

## Utah Geological Survey

Project: Preliminary hazard assessment of the Frontier Drive landslide, Mountain Green, Morgan County, Utah			Requesting Agency: Emergency Response
By: Francis X. Ashland	Date: 9-4-01	County: Morgan	Job No:  01-07
USGS Quadrangle: Snow Basin (1088)		Section/Township/Range. Section 23, T. 5 N., R. 1 E.	

### INTRODUCTION AND PURPOSE

In late February 2001, landslide movement initiated on the west-facing slope west of Frontier Drive in Mountain Green, Utah. The landslide affected seven residential lots and abutting common-area open space and caused the most severe damage to the two lots on the south end of Frontier Drive. Utah Geological Survey (UGS) geologists conducted an initial reconnaissance of the landslide on May 8, 2001, and monitored landslide movement and ground-water levels on subsequent visits to the site. This report summarizes the conclusions of the UGS regarding the landslide hazard. In addition, the report documents site conditions, landslide features, and landslide damage.

### CONCLUSIONS

Based on observations, measurements, and stability analysis of the Frontier Drive landslide, the UGS concludes the following.

- The landslide will continue to pose a threat to the residential properties along the west side of Frontier Drive south of Woodland Drive until the slide is stabilized.
- With the exception of the houses on lots 48 and 49 (6827 N. and 6815 N.), the houses on the west side of Frontier Drive appear to be adequately set back from the active main scarp zone of the landslide such that the immediate threat to the houses is low.
- If the landslide is not stabilized, additional damage to the house at lot 49 (6815 N. Frontier Drive) will likely occur and enlargement of the landslide in an upslope direction is possible, potentially endangering the houses to the north.
- Movement of the Frontier Drive landslide triggered in late February and continued through May and June.
- Movement in 2001 was a partial reactivation of a pre-existing landslide that was modified during development of the Trapper's Pointe subdivision.

- Landsliding was triggered despite near-normal precipitation prior to and during the period of movement and suggests the pre-existing landslide was marginally stable prior to hillside modifications.
- Reactivation of the remainder of the pre-existing landslide north and south of the Frontier Drive landslide is possible, particularly if hillside modifications are made.

## **STUDY RESULTS**

### **Landslide Description**

The Frontier Drive landslide is on a generally west-facing slope between an unnamed creek on the west and the approximate crest of the natural slope on the east (figure 1). The landslide is along the western edge of the Trapper's Pointe subdivision (Landmark Surveying and Engineering, Inc., [LSE], 2001) in Mountain Green, Morgan County, and is approximately between elevations 5,020 and 5,100 feet. The main scarp of the landslide (figure 2) generally coincides with the inferred position of the natural crest of the slope prior to hillside modifications during development of the site. Locally, an individual main scarp is difficult to recognize and instead a zone of scarps and transverse ground cracks or crown cracks exists (figure 2b). The main scarp steps to the west and transitions into a ground crack with no vertical offset at the north end of the landslide (figure 2c). The ground crack does not extend downslope to the creek. Thus, the exact position of the northern boundary of the landslide is uncertain. The toe of the landslide is along the east edge of the creek at the base of the slope in the southern part of the landslide. The toe locally consists of zones of overriding thrusts that form a stair-stepped geometry in the lower slope (figure 3). The location of the toe in the northern part of the landslide is less certain. I observed probable toe-like features in the lower third of the slope in the northern part of the landslide. The southern edge of the landslide is bound by a discrete left-lateral shear.

The Frontier Drive landslide is about 800 to 1,000 feet wide (north-south) and, on average, about 300 feet long (east-west). Table 1 summarizes the landslide width measurement data. Based on these dimensions, I estimate the landslide area to be about 27,000 to 33,000 square yards. Rock was encountered beneath the landslide deposits at depths of 68 and 28 feet in two boreholes (Earthtec Testing and Engineering, P.C. [Earthtec], 2001). Assuming an average depth of about 50 feet for the landslide deposits, I estimate the landslide volume to be between approximately 440,000 and 560,000 cubic yards.

The average slope of the landslide, from the toe to the crown, ranges from about 20 to 30 percent. I determined the average slope angle in two locations south of lot 45 using the topography on the LSE (2001) plan. Table 2 summarizes average slope information for the landslide south of lot 45. I observed the slope north of lot 45 and estimated that the average slope of the landslide in that area is flatter than 23 percent.

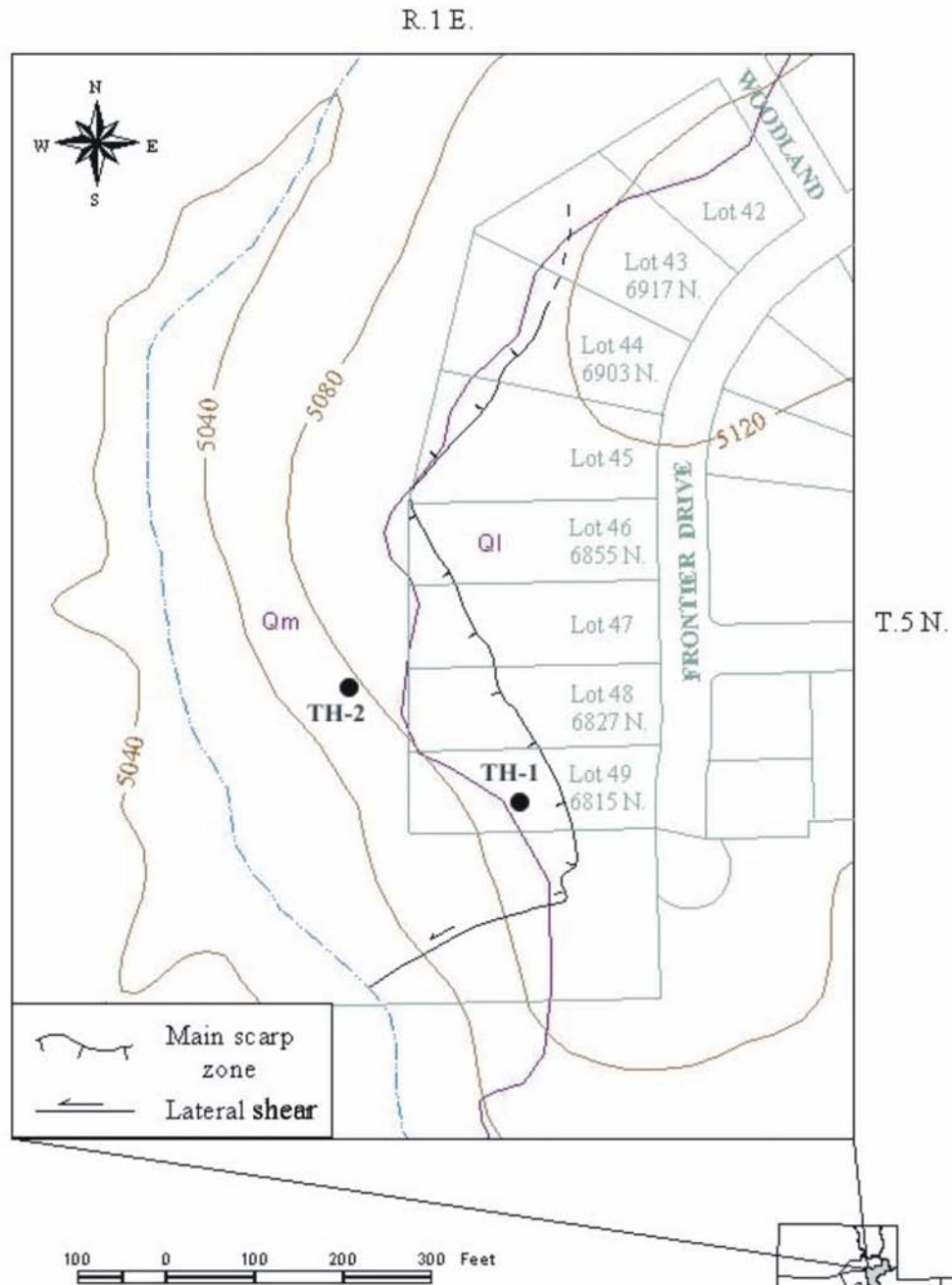


Figure 1. Location and sketch map of the Frontier Drive landslide in Mountain Green, Morgan County, Utah. The landslide is bounded on the east by a main scarp zone and on the west by an unnamed creek. The main scarp zone transitions to the north into a zone of ground cracking (dashed line). The main scarp zone roughly coincides with the contact between landslide deposits (Qm) and lacustrine deposits (Ql) of King and others (in preparation). A lateral shear bounds the landslide on the south. Earthtec (2001) boreholes TH-1 and TH-2 shown.



*Figure 2. Main scarp zone of the Frontier Drive landslide. (a) View to the southeast of main scarp at lot 49 (6815 N.). (b) View to north of main scarp zone near lots 44 and 45. (c) View to the north of main scarp-ground cracks along west edge of lot 43.*

*Figure 3. Toe of the Frontier Drive landslide. Overriding thrusts form stair-stepped geometry in lower slope. View is to the northeast. Field book measures about 9 inches in height.*



*Table 1.*  
*Summary of landslide width measurement data.*

<b>Source of Data</b>	<b>Width (feet)</b>	<b>Notes</b>
UGS GPS <sup>1</sup> survey by G.N. McDonald	720	Minimum dimension. Main scarp zone extends north of northernmost survey point.
LSE (2001) topographic plan	625	Width of southern part of landslide south of lot 44.
Aerial photograph dated October 4, 1997	1,000	Maximum dimension. Limited features to define boundaries of 2001 landsliding.

<sup>1</sup>GPS = Global Positioning System.

*Table 2.*  
*Summary of average slope information.*

<b>Location</b>	<b>Slope (percent)</b>	<b>Gradient (Horizontal:Vertical)</b>	<b>Local Relief (feet)</b>
Southwest of the house at lot 49	30	3.3H:1V	81
West of lot 46	23	4.3H:1V	74

The Frontier Drive landslide is a partial reactivation of a pre-existing landslide. King and others (in preparation) mapped the area west of the natural crest of the slope as landslide deposits. The eastern boundary of their landslide is similar to the trace of the main scarp zone of the Frontier Drive landslide particularly north of lot 46 (figure 1). Based on field observations and review of the September 17, 1980, aerial photograph, I believe that the crest of the natural slope is the scarp of a pre-existing landslide. This crest-line scarp extends more than 300 feet south of the Frontier Drive landslide (figure 4). The pre-existing scarp is obscured by development and grading to the north. On the aerial photograph, two arcuate scarp-like features appear east of the crest-line main scarp of the pre-existing landslide. I believe these features are small scarps or ground cracks in the crown of the pre-existing landslide. The easternmost of these features appears to be east of the lots along the west side of Frontier Drive and is about 1,400 feet long. These features appear to coincide with a subtle break in slope in the areas south of the Frontier Drive landslide, but have been removed or buried by regrading and construction of Frontier Drive. On the 1980 aerial photograph, the slope below the crest-line main scarp of the pre-existing landslide appears deformed by localized small landslides and landslide deformation features. The latter are likely associated with movement of the entire pre-existing landslide.

King and others (in preparation) map the remainder of the subdivision east of the crest of the slope as lacustrine deposits. The slope failure which formed the pre-existing landslide likely initiated after the unnamed creek incised through the lacustrine deposits into the underlying Tertiary Norwood Tuff. The surficial lacustrine deposits which were temporarily exposed in cuts south of



*Figure 4. Scarp of pre-existing landslide (vegetation-covered slope on right) south of the Frontier Drive landslide. View is to the north. House in background is on lot 49 (6815 N.).*



Frontier Drive consist of reddish brown, laminated clay (figure 5). Atterberg limits tests of the clay soils by Earthtec (2001) indicate the soils consist of low (CL) and high plasticity (CH) clay. The arcuate scarp-like features that appear on the September 17, 1980, aerial photograph are in the area mapped by King and others (in preparation) as lacustrine deposits. Whereas the features may be caused by landsliding, their exact origin is uncertain.

*Figure 5. Exposure of laminated lacustrine clay south of the Frontier Drive landslide. Field book shown for scale.*



The landslide and lacustrine deposits are underlain by the Tertiary Norwood Tuff. Two boreholes (Earthtec, 2001) encountered highly to completely weathered claystone and sandstone beneath the soil deposits. Earthtec (2001) described the uppermost rock as friable and weak. Coogan and King (2001) described the Norwood Tuff as consisting of tuffaceous siltstone and

sandstone, altered tuff/claystone, and conglomerate. The lacustrine deposits were likely mostly derived from the underlying Norwood Tuff.

### **Damage Caused By Landsliding**

Landsliding has affected seven residential lots and common-area open space west of Frontier Drive. The most damage occurred to lots 48 (6825 N.) and 49 (6815 N.). Figures 6a through 6d show some of the damage. Table 3 summarizes the building and lot damage caused by the landslide.



*Figure 6. Damage caused by the Frontier Drive landslide. (a) Severed and segmented storm drain pipe downslope of lot 49. (b) Stair-stepping crack in wall of house on lot 49 ( 6815 N.). (c) Cracking of brick veneer of porch column of house on lot 49 caused by downslope movement (d) Damage to concrete patio or pad on lot 46 (6855 N.).*

*Table 3.*  
*Summary of damage caused by Frontier Drive landslide.*

<b>Lot Number, Address or Parcel Description</b>	<b>Description of Damage</b>
Storm drain pipe easement - open space parcel - common area (south of lot 49)	Storm drain pipe severed (figure 6a) and released water which caused accelerated landsliding, erosion, and perhaps earth flow. Ground surface along easement severely disrupted.
Lot 49 - 6814 N.	Main scarp zone underlies western part of house. Cracking of exterior brick walls on west and north (figure 6b) and porch column brick veneer (figure 6c), and of concrete patio. Tilting of patio and porch. Horizontal displacement of porch column. Severe disruption to ground surface in entire rear lot. Perimeter foundation drain pipe currently exposed in main scarp zone. Minor cracking inside house near structural beam.
Lot 48 - 6827 N.	Severe disruption to ground surface in western part of rear lot.
Lot 47 - Vacant	Main scarp zone crosses western part of lot.
Lot 46 - 6855 N.	Cracking, settlement, and tilting of concrete pad or patio (figure 6d). Main scarp zone crosses westernmost edge of lot.
Lot 45 - House under construction	Main scarp zone crosses near western boundary of lot. Crown cracks and incipient scarps cross recently placed fill.
Lot 44 - 6903 N.	Main scarp zone crosses western landscaped part of rear lot. Landscaping slightly disrupted. Slight offsets and cracks in lawn.
Lot 43 - 6917 N.	Transverse ground cracking along western edge of landscaped lot.
Western open space parcel - common area (lower slope)	Ground surface disrupted. Severity of disruption increases to south.

### **Landslide Movement**

Landslide movement continued throughout the period of this investigation (May 11, 2001 through June 25, 2001). Figure 7 shows cumulative displacement (movement) for this period at six survey stations in the main scarp zone. The survey stations measure stretching (extension) across the main scarp zone. The data show movement at the four northernmost stations (on or near [west of] lots 44 through 47). Field observations suggest movement possibly occurred at the other two southern stations (on lots 48 and 49), but the measurements indicate that the movement, if any, was less than the accuracy of the measurement technique. The maximum average rate of movement declined from a slow rate in early May to a very slow rate in late June. The absence of any significant movement in the main scarp zone in the southern part of the landslide may be due to the ability of the numerous minor scarps downslope of the main scarp zone (figure 8) to accommodate movement.



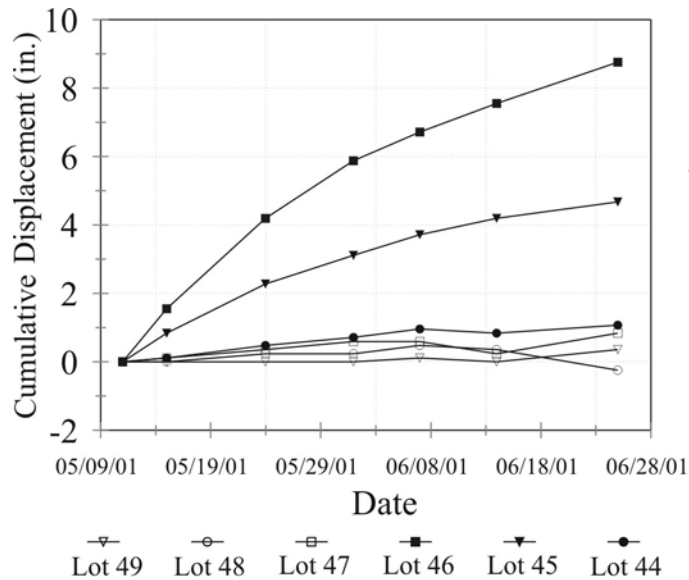


Figure 7. Cumulative displacement plot showing the amount of stretching across the main scarp zone between May 11 and June 25, 2001. Up to 8.8 inches of stretching occurred at lot 46 (6855 N.). Whereas movement continued through the period of measurement, the rate of movement decreased. Apparent movement amounts of less than a half inch are likely the result of measurement error or stake disturbance, and not landslide movement.

Figure 8. Minor scarps (in foreground below main scarp) in the upper part of the Frontier Drive landslide. View is to the east-northeast. House in background is on lot 48 (6827 N.).

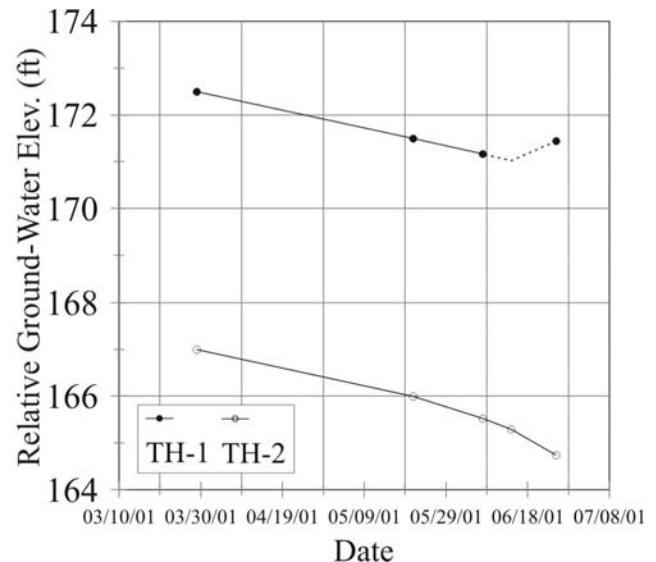


## Ground-Water Levels

Ground water in the slope is relatively shallow and ground-water levels declined slightly since the initial measurement by Earthtec (2001) in late March. During the measurement period (March 29 through June 25, 2001), ground water was about 18 to 19.5 feet deep in Earthtec's well TH-1 located near the main scarp zone. Ground water was less than 5 feet deep in Earthtec's well TH-2 located downslope of the main scarp and about 20 feet lower in elevation than well TH-1. Ground-water levels declined by about 1.3 to 1.5 feet between March 29 and June 25, 2001. Figure 9 shows that the rate of ground-water-level decline was relatively constant. Earthtec (2001) observed numerous seeps in the hillside in March that gradually dried up sometime after late April. Based on this observation, I infer that ground water was near or at the surface in the lower slope in March.

The slight decline in ground-water levels in the lower slope was sufficient to dry up the seeps in this area. Comparison of figure 7 with figure 9 indicates that the rate of landslide movement decreased with declining ground-water levels.

*Figure 9. Plot showing fluctuation in ground-water levels in two wells in the Frontier Drive landslide. Ground-water levels declined about 1.3 to 1.5 feet from March 29 to June 25, 2001. Well TH-1 is located in the main scarp zone on lot 49. Well TH-2 is located downslope of lot 48. Dashed line shows inferred level where data are lacking.*



### Cause of Landsliding

The Frontier Drive landslide was likely caused by hillside modifications associated with development of the Trapper's Pointe subdivision. Evidence supporting this includes the following.

- The recent movement occurred during a period of normal or slightly below-normal precipitation and was preceded by two calendar years (1999 and 2000) with below-normal precipitation.
- Although the landslide movement appears to have triggered in late February 2001 and coincides with the early part of the snowmelt, the amount of snow on the slope in February was likely significantly less than in previous wet years including 1998 (a year of numerous landslides in the Wasatch Front and adjacent canyon areas).
- Landsliding initiated only a few years after development began in the subdivision and within a year or so of hillside modifications on the west side of Frontier Drive.

In addition, the short amount of time between hillside modifications and landslide movement, including probable movement in 2000 which likely caused a break in the storm drain pipe south of lot 49 (6815 N.), suggests the pre-existing landslide was marginally stable prior to development. Based on my field observations and information provided by property owners of the affected lots, the significant hillside modifications included:

- regrading of the upper slope west of Frontier Drive and placement of fill on the head of the pre-existing landslide, which added a surcharge load,
- introduction of water-consumptive sod and vegetation and landscape irrigation, adding potential excess water to the hillside which likely contributed to a ground-water-level rise,
- construction of a perimeter drain around the house at lot 49 (6815 N.) that discharged onto the slope,
- construction of an unlined storm-water detention basin adjacent to the main scarp of the pre-existing landslide and south of the house at lot 49 (6815 N.), and
- construction of a storm drain pipe across the southern part of the landslide.

Based on the chronology of hillside modifications provided by Mr. George Sousa (2001, written communication), the property owner of lot 48 (6827 N.), and information inferred from the October 4, 1997, aerial photograph, I believe the surcharge load of the fill placed on the head of the landslide was likely the primary cause of the recent landsliding. The probable movement in the spring of 2000, an extremely dry year in northern Utah, also supports this inference. Infiltration from the detention basin and possible leakage from the storm drainpipe may have been a significant cause of the increased movement of the southern part of the landslide in 2001.

## **SCOPE AND METHODS**

The scope of this investigation included an initial site reconnaissance on May 8, 2001, by Greg McDonald and Francis Ashland (UGS), and numerous other site visits in May and June by UGS geologists to measure landslide movement and ground-water levels. We used 2-inch square wood stakes with finish nails and a Keson fiberglass measuring tape to record movement. The estimated accuracy of the measurement technique was about 0.01 foot in May and about 0.03 foot in June. The increase in measurement error was, in part, due to minor survey stake loosening and disturbance. We measured ground-water levels using a Slope Indicator model 51543 water-level indicator. In addition, I reviewed the available published and unpublished literature for the site including geologic and landslide maps (King and others, in preparation; Harty, 1992), pre-development site investigation reports (Geo Company, 1998; CTC-Geotek, 1992), the stabilization design report (Earthtec, 2001), and other written documentation provided by Mr. George Sousa. I also reviewed aerial photographs dated September 17, 1980, and October 4, 1997. UGS review comments related to the stabilization design proposed by Earthtec (2001) are included in a letter dated June 11, 2001, to Kent Wilkerson, Morgan County.

## **SUMMARY OF CONCLUSIONS**

The landslide will continue to pose a threat to the residential properties along the west side of Frontier Drive south of Woodland Drive until the slide is stabilized. With the exception of the houses on lots 48 and 49 (6827 N. and 6815 N.), the houses on the west side of Frontier Drive appear to be adequately set back from the active main scarp zone of the landslide such that the immediate threat to the houses is low. If the landslide is not stabilized, additional damage to the

house at lot 49 (6815 N.) will likely occur and enlargement of the landslide in an upslope direction is possible, potentially endangering the houses to the north.

Movement of the Frontier Drive landslide triggered in late February 2001 and continued through the period of this investigation. Reactivation of the remainder of the pre-existing landslide north and south of the Frontier Drive landslide is possible, particularly if hillside modifications are made. Movement in 2001 was a partial reactivation of a pre-existing landslide that was modified during hillside development west of Frontier Drive. Landsliding was triggered despite near-normal precipitation prior to and during the period of movement and suggests the pre-existing landslide was marginally stable prior to hillside modifications.

## **REFERENCES**

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