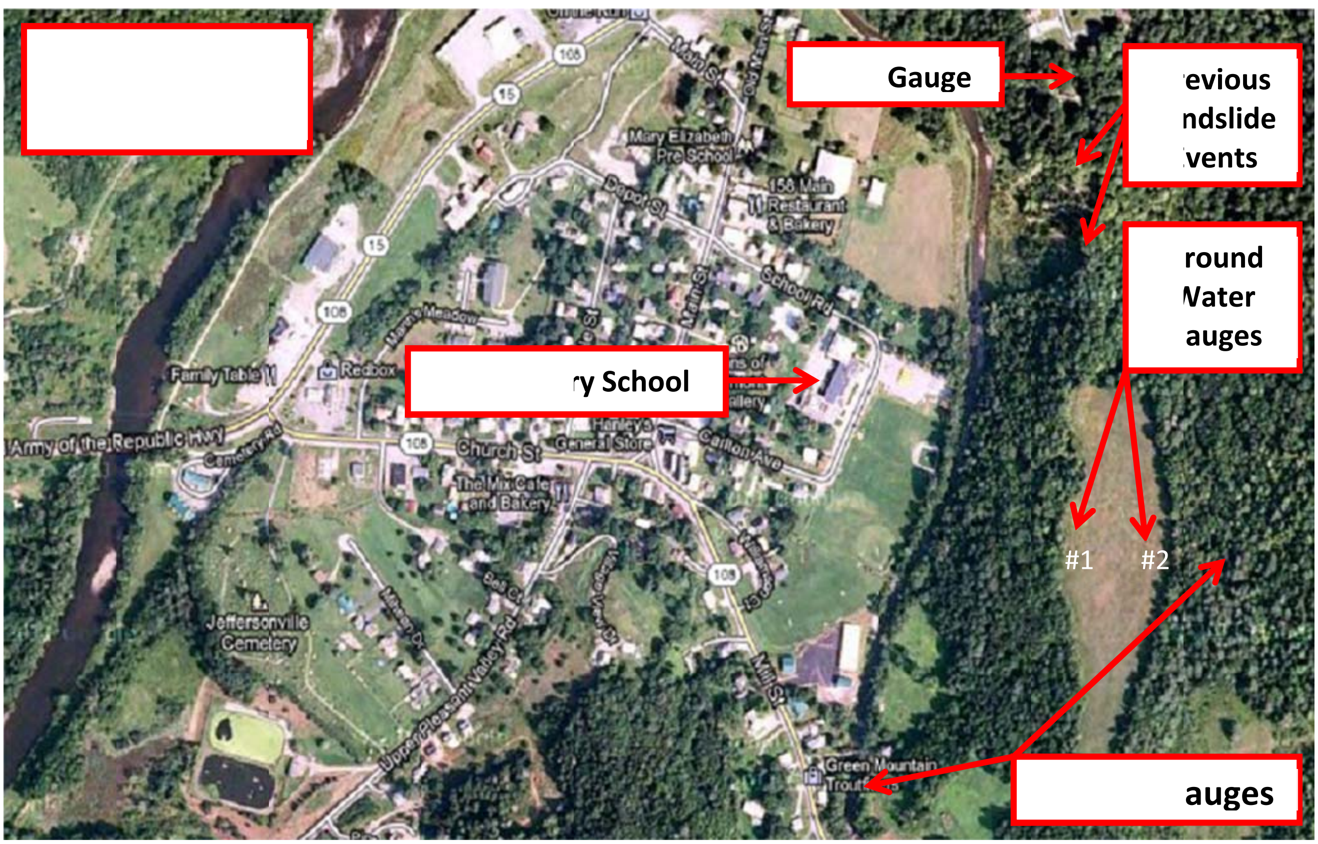


Figure 2. Map of Study Area: Jeffersonville, Vermont (Google 2011)

Purpose of Study

The purpose of this study is to monitor the changes in ground and surface water flows around Deer Run Heights in response to local precipitation to determine the relationship between water flow and slope instability.

Geological History of Study Area

As the Laurentide Ice Sheet, retreated west down the Lamoille River tens of thousands of years ago, it dammed the valley causing a series of lakes to form (Banks 2009). Deposited in this glacial lake, now the location of Deer Run Heights was poorly unsorted sediments (Banks 2009). Today, the soil consists of layers of clays, silts, and fine sands that alternate and become progressively coarser moving up the slope (Forsberg 2007). These sediments are in part responsible for the slope's instability and failure. Because the area is primarily supported by silty clays it is able to create steeper banks than sands alone and is able to support greater volumes of sands above. These conditions mean a larger landslide is likely to occur along Deer Run Heights (Kim 2000).

The Significance of Water in Relation to Landslides

Landslides are a form of mass movement, a term used to describe any sort of gravity-induced movement of sediment down a slope (Horton, 2011). All landscapes are held together by friction. The primary driving force of a slide is the force of gravity. Other environmental contributing factors increase the driving and decrease the resisting force. When the driving force overcomes the resisting force, a landslide occurs.

Water contributes to a slope's instability and failure in two significant ways: by increasing the driving force while decreasing the resisting force, both conditions are thought to be present at Deer Run Heights. Water increases the driving force by saturating the slope, which adds weight to the slope creating a greater driving force. The decrease in the frictional force is the result of the slipperiness that occurs as water acts as a lubricant between layers within the slope, resulting in a slip face. Water also decreases the resisting force by reducing the stability at the base of the slope when high river flows erode and undercut the slope's foundation.

Ultimately water is expected to increase the driving force and decrease the resisting force along the Deer Run Heights ridge.

Water is thought to influence Deer Run Heights specifically in several ways. First there is a small stream at the back east top part of the ridge that is thought to act as a feeding stream into the slope with increases in surface and groundwater flow as a result of precipitation. With this input of water along with the direct deposition of water that occurs during precipitation, weight is added to the slope. The differences in permeability cause water to percolate from the surface through the sandier layers until it reaches the clay-rich layer, which becomes saturated quickly. Here, water accumulates, increasing the weight and driving force of the slope. It is also expected that the boundary between the clay-rich and sandy-rich horizons is acting as the slip face as a result of the waters lubrication effect and is decreasing the resisting frictional force. And finally, probably the most easily seen influence of water is the result of the Brewster River which runs along the base of the ridge. During times of high river discharge, banks are under increased stress and are subject to erosion and can decrease the resisting force by undercutting the banks of rivers such as the Brewster, reducing the strength of the slope at the base, leaving it incapable of supporting the rest of the slope above (Highland 2008). The monitoring of water is significant around Deer Run Heights because it could ultimately cause the driving forces to overcome the resisting forces, resulting in slope failure.

Methods and Materials

To monitor the changes in ground and surface water flow in response to precipitation, we heavily relied upon the use of Onset HOBO Data Loggers, electronic sensors that collect absolute pressure data that can be used to calculate changes in water levels. Five of these loggers were deployed around the study area in conjunction with an Onset Rain Gauge which records precipitation events. The adjoining HOBOware Pro software is required to operate these loggers, and also is used to convert pressure data into water level data using a reference water level and pressure.

The Onset Rain Gauge uses the traditional tipping bucket design along with a recording device to collect and record precipitation events. The one rain gauge is being used as a general representation of the local precipitation around DRH because the study area is in a small enough radius.

Two loggers have been placed in pre-existing monitoring wells in nearby streams (The Brewster River and The “Upper Stream”); two are deployed in pre-existing monitoring wells in a field behind the top of the ridge to measure changes in groundwater. One logger is deployed at the top of one of the groundwater monitoring wells to record the surface barometric pressure to use as a reference for compensation in later calculations. The rain gauge is set in the back of a residence behind the top of the ridge (Figure 2).

About the Loggers:

HOBO Loggers are used to record absolute pressure data, which can later be used to calculate water level data, to monitor changes in water levels over time. Absolute pressure in a monitoring well includes both the atmospheric pressure as well as the water head that are present at a given time. Atmospheric pressure changes with altitude and weather; to compensate for these changes, one logger is used to record barometric pressure changes and is used as reference data. Using the HOBOware Pro software, the absolute pressure data is then converted into water level data, using the Barometric Compensation Assistant.

Before Launch:

Several tasks must be accomplished before loggers can be deployed in the field for data collection. The first is to install the HOBOware Pro onto your computer using the step by step guide that is provided by Onset. Next the logger needs to be connected to the computer using the HOBO Waterproof Shuttle, Coupler, and USB, also with step by step directions included. The shuttle can act as a base station in the field and is used to read out the data that is stored in the loggers. The computer will recognize the logger if it has been connected properly; now the logger is ready to be programmed for deployment. It is highly recommended that first time users allow for time to practice logging data before launching in the field, either at the office or home, just using a sink or bathtub; to become familiar with the equipment and software.

**Note: The logger has to be aligned just right within the coupler in order for the connection to be made. Make sure the "flat" parts line up and give a gentle twist; if it is aligned properly the logger will not twist. Also, a small amount of hand cream was used as lubrication between the coupler and logger for an easier fit.

In the case of Deer Run Heights, three monitoring wells, which help protect the loggers were already in place for our use; however this may not always be the case. In fact, The Upper Stream was still in need of a monitoring well and one was simply constructed using a PVC pipe. Holes were cut at the base of the PVC to allow for the movement of water in and out of the pipe, but to prevent sediment from entering and filling the bottom of the well; Marifi Filter Paper was wrapped around the base.

A non-stretch wire or cable should be used to suspend the logger from the top of the well to produce accurate measurements. A simple pull-test using your own hands is suitable to determine if the wire will stretch. This wire should be made of a non-rusting material, so degradation over time doesn't compromise the reliability of the wire.

Launching the Device:

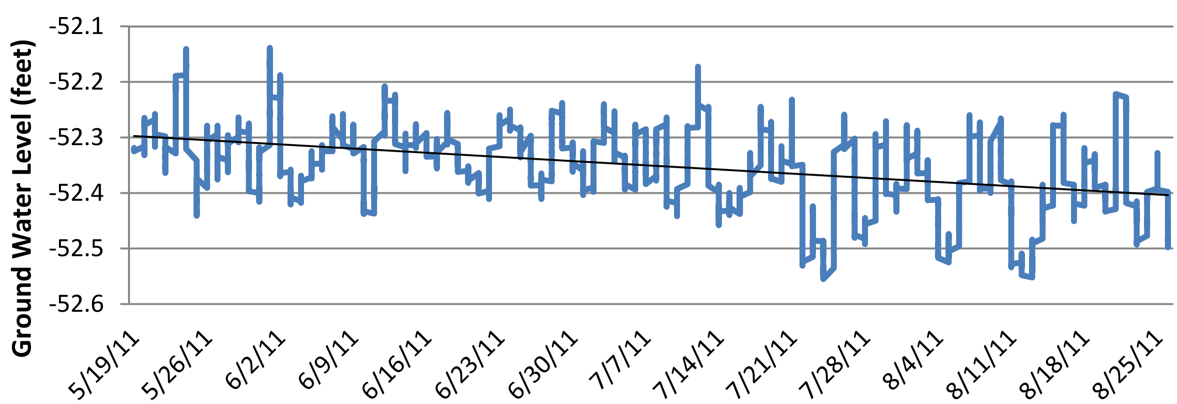
These loggers can be programmed, pre-deployment from home and launched using the Onset Shuttle, or from the field using a portable computer. A computer was used for the majority of the launches during the study at DRH. Once at the well location, the logger can be connected to the computer and parameters can be set. Just before launching the loggers, the depth from the top of the well to the water was measured and recorded using a Solinist Water Level Meter, to later be used as a reference measurement. It's important that this number be recorded as a negative number, because the water level is below the reference point (top of well), rather than above, such as height above sea level. Again, one logger was deployed at the top of the monitoring well, to record barometric pressure data, to later be used in the Barometric Compensation Assistant. Once the parameters were set and reference measurements were recorded, the loggers were launched and slowly lowered down into each of the monitoring wells until it reached the bottom.

Collecting Data:

Once the loggers are launched they will measure and record absolute pressure data at the specific intervals of time that were programmed, until the loggers are later retrieved and data read out. To read out the data, the loggers were retrieved from the monitoring wells and connected to the computer using the shuttle and software. Following the software instructions, the data is offloaded from the loggers to the computer. The logger recording barometric pressure data also is retrieved and data read out. The loggers can be redeployed, with new launch settings, but the reference water level measurement needs to be recorded before doing so. The rain gauge data can be programmed, launched, and collected in the same way; however the rain gauge only records precipitation events, not a continuous measurement. Once the data was offloaded from the loggers, the Hoboware Pro software was used to process the data. The Barometric Compensation Assistant is used to convert pressure data into water level data. To process the data properly, the assistant will ask for the previously recorded reference measurement with date and time, and to choose the proper water density box that best describes the water the logger is suspended in. This generates a new data series from pressure to water levels, which than can be exported to be processed.

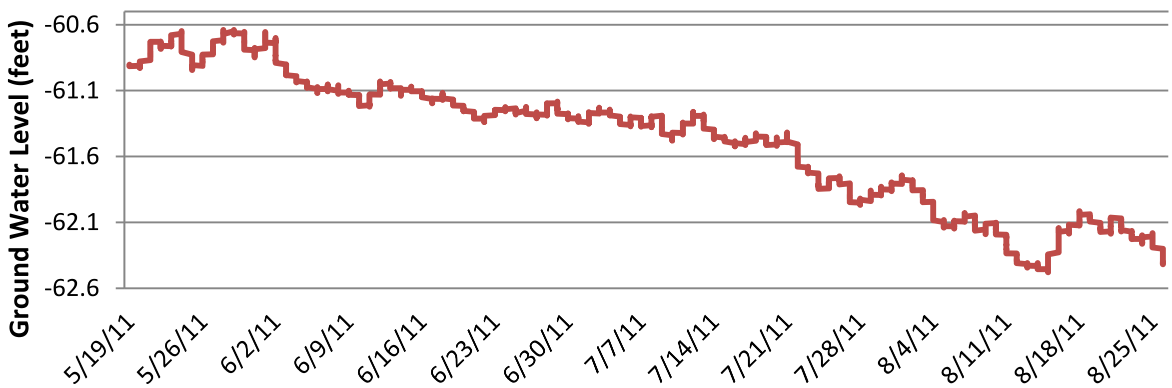
Results

Figure 3. Water Levels in Monitoring Well #1



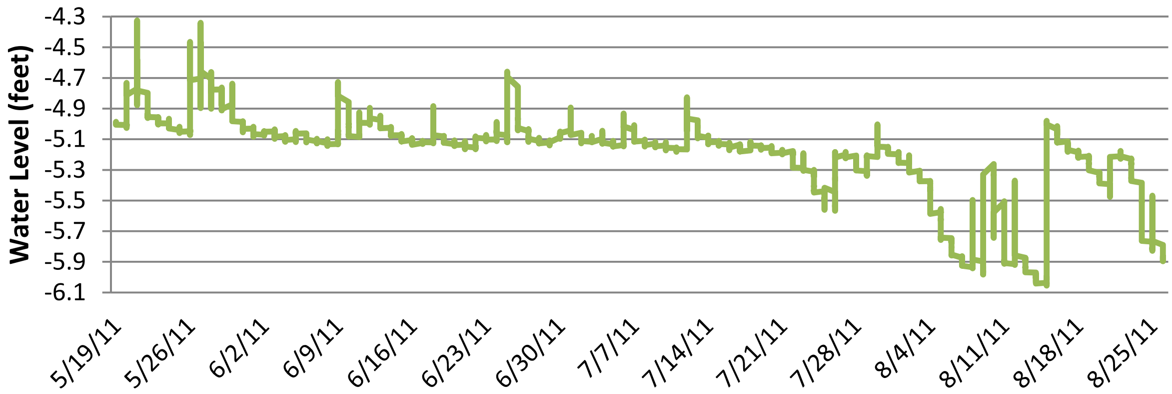
Throughout the collection period the data shows an overall decreasing trend in ground water levels in monitoring well #1. On launch day the water levels were at -52.319 ft., and then there were periods of increase and periods of decrease, on the last day of collection the water level was at -52.482 feet, ending with a total decrease of 0.163 feet throughout the collection period. Significant peaks and dips can be seen in the data; however, there were more peaks in the first half of the data, and more dips seen in the second half. The periods of lowest water levels lasted longer than the periods of highest water levels. Water levels were highest around May 23rd, June 1st and 13th, July 12th, and August 21st and lowest around May 25th, June 12th, July 24th, and August 5th and 13th. The highest the water level ever reached was -51.139 feet on June 1st and the lowest it reached was -52.555 feet on July 24th.

Figure 4. Water Levels in Monitoring Well #2



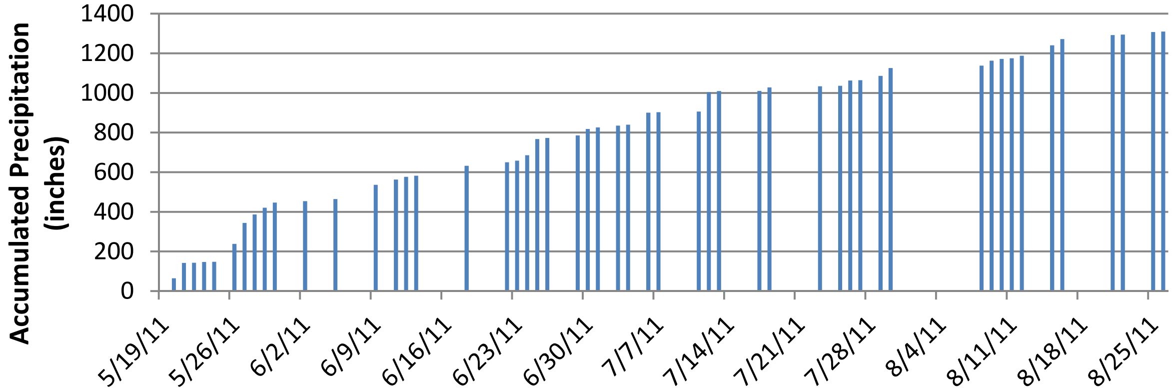
Although there were periods of increase and decrease, the data from monitoring well #2 shows an obvious decrease in ground water levels over time. On launch day the water was recorded at -60.904 feet but was only at -62.398 feet on the last day of data collection, this was a decrease of 1.494 feet, this is significantly higher than the difference in well #1. During the first two weeks water levels were on the rise, the highest it ever reached was -60.654 feet on May 28th; then they continued to steadily decrease for about two months. On August 15th the water reached its lowest point at -62.497 feet, but then rose quickly to -62.016 just two and a half days later where it began to fall again.

Figure 5. Water Levels in the Upper Stream



The upper stream saw an overall decrease in water levels similar to the monitoring wells; although the pattern is not as smooth as well #2, the upper stream responded more similarly to well #1. Again there were periods in increase and decrease throughout the collection period; however the periods of increase were more frequent in the first half, whereas the periods of decrease were more frequent in the second half. On launch day the water level was at -4.987 feet and ended on the last day of collection at -5.894, which is a total decrease of 0.907 feet. Monitoring well #1 experienced less of a change over time than the upper stream; however monitoring well #2 experienced a greater change. As with monitoring well #1, here were significant peaks and dips in the data for the upper stream. The highest water levels were seen on May 21st, 26th, and 28th, June 8th, 19th, and 25th; the lowest recordings were from June 23th-27th, August 4th-10th, and August 15th and 23rd. The periods of decrease lasted longer than the periods of increase, which was very similar to the data from monitoring well #1. The highest level was recorded just a couple of days after launch on May 21st where it reached -52.228 feet. The level reached its lowest point at -6.055 feet on August 15th. The most significant short term change occurred just after the water reached its lowest point; in just seventeen hours the water rose 1.074 feet, and most of the change occurred in a single hour.

Figure 6. Rain Gauge Data: Accumulated Precipitation



The data for precipitation was recorded as an accumulated total over time. So what you are seeing in the graph is where there were days of rainfall, which is added to the previous accumulated precipitation from the start of the study. The gaps in the graph between the bars represents days without precipitation. These gaps in data, or lack of precipitation corresponds to the data seen in the monitoring wells and the upper stream, where there were periods of decreased water levels there were also days without precipitation. The longest period without precipitation was eight days from July 30th through August 7th. This response is most evident in the data from the upper stream where a large drop in water levels can be seen. The response is also seen in monitoring well #1; however this response was delayed by about a day and a half. Monitoring well #2 shows an inconsistent response to the lack of precipitation, unless there was a delay in the response of a few days, in that case, a significant decrease in water levels can be seen. Then there is a spike in water levels at all three locations just after the period of no precipitation. These spikes correspond directly to the several days in a row of significant rainfall, seen in the precipitation data. When the study area received a lot of rain in a short amount of time, it’s represented in the graph by several bars close together. The upper stream seems to have the most direct response to amount of precipitation. Monitoring well #1, which is further from the hypothesized “feeding” stream, has a minor delay but still pretty direct response to precipitation. Monitoring well #2 which is closest to the hypothesized “feeding” stream seems to have a less significant response if any at all to precipitation events.

Brewster Stream Gauge

Unfortunately the data for the Brewster stream gauge was lost due to technical problems with the equipment. Although a quantitative analysis cannot be made, there are qualitative observations that should be noted. Small amounts of precipitation did not have drastic effects on the water levels of the Brewster. Water levels were more likely to rise after extended periods of rain, often several days in a row. The most significant rise in water levels occurred in the spring, where the combination of spring melt from the mountains and the high amount of precipitation that the area received rose levels a couple of feet. It's expected that during this period, the problem occurred with the equipment, but we were unable to retrieve the data during this time because the water levels were too dangerous. The rise in water levels did cause significant damage to the surrounding area, the most significant for this study is the erosion and undercutting that occurred along the stream banks. This often reduces the strength of the slope at its base which reduces its ability to support the rest of the slope (Highland 2010).

Future Work

This study is part of a larger comprehensive ongoing project; these results are only preliminary and a small piece of the larger picture. Due to the number of variables and ongoing nature of the many studies within the project, direct conclusions are difficult to draw at this point. There is still a great deal of collaborative work to be done in the future, leaving many questions still unanswered. The data from this study shows a correlation between precipitation and groundwater and stream water levels; however we don't know exactly how these interact with each other or influences the instability of the slope. Studies in this area are needed. The relationship between precipitation, water flow and slope instability is still unclear. Future work is needed to determine whether or not the upper stream is acting as a feeding stream to the ground water system, influencing slope instability. This, along with other information will allow for better understanding and prediction of a future landslide event along the ridge. The most immediate actions should be taken at the base of the slope, where the Brewster continues to naturally erode the banks, decreasing the stability of the slope. Rip rap has been used in the past to help eliminate the cutback and should be considered more extensively in the future for larger parts of the stream to help the stability of the base of the slope.

Acknowledgments

I give thanks to the Vermont Agency of Natural Resources for their partial funding of this project as well as Johnson State College for additional funding and the use of their equipment. I also thank Les Kanat of Johnson State College and George Sprinston of Norwich University for their knowledge and guidance. I thank the property owners for the use of their land within the study area.

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