Downslope movement of trees and unconsolidated sediment at Deer Run Heights in Jeffersonville, Vermont

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14-May-08

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Hypothesis

The ridge on Deer Run Heights will continue to cut back and trees marked on transects on the slope will slide downhill. If there is a large landslide during the term of this project it will occur when the water table is at its highest in the wells.

Abstract

Deer Run Heights in Jeffersonville, Vermont has experienced an ongoing problem of slope instability and landslide occurrence. Glacial deposits are responsible for the sediments found on Deer Run Heights. These sediments are the reason for the unstable slopes present. Monitoring the area has shown that the problem will likely continue. The water table at observation well 1 (B1) on Deer Run Heights has shown large fluctuations in level, changing by 8.5 feet during the study. It was recorded at its lowest on 26-Oct-07 at 62.9 feet below the ground and at its highest on 13-Apr-08 at 54.4 feet below the ground. Active erosion at the top of the slope revealed that cutback was experienced at a rate of 0.62 meters per year between 14-Nov-08 and 24-Apr-08. The aquifer experienced the greatest amount of recharge between 20-Mar-08 and 6-April-08 as snowmelt occurred releasing 21 centimeters of water over the entire area. This in combination with small precipitation events elevated the water table enough to saturate the silt and top portion of clay found at 120 centimeters below the ground on 12-Apr-08. The saturated soil destabilized the slope enough to produce a slide of about 100 square meters. The slide occurred in front of cutback reference stake number 15.

Introduction and Significance

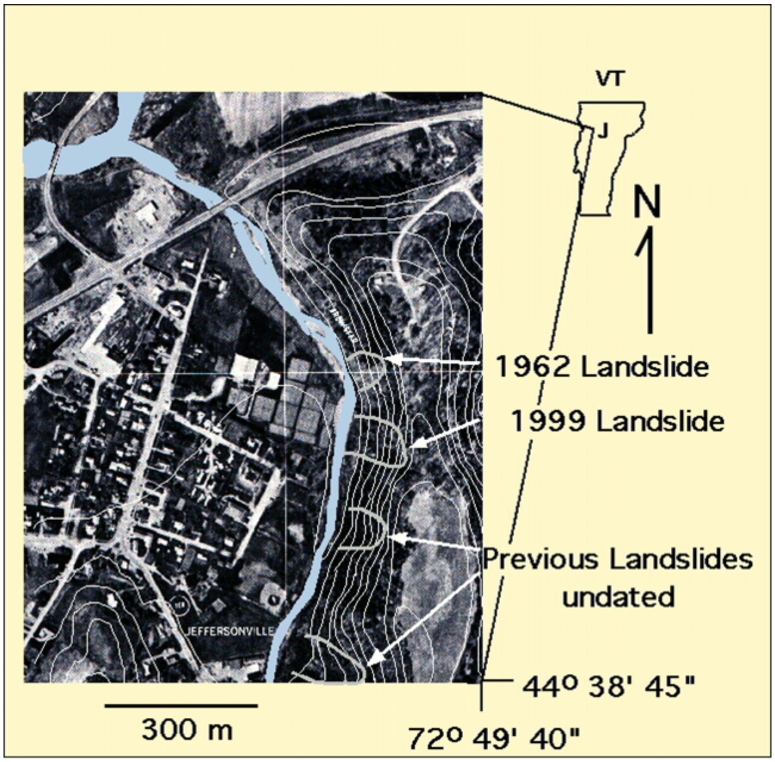

Figure 1. Past Slides on Deer Run Heights (Nichols, 2001)

Deer Run Heights Ridge in Jeffersonville, VT has been the location of documented landslides both recently and historically as shown in Figure 1 (Nichols, 2001). Landslides commonly occur in glacially conditioned settings that contain fine grained sediments such as the area found on Deer Run Heights (Nichols, 2001). Part of the residential area including two homes on the ridge, the Farara's and the McCuin's, are threatened by the land forms and geology found there. Both properties have small landslides in close proximity to their homes. One home has been removed from the ridge due to a large mass wasting event that occurred in 1999 (Nichols, 2001). Cambridge Elementary school is located in close proximity to a large gully on the slope that threatens to be the site of another large slide (Forsberg, 2007). If a large slide in this area did occur it could spill debris well beyond the school and do extensive damage to the property.

There are several factors attributing to the occurrence of landslides on Deer Run Heights. One is the materials that make up the ridge. The top horizon consists of top soil and extends four inches down. From four to 30 centimeters is fine sand. Between 30 and 90 centimeters is a conglomeratic layer consisting of sand and rocks ranging from pebble size to the entire width of the layer, 30 centimeters. Below this from 90 to 120 centimeters is a fine silt layer. The next layer of the soil profile that was able to be

Figure 2. Layered Sediment Near Stake 15

observed is clay. This can be seen in Figure 2. When precipitation or snowmelt occurs the water is able to infiltrate the soil profile and percolate down until the clay layer is reached. The clay forces the water to change direction and flow parallel to the layer. This causes the top of the clay layer and the silt layer to become saturated with water. When the clay becomes saturated with water it becomes slippery (Montgomery, 2006) making the sand prone to sliding off it. This would not be such a concern on level ground, but the oversteepness of the slopes requires a large frictional force to keep the sand in place. The saturated soil greatly reduces the frictional force holding the slope in place and increases the potential for a landslide. The maximum angle at which the slope is stable is called the angle of repose (Montgomery, 2006). The angle of repose is reduced when the slope consists of fine unconsolidated material (Montogmery, 2006), such as that found on Deer Run Heights. The force pulling downward on the slope is called shearing stress (Montgomery, 2006). When enough water is present the sand increases in weight and the clay becomes saturated with water. The frictional force holding the slope in place is reduced, therefore, reducing the angle of repose and increasing the chance that the shearing stress will become strong enough to push material down slope.

Deer Run Heights has been monitored since August 2006 Leslie Kanat and Michaela Forsberg (Forsberg, 2007). The rate of cutback along the slipface is being monitored in areas that appear likely to slide based on observation and reference points established by Michaela Forsberg. New work in this area is being done by measuring the amount of precipitation using rain gauges. Four wells of varying depth have been drilled on the Farara property and are being used to measure the depth to the water table. A correspondence between a high water table and slope instability was observed. The amount of snow pack prior to spring melt was also estimated using a core sample from the surface to the ground indicating the snow volume. Four transects have been marked that run parallel to the slope; each of these transects are adjacent to the Farara property. 30 trees along these transects have been identified and the distance between the trees along has been recorded. A change in the distance between trees will indicate that the slope is moving.

Methods and Materials

Figure 3. Before Slide, Stake 15 Behind Cambridge Elementary 6-Apr-08   Figure 4. After Slide 12-Apr-08

The rate of cutback was measured by Michaela Forsberg using rebar stakes as reference points for the period between 23-Aug-2006 and 20, Apr-2007. The distance from the stake to the beginning of the slope was measured. Two additional measurements were taken at 30 degrees on either side of the initial measurement. The average of the three measurements provided the recorded distance. A total of 19 stakes were placed along the ridge to be used for this purpose. These measurements were continued beginning on 13-Nov-2007 and ending 27-Apr-2008 (Appendix A). The rate of cutback is found by comparing old measurements to more recent ones. When the measurements reveal cutback it shows that sediment had moved from the top of the slope downhill. Figure 3 shows the undercut gully behind Cambridge Elementary near stake 15 on 4-April-2008 (left) and again on 12-April-2008 (right) after the gully experienced 100 meters^2 of cutback.

Figure 5. Solinst Water Level Meter in use at B1

Four observation wells have been drilled by Wilcox Environmental Services on the Farara's property to measure the distance down to the water table. The First well (B1) is located on the northeast corner of the property B2-4 are located about 20 meters west. A Solinst Water Level Meter, Model 101 has been used daily to monitor the height of the water table in each of the wells (Figure 5). The portion of the device that senses water is lowered into the well until the instrument beeps signifying it has reached water. The sensor is attached to a tape measure that is mounted on the device. The distance from the top of the water table to the top of the PVC pipe was recorded. Some days were not recorded as a result of being away from the area or the well caps being frozen.

Figure 6. Rain Gauge 1 (RG1) Located on the Farara Property

Two rain gauges have been placed on Deer Run Heights and are being monitored daily (Figure 6). They are in close proximity to B1. One is slightly northeast of the first drill hole the other is about 30 meters north. The purpose of these rain gauges is to correlate precipitation events with changes in the water table and to potentially establish a lag time between the two. Readings are taken after a precipitation event from the side of the gauges where precipitation depth is marked in centimeters and inches. After each reading the rain gauges are emptied. These measurements were taken only in the fall because of freezing in the winter. The rain gauges could not accurately collect snowfall. During the winter, ice buildup cracked the rain gauges. Since they could no longer hold water measurements were stopped.

Figure 7. Snow Core Sampler In Use

Snow pack prior to spring melt was measured using two methods. Both measurements were taken using a PVC pipe to extract a core sample of the snow (Figure 7). This was done by driving the pipe into the snow until it reached the ground. Once the ground was reached the pipe was tilted towards the ground. This allowed the sampler to see beneath the core that was being removed to be sure the ground was reached. If the ground could be seen the end was of the coring sampler was covered with a flat surface in order to be transported; the sample was dropped into a bucket. The bucket was weighed and the sample was discarded. Since one gram of water is one cubic centimeter, the amount of water produced by the snow melting could be found. The second method differed because each sample was placed into a plastic bag. The bags were brought inside and allowed to melt. Once melted the volume of water was measured using a graduated cylinder. The snow in the area did not cover the ground everywhere; approximately 65% of the ground was covered with snow. This was taken into consideration when calculating the total snow pack available for aquifer recharge. Bare spots as well as deep snow drifts were present and an effort was made to sample areas where the snow depth was close to average.

Figure 8. Measuring Distance Between Trees 1 and 2 (T1 and T2)

Four transects decending down the slope to the north were established. Thirty trees were identified in these transects. The distance between a tree up slope and a tree down slope was measured (Figure 8) and recorded. The distance was measured to a given point on each tree marked by a nail and tagged with a number indicating the sequence of the trees in the transects. Any change in the distance between trees indicates movement along the slope. The transects extend from the top of the ridge, west, down slope towards the Brewster River and end at various locations on the toe or bench of the slope. A map was attempted but the tree cover did not allow for the use of a GPS device. The transects all begin on the Farara property at the top of the slope. T1 begins directly behind observation well B2. T2-4 are located to the west.

Results

The results of the data collected from the observation wells and the rain gauges between 26-Oct-07 and 10-Dec-07 can be seen in Figure 9, page 11, for all results refer to Appendix A. This data shows the variable height of the water table with respect to rain events and seasonal changes. The depth of the water table in the ground was found to vary greatly. In the time of the study the water table height in B1 changed by 8.5 feet. The lowest point in B1 was on 10-Oct-2008 at 62.9 inches and the highest was in the spring on 13-Apr-2008 at 54.4 inches. There is a clear indication that precipitation events raise the water table between two and three days after the storm, and that the water table begins to drop shortly after. The graph shows the entire area gradually loosing water as the winter progressed. The water table fluctuates in height with short term recharge events caused by precipitation as well as seasonal changes such as frozen ground in the winter and snowmelt in the spring. The water table is subject to large variation in a short time span suggesting large aquifer recharges can occur suddenly but are most likely in the spring when snowmelt and precipitation recharge the aquifer. Data from the observation wells indicates that during the beginning half of April the water table is at its highest. Water table height and slope instability showed correlation. A slide occurred near stake 15 behind Cambridge Elementary between April 6th and 12th 2007.

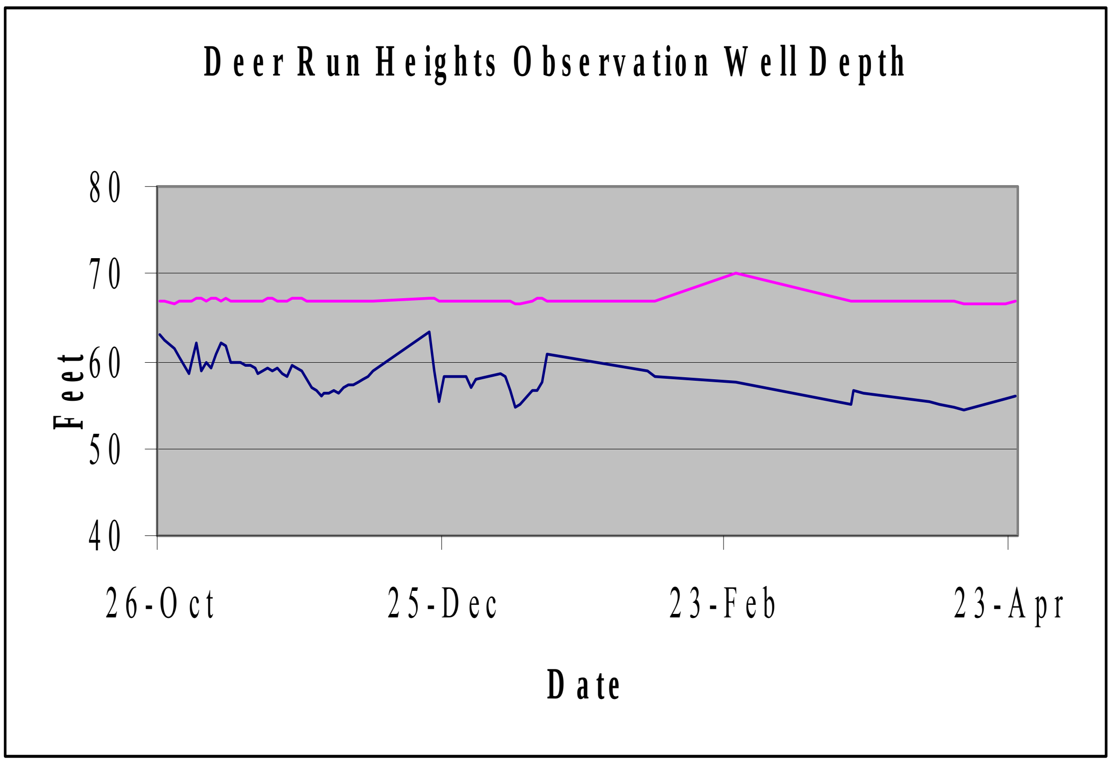

Figure 9. Water Table Height for 26-Oct-07 to 10-Dec-07

Tree Transects

The tree transects showed minimal slope movement between 28-Oct-07 and 24-Apr-08 as shown in Tables 1-4. The movement that was recorded was not significant enough to show is an immediate threat of a landslide in close vicinity to any marked trees. The greatest difference was between trees 28 and 29 on transect four with a distance of 0.4 meters. This change in distance occurred between 28-Oct-07 and 13-Jan-07. This area showed no change between 13-Jan-07 and 24-Apr-07. This is evidence that the area has become stable. On 24-Apr-07, in the area between trees 17 and 18 new erosion was noticed but the trees did not move. The erosion was caused by surface runoff possibly reaching the surface because of an impermeable clay layer common in the area.

Transect 1	T1-T2	T2-T3	T3-T4	T4-T5	T5-T6	T6-T7	T7-T8	T8-T9
28-Oct-07	5.21	4.95	1.02	10.30	16.00	7.80	12.25	6.58
13-Jan-07	5.21	4.95	1.20	10.29	16.10	7.80	12.15	6.56
24-Apr-08	5.21	4.95	1.10	10.29	16.03	7.80	12.25	6.55
Difference (m)	0	0	-0.08	0.01	-0.03	0	0	0.03

Transect 2	T10-11	T11-12	T12-13	T13-14	T14-15
28-Oct-07	3.90	1.45	3.57	13.75	11.53
13-Jan-07	3.80	1.45	3.57	13.75	11.53
24-Apr-08					
Difference (m)	0.10	0	0	0	0

Transect 3	T16-17	T17-18	T18-19	T19-20	T20-21	T21-22	T22-23
28-Oct-07	12.24	10.50	5.69	5.15	8.85	7.70	12.56
13-Jan-07	12.23	10.50	5.69	5.15	8.86	7.70	12.55
24-Apr-08	12.24	10.50	5.70	5.15	8.83	7.70	12.57
Difference (m)	0	0	-0.01	0	0.02	0	-0.01

Transect 4	T24-25	T25-26	T26-27	T27-28	T28-29	T29-30
28-Oct-07	9.28	5.98	10.33	11.8	1.45	11.95
13-Jan-07	9.29	5.98	10.34	11.98	1.85	11.96
24-Apr-08	9.29	5.99	10.35	11.98	1.85	11.96
Difference (m)	-0.01	-0.01	-0.02	-0.18	-0.4	-0.01

Tables 1-4 Tree Distance Changes for 28-Oct-07 to 24-Apr-08

Cutback

Cutback measurements show continued cutback along the ridge at Deer Run Heights. The ridge is cutting back at an average rate of 0.61 meters per year. This is very close to Michaela Forsberg's measurement of 0.62 meters per year. This shows that the rate of cutback has been consistent for the last two years. The majority of this cutback occurred in April during snowmelt. Table 5 displays all the measurements. A negative number within table 5 indicates a gain in land. Land gains are found because of the slumping at the top of the slope. Undercut portions of the slope begin to slump down slope while remaining attached to the soil on the top of the slope. This makes determining the edge of the slope difficult. This is most noticeable when the top portions of the slope are covered in grass. Continuous stretches of grass can be seen extending from well before the edge of the slope to well after the edge making the range of distance from the rebar subject to variation because the edge is difficult to determine.

	mf	mf	mf	jc	jc	jc	Average Cutback (m)		
Stake #	23-Aug-06	22-Oct-07	20-Apr-07	14-Nov-07	13-Jan-08	24-Apr-08	8 Months	20 Months	Meters/Year
1	3.63	3.58	3.55				0.08		0.12
2	4.8	4.13	4.67				0.13		0.195
3	6.23	6.18	6.2	6.48	6.19	6.25	0.03	-0.02	-0.01
4	11.28	11.27	11.17	11.88	10.43	11.03	0.12	0.25	0.15
5	7.48	7.3	7.18	7.37	7.78	6.83	0.3	0.65	0.39
6	4.93	4.87	4.8	4.91	6.00	4.57	0.13	0.36	0.22
7	6.14	5.98	6.02	6.01	6.20	6.25	0.12	-0.11	-0.07
8	6.4	5.38	5.1	5.17	4.74	4.90	1.3	1.50	0.90
9	4.77	4.78	4.57	4.85	5.45	4.95	0.2	-0.18	-0.11
10				3.98	4.43	3.60		5 Months 0.38	0.91
11	3.72		2.93	2.88	3.60	2.92	0.79	0.80	0.48
12	6.75		4.72	6.10	3.85	4.77	2.03	1.98	1.19
13	3.58		3.53	3.97	5.03	3.23	0.05	0.35	0.21
14	3.67		3.6	3.62	3.77	3.23	0.07	0.44	0.26
15	3.61		3.67	3.62	3.55	3.58	-0.06	0.03	0.02
16	3.6		3.46	3.67	3.68	3.10	0.14	0.50	0.30
17	3.54		3.3	3.40	3.72	3.57	0.24	-0.03	-0.02
18	3.08		1.75	2.32	1.22	2.15	1.33	0.93	0.56
19				10.33	5.73	7.90		5 Months 2.43	5.83
									Average 0.61

Table 5 Rate of Cutback from 23-Aug-06 to 24-Apr-08 (23-Aug-06 to 20-Apr-07 by Michaela Forsberg)

Snow

The amount of water produced by the spring snowmelt on Deer Run Heights was equal to 21 centimeters on 20-Mar-08. Between 20-Mar-08 and 30-Mar-08 much of the snow melted the equivalent of only 5 centimeters of water remained. This shows that in the 10 days between measurements 16 centimeters of water either infiltrated the soil or ran off. This is a very substantial water input on 20-Mar-08 the level in observation well B1 had increased to 55.05 showing a response to the input. By 8-Apr-08 the well had reached its highest point, 54.4. This shows a direct correlation between snow melt and recharge of the aquifer. The slide that occurred between the 6th and the 12th of April occurred partially as a result of water input from the snowmelt.

20-Mar-08	*Msr weight***	30-Mar-08	*Msr volume***
Snow Depth (cm)	Water Equivalent (cc)	Snow Depth (cm)	Water Equivalent (cc)
25	1451	11	230
22	1360	15	460
24	1451	23	685
26	1451	12	335
24	1542	14	395
24	1632	13	380
23	1451	15	420
26	1723	12	255
Total 194	12061	115	3160
Average 24	1508	14	395
Water Equivalent (cm)	21		5

Table 6. Snow Depth Water Equivalent for 65% Coverage

Discussion

During previous cutback measurements made by Michaela Foresberg the severe undercutting at the top of the slipface was observed. This undercutting causes cutback measurements to show minimal change although the loss of sediment is visually apparent (Forsberg, 2007). The bank undercutting stabilizes the bottom of the slope by removing weight from above. However, it destabilizes the top of the slipface by removing material that was providing support for the trees and other vegitation above. When the weight of the vegetation at the top of the slope becomes greater than the support of the sediment underneath the slop will fail. This will continue until a sustainable angle of repose is established (Forsberg, 2007; Montgomery, 2006). It is possible that the angle of repose at the bottom of the slope will be reduced by bank undercutting lessining the severity of a future slide that includes material at the top of the ridge. This was observed in April, 2008 when a severely undercut portion of the slope near rebar stake number 15 failed displacing 100 m^3.

Figure 9. Long Runout of the 1999 Landslide (Nichols, 2001)

1999 Deer Run Heights Slides, Jeffersonville

The 1999 landslide was a large mass wasting event consisting of three separate mass movements (Nichols, 2001). The first landslide occurred on 11-April-1999. The second landslide was the largest and occurred a week later on 18-April-1999; together the two landslides displaced 23,000 m^3 of glaciolacustrine material (Nichols, 2001). The third slide occurred on 4-July-1999 and displaced 4,300 m^3 of debris (Nichols, 2001). The debris from the slide crossed the Brewster River onto the adjacent floodplain covering 31,400 m^2 (Nichols, 2001).

The runout length of the 1999 landslides extends 290 m from the bottom of the slope (Figure 9., Nichols, 2001). Runout length and the orientation of the debris suggest that the landslide movement was partially a debris flow (Nichols, 2001). A debris flow or debris avalanche is when the material transported is not coherent and moves in a chaotic disorganized fashion (Montgomery, 2006). The second slide most likely exhibited these characteristics (Nichols, 2001). This type of flow was responsible for the extremely long runout produced by the slides.

Hazardous Location of Cambridge Elementary

If another slide were to occur along the gully identified by Michaela Forsberg in sight of the Cambridge Elementary School it is possible that a long runout such as that produced by the 1999 landslides would do sufficient damage to the school and school property. The school is located 120 m from the ridge, less than half the distance of the 1999 runout of 290 meters. The property of the school extends to the area directly adjacent to the Brewster River. A short runout would likely be sufficient to engulf the buses parked behind the school only a few meters from the Brewster.

The gully has been monitored since August 2006 by Michaela Forsberg and has continued to be monitored since. The gully is located along stakes 13-19 and has severely undercut the ridge along these stakes (Forsberg, 2007). A slide in this area was noticed in this area on April 6, 2008 (Figures 3 and 4) just in front of stake 15. The slide included a portion of the undercut bank at the top of the gully. The slide displaced a small amount of material that remained intact. It was displaced by about two meters. By April 12 the small slide in front of stake 15 had increased to include an estimated 100 cubic meters of sediment. A large portion of this slide consisted of an intact piece of sediment that had been the undercut portion of the gully. After the slide occurred the gully was no longer undercut and had vertical sides. This slide flowed straight towards the school at a bearing of 270°. This slide is insignificant in material size and displacement but serves as a reminder of the instability of the slope and the threat of damage to the elementary school.

Conclusion

The geology and landforms present on Deer Run Heights in Jeffersonville threaten to cause damage to two houses owned by the Fararas and the McCuins. The water table on Deer Run Heights is highly susceptible to fluctuations caused by various recharge events, during the month of April in particular. These fluctuations occur over short periods of time with precipitation events and over longer periods of time durng the time the ground is frozen during the winter. Snowmelt and precipitation combined to produce a larger aquifer recharge than at any other point during the year. This is why both the large slides in 1999 occurred in April and the small scale slide observed during this study. A slide could be triggered if a large enough rain storm or snowmelt occurs at any other time of the year. The small scale slide proved my hypothesis to be correct, it occurred when the water table was closest to the surface. The slide also showed that the Cambridge Elementary is close enough to the unstable slope to be damaged if a large slide occurred. The slope showed minimal progression of slumping downhill because trees identified on the tree transects did not move. Cutback was measured at rate of 0.62 meters per year, nearly identical to the rate measured last year by Michaela Forsberg of 0.61 meters per year.

Appendix A

Observation Well Depth and Rain Gauge Measurments

	B1(Inches)	B2(Inches)	B3(Inches)	B4(Inches)	RG1(cm)	RG2 (cm)
26-Oct	62.9	67	Dry	Dry		
27-Oct	62.5	66.9	Dry	Dry		
29-Oct	61.5	66.6	Dry	Dry	0	0
30-Oct	60.6	66.8	Dry	Dry	0	0
1-Nov	58.6	66.8	Dry	Dry	0.1	0.1
2-Nov	59.7	67	Dry	Dry	0	0
3-Nov	62.2	67.1	Dry	Dry	0	0
4-Nov	58.75	67.1	Dry	Dry	T(Trace)	T
5-Nov	59.7	67	Dry	Dry	0	0
6-Nov	59.1	67.2	Dry	Dry	1.4	1.2
7-Nov	60.7	67.1	Dry	Dry	0.2	0.2
8-Nov	62.1	67	Dry	Dry	0.1	0.1
9-Nov	61.9	67.1	Dry	Dry	0	0
10-Nov	60	67	Dry	Dry	0	0
11-Nov	60	66.9	Dry	Dry	0	0
12-Nov	59.9	67	Dry	Dry	0	0
13-Nov	59.4	66.8	Dry	Dry	0.1	0.2
14-Nov	59.5	66.8	Dry	Dry	0	0
15-Nov	59.1	67	Dry	Dry	0.6	0.7
16-Nov	58.7	66.9	Dry	Dry	1	1
17-Nov	58.8	67	Dry	Dry	Ice	Ice
18-Nov	59.3	67.1	Dry	Dry	Ice	Ice
19-Nov	59	67.1	Dry	Dry	Ice	Ice
20-Nov	59.1	67	Dry	Dry	Ice	Ice
21-Nov	58.6	67	Dry	Dry	4	3
22-Nov	58.1	66.9	Dry	Dry	0.5	
23-Nov	59.4	67.1	Dry	Dry	10 snow	12
25-Nov	58.9	67.1	Dry	Dry	0	0
26-Nov	58	66.9	Dry	Dry	0	0
27-Nov	56.9	66.8	Dry	Dry	1.6	1.7
28-Nov	56.8	66.9	Dry	Dry	9	9

29-Nov	56.1	66.9	Dry	Dry	T	T
30-Nov	56.3	66.9	Dry	Dry	0	0
1-Dec	56.4	66.9	Dry	Dry	0	0
2-Dec	56.8	66.85	Dry	Dry	2	1.5 snow
3-Dec	56.4	66.9	Dry	Dry	7+ Snow	7+
4-Dec	56.9	66.9	Dry	Dry	4+ Snow	4+
5-Dec	57.3	66.9	Dry	Dry	2	2.5
6-Dec	57.25	66.85	Dry	Dry	2	2
7-Dec	57.7	66.9	Dry	Dry	0	0
8-Dec	58	66.9	Dry	Dry	0	0
9-Dec	58.4	66.9	Dry	Dry	0	0
10-Dec	58.9	66.9	Dry	Dry	0	0
22-Dec	63.25	67.15	Dry	Dry	0	0
23-Dec	59	67.15	Dry	Dry	0	0
24-Dec	55.4	66.9	Dry	Dry	1.5	1.2
25-Dec	58.25	66.9	Dry	Dry	0	0
26-Dec	58.3	6.9	Dry	Dry	0	0
27-Dec	58.3	6.8	Dry	Dry	0	0
28-Dec	58.3	6.8	Dry	Dry	1	1
29-Dec	58.3	66.75	Dry	Dry	0	0
30-Dec	58.3	66.75	Dry	Dry	0	0
31-Dec	56.9	66.9	Dry	Dry	5	10
1-Jan	57.9	66.8	Dry	Dry	2	2
6-Jan	58.6	67	Dry	Dry	0.5	0.5
7-Jan	58.1	66.95	Dry	Dry		
8-Jan	56.6	66.8	Dry	Dry		
9-Jan	54.7	66.65	Dry	Dry		
10-Jan	55	66.7	Dry	Dry		
13-Jan	56.8	66.9	Dry	Dry		
14-Jan	56.7	67.05	Dry	Dry	3	3
15-Jan	57.75	67.3			0.3	0.2
16-Jan	60.8	66.9				
6-Feb	58.8	66.8				

8-Feb	58.3	66.9				
25-Feb	57.7	70.05				
20-Mar	55.05	66.9				
21-Mar	56.7	67				
23-Mar	56.4	66.9				
6-Apr	55.2	66.9				
8-Apr	55	66.8				
11-Apr	54.7	66.9				
13-Apr	54.4	66.7				
22-Apr	55.6	66.7				
24-Apr	55.95	66.8				

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