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History of the Logan Bluff Landslide Zone

Seth P. Olsen
Utah State University

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History of the Logan Bluff Landslide Zone

By
Seth P. Olsen

A report submitted in partial fulfillment
Of the requirements for the degree
Of
MASTERS OF SCIENCE
In
Civil and Environmental Engineering

Approved:

Robert T. Pack
Major Professor

James A. Bay
Committee Member

Marvin W. Halling
Committee Member

UTAH STATE UNIVERSITY
Logan, Utah
2006
Abstract

History of the Logan Bluff Landslide Zone

By

Seth P. Olsen, Master of Science

Utah State University, 2006

Major Professor: Dr. Robert T. Pack Department: Civil and Environmental Engineering

On September 10, 2005, a landslide occurred to the south of Utah State University Campus and Highway 89. This landslide did considerable damage to the Logan and Northern canal, which is cut into the slope, and to a residence at the toe of the slope. This event brought many parties together to collaborate on possible solutions to the immediate fix of the slide as well slides that could occur in the future. The purpose of this report is to compile information useful to the study of the area and the possible solutions and/or risk assessment of the Logan Bluff Landslide Zone. The study includes the records of any landslides, possible causes of slope failures, historical precipitation analysis, construction and land use changes over time, and a specific study of the September 2005 slide. The information presented in this report still leaves many questions unanswered and other data is likely available. However, it can be used as the starting point for a more in depth study of the bluff area.
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1.0 Introduction

The September 10, 2005 landslide brought several stakeholders together to look for a solution to a recent landslide and make plans for the future to prepare for and assess the probabilities of additional failures. The discussions brought Logan City Officials, Utah Department of Transportation, Utah State University, the Logan Irrigation District Canal Company, geologists, concerned Canyon Road residents, and other curious citizens together in an effort to come to an understanding of the situation.

A committee was formed to assess the plan of action for the study of the area. Among other things, it was determined that a comprehensive study of the history and overall landslide risk of the Logan Bluff area is necessary. This report is the beginning of this study to be done by Utah State University and focuses on the collection of available data. The synthesis of this data is to follow in subsequent studies.

2.0 Landslide Events

2.1 History of Landslide Events

In the past 100 years, periodic landslide events have been documented along the Logan Bluff study area. This area's material properties, depositional characteristics, hydrology, and topography make it prone to slope instability.

The Logan Bluff landslide zone is located at the mouth of Logan Canyon where the Logan River enters Cache Valley. The Logan River has exposed alluvial deposits over Lake Bonneville sediments leaving a steep slope to the north of the position of the river currently. (See Figure 1) The area of the study comprises the slope to the south of US Highway 89 and Canyon Road in Logan, UT. Given the observed instability, the area
between 500 East and 1500 East will be examined. Canyon Road follows the toe of the slope for a good portion of the study area.

Many old beaches (referred to as benches) remain at the shorelines of what once was Lake Bonneville. The study area lies on the Provo Bench at an elevation of approximately 4800 feet. As seen from the topographical map in Figure 2, the majority of the slope along the study area slopes downward to the south from that elevation. A more detailed topographical map is presented later in this report.

Figure 1. 1993 aerial photo of the study area[1].
The Logan and Northern Canal runs along the length of the hillside throughout the study area. The canal was built in 1865-1867 by The Logan and Richmond Irrigating Company[3]. The early settlers of Cache Valley engineered the canal for the water to reach the far north end of Cache Valley. In order to accomplish this, however, the canal was cut into the slope along the entire study area. Cutting the canal into the slope further steepened the slope from its natural geometry and increased instability.

The earliest instance of slope failure were recorded in the Journals of the canal company in January of 1899[4]. Bills were paid for the repair of the canal and the journal takes an account of that transaction. The following caption was written with the picture shown in Figure 3:

"Logan and Northern canal on hillside south of USU campus ca. 1902. Note board retaining wall on hill bank and log braces across canal. Bracing done to stop landslides from washing out the canal. Considerable controversy
ensued between water users and college officials about whether watering of college grounds causes seepage which started slides." [5]

A major slide occurred in December of 1904, which continued to add to the controversy. A more detailed discussion of this controversy is presented later in this report.

The next slide occurred on August 20, 1916. As shown in Figure 4, the slope failed in a typical sapping failure mode exposing an area of the underlying sand, silt, and clay. At approximately 500 East the failure opened up a scarp approximately 150 feet
wide into the bluffs. In Figure 4 the X in the photograph marks the place where the canal was before the slide event.

![Figure 4. Slope failure at 500 East in 1916](image)

When slides occur, they leave scars. The study area shows evidence of various slides. Previous to the slides mentioned, the evidence of more slides are recorded in the bluff itself. As shown in Figure 5, at least two large failures occurred before 1919 between 1100 and 1500 E. Figure 6 shows that from 1100 East heading west at least three major slides occurred in this section prior to 1943. The slides shown in figures 5 and 6 are also reported in a 1978 Utah Geological and Mineral Survey Report[7].

---

1 There is some uncertainty as to whether 500 East at that time is the same as 500 East a present. This still needs to be determined.
Figure 5. Panoramic view of first dam and bluff area 1919[8].

Figure 6. Aerial photo of bluff area 1943[9].
The next recorded landslide occurrences took place in 1973 and later in 1976[10].

During these and other previous slides much of the damage that came as a result of the slope failures is from homes along Canyon Road where the slides came to rest. One such instance was on October 19th, 1976. Dean Johnson lived at 905 Canyon Road at the time of the slide. Mike Donahue of the Herald Journal wrote the following in regard to the slide and Mr. Johnsons home,

“A soil slide carrying rocks, brush and trees slipped down the high north bank of the canal behind Johnson’s house and dammed it. The water, as a result, filled the canal and poured down over the south bank causing another massive rock slide which covered Johnson’s yard.”[11].

In the report by the Utah Geological and Mineral Survey dated 1978 it stated, “Since this time two additional failures, one in the late fall of 1977 and another during the week of March 26, 1978, have been observed.”[7] The report was undertaken to study the area due to these landslide events.

One of the biggest failures that occurred in more recent history happened in 1983. Mrs. Perry Bundy, whose home is in the study area, stated in 1983 that “she and her husband have lived at that location since 1937, and last summer (1983) was the first time they have had any trouble with the hill.”[12] This statement is an example of how residents can sometimes have imperfect recollections in that the events in the 1970’s were not mentioned. 1983 was the same year of the large and costly Thistle Landslide near Spanish Fork, Utah. The initial slope failure in the study area of 1983 occurred on the 29th of June.

“The slide, about 50 yards wide, started last Wednesday (June 29th), and on Sunday (July 3rd) water to the canal was shut off to avoid possible flooding of
houses below, according to Jack Howard, foreman of UDOT's Logan equipment shed."[10].

This initial incident was thought to be all that might happen. Clyde Hardy, a USU geology professor at the time stated:

"The hillside has been remarkably stable since the 1976 slide, with only little bits of the hill sliding at any one time. My point of view is that we aren't going to have anything of the magnitude of the '73 and '76 slides."[10]

In the same article Jim McCalpin, another USU geology professor, was quoted as saying:

"There are cracks in the hill above the present slide that have grown 'appreciably' in the last two days. The cracks indicate two highly unstable areas that could slide and fill the canal. The saturated hillside will be difficult to stabilize."[10].

The unstable areas did fail as Professor McCalpin predicted. On July 9, 1983 the same area failed and sent water and debris down the slope again.

"Of special concern today is how to stabilize the hillside. Large pieces of earth and rock continue to drop into the 30-foot wide chasm created by the slide, only to be washed down the hill by the water that continues to flow out of the hillside. Lynn Zollinger, Utah Department of Transportation District 1 design engineer, said he is 'very concerned' that the present rate of slippage could endanger State Highway 89, about 150 feet above the slide. The mud from this latest event has filled a 50-foot section of the canal bed and is eight feet deep in some places."[13].

By the time the slope "stabilized" for the time being it got to within 100 feet of the highway and five homes had been damaged from the water and debris[14].
So much water and debris was spewing from this slide that Crocket Avenue, running north and south just below the slide, had to be made into a diversion channel, diverting the water and debris back into the Logan River [14]. Figure 7 shows a photograph of the slope failure.

Figure 7. Photograph of July 1983 slide [15].

In December of 1983, another slide occurred about a block east of the event over the summer. "Jack Howard, foreman of UDOT's Logan equipment shed, said, "Water keeps coming out of the hill and taking big chunks of dirt with it, just like last summer." [12] The size of this failure wasn't as great and the damage it did was much less because the water and mud that flowed down the hill crossed between two homes at 925 and 975 Canyon Road.
The slope failures discussed in this report thus far were major events that caused major damage. This does not mean that smaller, less drastic slides have not occurred more frequently. Jess Harris, president of the Logan Northern Irrigation Company for 10 years in the nineties, for example, said that there were 3 slides in the nineties that required a repair of the canal to restore flow.

The next notable slope failure occurred on September 10, 2005.

“A landslide bringing down trees, rocks and topsoil came crashing through the basement of a Logan home around 5 a.m. on Saturday. The home located at 975 East Canyon Road is owned by Dan Topel and his wife, who said the slide was a bit of a ‘rude awakening’ this morning.”[16]

A further discussion of this slide will be done later in this report.

Figures 8-10 show the placement of each of the landslides discussed in this section of the report. The locations are derived from observations of photographs by the author as well as plotted locations in the 1978 UGS report [7] and a 2005 Golder and Associates Report [17]. The figures show 2’ contours and curb and gutters of Logan City [18]
Figure 8. Topo map showing slides 500 East to 800 East.
Figure 9. Topo map showing slides 800 East to 1100 East.
Figure 10. Topo map showing slides 1100 East to 1400 East.
2.2 Causes of Landslide Events

For any given slope, if the shearing resistance is less than the shear force applied then the slope fails.

"The causes producing a decrease in slope stability are termed external and internal. External causes include, a steepening of the slope due to man-made excavations; internal causes occur without any change in surface conditions due to a decrease in the shearing resistance of the material. Commonly, the shearing resistance decrease is the result of an increase in pore-water pressure and a progressive decrease of the cohesion of the material adjoining the slope (Terzaghi, 1950)" [7]

For most of the length of the slope in the study area the Logan Northern Canal has been excavated into the hillside and further steepened the slope above the canal, for example. This is one of the possible external causes of the slope instability.

The internal cause of the slope failures in the study area is due to the increased pore-water pressure. The UGS 1978 Report State:

"A working hypothesis for mode of failure that we are suggesting is the following . . . Groundwater migrating laterally in the stratified, interbedded fine sands of the Provo Formation exerts pore-water pressure upon the relatively homogeneous veneer of colluvial material. The colluvial cover with its high angle of interface with the underlying Provo Formation eventually fails, and the mobilized material reaches the canal or beyond. This leaves the Provo Formation sediments exposed in a high-angle cut face. Pore-water pressure in the fine sand horizons builds up to the point of failure by flowage. Undercutting of the remaining exaggerated slope face then
easily occurs, and the sapping action slowly results in recession of the steep face up the hillside." [7]

It's interesting to note that in almost every slide investigated, the failure occurred in the summer, late fall, and winter. Spring is the wettest time of year, when it comes to precipitation and/or runoff. One possible explanation of this could be that the failures are delayed.

A delayed failure landslide has three characteristics:

1. "The soil in the slope is an overconsolidated clay, clayey silt, or silt (i.e., slow draining, with dilatant shear behavior).

2. An event occurs that reduces the stability of the slope and increases the shear stresses in the soil; examples are manmade cuts and fills, and erosion.

3. The velocity of the shear movements within the discrete shear zone progressively increase with time. In delayed failure, the slope failure does not occur concurrently with the causative factor, which may be a cut, fill, or erosion. The reason for the delayed failure is that overconsolidated clays dilate when sheared and develop negative changes in pore water pressures.

The induced negative changes in pore pressures temporarily increase the shear strength and provide slope stability. As the pore pressures rise toward long-term equilibrium levels within the slope, the shear strength of the soil decreases with elapsed time and may cause a landslide years or decades after construction. A . . . scenario would be a natural groundwater table that fluctuates between summer and winter. In this case, it can be anticipated that the clay will lose strength in the winter months at a faster than average rate because the differential between the depressed pore water pressure and the higher winter groundwater level will be greater than average. Conversely,
the clay will lose strength at a slower rate than average over the summer when the groundwater is lower than in winter. The roller-coaster curve overlaid on the broken curve is a simplified representation of this effect. With a fluctuating groundwater regime, it is likely that a delayed failure will occur in winter when a high groundwater spike (or just seasonally high groundwater) triggers the slope failure.” [19]

The evidence is still unclear if the failures in the study area are delayed, but much of the discussion and argument has come as to the source of the groundwater. In a letter to the Agricultural College of Utah (Utah State University), the Canal company wrote a letter dated January 3, 1905.

"On behalf of the Logan and Richmond Irrigation District we take this occasion to call to your attention the very serious conditions which have arisen on account of seepage water from that part of the college farm lying easterly from the college buildings."

In another letter to the College it states:

"the said land owners as aforesaid claim that the land canal has been injured, and that they have been greatly damaged by landslides, and wash-outs, caused by the Agricultural College of the State of Utah, on account of the said Agricultural College having irrigated its farm lands, which lie on an elevation immediately above the said canal, and causing the damage to the said claimants as aforesaid."[20]

During the last 6 months, meetings have been held to discuss the slide that occurred in September of 2005. In these meetings many of the same arguments have been made as to the source of the seepage water, although more than just the University has been pointed out.
“In the three months following an early morning landslide that washed out the bottom portion of his 975 East Canyon Road home in Logan, Don Topel says his gray hair has gone white. ‘Generally speaking, the biggest problem is nobody is stepping forward to take the blame for this thing happening,’ he said. Mark Nielsen, Logan’s public works director, told the Municipal Council that his office is determined to work cooperatively to root out the source of the slide and pay for improvements. ‘I think everybody thinks that all parties that have water sources north of that slope have some culpability,’ he said.” [21]

According to the 1978 UGS Report [7], the increase in groundwater is likely due to a combination of factors. The irrigation on the Utah State University campus is most likely a player. The golf course, surrounding residences, and development probably also contribute. Another likely contributor is also the Logan, Hyde Park, and Smithfield Canal that runs along the golf course and then heads north. In connection with this canal a study was done,

“The canyon portion of the canal was never properly constructed, and the loss through leakage is very great. On August 31, 1893, the discharge at the head gates, as measured by the writer, was 48 second-feet. At a point 7,000 feet lower down the volume had been decreased, on account of waste, to 26.7 second-feet, a loss of 21.3 second-feet, or 44 per cent of the volume diverted.” [3]

The study done by Fortier was over 100 years ago so a more in depth study of what has been done with the Logan, Hyde Park, and Smithfield Canal since that time would be beneficial to the study. Another probable player is the precipitation that falls and recharges the groundwater aquifer.
3.0 Precipitation

Water is always present when landslides occur along the Logan Bluff area. Whether that water is precipitation, seepage, or comes from another source, it has an effect on the slides.

"Most of the groundwater in the Cache Valley is derived from precipitation within the Cache Valley drainage basin. Recharge to the principle groundwater reservoir in Cache Valley occurs mainly by infiltration of water from direct precipitation, streams, canals, ditches, irrigated fields, and subsurface inflow (Bjorklund and McGreevy, 1971)\(^2\). Bjorklund and McGreevy (1971) also state that direct recharge from precipitation occurs in the Cache Valley mainly during periods of snowmelt and that recharge directly from rainfall is small due to the fact that most of the water from heavy rains runs off before entering the soil. Of the water that does infiltrate, a greater percentage is transpired by vegetation, evaporated, or retained as soil moisture." [7]

On September 24, 1973, the year of a landslide event, the Harold Journal reported, "Northern Utah isn't any danger of becoming a tropical rain forest, but more than one inch of rain that fell on the valley this weekend made the year the wettest in history." [22] This was reported from Salt Lake City, but the precipitation in Cache Valley also made an impact. Figure 11 shows the three year average for precipitation measured at the Utah State University weather station. In 1973, the station at Utah State

University had the highest 3-year average since 1909. 1973 was the year of a major landslide event.

![Precipitation Data](image)

**Figure 11. 3-year average precipitation data [23].**

Many slides have occurred over time, but 6 slides in the last 100 years will be analyzed in more detail regarding the precipitation data prior to each specific event. (See Table 1) The 1978 UGS Report [7] provides a figure showing a comparison of monthly accumulation of precipitation to monthly average precipitation for the 8 months prior to the October 20, 1976 landslide. They indicate that the monthly precipitation is not strongly correlated with the landslide event. They suggest that high intensity storms just prior to the slide may have had a more significant effect. In order to expand the UGS analysis to each of the six major landslide events discussed in this report, Figures 12 through 17 show a comparison of monthly accumulation of precipitation to monthly average precipitation for 12 months prior to each event [23].
Major Landslide Events

1 - December 1904
2 - August 1916
3 - October 1976
4 - July 1983
5 - December 1983
6 - September 2005

Table 1. Major landslide events.

12 Months Prior to December 1904 slide

Figure 12. 12 months prior to December 1904 slide.
12 Months prior to August 1916 slide

Figure 13. 12 months prior to August 1916 slide.

12 Months prior to October 1976 slide

Figure 14. 12 months prior to October 1976 slide.
12 Months prior to July 1983 slide

Figure 15. 12 months prior to July 1983 slide.

12 Months prior to December 1983 slide

Figure 16. 12 months prior to December 1983 slide.

Figure 17: 12 months prior to September 2005 slide.

Figure 17. 12 months prior to September 2005 slide.
As with the UGS findings, these graphs indicate that for a couple months prior to each event, the monthly accumulation is less than the 30-year average, and is therefore not directly correlated with the event. However, there is still the possibility that cumulative precipitation over the year prior to each event might be above average and that a rising groundwater table may be adding to the instability of the slopes. In Figure 18 we see that there is a definite increase in the early 1980’s in the yearly precipitation totals. This is consistent with the fact that two major slides occurred during that time period. The fact that this increase in precipitation total prior to the other events is not as clear will require further investigation.

![Precipitation Data](image)

Figure 18. Yearly precipitation totals 1900-2005 [23]

A trend that has become apparent when analyzing the six-month totals throughout the 105 years of precipitation data from the Utah State University campus is that there have been only four times that over 20 inches of precipitation have been recorded. (see Appendix A) The first was July through December 1983, the second was August 1983
through January 1984, the third was November 1985 through April 1986, and the fourth time was January through June 2005. In three of the four occasions a major slide has occurred during or within a few months of the wet six-month period. The wettest of the four 6-month periods was from July through December 1983 when more than 22 inches of rain was recorded on the Utah State University campus. The wettest period from January through June of the 105 years of data was in 2005. A more detailed analysis can be performed using the data provided in Appendix A.

As shown in Figure 18, 1982-1984 were the wettest years in the 105 year precipitation history. During that period, two major landslides occurred.

4.0 Construction

4.1 Buildings
The growth of Logan has been consistent since the time it was settled. The growth initiates the construction of new homes, industrial buildings, utility structures, and many other developmental necessities for a growing city. Figures 19 through 28 show how Logan, UT and Utah State University has grown and changed.

What started as agricultural fields of the Agricultural College at the turn of the century has now developed into residential neighborhoods, a golf course, and more buildings on the University Campus itself.
Figure 19. Photograph of slope and USU campus approximately 1900 [24]
Figure 20. 1939 photograph of Utah Agricultural College [25]
Figure 21. 1943 aerial photograph of bluff area north [26].
Figure 22. Early 50s aerial photograph [27].
Figure 23. 1952 photograph of bluff area and USU [25].

Figure 24. 1963 photograph of bluff area and island [28].
Figure 25. 1966 Photograph of Utah State University [29]
Figure 26. 1970 Photograph of Utah State University [30].
Figure 27. 1981 Photograph of Utah State University [31].
As shown in Figure 20, in 1939 the Utah Agricultural College didn't extend east of where the Business building now stands, and didn't extend north beyond where the HPER building now stands. Much of the University at that time was agricultural fields. Between 1939 and 1952 some of the major buildings constructed included: Janet Quinney Lawson Building, Lilliwhite Building, and the Technology Building [32].

From 1952 to 1966 much of the expansion on the campus was for student housing. The housing buildings constructed included: Moen Hall, Greaves Hall, Reeder
Hall, Merrill Hall, Bullen Hall, Richards Hall, the Junction, Mountain View Tower, and Valley View Tower. Other University buildings constructed during this time included: Edith Bowen School, Biology-Natural Resources, Agricultural Science, Biotechnology Center, Engineering-Laboratory, Engineering-Classroom, the Merril Library, Fine Arts Center, the Taggart Student Center, and the Forage & Range Research Laboratory [32].

Between 1966 and 1970 the HPER, the Business building, the Nutrition and Food Science, and the Industrial Science building were constructed on the main campus. Housing complexes continued to be built off of 1200 East to the northeast of campus. From that time through 1981, not a lot of construction took place on campus directly above the bluff area. However, since that time major buildings have been constructed including: Science Engineering Research, Eccles Conference Center, the New Engineering Building, Recital Hall and the New Merril-Cazier Library. The agricultural fields that at one point made up a large portion of the campus have been replaced with buildings and parking lots and other more impervious surfaces. With that development, most of the precipitation that falls is more likely to be transported as runoff.

Another major change in development in the study area is the presence of residences. In the 1939 [25] and 1943 [26] photographs we see that east of the University there are very few homes, if any. However, from the early 50s to now, basically the whole bench area above the bluffs has been developed. Logan City has filled in all the way to the foot of the mountains since that time.
4.2 Canals

The canal that follows the contours of the bluff and cuts into the slope is the Logan and Northern Canal, built in 1865 [3]. Many changes to this canal have been made subsequently, the complete history of which has not been reviewed in this study.

The Logan, Hyde Park, and Smithfield Canal runs along Logan Canyon for about a mile and then heads north through the golf course and then beyond the study area.

Figure 29. 1902 photograph of the canal [33].
"The Logan, Hyde Park, and Smithfield Canal was completed in June, 1882. Its head gate is located about 1-1/2 miles above the mouth of the canon, and at an elevation of 326 feet above the business center of Logan City." [3]

Limited time and resources prevented reviewing in more detail the history of the canals as they relate to potential effects on groundwater levels and slope instability. This should be a major focus in a subsequent study.

In summary, the growth reviewed in this section has likely had an effect on the rates of precipitation recharge in the areas above the bluff. An estimation of the magnitude of the change in recharge is beyond the scope of this study. However, it is clear that the amount of change has been significant enough to warrant further study of this issue.

5.0 September 2005 Slide

5.1 Introduction

On September 10, 2005 a slope failure occurred just to the south of the old Merril Library on the Utah State University Campus. This failure sent rock and debris down the slope, filling the canal and continuing down the slope and into the basement of the residence on Canyon Road. (see Figure 30) There was an outlet structure for the canal just upstream of the failure so the canal didn’t overtop as well.

5.2 Geologic Units

Figure 31 shows the slope just above where the failure occurred. It’s clear that there are two distinct zones of vegetation along the length of the slope. Trees and thick brush grow all along the lower slopes where the seeps are exiting the bluff. Above that
zone it is the more grassy dry slope underlain by well drained gravels. This zoning suggests that the subsurface stratigraphy is relatively consistent throughout the entire length of the slope. This evidence and that observed within the landslide scar enables us to classify the area into two distinct Geologic units as shown in Figure 32. The upper unit is made up of clast supported pebble and cobble beds from deltaic deposits and related to younger shorelines (Evans et al, 1996) [7] The lower unit comprises of lacustrine sand and silts related to the Lake Bonneville shoreline of Quaternary age (Evans et al, 1996) [7]
Figure 30. Photographs of September 2005 slide.
Figure 31. Photograph looking east just above September 2005 slide.

Figure 32. Photograph showing two distinct geologic units.
5.3 Laboratory Tests

Soil samples have been taken in the lower silty geologic unit at random locations within and where there was observed to be a change in strata. The lab tests performed included: moisture content, hydrometer analysis, sieve analysis, and 200 wash. Samples were taken at various depths of the exposed landslide scar (see Figure 33 and Table 2). The laboratory tests in no way show the specific layers and properties of the slope in the study area, but are for general classification purposes.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Elevation (ft) Relative to the Lowest Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
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<td>7</td>
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</table>

Table 2. Sample elevations.

The lab tests resulted in the classification of two very distinct soil types. One is the lacustrine sand and silt with 22-27% moisture and 44-53% fines. The other is the cobble gravelly material with 9-10% moisture and less fines. With depth the sand and silt layers don’t vary much in moisture content. This consistency in material is also noted in the boring logs taken by the Utah Department of Transportation [34] and Golder and Associates [35] who performed borings at the slope failure site at the top of the slope and the toe of the slide respectively.
A hydrometer analysis was performed on three of the sand and silt samples to determine the clay fraction of the material. All three samples had a clay content of approximately 8%. Figure 34 shows a typical particle size distribution (\(<#200\) sieve) expressed as a percentage by weight of the entire sample.
Figure 34. Hydrometer analysis results for one of three samples analyzed.

Figure 35 shows the Grain Size Distribution for Sample #5. This sample was taken from a gravelly layer 17 feet below the initial change in strata at the head scarp of the slope failure (See Figure 33). The sample was 51% gravel (35% coarse gravel, 16% fine), 27% sand (3.3% coarse sand, 2.7% medium, and 21% fine), and 22% fine material (silt and clay). The sample is classified as a silty gravel with sand. Below this depth, the exposed scarp showed no more evidence of these gravelly layers.

Figure 35. Grain Size Distribution for Sample #5.
The cobble and gravel layers are pervious and readily allow any water to migrate and recharge the groundwater aquifer sitting on the underlying, less pervious sand and silt layer. This water then migrates laterally in the stratified, interbedded fine sands and silts until it can be released along the bluff area.

Figure 36 shows the Lab Summary of all of the samples taken at the slope. Using the Unified Soil Classification System the interbedded sand, silt, and clay is classified as an SM/ML or a Silty Sand or Sandy Silt. Figure 37 shows a profile of the interbeds associated with this deposit. The colluvium material is classified as a GM or Silty Gravel. These same classifications were made from the borehole samples taken by Golder and Associates [35] and UDOT [34] at the toe of the slope failure.

<table>
<thead>
<tr>
<th>LE</th>
<th>DEPTH BELOW GROUND SURFACE</th>
<th>% CLAY FRACTION</th>
<th>UNIT WEIGHT Dry / Wet LB./FT.3</th>
<th>% MOISTURE</th>
<th>% GRADATION</th>
<th>% PASSING NO. 200 SIEVE</th>
<th>ATTERBERG LIMITS</th>
<th>UNIFIED SOIL CLASSIFICATION</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SAND</td>
<td>GRAVEL</td>
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<td>P.L.</td>
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<td></td>
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<td>55.1</td>
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</tr>
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<td>22.8</td>
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</tr>
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</table>

Figure 36. Soil testing summary.
5.4 Changes over time

Changes have occurred over time as long as the slope has been exposed. These changes take place as the slope moves in an attempt to achieve and/or retain equilibrium. Figures 38-40 show how the September 2005 slide has changed over time. Figure 38 shows the slide within a few weeks of the failure (October 13, 2005). Figure 39 shows the same slide a month later (November 11, 2005) and Figure 40 a month after that (December 13, 2005). Note how the gravel talus within the scar has grown in size over this period of months.
Figure 38. Photograph of slide 10/13/05.

Figure 39. Photograph of slide 11/11/2005.
5.5 Groundwater

Groundwater fluctuates at different times of year and during any changes that take place in the temperatures and/or precipitation. After the slide in September of 2005, the Utah Department of Transportation installed a piezometer in a borehole located at the top of the slope area [34] (See Figure 41). Figure 42 shows the path of the seep after it emerges from the slide scar.

The piezometer was installed to measure the fluctuations in the groundwater as remediation measures were carried out and throughout the winter. Before an automatic piezometer reader was installed, the author took measurements for approximately 2 months at varying intervals. The piezometer was installed at a depth of 96 feet from the ground surface. Therefore, the piezometric levels shown in figure Table 3 are relative to
the 96 foot depth or approximately at a depth of 87.5 feet on average. The gauges installed are sensitive to changes in barometric pressure and other noise sources that introduce error in the readings. Over the two-month period shown in Table 3 there is a downward trend of the piezometer readings of approximately 0.5 feet. This trend is not likely the product of random gauge errors. The precipitation during this same period is also shown in Table 3. There is no clear correlation between precipitation and groundwater level though further correlation analysis might be warranted.

The 1978 Utah Geological and Mineral Survey states:

“Regional groundwater flow in the Logan area is generally from east to west, but locally in the study area and that area to the north (Utah State University campus, golf course, subdivisions) the flow is from north-northeast to south-southeast. This fact was noted by Dr. Windsor as a result of a dye study performed in the 1930’s (Fletcher, 1978). Sodium fluorocine dye was placed in the north-south oriented irrigation ditch located in an alfalfa field east of the present library and Lund Hall. The first traces of the dye were noted seeping from the bluff in the study area approximately one week later; the major discharge was noted in approximately one month.” [7]

This points to the possibility that the water from the University and other developments at the top of the slope add to the recharge of the groundwater aquifer. The underlying sand, silt, and clay listed in order of abundance, isn’t completely impervious, but is much less pervious than the overlying cobble and gravel strata. This allows the groundwater to accumulate on the less pervious surface.

---

3 Fletcher, Joseph. 1978. verbal communication.
<table>
<thead>
<tr>
<th>Date</th>
<th>Precipitation</th>
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Table 3. Piezometer readings December 2005 through February 2006.
Figure 41. Cross section of September 2005 slide [36]

Figure 42. Topography of September 2005 slide area [36]
6.0 Conclusions

The slopes along the Logan bluff landslide zone are unstable. The question is not if another slide will occur, it's when. The slides will continue to happen until a more stable slope is reached.

The water seeping from the slope has a definite effect on the stability of the area. Measures taken to limit the amount of water adding to the groundwater aquifers would help slow the process of recharge.

As to the cause of the failures, there are a few. In some areas along the slope, the cut made for the construction of the canal possibly has contributed. In other areas the slope is just too steep to remain stable. Whether it's the canal cut, too steep of slopes, or other unstable areas, water is the initiating cause of every slide investigated during this study. One of the major sources of this water is more than likely the precipitation. Another possible contributor is the Logan, Hyde Park, and Smithfield Canal. Water from the University and surrounding development also add to the groundwater.

Whether it's this year or in 50 years that the slope fails again, the important thing is that we've taken the necessary steps to ensure that the damage done by the failure is as minimal as possible.
Works Cited


5. Photograph: Canal Repair. USU Merrill Cazier Library, Special collections, photo A-0103. 1902.


18. Logan City. Logan City Data including two-foot contours and GIS formatted data. Department of Planning and Development.


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25. Logan City. Logan City Data including two foot contours and GIS formatted data. Department of Planning and Development.

