TECHNICAL REPORTS FOR 2002–2009 GEOLOGIC HAZARDS PROGRAM

COMPILED BY ASHLEY H. ELLIOTT

UTAH DNR GEOLOGICAL SURVEY

Report of Investigation 269
Utah Geological Survey
a division of
Utah Department of Natural Resources
2010

TECHNICAL REPORTS FOR 2002–2009 GEOLOGIC HAZARDS PROGRAM

Compiled by

Ashley H. Elliott

Report of Investigation 269
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2010

STATE OF UTAH
Gary R. Herbert, Governor

DEPARTMENT OF NATURAL RESOURCES
Michael Styler, Executive Director

UTAH GEOLOGICAL SURVEY
Richard G. Allis, Director

PUBLICATIONS
contact
Natural Resources Map & Bookstore
1594 W. North Temple
Salt Lake City, UT 84114
telephone: 801-537-3320
toll-free: 1-888-UTAH MAP
Web site: mapstore.utah.gov
email: geostore@utah.gov

UTAH GEOLOGICAL SURVEY
contact
1594 W. North Temple, Suite 3110
Salt Lake City, UT 84114
telephone: 801-537-3300
Web site: geology.utah.gov

PREFACE

The Geologic Hazards Program of the Utah Geological Survey (UGS) provides assistance to Utah citizens and local governments (cities, towns, counties, and related entities) by responding to emergencies such as earthquakes, landslides, and wildfires (where subsequent debris flows are a hazard) with a field investigation and a report of the geologic effects and potential hazards. We also investigate and map geologic hazards such as debris flows, shallow ground water, rock falls, problem soils, landslides, and earthquakes, and we perform preliminary site-screening evaluations of geologic-hazard potential for schools. In addition, we provide reviews of detailed geologic-hazard reports prepared by consultants for proposed school building sites. Prior to July 1, 2008, we also reviewed and commented on geologic-hazard investigations documented in geologic and geotechnical reports prepared by consultants (for development of residential lots, subdivisions, and private waste-disposal facilities) and submitted to local governments for project permits.

A major goal of the UGS is to provide assistance to Utah citizens and local governments by disseminating geologic information. Geological studies of potential interest to the general public are published in several UGS formats. One format is a Technical Report, which is used to address geologic-hazard-related problems of site-specific projects of interest to a limited audience, and includes emergency-response reports. These reports are distributed on an as-needed basis. In addition, we maintain copies of these reports and make them available for inspection upon request. This Report of Investigation presents, in a single document, the Geologic Hazards Program's 63 Technical Reports completed from 2002 to 2009 (figure 1). The reports are grouped into two categories, geologic-hazard reports and reviews of geologic/geotechnical reports. Each report identifies the author(s) and requesting agency. Minor editing has been performed for clarity and conformity, but I have made no attempt to upgrade the original graphics.

Ashley H. Elliott

April 21, 2010

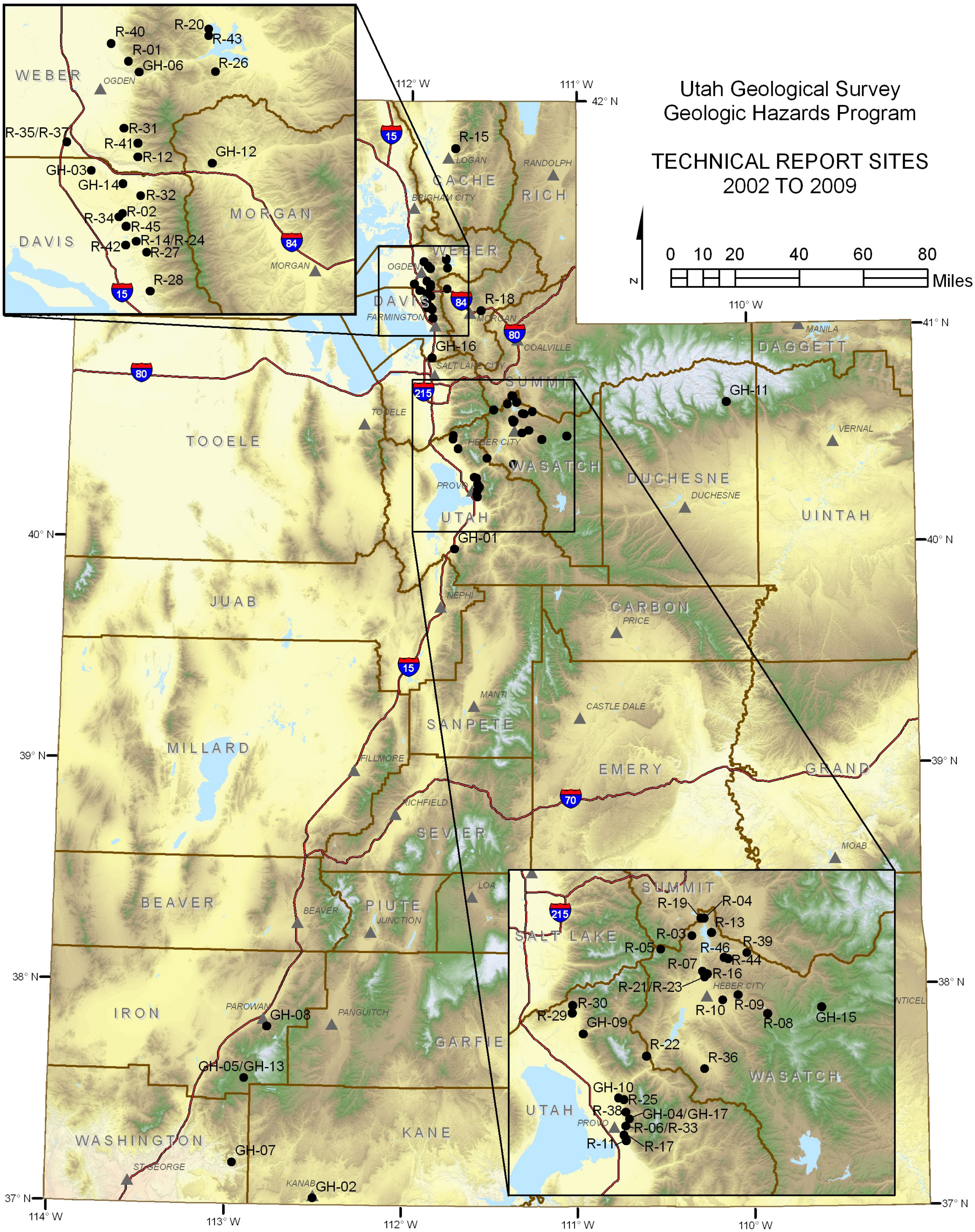


Figure 1. Locations of the 2002 to 2009 Technical Report sites.

ADDITIONAL INFORMATION AND GUIDELINES

In addition to the reports contained in this compilation, the UGS Earthquakes and Geologic Hazards Web page at http://geology.utah.gov/utahgeo/hazards/index.htm provides links to general information on geologic hazards in Utah. The Web page for Consultants and Design Professionals (http://geology.utah.gov/ghp/consultants/index.htm) provides links to information on recommended guidelines for geotechnical and/or geologic-hazard investigations and reports, UGS geologic-hazard maps and reports, geologic maps, ground-water reports, historical aerial photography, and links to other sources of useful information.

The UGS advises following the recommended guidelines when preparing site-specific engineering-geologic reports and conducting site-specific hazard investigations in Utah. Typically, engineering-geologic and geologic-hazard considerations would be combined in a single report, or included as part of a geotechnical report that also addresses site foundation conditions and other engineering aspects of the project.

CONTENTS

FIGURE

GEOLOGIC HAZARDS

Utah Geological Survey

Project:			Requesting Agency:
September 12, 2002, fire-related debris flows east of Santaquin and Spring Lake, Utah County, Utah			Santaquin City
By: Greg N. McDonald Richard E. Giraud	Date: 11-20-02	County: Utah	Job No.: 02-09 (GH-01)
USGS Quadrangles: Payson Lakes (965) Spanish Fork (1006) Springville (966) West Mountain (1007)	Section/Township/Range: Sections 31 and 32, T. 9 S., R. 2 E.; Sections 6 and 7, T. 10 S., R. 2 E.		

INTRODUCTION AND PURPOSE

On the evening of September 12, 2002, intense rainfall triggered fire-related debris flows in multiple drainages on Dry Mountain east of Santaquin and Spring Lake at the south end of Utah Valley (figure 1). Major debris flows originated in tributaries 2, 3, 4, 5, and 6 (as defined by the U.S. Forest Service [2001]), and deposited debris on alluvial fans west of Dry Mountain (figure 1). Farther south, smaller flows from tributaries 7, 9, 11, 12, and 14 were reported (U.S. Forest Service, 2002) but not evaluated as part of this investigation. Debris and floodwater from tributaries 2, 3, and 4 flowed into developed areas causing property damage in two subdivisions. Floodwater from tributary 5 entered a subdivision but caused no reported damage. Prior to the event, Dry Mountain was determined to have a heightened debris-flow and flooding hazard due to the Mollie wildfire that burned much of the west side of the mountain during the summer of 2001.

At the request of Roger Carter, Santaquin City Manager, we performed this investigation to describe and document the debris flows. The scope of work for this investigation included review of aerial photos, published geologic reports and maps, and post-fire assessment letters and reports; field mapping of debris-flow deposits; and a field traverse of the drainage basin of tributary 4. Our investigation included evaluation of volume, runout distance, and deposit area. We visited the area on September 13, 2002, as part of the Utah State Division of Emergency Services Interagency Technical Team (IAT), and performed additional field work on September 17, 24, and October 9, 2002.

CONCLUSIONS AND RECOMMENDATIONS

Based on this geologic investigation of the September 12, 2002, fire-related debris flows east of Santaquin and Spring Lake, the Utah Geological Survey (UGS) concludes the following:

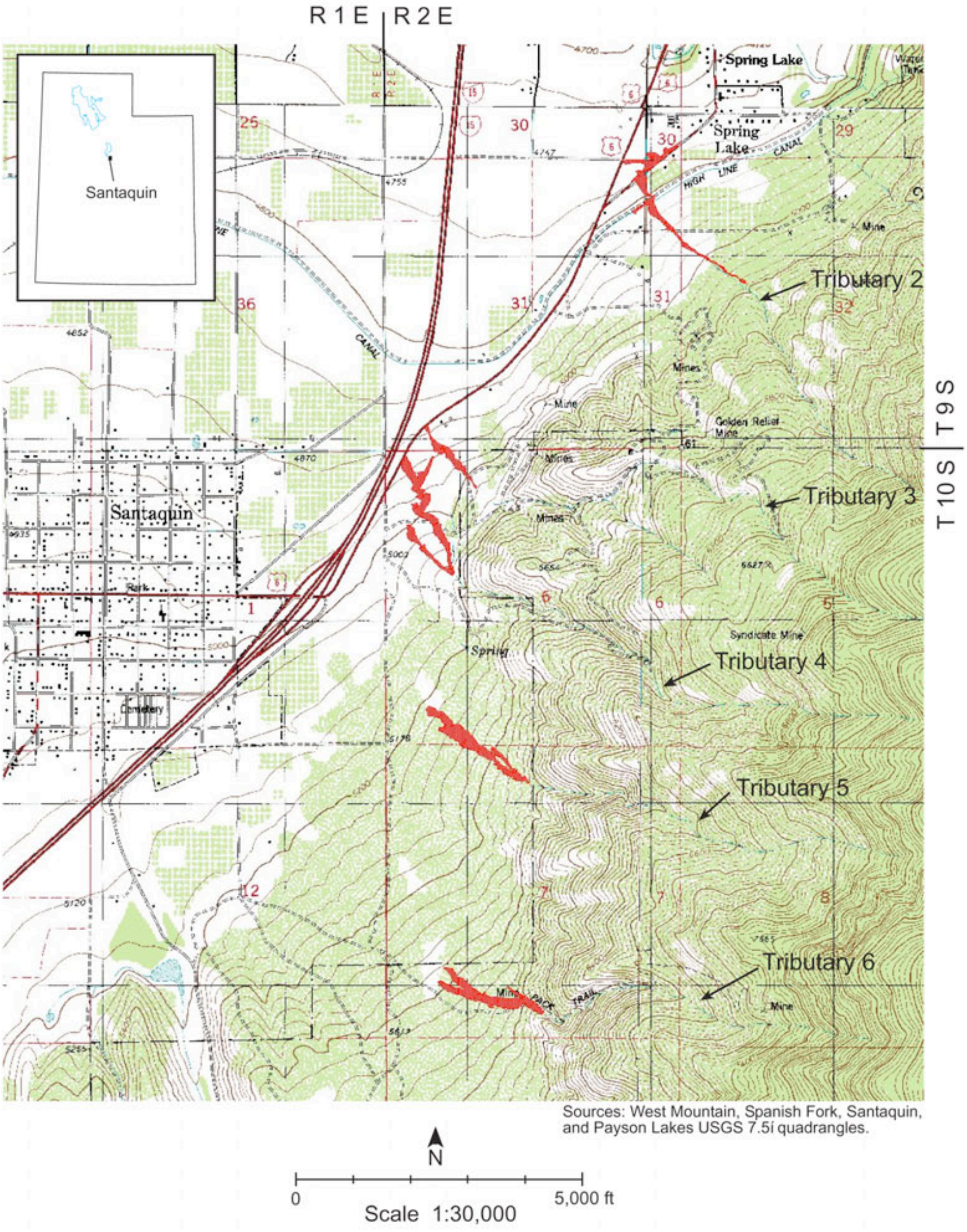


Figure 1. Approximate extent of September 12, 2002, debris-flow deposits and alluvial-fan flooding (red).

- The debris flows were triggered by intense thunderstorm precipitation on the upper burned slopes of Dry Mountain, which eroded soil by sheetwash and rilling. Runoff rapidly concentrated into channels, eroding and bulking sediment to a debris-flow sediment-water concentration. The flows continued to grow by accumulating channel sediment until they reached the canyon mouths where they spread out and deposited debris on alluvial fans.

- Water-repellent soils and diminished vegetation in the tributaries caused by the Mollie fire contributed to the debris flows of September 12, 2002. Because it takes several years for soil and vegetation in burned watersheds to recover to pre-burn conditions, the short-term debris-flow hazard will be heightened for several years.

- Field reconnaissance of the tributary 4 drainage basin indicates ample sediment remains for future debris flows. Given the similarities of tributary 4 to the other drainages, they likely also have ample sediment for future debris flows.

Regarding the continuing debris-flow hazard east of Santaquin and Spring Lake, the UGS recommends:

- The guidelines and recommendations outlined in Pietramali (2002), Solomon (2001), Rasely (2001), and U.S. Forest Service (2001, 2002) BAER reports to manage the debris-flow hazard should be followed.

- A debris-flow hazard existed before the fire and will remain after the drainage basin vegetation recovers to pre-burn conditions. Therefore, measures will also need to be taken to reduce the long-term non-fire-related debris-flow hazard.

- Future development will likely encroach farther onto the alluvial fans, exposing more property to hazards. Evaluation of the hazards and implementation of hazard-reduction measures are more easily accomplished prior to development and should therefore be considered now as part of the long-term planning of east Santaquin and Spring Lake.

- Designs to reduce hazards should include evaluation of the drainage basins for potential debris-flow-volume yields and consider the long-term maintenance of any structures.

During our investigation, we also recognized the potential for other geologic hazards, including rock fall and surface fault rupture, and recommend all hazards be addressed as part of long-term planning for development east of Santaquin and Spring Lake.

BACKGROUND

Physical Setting and Geology

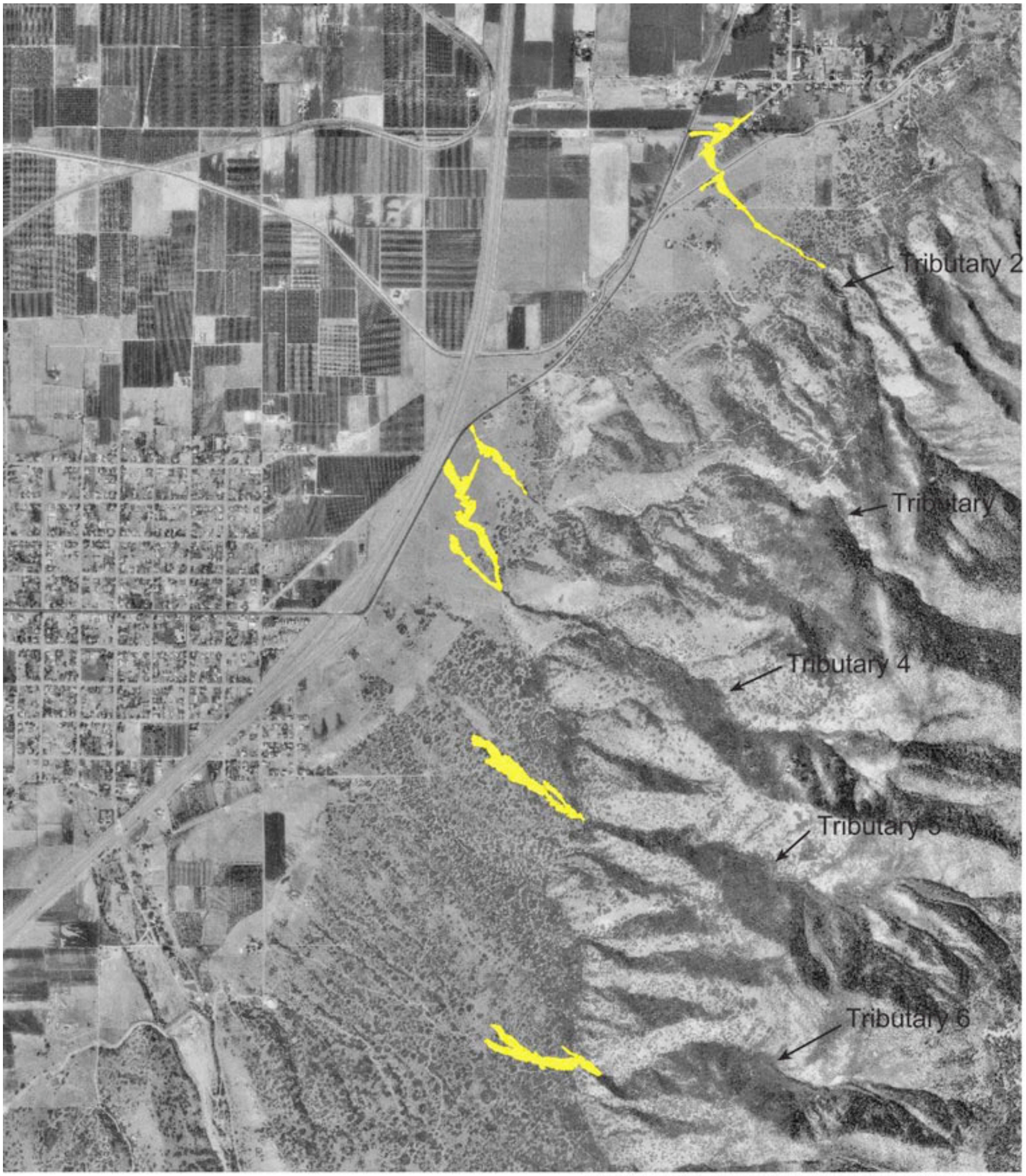
Santaquin City is at the southern end of Utah Valley at an elevation of about 5,000 feet. The community of Spring Lake is about 2 miles northeast of Santaquin at an elevation of about 4,800 feet (figure 1). East of Santaquin and Spring Lake, a section of the Wasatch Range called Dry Mountain rises to elevations of over 9,800 feet. Drainages involved in the September 12, 2002, fire-related debris flows (tributaries 2 through 6) drain the west side of Dry Mountain and rise in elevation from about 5,200 to 5,600 feet at their mouths to about 8,200 to 9,000 feet. Tributary 4 is roughly 9,500 feet in length and channel gradient ranges from about 16 percent (9 degrees) near its mouth to nearly 43 percent (24 degrees) in its upper reaches; the average gradient is about 29 percent (16 degrees).

Dry Mountain is composed of generally north-striking, east-dipping, Precambrian quartzite, sandstone, siltstone, schist, gneiss, and amphibolite that have been locally intruded by pegmatite and granite dikes, overlain by Mississippian limestone and shale (Demars, 1956; Witkind and Weiss, 1991). Dry Mountain contains local Quaternary deposits of alluvium, colluvium, talus, and mass-movement deposits. Quaternary deposits west of Dry Mountain include sediments of Pleistocene Lake Bonneville, and colluvium and alluvial-fan deposits ranging in age from pre-Lake Bonneville to modern (Machette, 1992; Harty and others, 1997). The Nephi segment of the Wasatch fault zone is exposed east of Santaquin as prominent escarpments along the base of Dry Mountain. Figure 2 shows the debris flows on the alluvial fans at the fault-bounded mountain front.

Mollie Wildfire and Post-Fire Hazard Assessment

The September 12, 2002, debris flows partly resulted from a wildfire that burned much of Dry Mountain during late summer 2001. The Mollie fire was a human-caused event that burned over 8,000 acres of U.S. Forest Service, State of Utah, and private land primarily on the west side of Dry Mountain between August 18 and September 1, 2001 (U.S. Forest Service, 2001). Nearly half of the burned area, including most of the higher elevations, has soils with high to very high erosion potential (U.S. Forest Service, 2001). The Mollie fire is described in detail in the Burned-Area Emergency Rehabilitation (BAER) report (U.S. Forest Service, 2001).

Post-fire assessments of the burn area included, in addition to the BAER report, debris-flow and flood-hazard assessments by the UGS (Solomon, 2001) and the U.S. Natural Resources Conservation Service (NRCS) (Rasely, 2001). All of the assessments recognized a heightened debris-flow/flooding hazard for the tributaries on the west side of Dry Mountain. The BAER report recommended emergency treatments and a warning system be implemented. The UGS noted "…heightened debris-flow and flood hazards exist at subdivisions in Santaquin east of Interstate-15 as a result of the fire, particularly at the mouths of tributaries 3 and 4…" and "A heightened flood hazard exists along the east side of subdivisions directly west of tributary 5…" The NRCS concluded "Santaquin is in a high risk condition for intense flooding, avalanches, and destructive debris yielding events…for the next few years…" and proposed flood routing and



Sources: West Mountain, Spanish Fork, Santaquin, and Payson Lakes USGS 7.5í orthophoto quads (1997).

N

0 5,000 ft

Scale 1:30,000

Figure 2. Orthophoto map showing debris-flow deposits (yellow).

“debris trapping treatments” to reduce the hazard. Some efforts were made to reduce the debris-flow and flooding hazards. However, the September 12, 2002, debris flows showed the need for more comprehensive risk-reduction measures.

SEPTEMBER 12, 2002, DEBRIS FLOWS

Debris-Flow Initiation and Sediment Bulking

The debris flows from Dry Mountain were triggered by intense thunderstorms on the evening of September 12, 2002. Specifically, the initiating event was a convective thunderstorm imbedded within stratiform cloud precipitation (Brian McInerney, Hydrologist, National Weather Service, verbal communication, October 1, 2002). Scattered rain showers had occurred earlier in the day. Rain-gage data collected in 1-hour intervals at a weather station near the ridgeline above tributary 4 (National Weather Service Forecast Office, 2002) showed elevated precipitation levels between the hours of 4:30 and 7:30 p.m. (figure 3). Homeowners in the neighborhood below tributary 4 indicated the debris flow entered the subdivision around 6:40 p.m. The precipitation measured between 4:30 and 7:30 p.m. apparently triggered the debris flows and subsequent flooding. Even though the weather station only records data hourly, the triggering rainfall likely fell as intense short-duration precipitation. Total rainfall recorded for September 12, 2002, was 0.55 inches.

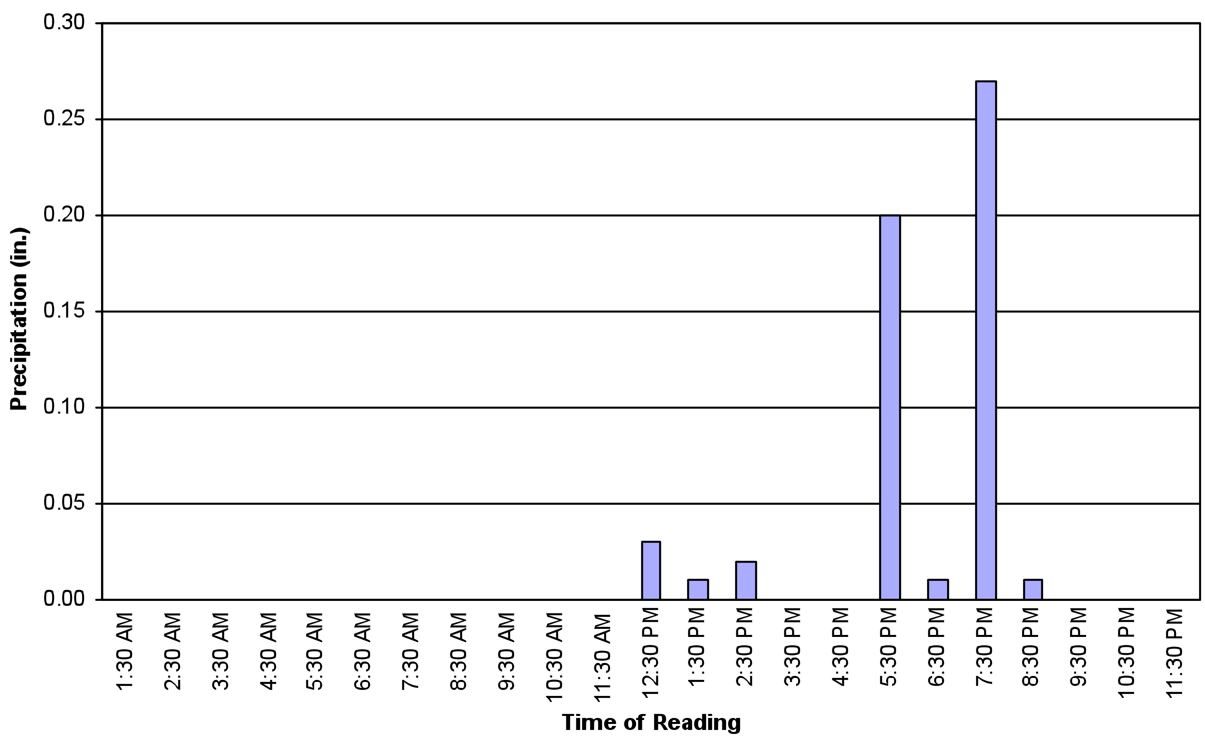


Figure 3. *September 12, 2002, hourly rain-gage data. (Data source: National Weather Service Forecast Office, 2002)*

We traversed up tributary 4 on September 17, 2002, to assess debris-flow initiation processes and sediment bulking characteristics. Hillslopes in the upper reaches of the basin showed evidence indicating the debris flow began as intense runoff and sheetwash erosion concentrated as rills and in local drainages. Whereas areas burned in the Mollie fire had begun to revegetate, some of the soils still exhibit water-repellent conditions. The debris flow began entraining sediment in the upper portion of the drainage basin and continued to bulk sediment, progressively downstream, through erosion and scour of the main channel. We observed no evidence of significant sheetwash or hillslope erosion in the lower portion of the drainage. We observed minor debris-flow deposition in the main channel in the drainage basin, mostly along sections of the middle and lower reaches, as levees, mud coatings, and overbank deposits. Most of the debris-flow volume was deposited on the alluvial fan at the mouth of tributary 4. The other four debris flows likely originated in a similar manner, as opposed to initiation caused by shallow landsliding. Initiation processes observed in tributary 4 are similar to those that have been documented by Meyer and Wells (1997) and Cannon (2001) at other fire-related events.

Debris-Flow Deposits

The UGS performed field reconnaissance of the debris-flow deposits that included mapping their extent and estimating flow thickness to derive volumes, and observations of physical characteristics including the effects of post-debris-flow flooding. The debris flows were deposited as narrow linear lobes on alluvial fans at the base of Dry Mountain (figures 1, 2, and 4a). Most of the debris flows were a viscous mixture of sediment and water in the upper fan area that exhibited more dilute behavior downfan. Narrow, linear, paired levees formed that flanked the viscous debris flows on the alluvial-fan apices. The levees confined flows and channeled sediment farther downfan, increasing the runout distance. The levees have sharp lateral margins and steep flanks and are up to 3 feet thick (figure 4b). The main lobes that were deposited farther downfan exhibited features related to higher water contents. These main lobes were generally less than 2 feet thick and had margins less steep than the levees. All deposits had a consistency similar to wet concrete when saturated and exhibit high dry strength.

Soil types in the debris-flow deposits are highly variable, ranging from clayey gravel near the mountain front to clayey sand in distal deposits downfan. We observed clasts up to about 3 feet in diameter in the upper parts of the deposits near the mountain front, where exposures indicated deposits are matrix-supported. All of the debris flows were followed by a period of muddy stream flooding that washed fine-grained sediments from portions of the deposits, leaving a clean, gravel and cobble lag in the channel and redepositing the fines downfan. Data for the deposits are summarized in table 1. Deposit areas and volumes were calculated using GPS survey data and thickness estimates. Brief descriptions of each deposit are presented below.

(a) View looking west of tributary 4 north deposit in Santaquin subdivision.
Photo by Dale Deiter, U.S. Forest Service.

(b) Levee deposits of tributary 4 north lobe on the fan apex.

Figure 4. *Debris-flow deposits.*

(c) Toe of tributary 5 overbank deposit north of main lobe.

(d) View of tributary 6 deposit looking downfan (eastward).

Figure 4. *(continued)*

Table 1. Summary of debris-flow deposit area, volume, and runout.

Flow	Deposit Area (square yards; acres)	Deposit Volume (cubic yards; acre ft.)	Runout Distance (feet)
Tributary 2	33,700; 7.0	5,500; 3.4	3,000
Tributary 3	12,800; 2.6	2,200; 1.4	1,400
Tributary 4	46,000; 9.5	20,000; 12.4	2,300 (N. lobe), 1,300 (S.lobe)
Tributary 5	41,500; 8.6	13,000; 8.1	2,200
Tributary 6	21,800; 4.5	10,000; 6.2	1,200

Tributary 2

The debris flow from tributary 2 remained channeled from the mouth of the drainage for about 1,600 feet before spreading out and depositing much of its sediment. Debris from the flow blocked a section of the High Line Canal. Below the canal, the debris flow and canal water flooded property and houses in a Spring Lake subdivision.

Tributary 3

The deposit from tributary 3 was the smallest of the five. Part of the deposit filled a subdivision storm-water detention basin. Below the basin, part of the flow ran through an equipment yard causing minor damage. No houses were impacted by the tributary 3 debris flow.

Tributary 4

The debris flow from tributary 4 was the most damaging of the five. When the flow reached the mouth of tributary 4, it split into two lobes. The larger, north lobe flowed through the Santaquin subdivision causing substantial property damage (figure 4a, figure 5). Most of the north lobe did not follow city streets but established a direct path down the alluvial fan. Subsequent floodwater traveled down roadways. The south lobe flowed down an undeveloped portion of the fan and deposited debris on a newly excavated subdivision road south of the existing development.

Tributary 5

The debris flow from tributary 5 deposited sediment at the mouth of the drainage east of developed areas. Post debris-flow floodwater reached a subdivision, including a newly excavated road; however, no major property damage was reported. The debris-flow deposit on the upper portion of the fan contained considerable woody debris and trees up to several inches in diameter (figure 4c). Near the top of the deposit a moderate-sized lobe is present north of the main flow that contains much less woody debris and large clasts, and likely represents a later surge.

Tributary 6

The tributary 6 deposit was similar in character to the tributary 5 deposit. Neither the debris flow nor associated floodwater affected any developed areas (figure 4d).

(a) Debris-flow sediment deposited at the intersection of Lambert Avenue and Apple View Street. The debris flow rafted vehicles and filled basements with sediment.

(b) The debris-flow impact broke through this basement window of a house on Apple View Street.

Figure 5. *Debris-flow/flooding damage in Santaquin subdivision.*

(c) Debris-flow damage to garage doors of house on Peach Street.

(d) Debris-flow damage to the back wall of house on Peach Street.

Figure 5. *(continued)*

Debris-Flow Impacts and Damages

Three of the five debris flows and associated flooding caused damage to infrastructure, property, and houses in the communities of Santaquin and Spring Lake. Most of the damage occurred at the Santaquin subdivision from the north lobe of the tributary 4 debris flow. Vehicles were moved (figure 5a), some were pushed into houses; basements were flooded and filled with debris as ground-level windows were broken (figure 5b); house and garage doors were buckled inward (figure 5c); and the back wall of one house was broken by impact forces (figure 5d). A preliminary report prepared by Ryan Pietramali of the Utah Division of Emergency Services indicates five homes and two businesses received major damage and 27 homes received minor damage at a total cost of about $500,000 (U.S. Small Business Administration Damage Assessment Report dated September 19, 2002).

SUMMARY

The September 12, 2002, debris flows east of Santaquin and Spring Lake were related to the 2001 Mollie fire and triggered by intense precipitation on the upper slopes of Dry Mountain. Because it takes several years for soil and vegetation in burned watersheds to recover to pre-burn conditions, and ample sediment remains in the basins, the short-term debris-flow hazard will be heightened for several years. In addition, a debris-flow hazard existed before the fire and will remain after the drainage basin vegetation recovers to pre-burn conditions.

To reduce the hazard, the guidelines and recommendations outlined in Pietramali (2002), Solomon (2001), Rasely (2001), and U.S. Forest Service (2001, 2002) BAER reports should be followed. Any measures taken to reduce the short-term risk of fire-related debris flows should not preclude the need for risk reduction from long-term non-fire-related debris flows. As development encroaches farther onto the alluvial fans, hazard evaluation and reduction measures should be considered as part of long-term planning and development in east Santaquin and Spring Lake. In addition to debris flows, other geologic hazards, including rock fall and surface fault rupture, exist east of Santaquin and Spring Lake and should also be addressed in planning for development in the area.

DISCLAIMER

REFERENCES

Cannon, S.H., 2001, Debris-flow generation from recently burned watersheds: Environmental and Engineering Geoscience, v.12, no. 4, p. 321-341.

Demars, L.C., 1956, Geology of the northern part of Dry Mountain, southern Wasatch Mountains, Utah: Brigham Young University Research Studies Geology Series, v. 3, no. 2, 50 p., 1 plate, scale1:24,000.

Harty, K.M., Mulvey, W.E., and Machette, M.N., 1997, Surfical geologic map of the Nephi segment of the Wasatch fault zone, eastern Juab County, Utah: Utah Geological Survey Map 170, 14 p. pamphlet, scale 1:50,000.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, 26 p. pamphlet, scale 1:50,000.

Meyer, G.A., and Wells, S.G., 1997, Fire-related sedimentation events on alluvial fans, Yellowstone National Park, U.S.A.: Journal of Sedimentary Research, v. 67, no. 5, p. 776-791.

National Weather Service Forecast Office, 2002, Fire weather products: Online, <http.www.wrh.noaa.gov?TotalForecast/miscObs/raws/UT/BAER.10.html>, accessed September 16, 2002.

Pietramali, R., 2002, Santaquin City debris flows – Interagency Technical Team on-site report: Salt Lake City, unpublished Division of Emergency Services and Homeland Security letter report dated September 24, 2002, to Santaquin City, 1 p.

Rasely, R.C., 2001, Emergency watershed protection – Mollie fire hazards impacting Santaquin, Utah County, Utah: Salt Lake City, unpublished Natural Resources Conservation Service report to Neil Pellman, State Conservation Engineer, 4 p., 5 attachments.

Robison, R.M., 1990, Utah County natural hazards overlay (NHO) zone, southern Utah County: unpublished Utah County Planning Department maps, scale 1:50,000.

Solomon, B.J., 2001, unpublished Utah Geological Survey letter dated September 17, 2001, to Roger Carter, Santaquin City manager: Salt Lake City, Utah Geological Survey, 2 p., 1 attachment.

U.S. Forest Service, 2001, Initial burned-area emergency rehabilitation (BAER) report for the Mollie fire incident: Unpublished Uinta National Forest report for the Mollie fire incident, 69 p.

- - - 2002, Interim BAER report for the Mollie, Oak Hills, Birch, and Nebo Creek fires: Unpublished Uinta National Forest report, 27 p., 4 appendices.

Witkind, I.J., and Weiss, M.P., 1991, Geologic map of the Nephi 30 x 60 minute quadrangle, Carbon, Emery, Juab, Sanpete, Utah, and Wasatch Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1937, 16 p. pamphlet, scale 1:10,000.

Utah Geological Survey

Project: March 12, 2005, fatal earth-fall landslide along Kanab Creek, Kane County, Utah			
By: William R. Lund, P.G.	Date: 03-xx-05	County: Kane	
USGS Quadrangles: Kanab (29)	Section/Township/Range: NW¼NW¼ section 33, T. 43 S., R. 6 W., SLB&M		
Requested by: Fatality Investigation			Job number: 05-02 (GH-02)

INTRODUCTION

At about 5:30 p.m. on Saturday, March 12, 2005, a vertical arroyo (gully with steep walls in unconsolidated sediment) wall along Kanab Creek (figure 1) failed and buried a 10-year-old boy and partially buried two girls. The girls, one covered by landslide material to her waist and the other to her knees, were able to free themselves and began searching for the boy, but were forced to flee when a second section of the wall collapsed. The landslide involved about a 100-foot-long section of the approximately 60-foot-high vertical west bank of Kanab Creek within the city limits of Kanab, Utah (figure 2). Workers using heavy equipment required 15 hours to recover the boy's body.

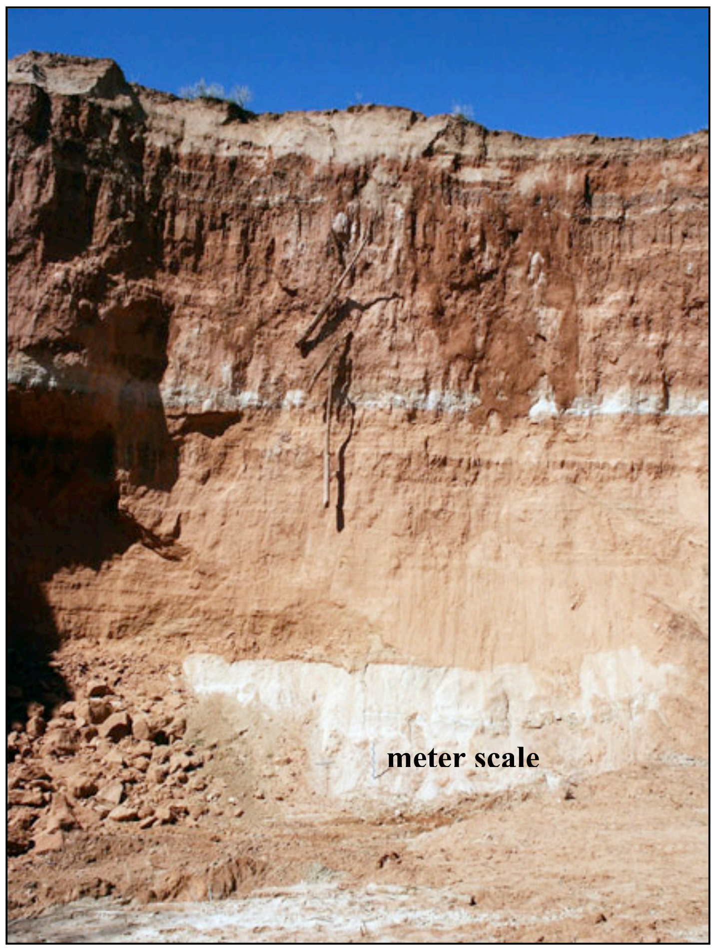


Figure 1. *This approximately 60-foot-high arroyo wall failed on March 12, 2005, creating an earth-fall landslide that buried one child and partially buried two others. Alternating layers of sand, silty sand, and silty clay comprise the majority of the stream cut.*

Because of the resultant death, the Utah Geological Survey (UGS) made an investigation to determine the characteristics of the fatal landslide and the likelihood of similar slope failures in the future. The scope of the investigation included a review of applicable geologic literature, examination of 1:40,000-scale stereoscopic aerial photographs, and a

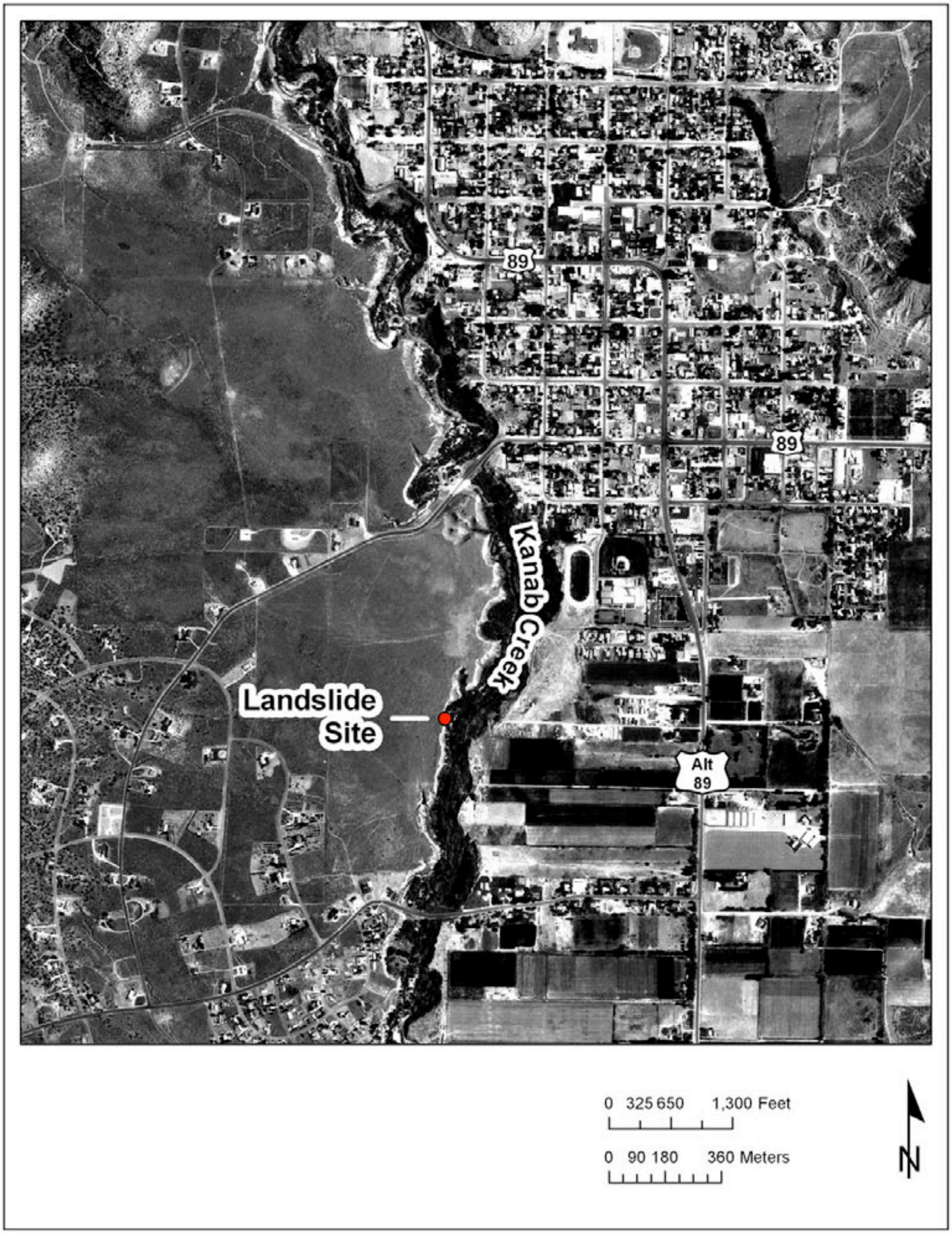


Figure 2. *Ortho-photograph map of the Kanab area showing landslide site.*

field reconnaissance of the landslide site on Tuesday, March 15, 2005. The field reconnaissance included an interview with Kanab City Police Chief Tom Cram, who directed the rescue and recovery efforts. Because of continued slope instability during the field reconnaissance, direct access to the arroyo wall where the landslide occurred was not safe.

CONCLUSIONS AND RECOMMENDATIONS

The slope failure that buried the young boy and his companions was an earth-fall-type landslide (Cruden and Varnes, 1996), which resulted from the long-term effect of gravity on over-steepened, unconsolidated material in the arroyo walls. A section of the wall detached along one or more wall-parallel cracks and fell to the stream bottom below where the children were playing. Although the upper few feet of material in the wall were moist as a result of greater than normal precipitation over the past several months, the bulk of the landslide material was dry at the time of failure. Inspection of vertical arroyo walls both up- and downstream from the landslide showed that wall-parallel cracks also are present in those areas, and likely are common elsewhere along Kanab Creek.

The presence of wall-parallel cracks along Kanab Creek where landslides have not yet occurred, and the fact that the earth-fall landslide took place under what were essentially dry conditions, indicates that similar landslides may occur along Kanab Creek at any time in the future. Increased precipitation over the past several months does not appear to have been a major contributing factor to the landslide, further indicating that similar failures may occur regardless of precipitation conditions.

Measures that may help reduce future injury or loss of life from similar landslides along Kanab Creek include:

- Identifying areas of Kanab Creek bordered by vertical arroyo walls and posting them as hazardous.
- Grading vertical arroyo walls back to a safe slope angle.
- Implementing a hazards-education program in local schools to educate children and parents regarding landslide hazards along Kanab Creek and the dangers they pose.

GEOLOGIC SETTING

Kanab Creek is a typical semi-arid southwestern U.S. arroyo (figure 3), which deeply incised its channel during a series of floods beginning in the early 1880s (Webb and others, 1991). Prior to that time, the creek was described as a "shallow braided stream" that meandered across a broad, nearly flat meadow formed where the stream exited the Vermillion Cliffs to the north. Currently the high arroyo walls of Kanab Creek range from vertical where the stream is close to the base of the wall and erosion is active, to near the angle of repose for sandy material (about 40° or less) where the stream is more distant and colluvium has accumulated at the base of

Figure 3. *View to the southwest of Kanab Creek, showing the steep-walled arroyo that formed due to floods in the 1880s.*

the wall. Cottonwood and willow trees line the sides of the active stream channel, and sagebrush and grasses grow on the arroyo walls where slopes permit.

Although flowing within a few tens of feet of the arroyo wall at the time of the landslide, Kanab Creek was not actively eroding the base of the wall prior to the landslide. To facilitate rescue and recovery operations, workers used heavy equipment to divert Kanab Creek away from the west side of the arroyo, confining it to an artificial channel around the landslide site, where it remained at the time of the field reconnaissance. The workers also used the heavy equipment to move much of the landslide debris during the rescue and recovery operation, so that documentation of the amount and distribution of material generated by the landslide was not possible. However, according to Tom Cram (Kanab City Police Chief, verbal communication, 2005), the landslide resulted in a pile of material at the base of the arroyo wall as much as 20 feet thick and several tens of feet wide.

Geologic materials exposed in the arroyo wall where the landslide occurred consist chiefly of alternating layers of medium- to thick-bedded (6 inches to 2 feet) red sand, silty sand, and silty clay with discontinuous, thin interbeds of well-sorted white sand, gray clay, and gravel and cobbles (figure 1; appendix). These materials were deposited by Kanab Creek, and were derived chiefly from Mesozoic sedimentary rocks (sandstone, siltstone, and claystone) that crop out in the Kanab Creek drainage basin (Sargent and Philpott, 1987). A few feet of loose, wind-blown sand caps the cut.

LANDSLIDE FAILURE MECHANISM

Examination of the arroyo wall where the landslide occurred revealed several deep, vertical cracks oriented parallel to the wall and spaced several feet a part (figure 4). One or more of these cracks served as the failure plane for the landslide as material in the wall detached along a crack(s) and fell into the arroyo. Similar cracks are present in the arroyo walls both up- and downstream from the landslide (figure 5). Evidence of cracks at the ground surface at the top of the arroyo was limited, except in one area immediately adjacent to the landslide where additional failure is imminent (figure 6). The unstable arroyo wall continued to spall material during the field reconnaissance, making close inspection of the cracks unsafe.

Figure 4. *Deep, vertical cracks parallel to the arroyo wall along which a section of the wall detached creating an earth-fall landslide.*

Like much of southwestern Utah, the Kanab area has experienced greater than average precipitation, mostly in the form of rain, over the previous several months. However, despite the significant increase in rainfall, only the upper few feet of material exposed in the arroyo wall was moist when the failure occurred; the deeper material comprising most of the wall was dry. While additional water weight in the upper few feet of the arroyo wall may have contributed in a small way to the landslide, the failure occurred under essentially dry conditions, and the landslide most likely resulted from the long-term effect of gravity acting on the over-steepened unconsolidated material in the wall.

FUTURE HAZARD POTENTIAL

The presence of additional wall-parallel cracks where arroyo walls along Kanab Creek are vertical and the fact that the earth-fall landslide that killed the young boy took place under essentially dry conditions indicates that similar slope failures may occur along Kanab Creek at anytime in the future and are largely independent of precipitation conditions.

Figure 5. *Vertical cracks parallel to the arroyo wall in an area adjacent to the landslide that has not yet failed; such cracks are typical where arroyo walls are vertical.*

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, express or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCES

American Society for Testing and Materials (ASTM), 1984, Standard practice for description and identification of soils (visual – manual procedure) – Designation D 2488-84: Annual Book of ASTM Standards, v. 04.08, p. 409-423.

Figure 6. *Partially detached section of the arroyo wall where additional failure is imminent.*

Cruden, D.M., and Varnes, D.J., 1996, Landslide types and processes, *in* Turner, K.A., and Schuster, R.L., editors, Landslides, investigation and mitigation: Washington, D.C., National Academy Press, National Research Council Transportation Research Board Special Report 247, p. 36-75.

Sargent, K.A., and Philpott, B.C., 1987, Geologic map of the Kanab quadrangle, Kane County, Utah and Mohave and Coconino Counties, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1603, scale 1:62,500.

Webb, R.H., Smith, S.S., and McCord, V.A.S., 1991, Historic channel change of Kanab Creek – southern Utah and northern Arizona: Grand Canyon Natural History Association Monograph Number 9, 91 p.

APPENDIX

Description of Soil Units Involved in the Landslide

Due to continued instability of the arroyo wall at the time of the field reconnaissance, access to the materials involved in the landslide was limited. The following soil descriptions are based on field soil classification procedures (ASTM, 1984) of materials available at the base of the arroyo wall. Unit thicknesses are estimates.

Top of Arroyo Wall

Unit	Estimated Thickness (feet)	Description
7	3	Sand (SP), light brown (7.5 YR 6/4), loose, moist, well-sorted, well-rounded, medium quartz sand; slight reaction to HCl, non-cemented; eolian dune sand.
6	5	Interbedded thin (0.5-2 inches) layers of clay and sand, no direct access to this unit, appears similar to unit 1 below.
5	14	Interbedded medium to thick (6 inches to 2 feet) layers of silty sand and silty clay, no direct access to this unit, appears similar to unit 3 below.
4	2	Silty clay (CL?), light gray (~7.5 YR 8/1), no direct access to this unit, properties are estimated.
3	24	Interbedded medium to thick layers of (1) silty sand (SM), red (2.5 YR 4/6), 20% silt, 80% moderately indurated, dry, well-sorted, well-rounded, fine quartz sand; moderate reaction to HCl, slightly cemented, and (2) silty clay (CL), red (2.5 YR 4/6), moderately plastic, dry; moderate reaction to HCl, slightly cemented; alluvial sand and clay.
2	3	Sand (SP), pinkish white (7.5 YR 8/2), loose, dry, well-sorted, well-rounded, fine quartz sand; slight reaction to HCl, non-cemented; alluvial sand.
1	5*	Interbedded thin layers of (1) sand with silt (SP), light reddish brown (5 YR 6/4), 10% silt, 90% moderately indurated, dry, well-sorted, well-rounded, fine quartz sand; moderate reaction to HCl, slightly cemented, and (2) silty clay (CL), yellowish red (5 YR 4/6), moderately plastic, dry; moderate reaction to HCl, slightly cemented; alluvial sand and clay.

**Base of unit buried.*

Utah Geological Survey

Project: Reconnaissance of the 425 East South Weber Drive landslide, South Weber, Utah			
By: Richard E. Giraud, P.G.	Date: 04-05-05	County: Davis	
USGS Quadrangles: Ogden (1345)	Section/Township/Range: SE¼NE¼ and NE¼SE¼ section 29, T. 5 N., R. 1 W., SLBLM		
Requested by: Boyd Davis, South Weber City Engineering			Job number: 05-03 (GH-03)

INTRODUCTION

Upon notification by a member of the State Hazard Mitigation Team, Gary Christenson (Utah Geological Survey [UGS]) and I conducted a reconnaissance of the 425 East South Weber Drive landslide in South Weber, Davis County, Utah (figure 1) on February 21, 2005. Rick Chesnut (Terracon) and Lee Cammack (JUB Engineers) were also conducting a field study of the landslide at the time of our visit as a follow-up to ongoing studies (Terracon, 2005) for the Davis-Weber Canal Company. I again visited the landslide on March 4, 2005 with Francis Ashland (UGS).

The landslide occurred shortly after 6 p.m. on the evening of February 20, 2005, just below the Davis-Weber Canal, demolishing a barn and blocking State Route 60 (South Weber Drive). The purpose of my investigation was to determine the physical characteristics of the landslide and evaluate its hazard potential to aid South Weber City in assessing the risk to development at the base of the bluff from landslides and potential canal breaches.

CONCLUSIONS AND RECOMMENDATIONS

Based on this geologic investigation and hazard assessment of the 425 East South Weber Drive landslide, the UGS concludes the following:

- Landsliding will likely continue both above and below the Davis-Weber Canal in this area unless measures are taken to stabilize these slopes.
- The 425 East South Weber Drive landslide was a rapid earth-flow-type landslide involving the canal embankment and underlying slope materials that traveled 150 feet beyond the slope toe out onto flat ground.
- The steep slope, above-normal precipitation, shallow ground water, weight of the embankment fill, and weak geologic materials probably all contributed to landslide movement.

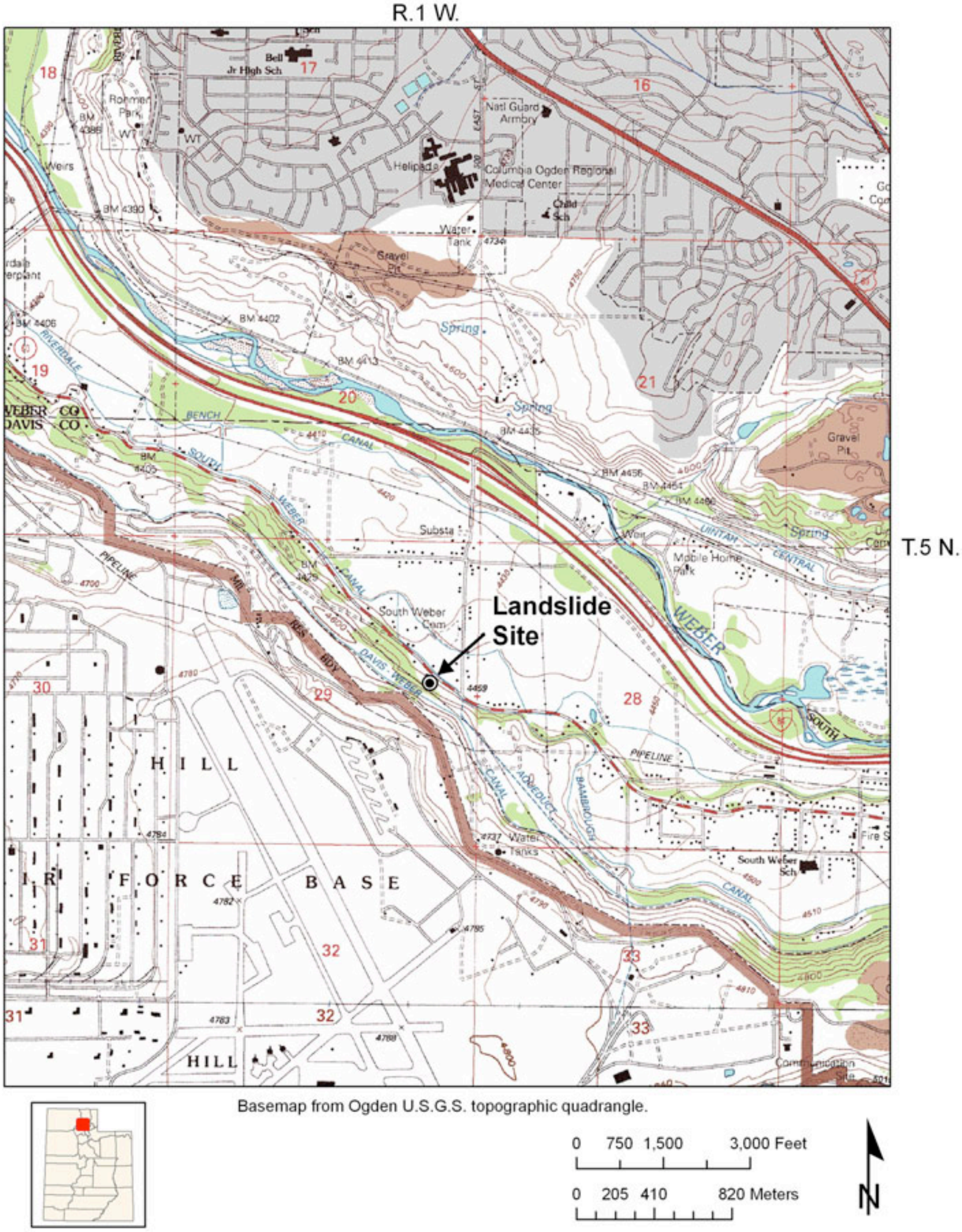


Figure 1. *Location for the 425 East South Weber Drive landslide.*

- Retreat of the landslide main scarp and possible expansion of the landslide to the east or west directly threatens the Davis-Weber Canal.

- If the canal were conveying water and a landslide caused a canal breach, widespread flooding and sedimentation could occur at the base of the slope.

To reduce the potential impacts of landslide movement and manage future movement of landslides in this area, the UGS recommends the following:

- This slope should be reconstructed and stabilized prior to delivering water into this canal section, or the canal or water should be rerouted in the area.

- Risk-reduction measures may also be needed to stabilize landslides above and below the canal pending results of additional study and emergency reconstruction measures.

- Monitoring of inclinometers for landslide movement and ground-water levels in piezometers should be continued to assess changes in conditions following the landslide and to aid in stability assessment before, during, and after reconstruction.

- South Weber City should consider the landslide potential and hazards related to a possible canal breach when evaluating existing or future development near the base of the slope along the city's entire south side.

GEOLOGIC SETTING

The 425 East South Weber Drive landslide occurred in the lower part of a northeast-facing slope on the edge of a bluff forming the south side of the Weber River valley (figure 2). The slope formed as the Weber River cut down into its former delta as Lake Bonneville receded after 16,000 years ago and the shoreline retreated to the present level of Great Salt Lake. The slope is approximately 200 feet high. The Davis-Weber Canal is about mid-slope and is a concrete canal with an impervious rubber liner. The demolished barn and State Route 60 (South Weber Drive) are at the base of the slope. The slope above the canal is about 80 feet high and has a gradient of 34%. Active shallow landslides in the slope above the canal locally override the southern canal bank. The slope below the canal is about 120 feet high and has an average gradient of 45%, but locally the gradient is up to 65%. Snow 1 to 3 inches deep covered approximately 40% of the slope above the canal and 20% of the slope below the canal on February 21, 2005.

Yonkee and Lowe (2004) mapped the northeast-facing slope as younger Holocene landslide deposits that display relatively recent movement and fresh scarps, local ground cracks, and distinct hummocky surfaces. These younger Holocene landslide deposits lie within older Holocene landslide deposits. Lowe (1988) shows the younger Holocene landslide deposits as a historically active landslide (LSa 316) and the entire northeast-facing bluff as an older landslide

Figure 2. *View to the south showing the landslide main scarp in the Davis-Weber Canal embankment, the demolished barn (right foreground), and runout onto the field.*

complex (LS 335). The younger and older landslide deposits are derived from Lake Bonneville fine-grained lacustrine and delta deposits. Shallow ground water and weak soil materials are present within the northeast-facing slope. All of these landslide deposits are within the large South Weber landslide complex mapped by Pashley and Wiggins (1972). The South Weber landslide complex has many landslides that have moved in historical time. Historical records and geologic evidence indicate relatively frequent landsliding on these slopes. Yonkee and Lowe (2004) mapped older Holocene stream alluvium from the base of the northeast-facing slope northward across an abandoned stream terrace of the Weber River. The stream alluvium consists of pebble and cobble gravel, gravelly sand, and silty sand.

LANDSLIDE DESCRIPTION

The 425 East South Weber Drive landslide is mostly a failure of non-engineered embankment fill of the Davis-Weber Canal but also involved underlying and downslope natural materials. Water was not flowing in the canal at the time of failure, and the canal was undamaged. The landslide occurred within the youngest Holocene landslide unit mapped by Yonkee and Lowe (2004) and a historically active landslide mapped by Lowe (1988).

The landslide occurred shortly after 6 p.m., and demolished a barn, took out telephone poles, and blocked State Route 60 (South Weber Drive) (figures 2, 3, 4). The landslide is approximately 480 feet long and 80 feet wide at its widest point (figure 3) and between stations 305 and 310 on the Davis-Weber Canal. According to Nolan Birt (verbal communication, March 4, 2005), the barn owner who witnessed the event, the total landslide travel time was about a

Figure 3. *Image showing landslide flow direction, the Davis-Weber Canal, main scarp, other scarps, and runout beyond State Route 60 (South Weber Drive).*

Figure 4. *Looking across the lower part of the landslide at the demolished barn. The clump of trees in the foreground was rafted downslope on top of the landslide debris.*

minute and the barn provided no resistance to landslide movement. Based on this approximate travel time, the estimated landslide velocity is about 8 feet per second, which classifies as very rapid landslide movement (Cruden and Varnes, 1996). The landslide is just below the Davis-Weber Canal and likely started moving as a rotational slide, but likely transformed into a rapid earth flow about midway downslope and ran out 150 feet beyond the toe of the slope across State Route 60 and onto a flat field. Grass, shrubs, and trees cover this northeast-facing slope. Some trees were rafted on top of the landslide debris (figure 4).

The steep landslide main scarp is in the canal and roadway embankment. Only 20-25 feet now separate the canal from the main scarp (figures 3, 5) and the canal is threatened by eventual retreat of the main scarp. The landslide main scarp has extended to the east (figures 3, 5) as adjacent pre-existing landslide deposits reactivated. Based on my observations, the landslide below the main scarp extension dropped approximately 10 to 12 inches between February 21 and March 4, 2005, indicating the slope east of the 425 East South Weber Drive landslide was still moving. Based on observations of the evacuated landslide main scarp area, the embankment fill was placed onto native slope materials and was not keyed into the underlying slope.

The landslide removed an inclinometer installed on June 11, 2004, in the canal embankment to monitor slope movement (Terracon, 2005). Terracon (2005) logged the following lithologies in the inclinometer borehole: fill from 0 to 7.5 feet, clay from 7.5 to 18 feet, silty sand from 18 to 40 feet, clay from 45 to 60 feet, silty sand from 60 to 90 feet, and clay from 90 to the bottom of the hole at 102 feet. The fill, clay, and silty sand in the upper part of the borehole are exposed in the landslide main scarp.

Figure 5. *View west of the landslide crown, the Davis-Weber Canal, and the landslide main scarp. Eastward extension of the main scarp in the foreground indicates movement in the slope east of the landslide.*

Ground water is relatively shallow in slopes both above and below the canal. Water was observed flowing from the sand unit exposed in the main scarp following the landslide and was ponding locally on the landslide deposits below. Terracon (2005) reported a ground-water depth of 30 feet in the inclinometer borehole, which coincides with the level of water observed flowing from the sand unit exposed in the main scarp. Water flowing from the main scarp later had to be channeled to flow into a small ditch to stop ponding and flow across State Route 60 (Nolan Birt, verbal communication, March 4, 2005). All of the landslide material was very wet the day after the landslide and too soft to support the weight of a 170 pound person.

PREVIOUS SLOPE-STABILITY INVESTIGATION

Terracon (2005) completed a slope-stability investigation in January 2005 on the slopes above and below the canal in this area for the Davis-Weber Canal Company. The investigation included installation of piezometers and inclinometers. Terracon (2005) estimated a static factor of safety of 1.0 to 1.2 for the overall slope above and below the canal. For the slope below the canal at the landslide, Terracon (2005) estimated a factor of safety of about 1.0. The occurrence of the landslide confirmed that this estimate was accurate. For earthquake ground shaking conditions, Terracon (2005) estimated the factor of safety to be well below 1.0, meaning the slope would fail during an earthquake. Terracon (2005) provided recommendations to reduce the potential for slope failure and potential impacts to the canal.

PROBABLE CAUSES OF MOVEMENT

Several factors likely contributed to landslide movement. The landslide included part of the canal and roadway fill embankment and the weight of the fill increased the load and shear stress in the underlying weak slope materials, promoting slope failure. Above-normal precipitation also contributed to the landslide as excess precipitation infiltrated into the ground and raised ground-water levels and pore pressures in the slope. Records from nearby National Weather Service stations indicate that prior to the landslide, the Layton-South Weber-Ogden area received 148% of normal precipitation for an informal landslide water year (LWY) that began in September 2004. The informal LWY tracks cumulative precipitation from September through May to monitor excess precipitation that infiltrates into the ground and raises ground-water levels in landslides (Ashland, 2003). In addition, the area received greater than normal precipitation during the previous LWY. About 0.72 inches of rain fell in Layton on the day of the landslide (National Weather Service, 2005), likely wetting and increasing the weight of the fill. The steep slope, above-normal precipitation, shallow ground-water conditions, weight of embankment fill, and weak underlying geologic materials probably all contributed to the landslide.

FUTURE HAZARD POTENTIAL

The February 20, 2005, landslide clearly demonstrates the potential for rapidly moving earth-flow-type landslides with significant runout distances on similar slopes in South Weber. Flow-type landslides are destructive due to their velocity and impact. Where flow-type landslides occur above subdivisions within the landslide runout zone, the potential exists for loss of life in addition to property damage. Also, this landslide demonstrates the distance a small earth flow can travel beyond the toe of a slope. Future earth flows in this area could block State Route 60 again.

Several landslide hazards threaten the Davis-Weber Canal as a result of the 425 East South Weber Drive landslide. The most direct threat is from upslope retreat of the landslide main scarp, which could impact the remaining embankment and canal. Numerous shallow landslides are also present in the area, and movement of slopes directly east and west of the landslide also threaten the canal. Terracon (2005) estimated a factor of safety of about 1.0 for the slope below the canal at the landslide. Shallow active landslides in the slope above the canal are also a threat. Although all of the observed landslides are relatively shallow, deep rotational landslides must also be considered in hazard analysis. Earthquakes could trigger both shallow and deep landslides. If landslides impact the Davis-Weber Canal when the canal is conveying water, the potential exists for the canal to breach and cause widespread flooding and sediment deposition similar to the July 11, 1999, Davis-Weber Canal breach in Riverdale (Black and others, 1999).

SUMMARY

The 425 East South Weber Drive landslide was a rapid earth flow that demolished a barn and telephone poles and blocked State Route 60. The steep slope, above-normal precipitation, shallow ground-water conditions, weight of embankment fill, and weak underlying geologic materials probably all contributed to the landslide. The retreat of the landslide's main scarp directly threatens the Davis-Weber Canal. The landslide removed lateral support of the canal embankment and this slope should be reconstructed prior to putting water in this section of the canal, or the canal or water should be rerouted in the landslide area. Other shallow landslides above and below the canal also threaten the canal. Landsliding in this area will continue in the future as it has in the past unless measures are taken to stabilize these slopes.

LIMITATIONS

REFERENCES

Ashland, F.X., 2003, Characteristics, causes, and implications of the 1998 Wasatch Front landslides, Utah: Utah Geological Survey Special Study 105, 49 p.

Black, B.D., Christenson, G.E., and McDonald, G.N., 1999, Reconnaissance of flooding and sediment deposition from a breach of the Davis-Weber Canal near 1345 West 5300 South, Riverdale, Weber County, Utah, *in* McDonald, G.N., compiler, Technical reports for 1999, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 3-10.

Cruden, D.M., and Varnes, D.J., 1996, Landslides, types and processes, *in* Turner, A.K., and Schuster, R.L., editors, Landslides, investigation and mitigation: Washington, D.C., National Academy Press, Transportation Research Board Special Report 247, p. 36-75.

Lowe, M., 1988, Natural hazards overlay zone - slope-failure inventory map, Ogden quadrangle: Weber County Planning Department unpublished map, scale 1:24,000.

National Weather Service, 2005, Observed weather reports: Online, http://www.wrh.noaa.gov/climate/index.php?wfo=slc, accessed February 23, 2005.

Pashley, E.F., Jr., and Wiggins, R.A., 1972, Landslides of the northern Wasatch Front, *in* Hilpert, L.S., editor, Environmental geology of the Wasatch Front, 1971: Utah Geological Association Publication 1, p. K1-K16.

Terracon, 2005, Slope stability evaluation, Davis and Weber Canal at station 310, South Weber, Utah: Draper, Utah, unpublished consultant's report, 17 p., 4 appendices.

Yonkee, A., and Lowe, M., 2004, Geologic map of the Ogden 7.5-minute quadrangle, Weber and Davis Counties, Utah: Utah Geological Survey Map 200, 42 p. pamphlet, scale 1:24,000.

Utah Geological Survey

Project: Investigation of the May 12, 2005, 1550 East Provo rock fall, Provo, Utah			
By: Richard E. Giraud, P.G., and Gary Christenson, P.G.	Date: 06-09-05	County: Utah	
USGS Quadrangles: Orem (1088), Bridal Veil Falls (1087)	Section/Township/Range: Sections 32 and 33, R. 3 E., T. 6 S., SLBM		
Requested by: Robert Carey, DES Ed Scott, Provo City			Job number: 05-06 (GH-04)

INTRODUCTION

In the late afternoon of May 12, 2005, a rock fall released from a cliff band high on "Y" Mountain (figures 1 and 2) above Provo. One of the rocks severely damaged a guest house at 1468 South 1550 East in Provo (figure 3). No one was home at the time; the structure is likely a total loss. Some of the rocks crossed a buried Questar gas pipeline, and Questar personnel inspected the pipeline for damage.

Robert Carey, Utah Division of Emergency Services and Homeland Security, requested we investigate the rock fall shortly after it occurred on May 12, 2005. Francis Ashland and Michael Kirshbaum, Utah Geological Survey, investigated the rock fall around dusk on May 12, and Richard Giraud performed a more thorough investigation on May 13. The purpose of our investigation was to determine the geologic characteristics of the rock fall and evaluate the hazard potential for future rock falls to aid Provo City emergency managers in assessing the risk to houses and city infrastructure in the area. On May 16, 2005, we provided Provo City emergency manager Ed Scott and Provo Mayor Lewis Billings a letter with our initial conclusions and recommendations regarding the rock fall. This report provides supplemental information on the rock-fall hazard and restates our conclusions and recommendations.

CONCLUSIONS AND RECOMMENDATIONS

The rocks fell from a cliff band about 2,600 vertical feet above the guest house that was damaged (figure 2). We were unable to investigate the source area to look for unstable rocks. Abundant rock-fall sources are present all along the front of "Y" Mountain, and previous rock-fall debris throughout this neighborhood indicates the remaining house on the lot and adjacent houses are in a rock-fall-hazard area. This area is also within the rock-fall-hazard area mapped by Robison (1990). Unfortunately, the timing of rock falls cannot be predicted, although they are most common during and following storms and earthquakes, and during periods of freeze-thaw such as spring and fall. Therefore, although we were in a period of heightened hazard at the time of the rock fall because of recent precipitation, the occurrence of this rock fall does not necessarily indicate a greater hazard at this locality than elsewhere.

Because the remaining house on the lot and adjacent houses are pre-existing older homes, we recommend that residents be informed they are in a rock-fall-hazard area, and that they may wish to hire a geological consultant to investigate, to the extent possible, the risk from rock falls to the neighborhood or to individual houses. A geologic consultant could also evaluate rock-fall risk-reduction protection measures such as upslope catchment structures and their cost.

DESCRIPTION AND GEOLOGIC SETTING

The rock fall occurred on "Y" Mountain, a steep mountain front along the southern Wasatch Range above Provo. The source of the rocks was an upper cliff band in the Mississippian Deseret Limestone about 2,600 feet above the house (figure 4; Hintze, 1978). Plentiful other source-area cliffs extend throughout the source area of this rock fall. The lower slope where the rocks came to rest is mostly colluvium, and the upper slope below the cliffs is talus. The average slope from the apex of the talus slope to the rock's resting place, known as the "shadow angle" (Evans and Hungr, 1993), is about 28.5°. Minimum shadow angles are used to estimate maximum rock-fall runout distances, and typical minimum "shadow angles" for rock falls measured elsewhere are about 22° (Wieczorek and others, 1998). This indicates that rocks may potentially travel farther downslope and that the rock-fall hazard area includes parts of the neighborhood to the west as shown by Robison (1990).

The rock that impacted the guest house measures approximately 7 x 5.1 x 4.5 feet (figure 5), and we estimate that it weighs about 13 tons. Many other rocks from the same rock fall were present on slopes below the cliff band in the runout track (figure 6) and on the slope just above 1550 East. The guest house was severely damaged (figure 3), but none of the other structures in the area were affected. The rock impacted and displaced the southwest concrete foundation corner of the house onto the driveway (figures 3 and 5). The west house wall was detached from the main structure and contents inside the house were damaged (figure 3). Impact craters (bounce marks; figure 7) were evident on the 20° slope directly above the house. The rocks traveled a total slope distance of over 1 mile (about 5,500 feet) and likely achieved a relatively high velocity and bounce height as they advanced down the slope. Abundant previously fallen rocks on the slope and among the homes in the area indicate that rock falls are relatively common on a geologic time scale in this area.

PROBABLE CAUSES

The exact timing of rock falls can sometimes be attributed to a specific cause, but not always. Rock falls are generally the result of the cumulative effects of weathering, erosion, water and freeze-thaw in fractures in an outcrop, and other geologic processes (particularly earthquakes). In this particular case, the rock fall occurred shortly after a significant storm on May 10-12 that dropped over 3.7 inches of rain and snow at the Cascade Mountain Snotel site (MesoWest, 2005) about 3 miles southeast of the source area. It was raining at the time of the rock fall. Precipitation at the Orem National Weather Service station for the period September 2004 to April 2005 (National Weather Service Forecast Office Salt Lake City, 2005) was 121% of normal. Soil moisture and amounts of water infiltrating into fractures in rock outcrops have likely increased greatly this spring in the rock-fall source area, increasing pore pressures and the potential for rock falls. These conditions probably contributed to the timing of this event.

SUMMARY AND FUTURE HAZARD POTENTIAL

On May 12, 2005, a rock fall from a cliff band on "Y" Mountain about 2,600 feet vertically above 1550 East Street in Provo rolled over a mile and damaged a guest house at 1468 South 1550 East. A significant rainfall event, repeated snowfall and melting this winter and spring, and overall above-normal rainfall this year probably contributed to the timing of the rock fall on May 12. Abundant rock-fall sources are present all along the front of "Y" Mountain, and rocks throughout this neighborhood from previous rock falls indicate a significant rock-fall hazard in the area.

The timing of rock falls cannot be predicted, but they are most common during and following storms and earthquakes, and during periods of freeze-thaw such as spring and fall. Although we were in a period of heightened rock-fall potential, the occurrence of this rock fall does not necessarily indicate a greater hazard here than elsewhere; rock falls are possible at any time and typically occur with no warning. Residents should be informed they are in a rock-fall-hazard area, and that they may wish to hire a geological consultant to investigate the risk from rock falls to the neighborhood or to individual homes and the feasibility or rock-fall risk-reduction structures.

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, UGS, makes no warranty, express or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, UGS, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCES

Evans, S.G., and Hungr, O., 1993, The assessment of rockfall hazard at the base of talus slopes: Canadian Geotechnical Journal, v. 31, p. 620-636.

Hintze, L.F., 1978, Geologic map of the "Y" Mountain area, east of Provo, Utah: Brigham Young University Geology Series Special Publication no. 5, scale 1:24,000.

MesoWest, 2005, Current weather summary for Utah: Online, http://www.met.utah.edu/cgi-bin/droman/meso_base.cgi?stn=CAMU1&time=GMT, accessed May 26, 2005.

National Weather Service Forecast Office Salt Lake City, Utah, 2005, Monthly weather summary: Online, http://www.wrh.noaa.gov/climate/index.php?wfo=slc, accessed September 2004 thorough April 2005.

Robison, R.M., 1990, Utah County natural hazards overlay (NHO) zone: Unpublished Utah County Planning Department maps, scale 1:50,000 and 1:24,000.

Wieczorek, C.F., Morrissey, M.M., Iovine, G., and Godt, J., 1998, Rock-fall hazard in the Yosemite Valley, California: U.S. Geological Survey Open-File Report 98-467, map scale 1:12,000.

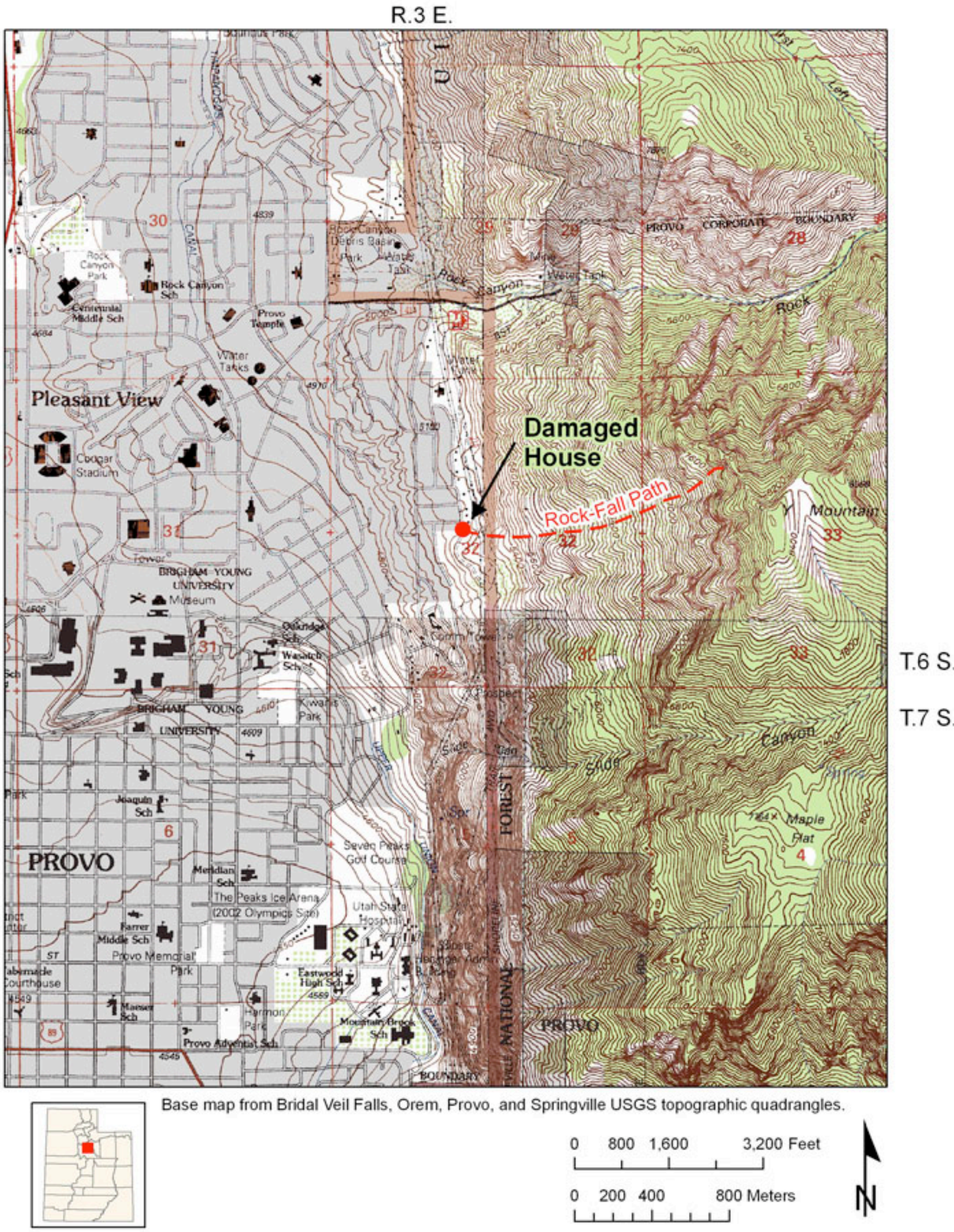


Figure 1. *Location map for the 1550 East Provo rock fall.*

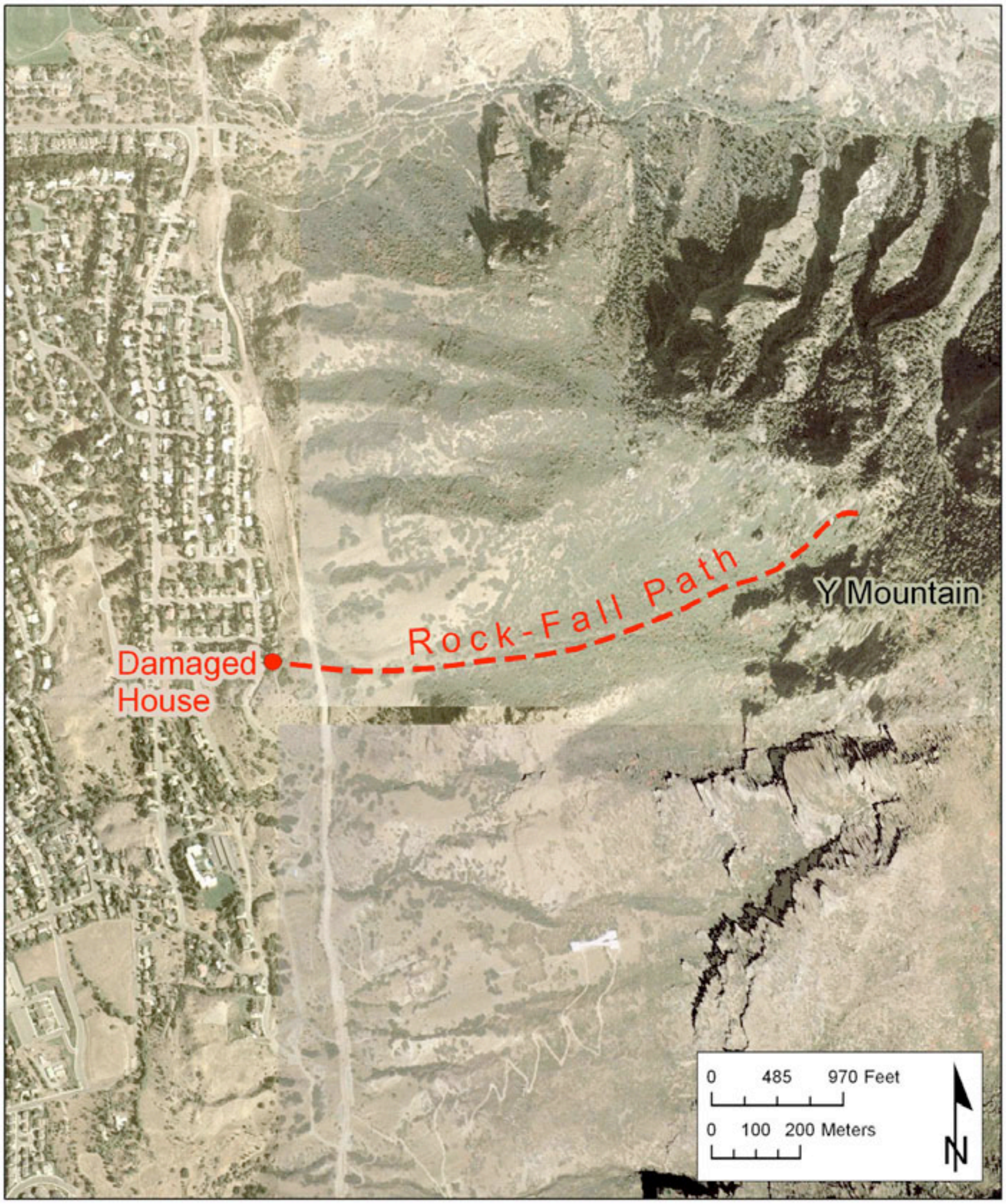


Figure 2. *"Y" Mountain source area, the rock-fall path, and damaged house.*

Figure 3. *Damage to the guest house. The damaging rock is on the left behind the trash can, against the base of the tree. Parts of the concrete house foundation are behind and to the right of the trash can.*

Figure 4. *View east to the rock-fall source area in the Mississippian Deseret Limestone on the north end of "Y" Mountain showing path of the rock fall (arrows) as indicated by dark soil and rock fragments on the snow surface.*

Figure 5. *The rock that damaged the guest house. Part of the concrete house foundation wall is in the foreground.*

Figure 6. *View of the rock fall runout track on May 17, 2005. Dark brown soil streaks show the path of rocks that traveled downslope. Recent snowfall obscures the runout track in the upper part of the photo (photo by Dave Bennett).*

Figure 7. *Impact crater (bounce mark) on the slope just above the guest house (yellow object is notebook for scale).*

Utah Geological Survey

<table>
<tr><td colspan="2">Project:
June 3, 2005, Black Mountain debris flow, Iron County, Utah</td><td rowspan="3"></td></tr>
<tr><td>By:
William R. Lund, P.G., Garrett Vice, & Joe Buckley</td><td>Date:
07-08-05</td><td>County:
Iron</td></tr>
<tr><td>USGS Quadrangles:
Webster Flat (196)</td><td colspan="2">Section/Township/Range:
NE1/4NW1/4 section 24, T. 37 S., R. 10 W., SLBL&M</td></tr>
<tr><td>Requested by:
Incident Investigation</td><td colspan="2"></td><td>Job number:
05-07 (GH-05)</td></tr>
</table>

INTRODUCTION

On the morning of Friday, June 3, 2005, a debris flow originated on the north flank of Black Mountain in southeastern Iron County and flowed approximately 1.5 miles down an unnamed tributary drainage before encountering Utah State Route 14 (SR-14) and Crow Creek in the NE1/4SW1/4NE1/4 section 12, T 37 S., R. 10 W., SLBL&M (figure 1) sometime between 8 and 9 a.m. (verbal communication, Utah Department of Transportation [UDOT] road maintenance worker, June 4, 2005). Upon reaching SR-14 the debris flow buried an approximately 100-foot-wide section of the highway with mud, boulders, and large trees (figure 2). It then turned to the northwest and flowed down Crow Creek (Cedar Canyon) for several more miles, blocking culverts with tree trunks, some more than 50 feet long and 3 feet or more in diameter at their base (figure 3), and causing erosion and flood damage to SR-14 at several locations (figure 4). As it proceeded down Cedar Canyon, additional water from Crow Creek and its tributaries diluted the debris flow and eventually transformed it into a debris flood. Finally, after having dropped the bulk of its coarse sediment and debris, the fine-sediment-rich flood water contributed to the flow in Coal Creek (Crow Creek is tributary to Coal Creek) that peaked at approximately 1700 cubic feet per second at the U.S. Geological Survey stream gauge near Cedar City later in the morning on June 3 (Havnes, 2005).

We investigated the debris flow on June 4, 2005, as UDOT personnel were attempting to clear and reopen SR-14. The purpose of our investigation was to document the occurrence and triggering mechanism of the debris flow.

CONCLUSIONS AND RECOMMENDATIONS

The June 3, 2005, Black Mountain debris flow began as a landslide/debris avalanche, probably in colluvium and weathered Upper Cretaceous sedimentary rocks, which then mobilized into a debris flow that damaged SR-14 along Crow Creek by local burial, erosion, and plugging of culverts with debris. The initiating landslide was probably caused by moisture infiltration into surficial deposits and weathered bedrock on Black Mountain as southern Utah's record snowpack began to melt, followed by a significant rain-on-snow event on June 2-3.

Once the snowpack on Black Mountain melts and the area where the debris flow initiated is accessible from the ground, the volume of the detached slide mass remaining above the debris chute should be determined, and an evaluation should be made of the susceptibility of that material to renewed movement and the possible generation of additional large debris flows. Additionally, a portion of Black Mountain has been logged; the location of the logged area relative to the detached slide mass remains obscured by snow. Once the snow melts, the relation of the logged area to the debris flow initiation point should be investigated to determine if logging may have contributed to the slope failure.

RECONNAISSANCE AND EVENT DESCRIPTION

A deep snowpack prevented direct access to the location where the debris flow initiated on Black Mountain. However, a preliminary reconnaissance on foot made on June 4 reached an observation point on a ridge top on the west side of the un-named tributary approximately 1000 feet below the debris-flow initiation point and close to the path that the debris followed off Black Mountain (figure 1). In addition, the Utah Highway Patrol (UHP) made an aerial reconnaissance of the debris flow on the morning on June 3 and provided pictures taken during the reconnaissance (Lt. David Excel, UHP, June 10, 2005). The observation point on the ridge top was approximately 800 feet higher than the stream channel at the foot of Black Mountain. In the vicinity of the observation point the ridge was heavily spattered by mud, debris, and boulders, some of which had clipped the tops off nearby trees, attesting to the speed and power of the passing debris mass. During the time spent at the observation point, small debris flows consisting of saturated aggregations of cobble- to boulder-size rocks continued to flow rapidly down the bedrock chute that now forms the upper part of the un-named drainage on Black Mountain.

Based on the foot reconnaissance and the UHP photos, the trigger for the debris flow appears to have been a landslide that detached above the snow line on Black Mountain at an elevation of about 9800 feet following the onset of the spring snowmelt and more than a day and a half of steady precipitation (3.6 cm of precipitation reported at Cedar City between 7 p.m. on June 2 and 7 a.m. on June 3 [Kociela, 2005]). Gregory (1950) shows the area where the debris mass detached as underlain by the Cretaceous Kaiparowits Formation, although the Upper Cretaceous units in Cedar Canyon have recently been redefined but not remapped by Moore and Straub (2002). The Kaiparowits Formation as defined by Gregory (1950) consists chiefly of thinly stratified sandstone beds that are highly irregular in texture and composition. Interbedded with the sandstone are lenses of shale, limestone, conglomerate, and lignite. The UHP photographs show that a large detached slide mass (figures 5 and 6), possibly several acres in size, remains perched at the top of the scoured debris chute.

Once detached, a portion of the landslide quickly descended as a debris avalanche approximately 1800 feet down the steep, narrow channel of the un-named tributary drainage, while simultaneously scouring the channel down to bedrock (figure 7). Upon encountering the gentler stream gradient at the foot of Black Mountain, the debris avalanche transformed into a debris flow and moved rapidly toward SR-14 while continuing to scour sediment and vegetation from the stream channel along its path and depositing debris along the channel banks (figure 8).

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, UGS, makes no warranty, express or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, UGS, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCES

Gregory, H.E., 1950, Geology of eastern Iron County, Utah: Utah Geological and Mineralogical Survey Bulletin 37, 153 p., folded map in pocket, scale 1:63,360.

Havnes, Mark, 2005, Heavy rains cause logjam on Coal Creek - SR14 closed: The Salt Lake Tribune, Thursday, June, 9, 2005.

Kociela, Ed, 2005, Rains swell Coal Creek - Highway 14 closed: Cedar City Daily News, Saturday, June 4, 2005.

Moore, D.W., and Straub, A.W., 2002, Correlation of Upper Cretaceous and Paleogene (?) rocks beneath the Claron Formation, Crow Creek, western Markagunt Plateau, southwestern Utah, *in* Erskine, M.C., and others, editors, The geologic transition, High Plateaus to Great Basin – A symposium and field guide – The Mackin Volume: Utah Geological Association Publication 30 and Pacific Section American Association of Petroleum Geologists Publication GB-78, p. 75-96.

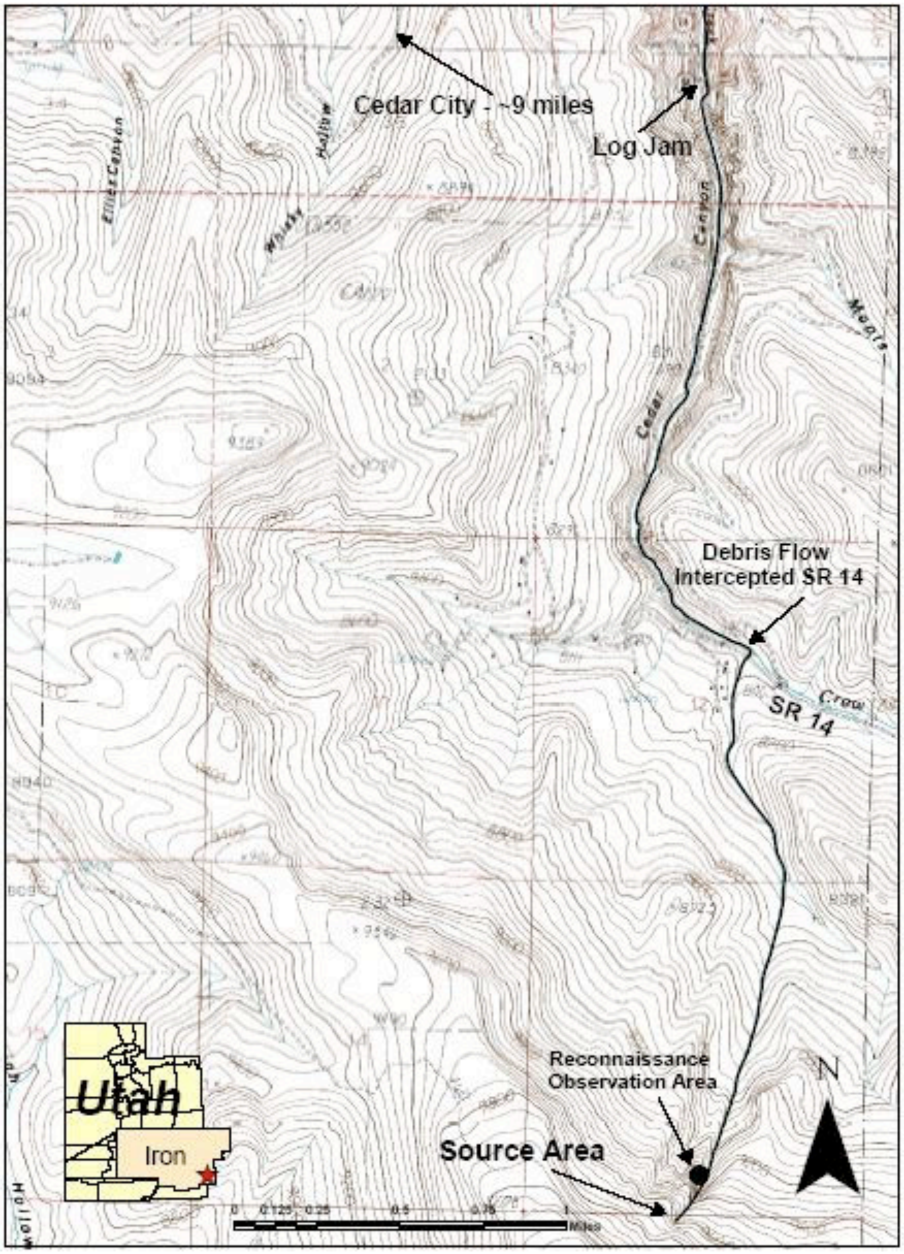


Figure 1. *Map showing the source area and flow path of the June 3, 2005, Black Mountain debris flow. Beyond the northern limit of this figure the debris flow had lost the bulk of its coarse sediment load and contributed to high flows in Coal Creek (to which Crow Creek is tributary) recorded on June 3 (base maps Webster Flat and Flanigan Arch U.S. Geological Survey 1:24,000-scale quadrangles).*

Figure 2. *Location where the Black Mountain debris flow crossed SR-14 on June 3, 2005; photo was taken on June 4 about 30 hours after the debris flow occurred during UDOT cleanup operations.*

Figure 3. *Log jam created by the Black Mountain debris flow at a box culvert beneath SR-14.*

Figure 4. *Small slope failure in the roadbed of SR-14 caused by undercutting and erosion of the stream bank by the Black Mountain debris flow.*

Figure 5. *Detached slide mass on Black Mountain from which the Black Mountain debris flow originated (UHP photograph).*

Figure 6. *Cracks in the snow upslope from and parallel to the crown scarp of the landslide on Black Mountain from which the Black Mountain debris flow originated (UHP photograph).*

Figure 7. *Headwaters of the un-named drainage on Black Mountain scoured to bedrock by the passage of the Black Mountain debris flow (photograph taken from observation point shown on figure 1).*

Figure 8. *Scoured channel of the un-named tributary of Crow Creek about 0.6 miles above the juncture of the two streams.*

Utah Geological Survey

Project: Investigation of a landslide north of the mouth of Ogden Canyon, Weber County, Utah			
By: Greg N. McDonald, P.G. Chris DuRoss	Date: July 15, 2005	County: Weber	
USGS Quadrangles: Ogden	Section/Township/Range: Section 23, T. 6 N., R. 1 W.		
Requested by: Incident investigation	Date report received at UGS: na		Job number: 05-08 (GH-06)

INTRODUCTION

On April 19, 2005, we conducted a reconnaissance of a landslide in northeastern Ogden, Weber County, Utah (figure 1). We were notified of the landslide on April 18, 2005, by Terrel Grimley of Pineview Water Systems. A Pineview Water Systems secondary water-supply line is buried under a dirt road now beneath the toe of the landslide (figure 2). For the investigation, we conducted a literature review and examined 1985 1:24,000-scale aerial photos. The purpose of the investigation was to evaluate and document the landslide and determine whether the landslide posed a threat to Ogden City residents.

CONCLUSIONS AND RECOMMENDATIONS

The landslide poses no threat to Ogden City residents except through possible flooding related to landslide-induced rupture of the Pineview Water Systems pipeline. The greatest existing threat is likely the weight of the landslide deposit loading the dirt road/water-pipeline easement potentially increasing the landslide hazard by either deepening of the basal slip surface at the toe or causing a landslide on the slope below the pipeline. In addition, landslide-related ground cracks could promote local infiltration instead of runoff, increasing the likelihood of future landsliding. The site should be monitored for additional landslide movement, signs of expansion of the landslide in the area of the pipeline, and for any effects on the pipeline.

DESCRIPTION

The landslide occurred sometime between the afternoon of Friday, April 15, and the morning of Saturday, April 16, 2005, according to accounts from Pineview Water Systems personnel and a local resident who often hikes the area. Based on the timing of the landslide and our field investigation of its extent and morphology, we infer that the landslide likely occurred as a rapid slump-earth-flow type failure. The toe of the deposit is covering the water line easement/dirt road (figures 3 and 4a). The landslide did not appear to involve any material at or below road level and therefore did not affect the pipeline. Access along the road is not being impaired, as vehicles can detour around the toe of the slide.

The April 2005 landslide deposit is about 56 meters long by 41 meters wide. The landslide has an arcuate crown about 30 meters wide with a 3.5-meter high main scarp. The estimated landslide volume is about 2,390 m^3 (3,120 yd^3). The upper part of the landslide has two scarp zones with relatively intact blocks of down-dropped soil between them (figure 5b). The lower part of the slide is a lobate toe covering the waterline easement/dirt road. Retreat and some rounding of the crown will likely occur due to erosion and sloughing of the vertical main scarp, given ground cracks observed in the crown above the main scarp and the relatively loose nature of the sand and gravel deposits.

The landslide occurred on alluvium/colluvium overlying Lake Bonneville sand and gravel deposits north of the mouth of Ogden Canyon (Nelson and Personius, 1993; Yonkee and Lowe, 2004). The deposits are horizontally bedded, Provo-level shoreline deposits at an elevation of about 4800 feet overlain by alluvial/colluvial slopewash (figure 4b). No fine-grained clayey or silty soils were observed in the landslide deposit or main scarp exposure. The shoreline deposits have been subsequently eroded by minor gullies and remain only as erosional remnants. In the vicinity of the landslide, the Pineview Water System pipeline is a cut/fill easement traversing the relatively steep mountain front (figure 1).

The pre-slide slope of the bluff face that failed was about 27 degrees and the slope of the resulting landslide deposit is about 13 degrees. Unmodified bluff faces in the area naturally slope about 21 degrees, suggesting local oversteepening by the water-line-easement cut. An adjacent bluff to the north, also cut by the pipeline alignment, appears to have failed in the past (figures 2 and 5a); our aerial photos indicate it may have occurred sometime between 1976 and 1985, and possibly in 1983 or 1984 when numerous other landslides occurred in the region.

POSSIBLE CAUSES

We are unsure what triggered the landslide. Northern Utah in general, including the Ogden area, has had higher than normal precipitation. However, climatological data indicate the area had received no precipitation for several days prior to the landslide. One week prior to the event, the area received only trace amounts of rain. Both the landslide deposit and soils in the area were relatively dry at the time of our reconnaissance. No springs or seeps were observed in the area. Pineview Water Systems personnel indicated they began moving water through the pipeline on Friday, April 15, 2005. No pipeline leakage was visible, and water leaking from the pipeline would not likely have an effect as the pipeline is lower in elevation than the landslide. Therefore, we cannot determine a cause of the landslide without further detailed investigations.

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, UGS, makes no warranty, express or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, UGS, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCES

Nelson, A.R., and Personius, S.P., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Map I-2199, 22 p., 1 plate, scale 1:50,000.

Yonkee, W.A., and Lowe, M., 2004, Geologic map of the Ogden 7-1/2 minute quadrangle: Utah Geological Survey Map M-200, 42 p. pamphlet, 1 plate scale 1:24,000.

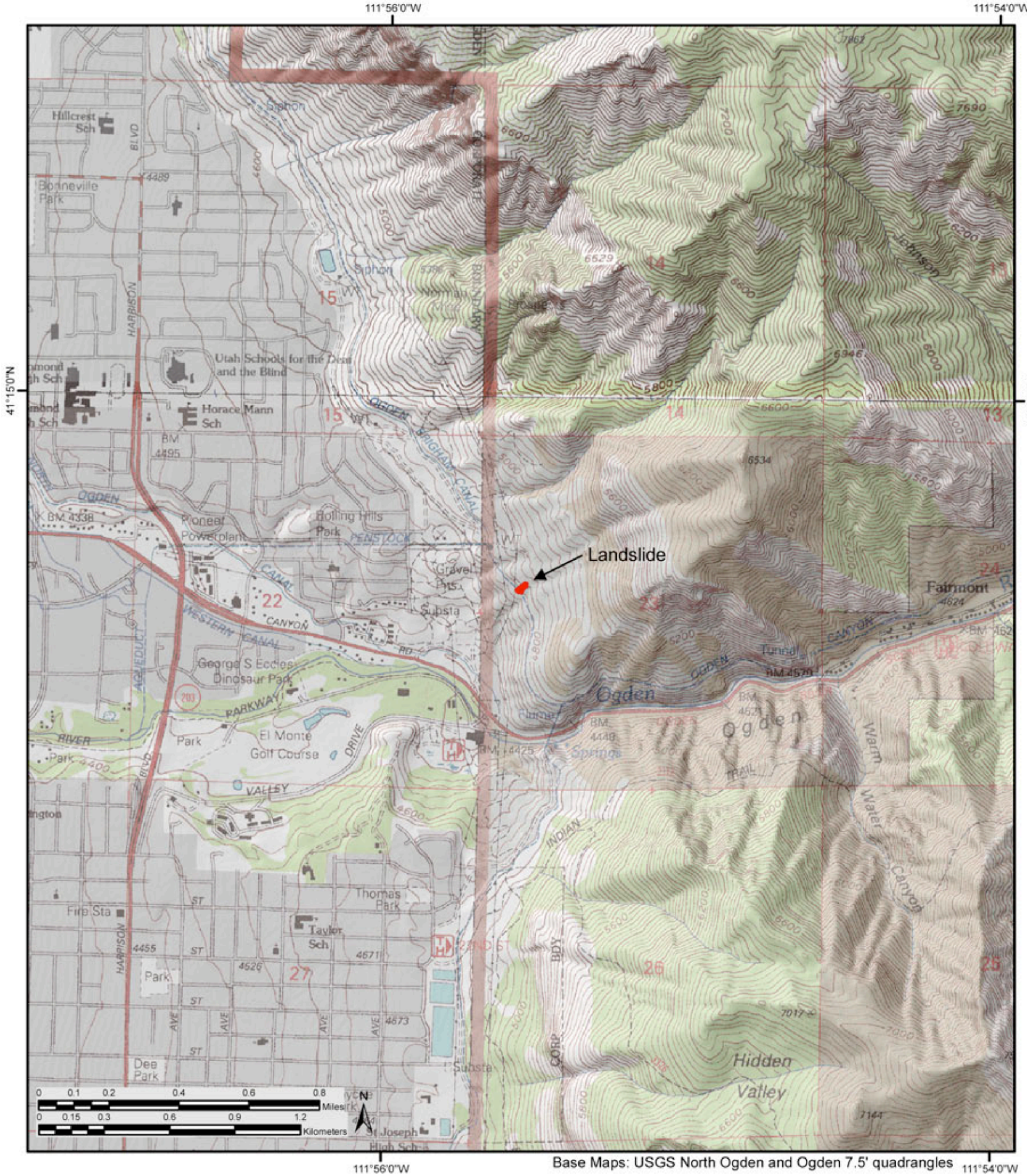


Figure 1. Location of the Pineview Water Systems pipeline landslide.

Base Maps: TerraServer 2004 aerial photo image

Figure 2. April 15, 2005, landslide deposit and main scarp.

Figure 3. Side view of landslide looking southeast.

Figure 4. a) Landslide main scarp and toe of deposit covering road.
b) Main scarp exposure showing post-Bonneville alluvium and colluvium overlying lacustrine sand and gravel.

Figure 5. a) Possible older landslide scarp northwest of 2005 landslide.
b) Side view of 2005 landslide showing down-dropped blocks of soil at head.

Utah Geological Survey

Project: May 2005 landslide in Springdale, Washington County, Utah			
By: William R. Lund, P.G. & Garrett Vice	Date: 07-14-05	County: Washington	
USGS Quadrangles: Springdale East (73)	Section/Township/Range: NW1/4SE1/4SW1/4 section 28, T. 42 S., R. 10 W., SLBL&M		
Requested by: Incident Investigation			Job number: 05-10 (GH-07)

INTRODUCTION

On June 3, 2005, we investigated a newly reported landslide within the city limits of Springdale, Utah (figure 1). Rick Wixom, Springdale City Manager, directed us to the landslide, and expressed his concern that the landslide or large rock-fall boulders derived from it might block the Virgin River and cause local flooding. According to Mike McMahan, a Springdale resident whose home on the west side of the Virgin River faces the landslide, he first noticed evidence of active slippage in early May and the landslide grew over a period of three to four weeks to its present size (figures 2 and 3). Mr. McMahan stated that a small crack was visible on the slope where the landslide initiated for several years prior to the onset of active slippage this spring. The purpose of our investigation was to determine whether the landslide could possibly affect the Virgin River and cause flooding, and to document the landslide's occurrence and geologic setting.

CONCLUSIONS AND RECOMMENDATIONS

The landslide's location away from development precludes damage to buildings and infrastructure. The large distance (197 feet) from the landslide terminus to the Virgin River should prevent the landslide from impinging on the Virgin River unless the landslide size and depth of rupture greatly increase. Several large boulders have dislodged from the landslide surface, but none have rolled more than a few feet beyond the landslide toe. None of the boulders remaining on the landslide are large enough to dam or significantly alter the flow in the Virgin River and are unlikely to reach the river channel. Examination of slopes formed on mapped landslide deposits north and south of the landslide showed no evidence of instability at this time. The fact that this landslide is present indicates that steep slopes in the preexisting colluvium/landslide complex are potentially unstable. The present landslide developed slowly and we expect that any increase in its size or the development of new landslides will likewise occur slowly, allowing time to implement emergency measures and take mitigation actions if necessary.

Because the landslide is well away from both the developed part of Springdale and from the Virgin River, it currently poses little risk. For that reason, we made a verbal recommendation to Rick Wixom, Springdale City Manager, that the landslide be monitored visually, and if evidence develops of significant new movement that he contact the Utah Geological Survey for further assistance. The two monitoring stations placed on the main scarp are temporary installations and are likely to be affected by scarp erosion over time. If it is deemed desirable that this landslide be monitored on a long-term basis, we recommend that more permanent and protected monitoring stations be installed. Also, any future development proposed at or near the base of this slope or any alteration to the slope should consider landslide and rock-fall hazards.

SETTING AND GEOLOGY

The landslide is on an undeveloped parcel of private property on the east side of the Virgin River in the NW1/4SE1/4SW1/4 section 28, T. 42 S., R. 10 W., SLBL&M (figures 1 and 2). Access to the site is on foot only; no roads exist on the east side of the Virgin River in this part of Springdale. The landslide formed in unconsolidated deposits that have accumulated at the base of the steep east wall of Zion Canyon. The pre-failure slope angle in these deposits was about 34^{o}. The landslide is roughly rectangular, and the slope-normal and slope-parallel dimensions are 290 and 400 feet, respectively. The estimated area of the landslide is approximately 2.6 acres. Thickness of the landslide is unknown, but is estimated at tens to a few hundred feet at most. The landslide toe abuts flat-lying alluvial terrace deposits along the Virgin River; the distance from the landslide terminus to the river is 197 feet (figure 4). The terrace deposits are not affected by the landslide.

Solomon (1996) maps the geologic unit on which the new landslide formed as colluvium, while Doelling and others (2002) (including Solomon) show it as a much larger, young (Holocene to upper Pleistocene) undifferentiated mass-movement slide and slump deposit (Qmsy) that originated in colluvium and steep talus deposits on the east side of Zion Canyon. The surface of the colluvium/landslide complex is characterized by cobble- to boulder-size sandstone clasts derived from rock formations exposed in the walls of Zion Canyon. Movement of the new landslide has destabilized several of these boulders, which have subsequently rolled from the landslide on to the adjacent alluvial terrace deposits along the Virgin River (figure 5).

The landslide is a rotational-slump-type slope failure with a pronounced main scarp up to 6 feet high (figure 6) and numerous internal transverse scarps (figure 7). The surface of rupture appears to be steep; a pioneer rock wall a few feet from the landslide toe remains undisturbed except where impacted by rock falls and talus shed from the landslide surface (figure 8).

Where exposed in scarps, the material comprising the landslide was dry and consisted chiefly of brownish-red fine sand derived from the sandstone formations exposed in the walls of Zion Canyon. Stratigraphically, the new landslide is in an interval of the Petrified Forest Member of the Chinle Formation, and exposures of this unit are mapped in the valley south of the landslide (Solomon, 1996; Doelling and others, 2002). The scarps did not expose bedrock, but the highly landslide-prone Petrified Forest Member likely underlies the older colluvium/landslide complex. Therefore, the Petrified Forest Member may be involved in the new slope failure, although Chinle bedrock is nowhere exposed in the vicinity of the new landslide.

No water was observed draining from or near the landslide. However, Zion National Park, less than a mile from the landslide, ended May 2005, at 26.59 inches of precipitation for the current water year, which is 14.7 inches ahead of this point in an average water year, so a much wetter than normal winter and spring likely contributed to development of the landslide.

MONITORING STATIONS

We established two stations on the landslide main scarp to monitor future landslide movement (figure 9). Both stations consist of two wooden stakes driven into the ground, one stake in the crown above the main scarp and the other stake on the landslide itself. We measured the distance between the stakes on June 3, 2005 (north station = 13.25 feet; south station = 12.14 feet [measurements were made from the west edge of both stakes]). Repeat measurements of the distance between the stakes will show if the landslide is moving (the distance between the stakes will increase). The coordinates for the two monitoring stations are:

Monitoring Station	Latitude	Longitude
North	37.189480 N.	112.991028 W.
South	37.189353 N.	112.991203 W.

LIMITATIONS

REFERENCES

Doelling, H.H., Willis, G.C., Solomon, B.J., Sable, E.G., Hamilton, W.L., and Naylor, L.P., II, 2002, Interim geologic map of the Springdale East quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 393, scale 1:24,000.

Solomon, B.J., 1996, Engineering geologic map folio, Springdale, Washington County, Utah: Utah Geological Survey Open-File Report 340, 5 plates, scale 1:14,400.

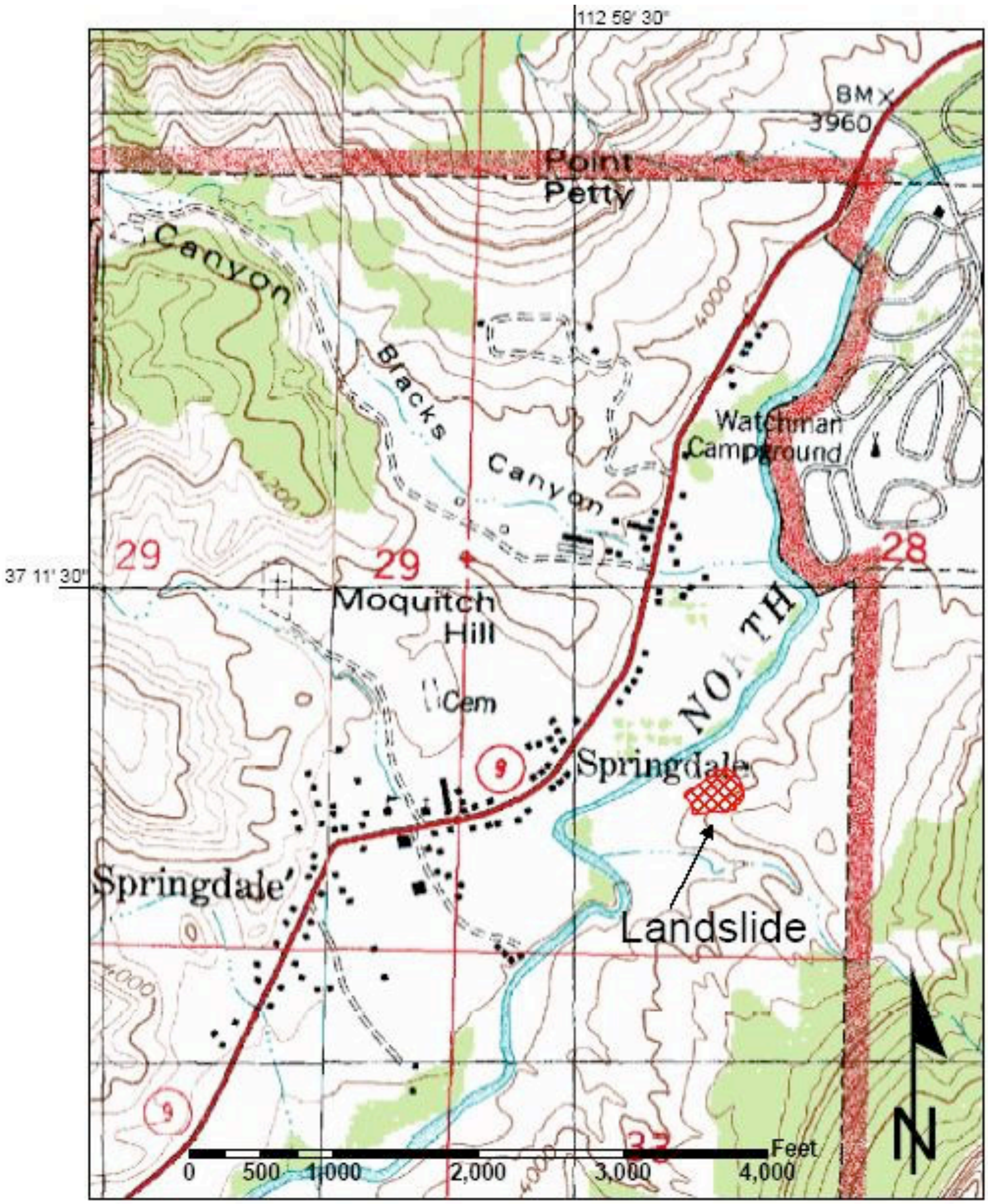


Figure 1. *Map showing the location of the landslide that developed on the east side of the Virgin River in the Town of Springdale during May 2005 (base map U.S. Geological Survey Springdale East 7.5' quadrangle).*

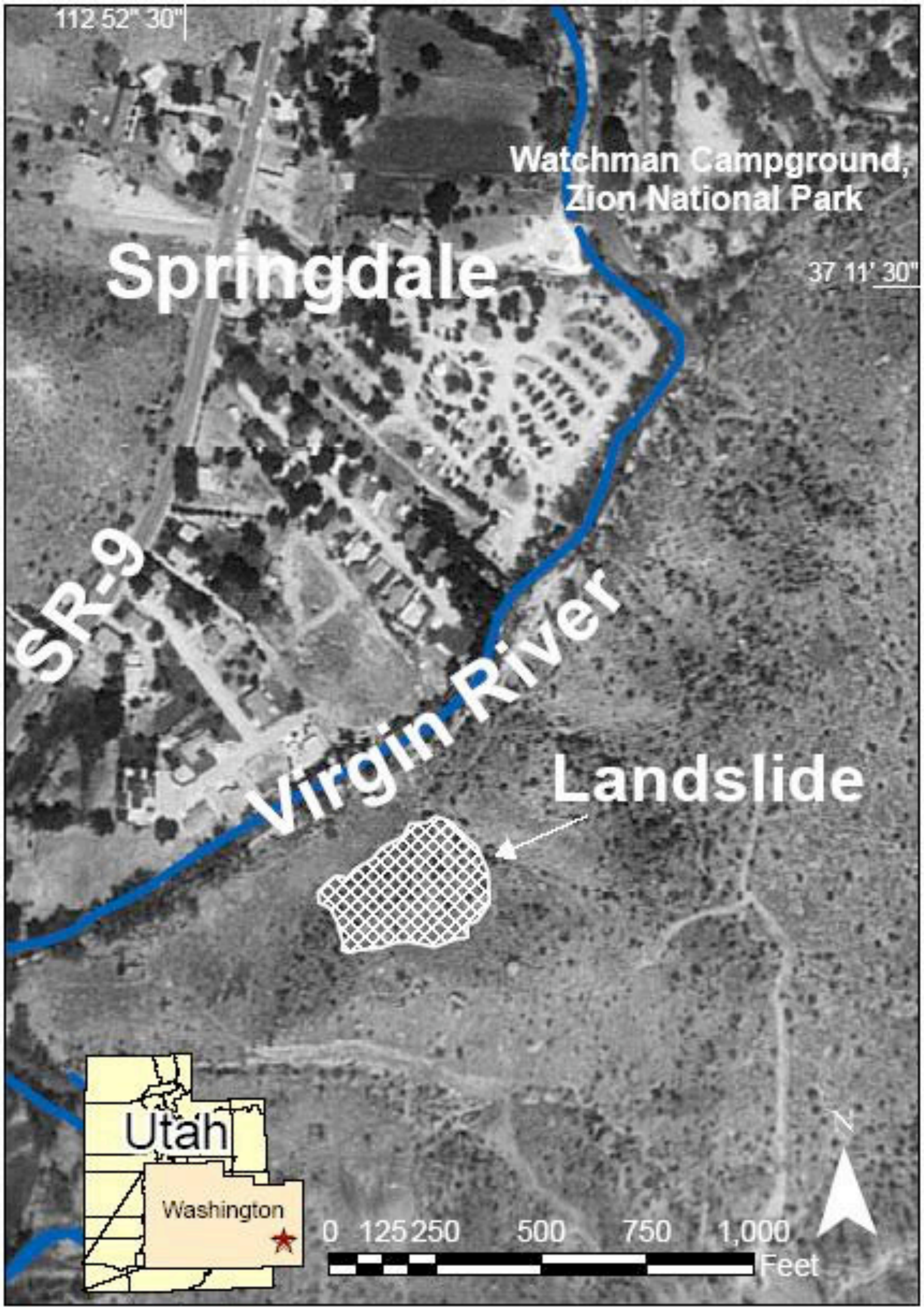


Figure 2. *Rotational slump landslide formed during May 2005 on the east side of the Virgin River in Springdale, Utah (base map U.S. Geological Survey Springdale East 7.5' orthophoto quadrangle).*

Figure 3. *View to the east of the landslide in Springdale on the east side of the Virgin River; landslide formed progressively during May 2005.*

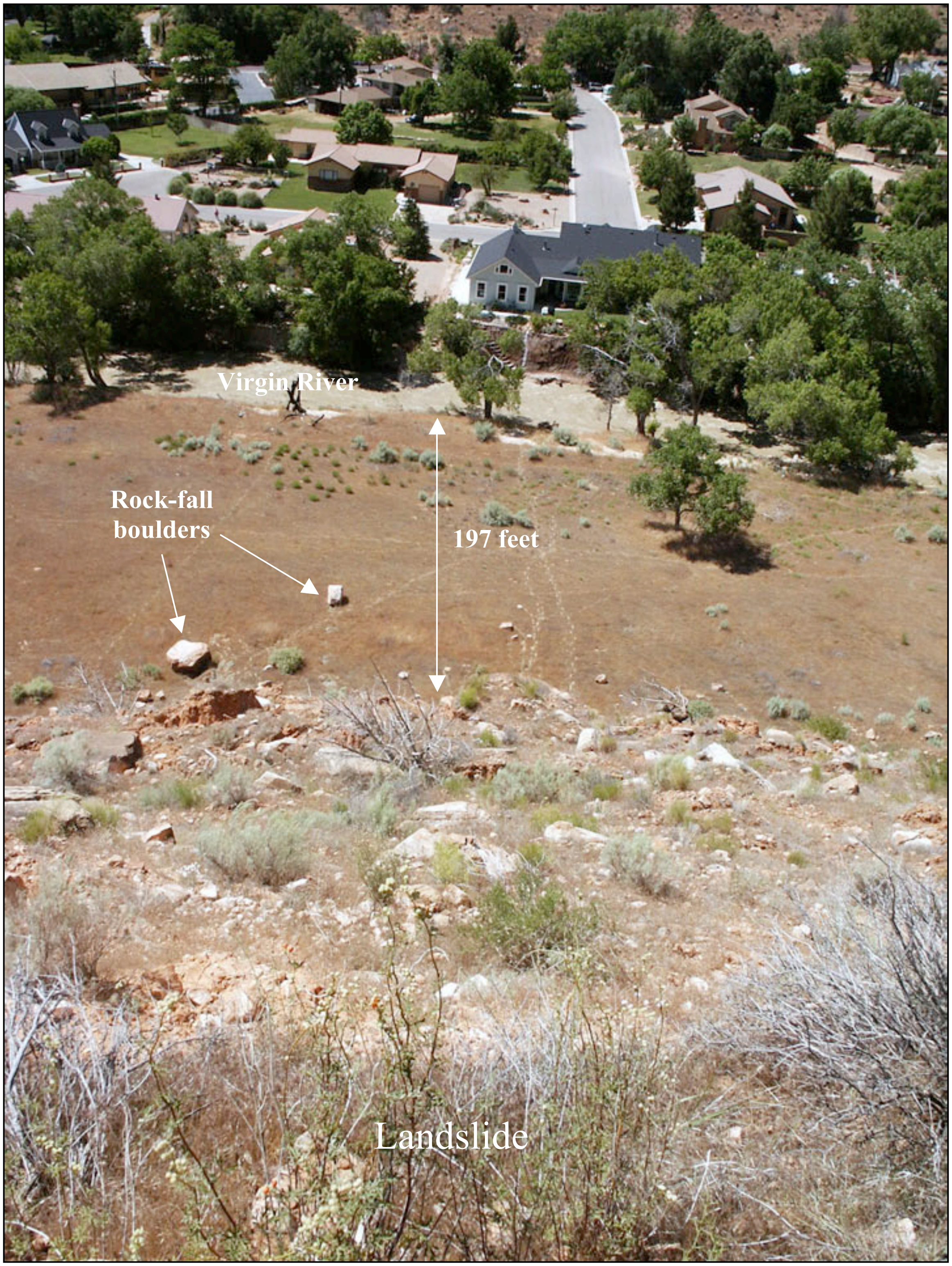


Figure 4. *View from the landslide toward the Virgin River, showing the 197 feet of separation between the landslide toe and the river; note the rock-fall boulders that have rolled from the landslide surface onto the alluvial terrace deposits along the river.*

Figure 5. *Rock-fall boulders at the base of the landslide; most have accumulated within a few feet of the landslide toe, but a few have rolled farther out on the alluvial terrace bordering the Virgin River.*

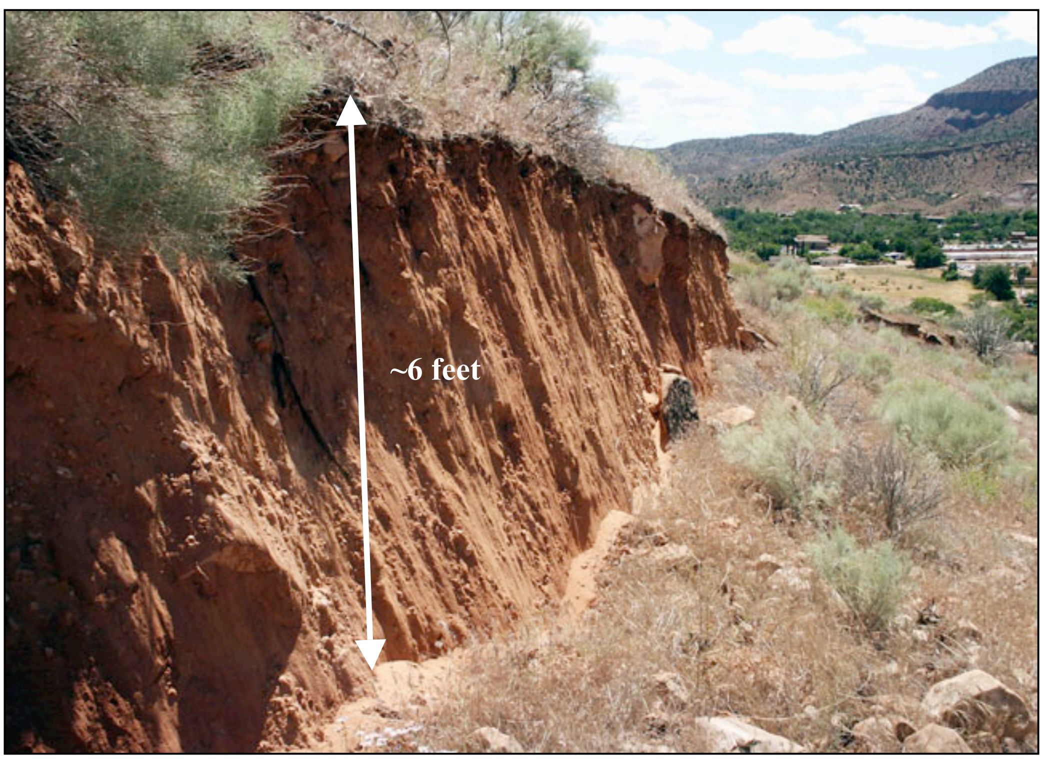


Figure 6. *Landslide main scarp.*

Figure 7. *Transverse scarps within the landslide mass.*

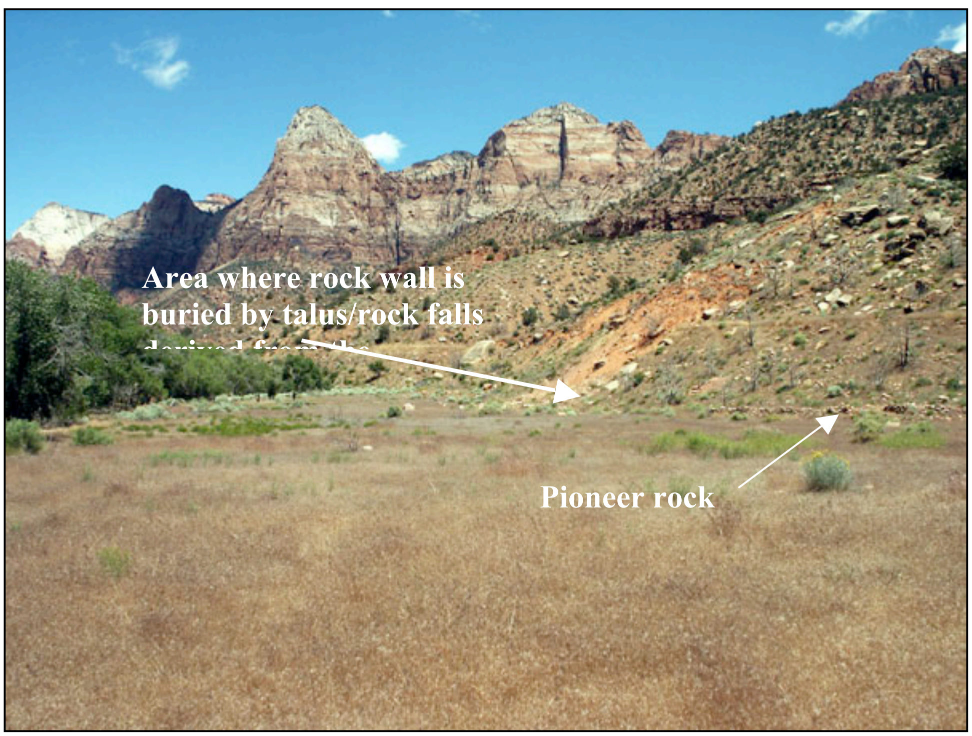


Figure 8. *Pioneer rock wall at the base of the slope is buried by talus/rock falls adjacent to the landslide, but has not been displaced by the landslide toe indicating the landslide rupture surface is shallow at the toe and does not extend beneath the wall.*

Figure 9. *North monitoring station; distance between wooden stakes is 13.25 feet.*

Utah Geological Survey

Project: June 3, 2005, rock fall in Parowan Canyon, Iron County, Utah			
By: William R. Lund, P.G.	Date: 07-29-05	County: Iron	
USGS Quadrangles: Parowan (277)	Section/Township/Range: NE1/4SW1/4NW1/4 section 31, T. 34 S., R. 8 W., SLBL&M		
Requested by: Incident Investigation			Job number: 05-12 (GH-08)

INTRODUCTION

On June 13, 2005, I investigated a rock fall in Parowan Canyon (figure 1), which crushed a 26-inch-diameter steel penstock pipe that conveys water to Parowan City's electrical power plant. The rock fall occurred on June 3, 2005, following 12 hours of steady rain that began about 7 p.m. on June 2 (Weaver, 2005). Precipitation recorded at Cedar City, approximately 22 miles south of Parowan, and the closest official weather recording station to the rock fall, showed a record rainfall of 0.62 inches between 12:04 a.m. and 6:53 a.m. on June 3. Average rainfall for June 3 is 0.02 inches, and the previous record was 0.51 inches established in 1952. Parowan City Manager Jared Black (verbal communication, June 13, 2005) stated that damage to the penstock is estimated at $120,000, and consists of a section of the penstock (about 80 feet [two lengths of pipe]) that was crushed by rock-fall boulders, and a much longer portion of the pipeline (about 1900 feet) that was deformed when water draining rapidly from the ruptured penstock created a strong vacuum inside the pipe. The purpose of my investigation was to document the rock fall's occurrence and geologic setting, and to determine if the penstock is at risk from future rock-fall damage.

CONCLUSIONS AND RECOMMENDATIONS

The rock fall that damaged the Parowan City penstock in the bottom of Parowan Canyon on June 3, 2005, likely resulted from a wetter than normal winter and spring combined with a 12-hour period of continuous moderate to heavy precipitation immediately preceding the rock-fall event. The source of the rock fall was an approximately 15-foot-high sandstone ledge of the Cretaceous Iron Springs Formation, which crops out on the steep east side of the canyon about 360 feet above the penstock. Two large boulders struck and ruptured the penstock; a third boulder came to rest within a few feet of the pipeline.

A reconnaissance along Parowan Canyon where the penstock is close to the base of the steep canyon walls (first approximately 1.5 miles along the pipeline down canyon from the penstock intake structure) showed numerous rock-fall boulders within the penstock right-of-way. Parowan City employees working to remove the current rock-fall boulders at the time of my field visit stated that in addition to the present occurrence, the penstock has been struck in the past by other rock falls. Based on these observations, the risk to the penstock from future rock falls is considered high, and will remain high without implementation of risk-reduction measures (for example, installation of rock-fall deflection structures or burying the penstock).

Although available space is limited, any future development in the bottom of Parowan Canyon should consider rock-fall and landslide hazards.

SETTING AND GEOLOGY

The rock fall occurred on the east side of Parowan Canyon in east-central Iron County. The canyon bottom is narrow at this location (approximately 500 feet) and contains Utah State Route 143 (SR-143) on the west side of Parowan Creek (a perennial stream) and the penstock and narrow dirt service road on the east side of the creek (figure 1). The canyon walls are steep and consist of nearly continuous exposures of the Cretaceous Iron Springs Formation (Maldonado and Moore, 1995) (figure 2). Maldonado and Moore (1995) describe the Iron Springs Formation as consisting chiefly of moderately resistant, fine- to medium-grained, thin-bedded to massive fluvial sandstone interbedded with siltstone, shale, and conglomerate. Vegetative cover on the canyon walls is sparse, consisting chiefly of pinyon pine and juniper (figure 2). Dense riparian vegetation along Parowan Creek in the canyon bottom includes oak, maple, willow, and other tree and brush species.

EVENT DESCRIPTION

The rock fall initiated as a rock topple (the canyon slope extended to the base of the rock ledge and there was no room for the rock to fall) involving the entire face of an approximately 15-foot-high, near-vertical sandstone ledge that is approximately 40 feet wide and 360 feet above the canyon bottom (figure 3). The numerous cobble- to large boulder-size clasts generated by the topple then rolled and bounced down the steep (average slope ~ 31°) bedrock slope below the ledge, clearing vegetation from a path about 50 feet wide (figure 4) until reaching a second prominent bedrock ledge, also about 15 feet high. The rock-fall debris cascaded over the second ledge and continued down slope until encountering the dense riparian vegetation in the canyon bottom. Most of the rock-fall debris either came to rest on the slope of the canyon wall or was stopped by the riparian vegetation before reaching the penstock. However, two large boulders continued through the vegetation and struck the penstock; a third large boulder stopped just before striking the penstock.

The largest boulder, measuring 14x9x8.5 feet and weighing an estimated 80 tons, came to rest directly on top of the penstock (figures 5 and 6). The second boulder that struck the penstock measured 8.5x4x4 feet and weighed an estimated 10 tons. After hitting the penstock (figure 7), that boulder rolled an additional approximately 50 feet before coming to rest in dense vegetation adjacent to Parowan Creek (figure 8). The third boulder, measuring 8x5.5x4 feet and weighing an estimated 13 tons, narrowly missed the penstock and caused no damage (figure 9).

At the time of my field visit, workers were using a large trackhoe to remove the boulder from on top of the penstock (figure 10). The workers estimated that two to three 40-foot sections of pipe would be required to repair the ruptured portions of the penstock, but were unsure how much of the vacuum-deformed pipe would require replacement.

HAZARD ASSESSMENT

The intake structure for the Parowan City penstock is on Parowan Creek at the intersection of Parowan Canyon and First Left Hand Canyon (Bowery Creek, a major west-flowing tributary to Parowan Creek [figure 1]) about a mile upstream from the site of the June 3 rock fall. From the intake structure, the penstock extends approximately 2.5 miles down Parowan Canyon to the Parowan City electrical power plant near the canyon mouth. For the first 1.5 miles of the penstock's length, Parowan Canyon is narrow, and the steep canyon walls consist chiefly of nearly continuous exposures of the Iron Springs Formation (Maldonado and Moore, 1995).

During a reconnaissance along the penstock, I observed numerous rock-fall boulders that had dislodged from the canyon walls, rolled into the canyon bottom, and come to rest within the penstock right-of-way. Additionally, workers repairing the damaged pipeline on the day of my field visit stated that the penstock has been struck by other rock falls in the past, although the present occurrence was the largest and most damaging that they could recall during the past several years.

Based on: (1) the penstock's location for much of its length at the base of steep, bedrock slopes, (2) the presence of rock-fall boulders along the penstock right-of-way in the narrow part of Parowan Canyon, and (3) a history of previous rock-fall damage to the penstock, I believe the penstock within the narrow part of Parowan Canyon, except for a short section buried beneath SR-143, is at risk from future rock falls. Possible risk-reduction measures include installing rock-fall deflection structures (berms, walls, or other devices) at high-hazard locations along the penstock, or burying all or part of the penstock through the narrow part of Parowan Canyon. A third option is to continue the current policy of making repairs as necessary when the penstock is damaged by rock falls. Such repairs will likely be required in the future if the penstock remains unprotected.

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCES

Maldonado, Florian, and Moore, R.C., 1995, Geology of the Parowan quadrangle, Iron County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1762, scale 1:24,000.

Weaver, Jennifer, 2005, Boulder crushes pipe: Cedar City Daily News, Friday, June 10, 2005.

Weatherunderground, 2005, Cedar City, Utah for June 3, 2005: Online, http://www.wunderground.com/US/UT/Cedar_City.html, accessed July 22, 2005.

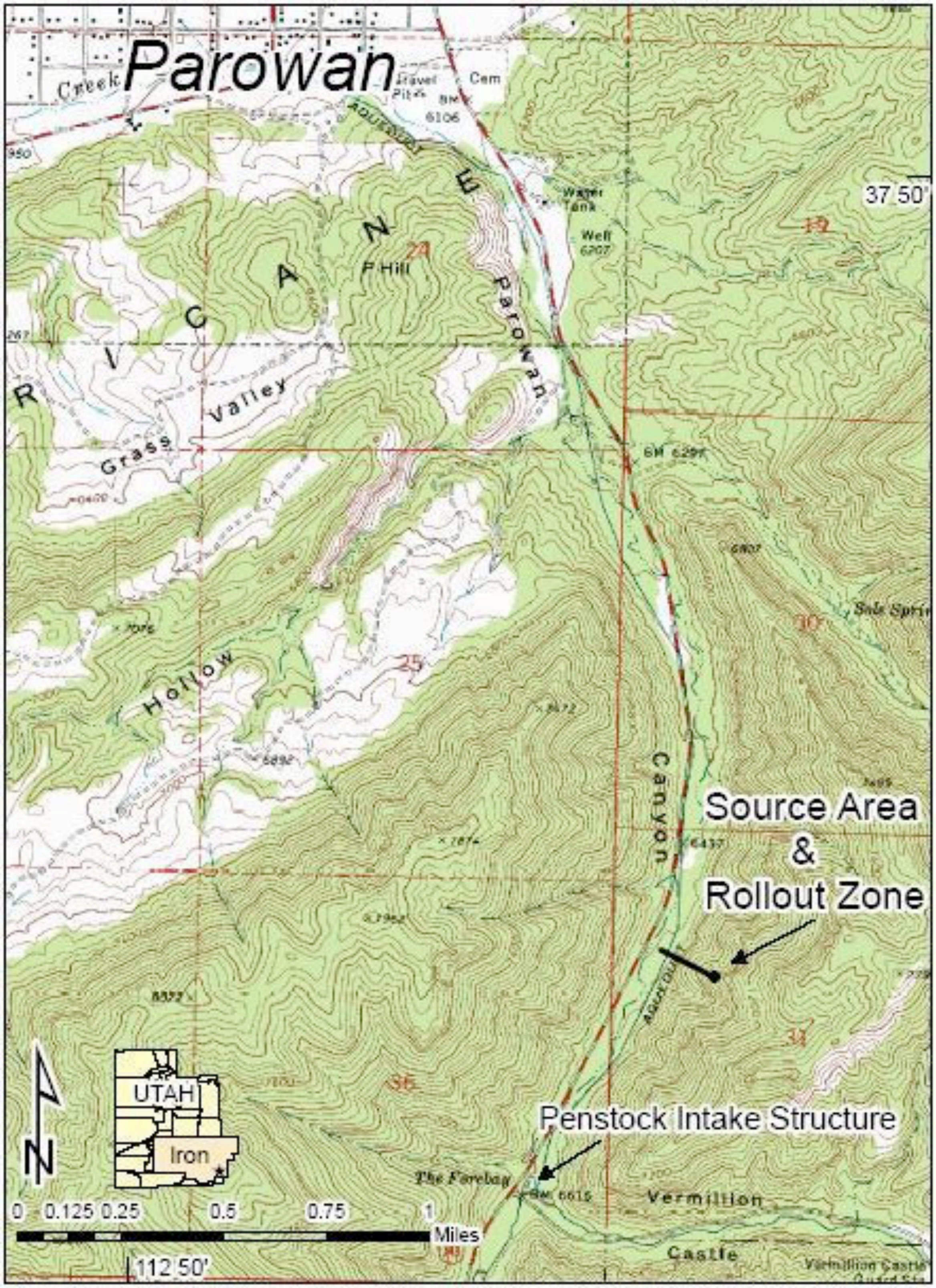


__Figure 1.__ Location of the June 3, 2005, rock fall in Parowan Canyon (base map from U.S. Geological Survey Parowan 7.5' quadrangle.)

Figure 2. *West wall of Parowan Canyon as it appears directly across from the June 3, 2005, rock fall that damaged the Parowan City penstock. The nearly continuous exposures of the Cretaceous Iron Springs Formation with sparse vegetative cover of pinyon pine and juniper shown here are similar to the conditions on the east canyon wall where the rock fall occurred. SR-143 and the dense riparian vegetation along Parowan Creek are visible at the bottom of the photo.*

Figure 3. *Approximately 15-foot-high sandstone ledge with thin interbedded shale lenses on the east side of Parowan Canyon where a rock topple initiated the rock fall that damaged the Parowan City penstock. The ledge is approximately 360 feet above the canyon bottom.*

Figure 4. *Rock-fall path stripped of vegetation down the east side of Parowan Canyon. Note the narrow canyon bottom, which accommodates SR-143, Parowan Creek, and the penstock and service road.*

Figure 5. *Sandstone boulder weighing an estimated 80 tons resting directly on top of a section of the Parowan City penstock. The rock-fall path down the east wall of Parowan Canyon is visible through the trees below the skyline.*

Figure 6. *Approximately 80-ton boulder resting on top of the 26-inch diameter Parowan City penstock pipe.*

Figure 7. *Ruptured Parowan City penstock where it was struck by a second rock-fall boulder weighing approximately 10 tons. After striking the penstock, the boulder continued toward Parowan Creek for an additional approximately 50 feet.*

Figure 8. *After striking the Parowan City penstock, this approximately 10-ton rock-fall boulder came to rest in dense riparian vegetation along Parowan Creek.*

Figure 9. *Approximately 13-ton rock-fall boulder, which stopped just before striking the Parowan City penstock.*

***Figure 10.** Trackhoe removing the 80-ton boulder from on top of the Parowan City penstock.*

Utah Geological Survey

<table>
<tr><td colspan="3">Project:
The Sage Vista Lane landslide, Cedar Hills, Utah</td><td rowspan="3"></td></tr>
<tr><td>By:
Francis X. Ashland, P.G., and Greg N. McDonald, P.G.</td><td>Date:
09-16-05</td><td>County:
Utah</td></tr>
<tr><td>USGS Quadrangles:
Timpanogas Cave (1129)</td><td colspan="2">Section/Township/Range:
Section 32, T. 4 S., R. 2 E., Salt Lake Base Line and Meridian</td></tr>
<tr><td>Requested by:
David Bunker, Cedar Hills Engineer</td><td colspan="2"></td><td>Job number:
05-14 (GH-09)</td></tr>
</table>

INTRODUCTION

On the afternoon of April 28, 2005, a landslide that had moved previously in 1983 (Machette, 1992) reactivated above Sage Vista Lane in a Cedar Hills subdivision (figure 1) and moved against the lower portion of the back wall of a four-unit townhouse (figure 2). Residents of the affected townhouse evacuated and the belongings of a neighboring family in a separate duplex across the street were moved out of their home temporarily. By April 29, the landslide toe had crushed vinyl fencing, air conditioners, and deck supports at the back of three of the units in the townhouse. After the damaging movement on April 29, the rate of landslide movement rapidly decreased to a very slow rate. Following a multiday storm event, during which about 3 inches of precipitation fell, the rate of landslide movement increased again, and by May 13 structural damage to the upslope foundation walls of two units in the four-unit townhouse had occurred. Landslide debris subsequently entered the lower parts of the two units as landslide movement again slowed to a very slow rate as defined by Cruden and Varnes (1996).

As part of the emergency response effort by multiple state, county, and city agencies, the Utah Geological Survey (UGS) performed a reconnaissance of the landslide on the morning of April 29, 2005, and deployed survey stakes to monitor movement of the landslide. We repeated measurements later in the day on April 29 to determine the rate of movement of the slide. We also deployed stakes for high-resolution Global Positioning System (GPS) surveying by the Utah County Public Works Department. UGS geologists visited the site on numerous occasions in May and June to monitor landslide movement, and document ground deformation and changes in the size of the area of landsliding.

The purposes of our investigations were to determine the geologic characteristics of the landslide and evaluate its hazard potential to aid Cedar Hills in assessing the risk to townhouses and city infrastructure. During our field investigations we met on-site with Cedar Hills Mayor Michael McGee, City Councilman Jim Perry, City Manager Konrad Hildebrandt, City Engineer

David Bunker, Utah Governor Jon Huntsman Jr., Chief of Staff Jason Chaffetz, Utah County Emergency Manager Dave Bennett, Bill Gordon (AMEC Earth & Environmental), Utah County Public Works Department surveyors, and numerous residents.

CONCLUSIONS AND RECOMMENDATIONS

The landslide will remain a threat to the area west and downslope across the street until engineering measures are taken to stabilize it. Downslope-directed loading of soils below the toe of the landslide may be occurring. Reactivation or an increase in the rate of movement is possible if significant precipitation falls on the slide and surrounding area or during subsequent snowmelt periods in the future. Downslope enlargement of the landslide may accompany future movement. To date, the landslide has moved relatively slowly and has not posed a life-safety threat, and likely will continue to behave in this way. However, should a rapid loading occur at the head due to collapse of the high, nearly vertical south-facing scarp, particularly during an intense rainfall event, the potential for rapid failure cannot be precluded. Future enlargement of the landslide in an upslope direction that causes the shallow, upper landslide area to merge with the main slide will also increase the overall hazard and potential for renewed movement.

The foundation of the damaged townhouse may be acting as a temporary buttress, possibly protecting against further downslope movement of the slide. We do not recommend removing any of the landslide debris abutting the upslope side of the townhouse while the slide is active and relatively moist. This could increase the movement rate and/or enlarge the landslide.

We recommend the following:

- The developer’s geotechnical consultants should assess stabilization options, recommend appropriate pre-design subsurface investigations, and provide final stabilization designs.

- Periodic monitoring of the landslide should be resumed if renewed movement is suspected and/or onset of movement upslope or downslope of the slide occurs.

- The appropriate officials should be perform periodic inspections of buildings, roads, paved areas, and buried utilities for signs of distress or damage. We are particularly concerned that downslope-directed loads from the landslide could affect the city’s buried water line near Sage Vista Lane.

Based on our inferred site conditions, we recommend that future studies and stabilization design consider (1) the potential expansion of the landslide upslope with addition of more material from the high, south-facing scarp and upslope areas, and (2) the potential for enlargement of the landslide downslope of the present toe into the area of the duplex and fill slope across Sage Vista Lane. We also recommend reassessment of the slope-stability and landslide-stability conclusions and recommendations in the original subdivision geotechnical report prior to any new development, particularly on lots east of Sage Vista Lane.

GEOLOGIC SETTING AND LANDSLIDE DESCRIPTION

The Sage Vista Lane landslide is a nearly complete reactivation of a southwest-facing historical (1983) slide in the southwestern part of a large prehistoric landslide complex (figure 3; Machette, 1992). The prehistoric landslide complex likely consists of debris derived from the Mississippian-age Manning Canyon Shale, a highly landslide-prone geologic unit found along the mountain front in much of northeastern Utah Valley. These older landslides are prone to reactivation, as indicated by younger active landslides mapped within the older complexes elsewhere in the area (Machette, 1992). The Sage Vista Lane landslide is along the Provo segment of the Wasatch fault, which crosses the slide, and may direct or concentrate ground water in the slide.

The landslide consists of two lobate foot sections and an arcuate head that narrows upslope (figure 4). The main foot of the landslide abuts the townhouse and consists of mostly disrupted debris. A second, smaller foot on the south side of the slide resulted from local southward movement below a pressure ridge or fold that formed near the crest of a cut slope. On April 29, the active landslide was approximately 350 feet (110 m) long and 110 feet (35 m) wide at its toe. The narrower upper part of the landslide was about 70 feet (21 m) wide. The average slope of the landslide was about 37 percent.

Landslide debris consists of cobbles and boulders in an olive-green to brownish clay matrix likely derived from the Manning Canyon Shale. Locally, decomposed black fragments of Manning Canyon Shale were observed in the debris. The lower part of the landslide was disrupted and appeared to be moving as a slow, moist debris flow (figure 5). Test pits excavated by AMEC Earth & Environmental on August 18, 2005, revealed shallow slickensided clay in the upper part of the landslide that varied in color from maroon to black. The clay may be weathered Manning Canyon Shale or clay smears derived from the shale within landslide debris.

The middle part of the landslide was relatively intact and consisted of fractured soil, whereas the upper part of the landslide was somewhat more deformed and disrupted. A cobble-lined drainage ditch in this area remained mostly linear suggesting that it was mostly translated in intact and undeformed blocks (figure 6). Dark gray, highly polished slickensides were locally exposed on top of exposed black clay in the upper part of the landslide, suggesting the upper part of the slide is locally shallow (possibly less than 10 feet deep; figure 7).

The main scarp zone is in the upper narrowest part of the landslide, and on April 29 consisted of several scarps less than 2 feet high in an area of relatively shallow translational landsliding. The main scarp zone joins with the nearly vertical south-facing scarp that bounds the north flank of the 2005 landslide, and that may have been the main scarp of the 1983 slide. On April 29, the combined height of the 2005 and 1983 scarps along the north flank of the landslide was about 40 to 50 feet; the upper 30 to 35 feet representing the scarp of the 1983 event (figure 8). Movement of the landslide caused scarps to form in a colluvial wedge at the base of the 1983 scarp as the colluvium moved downslope on the active part of the slide. The near-vertical scarp suggests that the subsurface geometry of the head of the landslide in a northwest-southeast direction may be asymmetrical with the deepest part being in the northwest part of the head nearest the south-facing scarp.

On April 29, no seepage was observed at the toe of the landslide. Seepage was observed in the upper part of the landslide, particularly near the easternmost part of the main scarp zone. By May 7, the shallow soils in the uppermost head of the landslide were saturated and extremely soft. Ground-water depth in a test pit excavated by AMEC Earth & Environmental on August 18, 2005, was about 8 feet.

Hillslope modifications to the 1983 landslide included excavation of the building pad for the four-unit townhouse across or near the toe of the slide and a cut slope in the lower part of the slide, and construction of a cobble-lined drainage ditch at the crest of the cut slope and a temporary irrigation system on the cut slope. Residents indicated that the toe initially emerged partway up the cut slope behind the townhouse and landslide debris subsequently flowed down against the back wall of the building. Landslide movement destroyed most of the cut slope, damaged the irrigation system, and displaced the drainage ditch relatively intact.

On May 5 we observed cracks in the crest of the south-facing scarp that extended several feet back from the top of the scarp. These cracks intersected the scarp at an acute angle. Significant raveling of the south-facing scarp occurred during the extended period of rain that ended on May 13. A triangular-shaped colluvial wedge of the eroded debris from the scarp formed near its center, and was approximately two-thirds the height of the scarp by May 31. The additional weight from this colluvium likely further destabilized the slide. On May 31, additional fresh cracks were superimposed atop a healed crown crack likely associated with movement of the slide in 1983, about 10 feet upslope of the top of the scarp.

MOVEMENT HISTORY

Between April 28 and June 30, 2005, the landslide experienced two episodes of rapidly accelerating movement followed by a similarly rapid decrease in the rate of movement and either intermittent or continued movement at a slow rate. Only anecdotal accounts exist of the initial landslide movement that began on April 28, but a rapid acceleration in the rate of movement likely occurred during and immediately after a rainstorm on that date. By noon on April 29, however, the rate of movement had already begun to decline. Slow movement of the landslide continued until May 10, when the rate began to accelerate during a multiday storm, during which about 3 inches of precipitation fell, until reaching a maximum measured rate of movement on May 12 of about 13.5 feet per day (4 m/day). After May 13, movement continued, locally intermittently, at a slow rate. By June 30, movement had slowed and GPS monitoring was ended because of the reduced risk.

Between April 29 and May 10, the most movement occurred in the uppermost head of the landslide (UGS stake SV5; figure 9), but minor movement was detected in the lower and upper parts of the slide. During the dry days following the initial movement episode (April 29-May 1), the head of the landslide moved an additional 20 inches (51 cm), and the rate of movement slowed. However, following a period of heavy rainfall beginning on May 5, the rate of movement increased. By May 10, about 10.4 feet (3 m) of movement had occurred in the head of the slide. The remainder of the landslide (figures 10 and 11) also continued to move slowly between April 29 and May 1, but by May 1, movement of the slide either suspended or occurred at a rate too slow to detect. During the extended period of rainfall that began on May 5, movement of the entire landslide resumed or increased in rate (see lower inset on figure 10). Between May 6 and 9 about 2 inches (5 cm) and 4 inches (10 cm) of movement was measured in the lower and upper parts of the landslide, respectively. Continued rainfall through May 13 resulted in a rapid increase in the rate of movement (figure 12). By May 13, the landslide had moved between 7 and 22 feet (2.2-6.7 m) since April 29, causing significant damage to the upslope side of the townhouse building. The return of dry weather was accompanied by a rapid reduction in the rate of movement. Between May 13 and May 31 the landslide moved less than 7 inches (18 cm) (see upper inset in figure 10). Only nominal movement of the landslide occurred in June during which less than 3 inches (7 cm) of movement of the upper part of the slide was measured. GPS survey measurements of stakes above the high, south-facing scarp showed no evidence of movement during the entire measurement period.

PROBABLE CAUSES OF MOVEMENT

The landslide is an almost complete reactivation of a 1983 landslide within a mapped prehistoric landslide complex. The movement in 1983 indicated that this part of the natural hillslope in the prehistoric landslide complex was unstable, and has likely remained marginally stable since it last moved. The 2005 movement indicates that the 1983 landslide was relatively sensitive to changes in soil moisture, ground-water levels, and slope modifications.

One likely cause of reactivation of the landslide was above-normal precipitation over an extended period prior to the landslide. Precipitation for the 2004 calendar year at the National Weather Service Pleasant Grove station was only slightly above normal (102 percent), but was exceptionally wetter than normal for the period between September 2004 and April 27, 2005 (162 percent). Landslide activation occurred during a 24-hour period during which 0.64 inch of rain fell between the mornings of April 28 and 29 at the nearby Pleasant Grove station (National Weather Service, 2005). Seepage was observed in the main scarp where it crosses a drainage, indicating that ground-water flow into the slide mass was occurring prior to movement. Soil moisture and ground-water levels have likely increased greatly as a result of infiltration of excess precipitation (approximately 7.9 inches above normal between September 1, 2004 and April 28, 2005) in the eight months prior to the slide.

We found no evidence for significant failure of the 1983 main scarp prior to the 2005 movement, although a wedge of colluvium at the base of the scarp may have contributed to loading of the head of the historical landslide.

Hillside modifications related to residential development of the area may also have contributed to destabilizing the historical landslide. Removal of part of the toe of the landslide accompanied placement of the townhouse. In addition, a cut slope existed in the slide east of the townhouse. Both of these modifications may have reduced resisting forces in the lowermost part of the slide. Two other hillslope modifications may have contributed to increased soil moisture or ground-water levels in the lower part of the landslide. A cobble-lined, but permeable, drainage ditch at the crest of the cut slope may have promoted infiltration of snowmelt and runoff. Excess irrigation water may also have infiltrated into the lower part of the landslide from a temporary above-ground irrigation system used to water grass seed in the cut slope. A resident reported that the irrigation system was left running prior to movement of the landslide. However, no corroborating evidence in the form of saturated soil or surface water in the area on April 29, or runoff rills or channels that should accompany excess irrigation was found.

ADDITIONAL LANDSLIDES UPSLOPE

On April 29, two additional, small, fresh scarps existed upslope of the main landslide in the prehistoric landslide complex that defined the upslope extent of two separate active shallow slides (figure 3). The scarps occurred within or near areas that had been disturbed by exploratory excavations (test pits or trenches) and subsequently backfilled several years prior to the 2005 landslide. The scarps were several inches high and connected to flanking structures such as ground cracks. The lower of the two slides had an internal longitudinal crack in its upper part and a main scarp that was several inches high with a fissure at least 2.5 feet deep (figure 13). The lower extent of the two upper landslides was unclear due to the absence of well-defined toe or flanking structures. By May 5, the two scarps had joined together to form a continuous scarp zone, suggesting the two small landslides had joined into a single slide (figure 3).

UGS measurements detected no movement during the afternoon of April 29, but the time interval between measurements may have been insufficient to detect very slow movement. However, measurements on May 5 and 7 indicated continued movement of the western part of the upper landslide area at a relatively steady, but very slow rate (figure 14). Subsequent measurements detected movement of the entire upper landslide area by May 12. The rate of movement accelerated between May 9 and 13 (figures 14 and 15), coincident with the increase in the rate of movement of the Sage Vista Lane landslide downslope. During this period, the maximum rate of movement of the upper shallow landslide reached about 2.8 inches per day (7 cm/day).

A reconnaissance of the remainder of the prehistoric landslide complex on April 29 indicated no other areas of active landsliding, but revealed a small historical slide in the complex (figure 3). By May 18, the small historical landslide had reactivated, most likely sometime around May 12. We also inferred, based on field observations and review of aerial photographs, that the prehistoric landslide complex may extend farther upslope than mapped by Machette (1992), likely to the base of the moderately steep, west-facing mountain slope at about elevation 5,780 feet (figure 3).

The upper shallow landslide area's presence indicates the marginal stability of material in the prehistoric landslide complex, particularly where soils are disturbed. Landsliding may have been triggered in the upper slide area due to a local rise in ground-water levels resulting from increased infiltration capacity of the test-pit backfill. In addition, disturbance of the native materials during excavation and backfilling likely resulted in the fill having lower strength than the surrounding landslide debris. The discontinuity between the base of the fill and the underlying debris may have also acted as a slide surface. Landsliding in the upper slide area clearly extended beyond the boundaries of disturbed ground, however, suggesting the marginal stability of shallow soils in the prehistoric landslide complex.

Continued movement and downslope enlargement of the upper landslide may eventually result in the joining of the main and upper landslides into a single slide. A joining of the two slides increases the likelihood of renewed movement of the main slide (in combination with the upper slide area) and enlargement of the slide area downslope of the toe of the original main slide.

POSSIBLE IMPACTS DOWNSLOPE

Horizontal loading caused by movement of the Sage Vista Lane landslide may reduce the stability of the slopes to the southwest of Sage Vista Lane, particularly if landslide deposits underlie surficial alluvial-fan deposits in this area. A steep and relatively high fill slope is directly downslope of the duplex unit across Sage Vista Lane (on the southwest side of the street) from the landslide. We conducted a reconnaissance on April 29 and on subsequent visits of the duplex and noted no obvious distress to the building or grounds. The steep fill slope downslope of the duplex is a concern; the bottom of the fill slope appeared oversteepened, but the cause of this condition was uncertain. A survey point and stake was placed at the base of the fill for movement monitoring, but measurements detected no movement through May 31.

SUMMARY AND FUTURE HAZARD POTENTIAL

On April 28, 2005, a 1983 landslide reactivated above a subdivision along Sage Vista Lane in Cedar Hills and moved against the back of a four-unit townhouse. Although the landslide slowed temporarily during a dry period following initial movement, it accelerated during an extended period of rainfall beginning on May 5 causing structural damage to the townhouse by May 13. The landslide will pose a continuing threat to the immediate area until engineering measures are taken to stabilize it. A threat of expansion of the landslide exists from failure of the main scarp and/or connection with a separate shallow landslide upslope, which may cause renewed (or an increased rate of) movement at the toe. Similarly, the possibility exists that movement of the landslide has reduced the stability of slopes below the landslide. These possibilities should be considered in the design of slope stabilization measures.

FIELD METHODS

The perimeter of the landslide, and estimated slide dimensions and average slope are based on field mapping using a hand-held GPS device. The accuracy of this method varies considerably depending on site conditions and satellite positions. Error typically increases next to high, vertical or near-vertical features such as the walls of the townhouse or south-facing scarp. The accuracy of elevation measurements is also highly variable.

We deployed pairs of wooden survey stakes on April 29, 2005 and on later dates to monitor landslide movement and ground deformation. Typically one stake was placed on the landslide and the other off the slide. For example, stakes SV3-4 consist of stake SV3 below the toe of the landslide, and stake SV4 on the toe (figure 4). Measurements of shortening or stretching between stakes were made using a fiberglass tape and used to estimate landslide movement. Our inferred accuracy is about 0.12 inch (0.3 cm). We also deployed other stakes (labeled 1, 2, etc., on figure 4) that were surveyed by Utah County Department of Public Works surveyors using accurate GPS equipment under the supervision of Assistant County Surveyor Gary Ratcliffe. Duplicate measurements were taking for each survey point and mean positions calculated reducing measurement error.

ACKNOWLEDGMENTS

Utah County Department of Public Works surveyors monitored landslide movement between April 29 and June 30, 2005, sometimes under extremely difficult conditions. Michael Kirschbaum and Richard Giraud, Utah Geological Survey, assisted with some of the field work. Lucas Shaw, Utah Geological Survey, helped prepare some of the figures in this report.

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, UGS, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, UGS, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCES

Cruden, D.M., and Varnes, D.J., 1996, Landslide types and processes, *in* Turner, A.K. and Schuster, R.L., editors, Landslides - investigation and mitigation: Washington, D.C., National Research Council, Transportation Research Board Special Report 247, p. 36-75.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, scale 1:50,000.

National Weather Service, 2005, State max/min temperature and precipitation table: Online, http://www.wrh.noaa.gov/climate/index.php?wfo=slc, accessed Apr. 29, 2005.

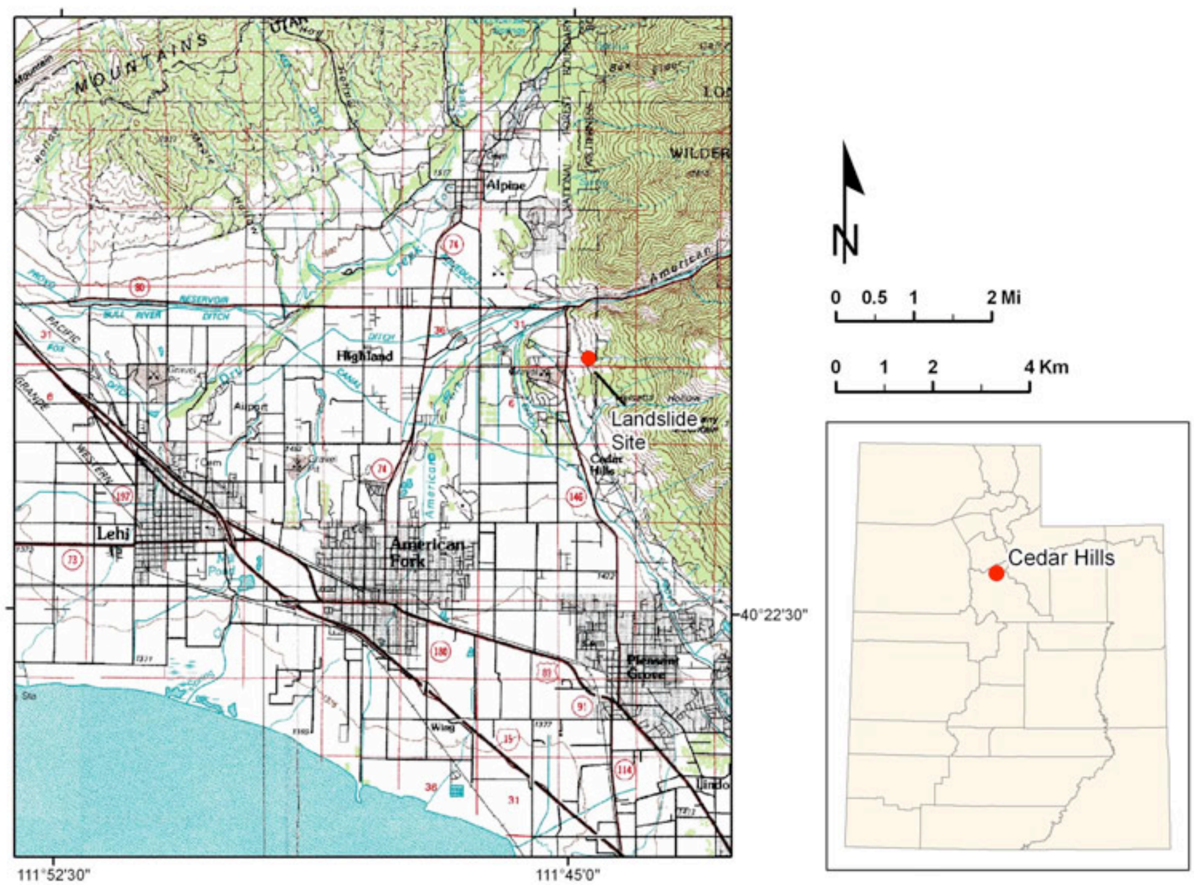


Figure 1. *Location map of Sage Vista Lane landslide in Cedar Hills, Utah. Base from U.S. Geological Survey 1:100,000-scale topographic map for the Provo 30'x 60' quadrangle.*

Figure 2. *View to the northeast of the landslide on April 29, 2005, from Sage Vista Lane.*

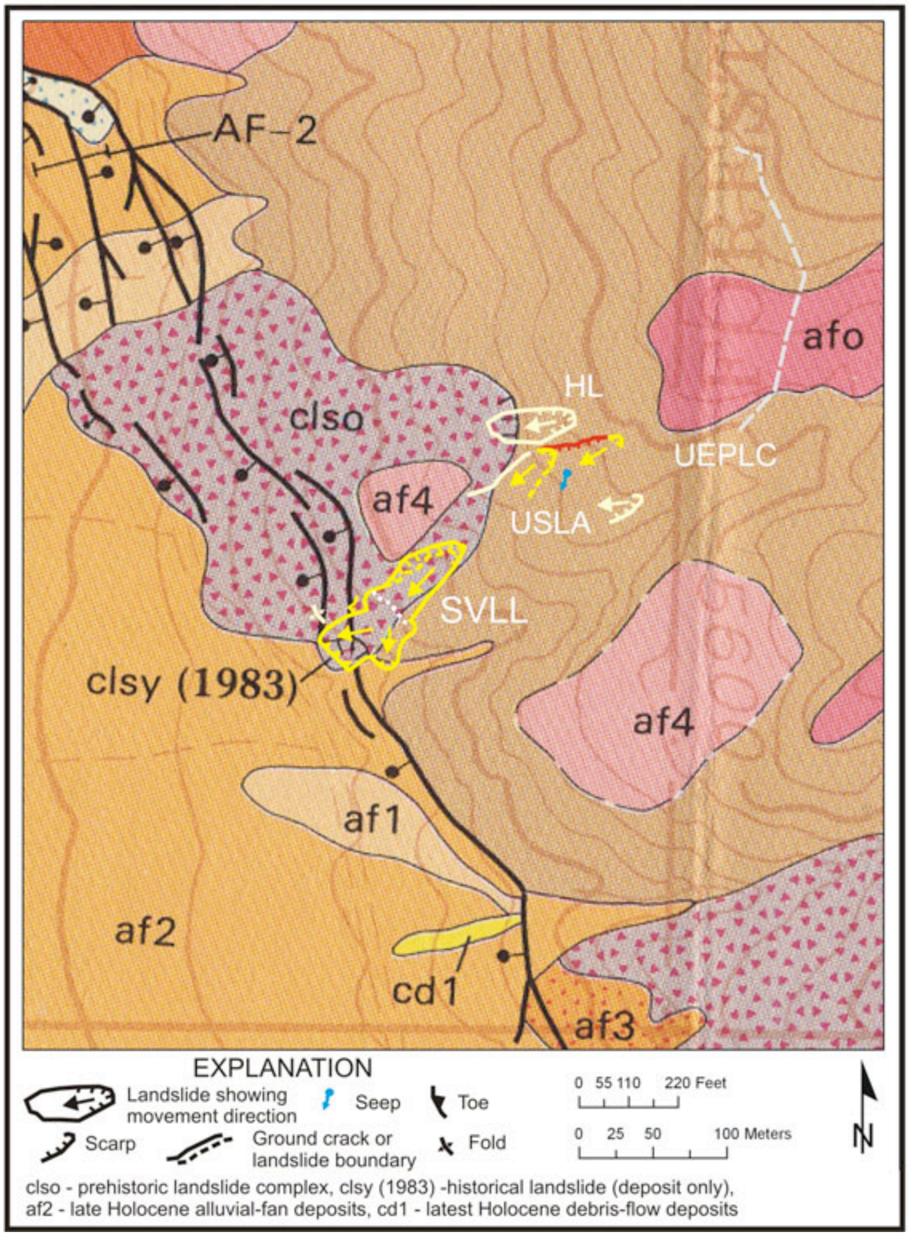


Figure 3. *Surficial geologic map of the site vicinity (after Machette, 1992). Approximate perimeters of Sage Vista Lane landslide (SVLL) and other reactivated historical landslide (HL), and active deformation features associated with upper shallow landslide area (USLA) also shown. UEPLC (light gray dashed line) indicates our estimate of upslope extent of prehistoric landslide complex. Yellow, red, and light yellow colors indicate features present on April 29, May 5, and May 13, respectively. Yellow dashed line in SVLL indicates active scarp position on April 29. By May 13 active scarp extended to or upslope of 1983 scarp. White dotted line in SVLL shows position of cobble lined ditch on May 5. Main geologic unit descriptions shown. Machette (1992) mapped unlabeled brown unit as Paleozoic rock, but lower part likely consists of landslide deposits and colluvium. Solid, thick black lines are traces of Wasatch fault zone. Bar and ball on downthrown side of fault. See Machette (1992) for other unit descriptions.*

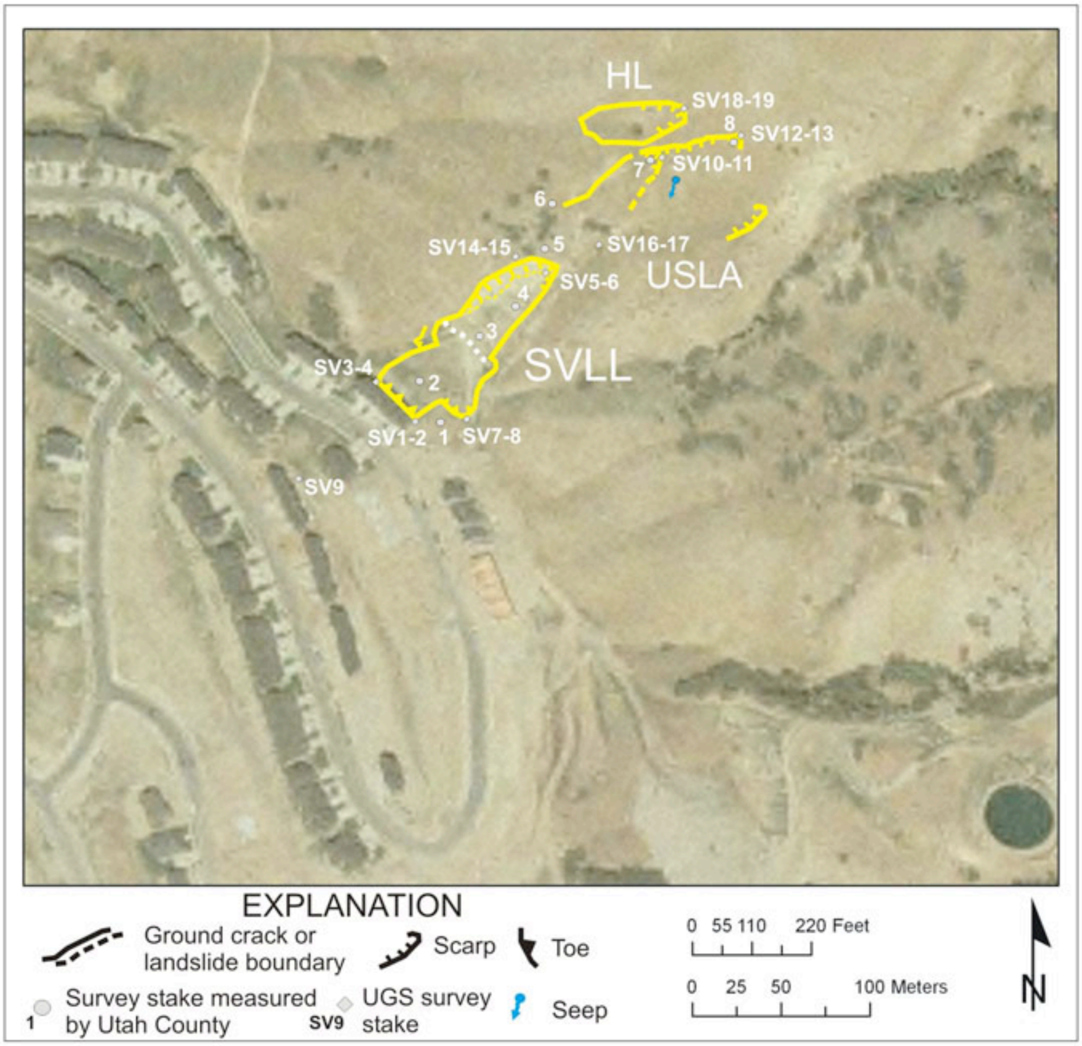


Figure 4. *Orthophotograph showing approximate locations of Sage Vista Lane landslide (SVLL), historical landslide (HL), and traces of landslide deformation features of upper shallow landslide area (USLA). Survey points measured by UGS (diamonds) and Utah County (circles) also shown. Orthophotograph from 2004 USDA National Agriculture Imagery Program.*

Figure 5. *View of the disrupted soil at toe of the landslide and damage to back of townhouse on April 29, 2005.*

Figure 6*. View of relatively intact, translated blocks near the middle of the landslide. Cobble-lined drainage ditch that was originally atop cut slope is translated downslope but relatively undeformed.*

***Figure** 7. View of slickensides in the upper, shallow part of the landslide.*

Figure 8. *View of south-facing scarp along north edge of landslide on April 29, 2005. The upper part of the scarp is from movement of the slide in 1983. The lower nearly vertical part is from movement of the Sage Vista Lane landslide in 2005.*

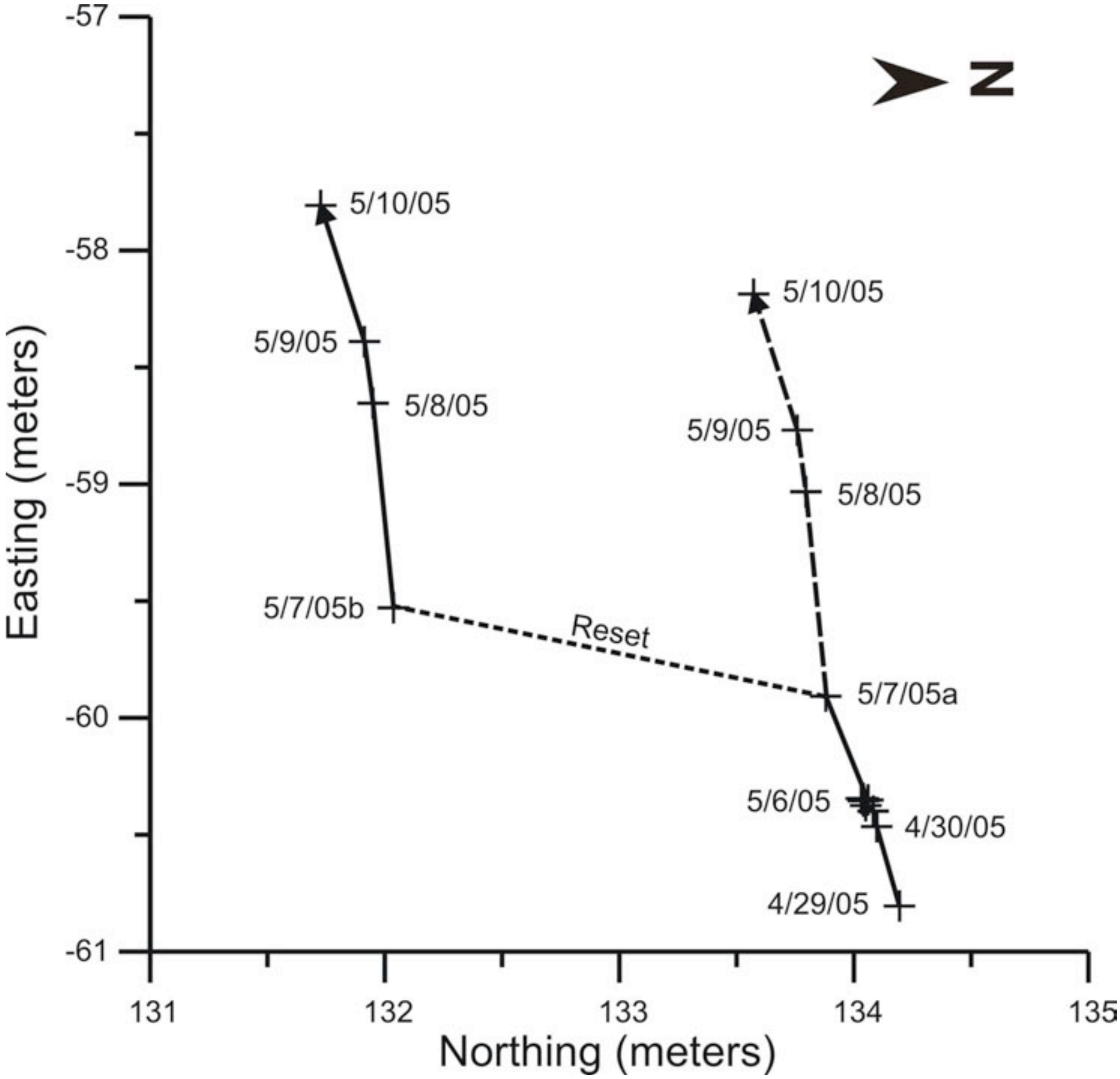


Figure 9. *Plot showing movement of the shallow head of landslide between April 29 and May 10, 2005. Head of landslide moved about 10.4 feet (3.2 m) during measurement period. Position of Utah Geological Survey stake SV5 in head of landslide surveyed by Utah County using accurate GPS equipment. Stake was relocated (reset) to avoid disturbance in saturated soils on May 7 (dashed line). Long dashed line shows probable displacement path for original stake position. Stake lost in saturated surface soils on May 11. Measurement location shown on figure 4. Stake coordinates reported in SI units by Utah County.*

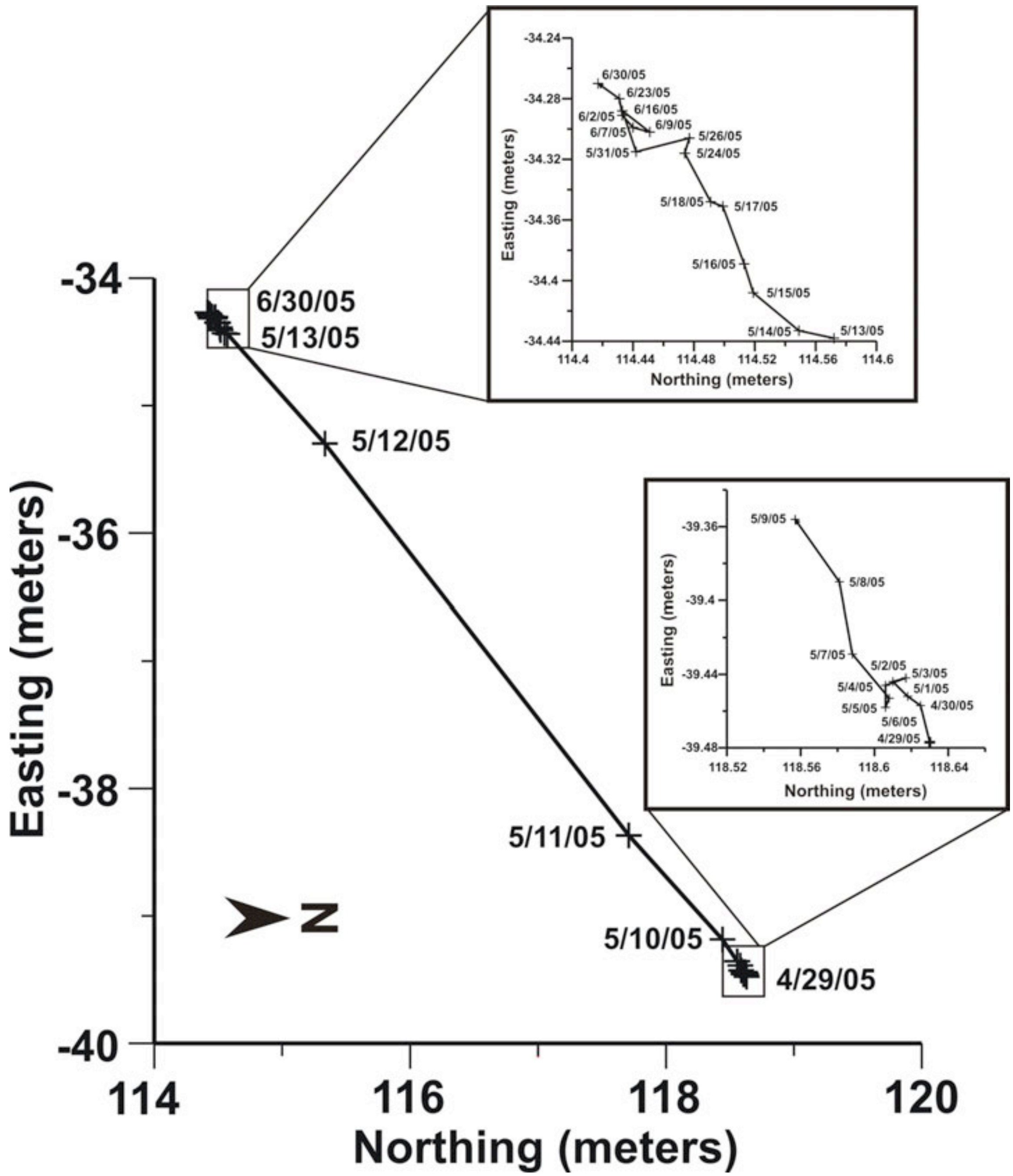
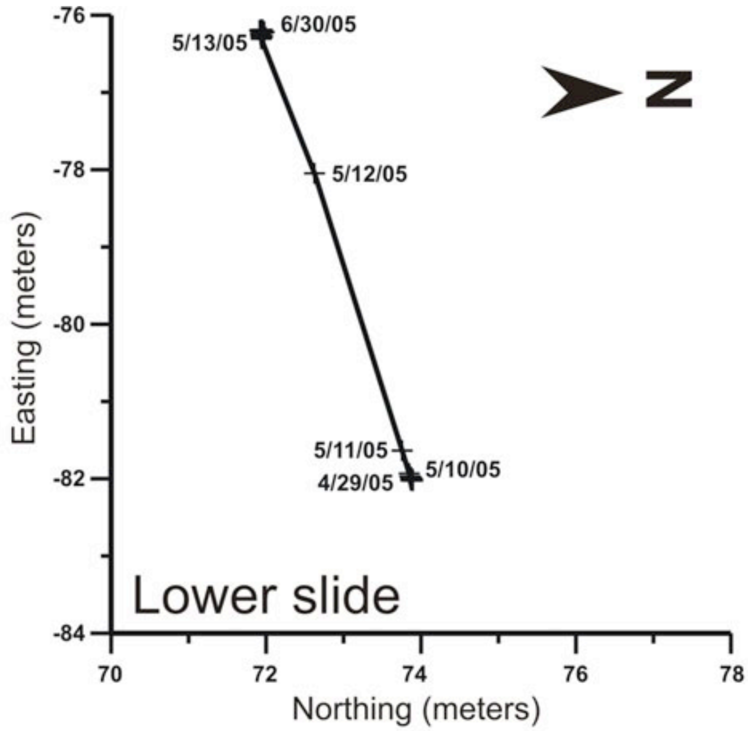


Figure 10. *Plot showing movement of the upper part of Sage Vista Lane landslide between April 29 and June 30, 2005. Total movement during the measurement period was about 23 feet (6.9 m). Most of the movement occurred between May 10 and 13, 2005, during which the townhouse was severely damaged. Insets show minor movement through May 9 (about 6 inches) and following May 13 (about 10 inches). Position of stake 4 (see figure 4 for location) in upper landslide surveyed by Utah County using accurate GPS equipment. Stake coordinates reported in SI units by Utah County.*



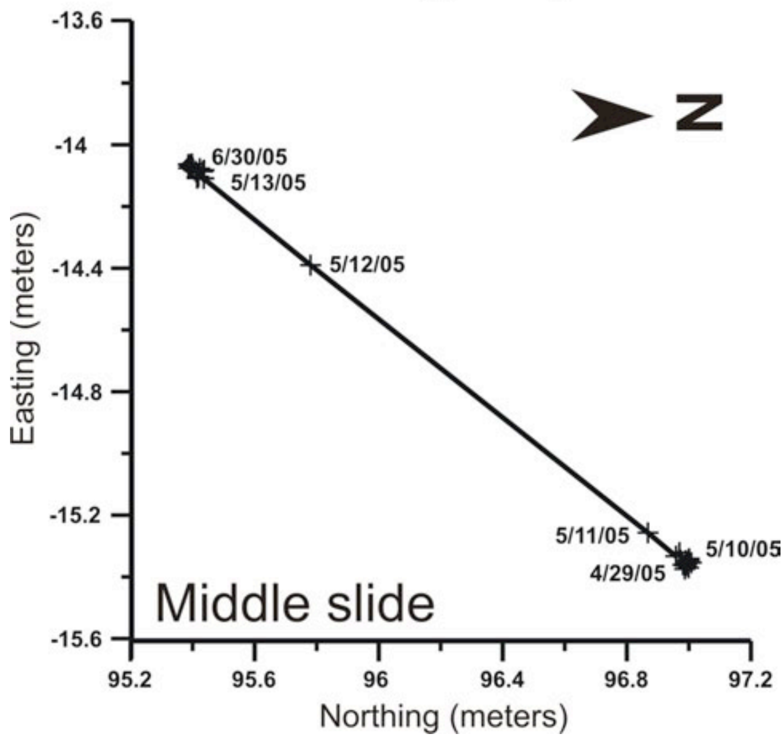


Figure 11. *Plot showing movement of the lower and middle parts of Sage Vista Lane landslide between April 29 and June 30, 2005. Total movement during the measurement period was about 21 feet (6.4 m) and 7.5 feet (2.3 m), respectively. Positions of stakes 2 and 3 (see figure 4 for locations) surveyed by Utah County using accurate GPS equipment. Stake coordinates reported in SI units by Utah County.*

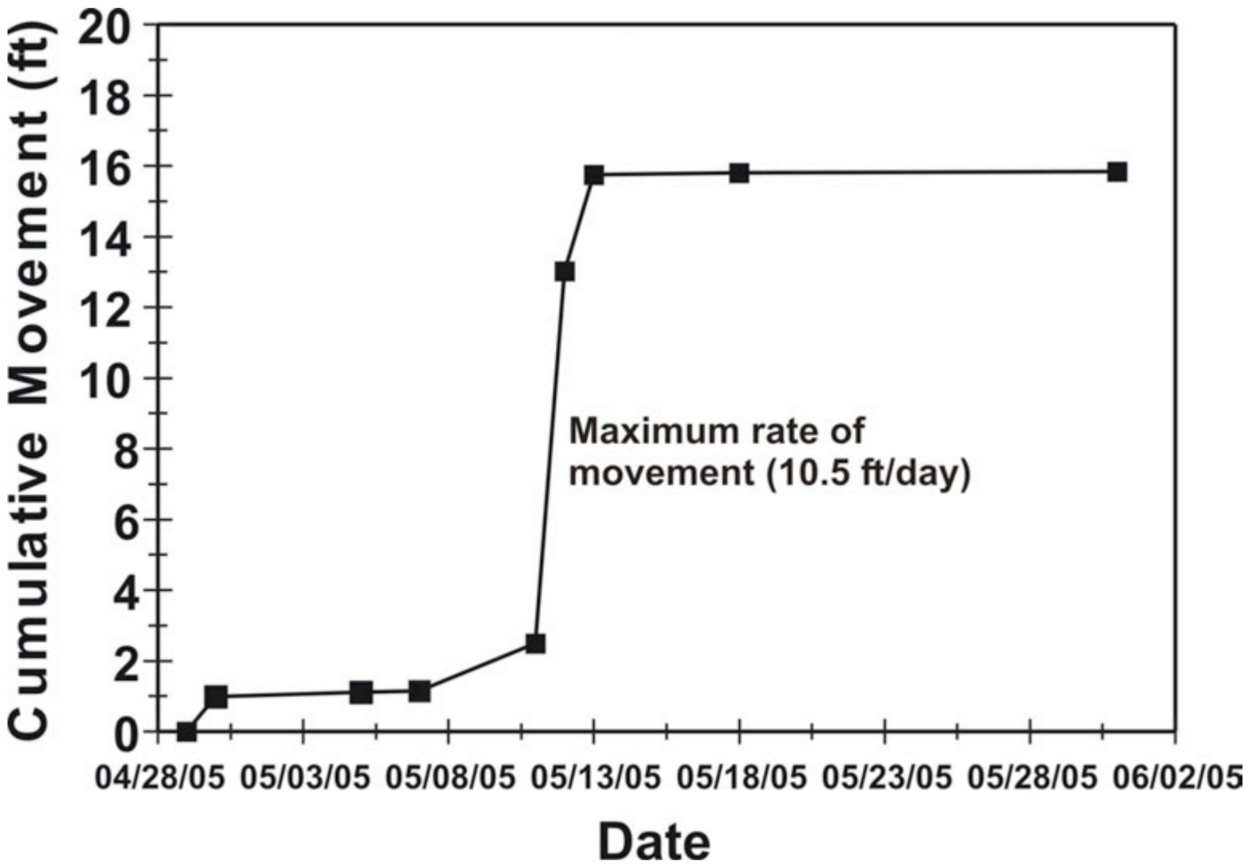


Figure 12. *Plot showing movement of north edge of toe of Sage Vista Lane landslide between April 29 and May 31, 2005. Total movement during the measurement period was about 15.9 feet (5 m). Distance between stakes SV3 and SV4 measured by UGS using fiberglass tape. Stake SV4 located on toe of landslide. Measurement location of station SV3-4 shown on figure 4.*

Figure 13. *View of main scarp of small landslide upslope of main slide on May 12, 2005. By May 5, 2005 another scarp connected this small slide to one farther upslope joining the two slides into a single shallow landslide.*

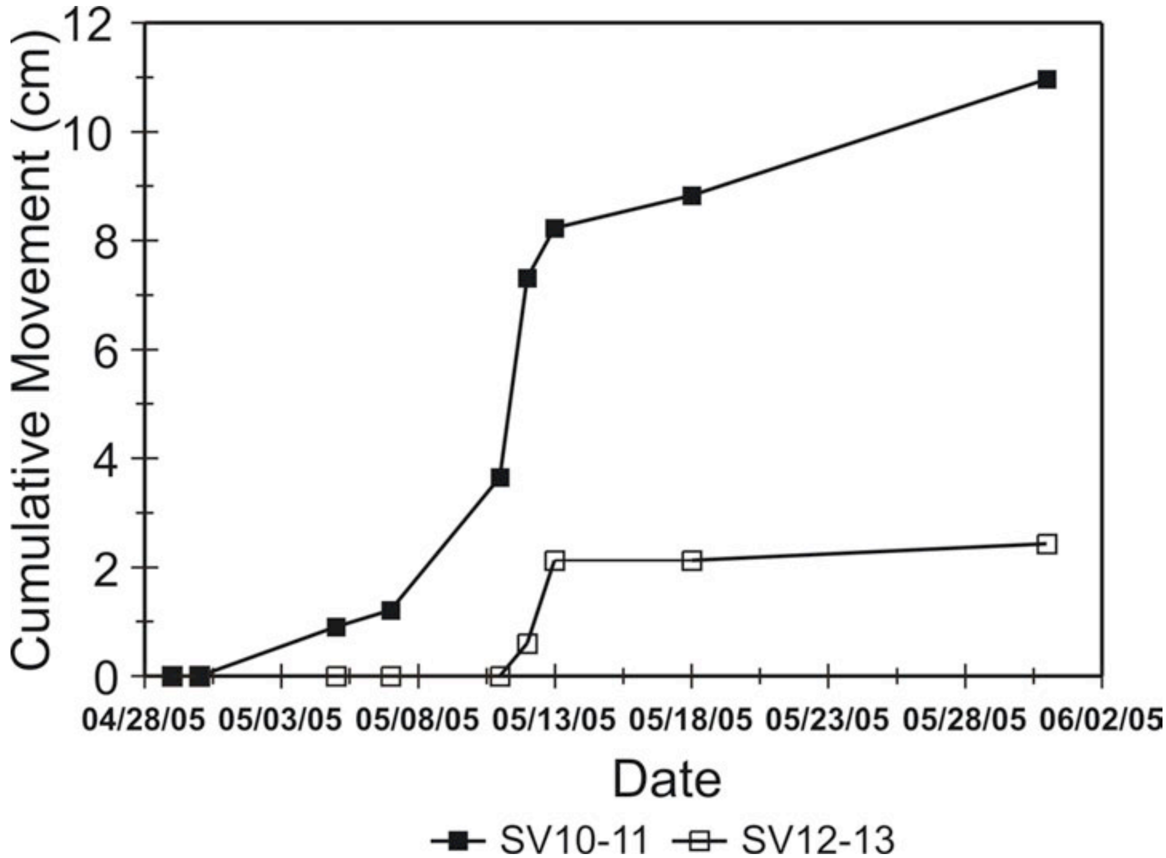


Figure 14. *Plot showing movement of the upper shallow landslide area northeast of Sage Vista Lane landslide between April 29 and May 31, 2005. Total movement during the measurement period was between about 1 and 4.3 inches (2.5-11 cm). Distance between stakes measured by UGS using fiberglass tape. Stake stations spanned scarps observed on April 29 (see figure 3). Measurement locations shown on figure 4.*

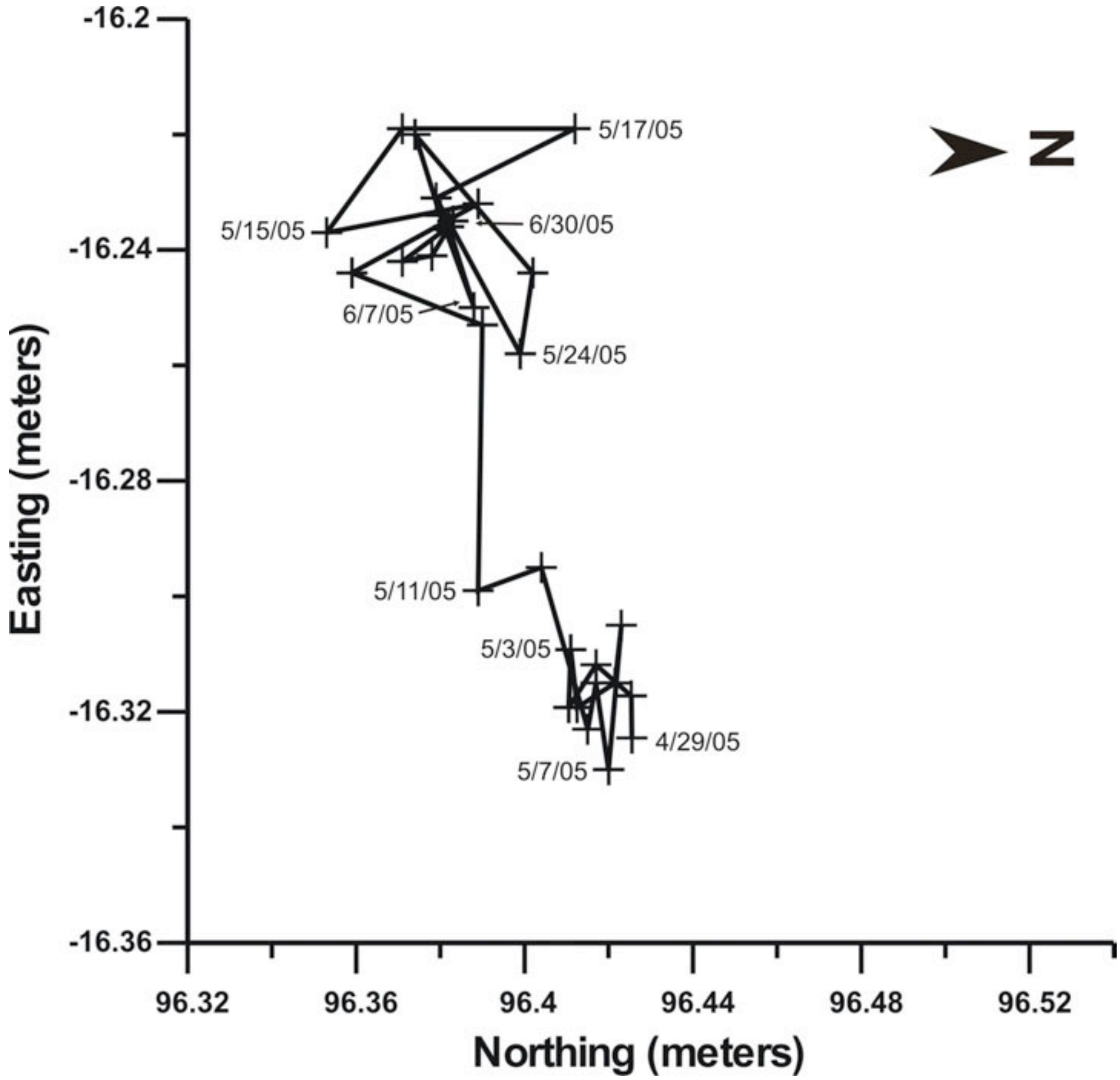


Figure 15. *Plot showing movement of lower part of upper shallow landslide area above Sage Vista Lane landslide between April 29 and June 30, 2005. Total movement during the measurement period was about 5 inches (13 cm). Positions of stake 7 (see figure 4 for location) surveyed by Utah County using accurate GPS equipment. Stake coordinates reported in SI units by Utah County.*

Utah Geological Survey Technical Report

Project: Landslides of 2005 at a horse ranch near the East Lawn Memorial Hills Cemetery, Provo, Utah County, Utah			
By: F.X. Ashland, P.G.	Date: January 11, 2006	County: Utah	
USGS Quadrangle: Orem (1047)	Section/Township/Range: Sec. 18, T. 6 S., R. 3 E.		
Requested by: Incident Investigation	Date report received at UGS:		Technical Report number: 06-01 (GH-10)

INTRODUCTION

On March 17, 2005, Utah Geological Survey (UGS) geotechnician Michael Kirschbaum observed a recent large landslide on a southwest-trending ridge east of the East Lawn Memorial Hills Cemetery in northern Provo, Utah (figures 1 and 2A). The landslide impacted the western part of a cooperative horse ranch property, affecting the ground surface in a corral area, and subsequently damaging a tack shed and fencing. Three other small landslides (figure 2) also occurred upslope of the main slide in cut and/or fill slopes.

UGS geologists made a reconnaissance of the main landslide on March 29, and subsequent reconnaissance visits on April 18 and May 12 to photograph changes to the main slide. On June 23, Michael Kirschbaum and I mapped the perimeters of each landslide and deformation features in the main slide in detail. The purpose of these investigations was to document the landslide, including the types of movement, amount and extent of ground deformation, and duration of landslide activity, particularly because of the geologic similarities between this site and the northern part of the Sherwood Hills subdivision to the south (figure 1).

CONCLUSIONS

The main landslide on the horse ranch property will likely reactivate in future wet years. Given the currently high measured ground-water levels in the Sherwood Hills subdivision directly to the south, reactivation of the main landslide in early 2006 is possible even with normal precipitation in the intervening time period. Reactivation may be accompanied by additional enlargement of the main landslide, threatening upslope infrastructure and the barn. Additional offset of existing internal (minor) scarps will cause more damage to the western part of the horse ranch, further damaging paved areas and the tack shed. Reactivation of the southern part of the landslide poses some risk of blocking the drainage at the base of the slope. Subsequent flooding from the eventual breach of such a blockage would likely impact the access corridor to the cemetery and possibly residential properties downstream and to the southwest.

This landslide also suggests the marginal stability of local steep slopes in prehistoric landslide deposits in northern Provo, particularly where hillslope modifications have occurred. The similarities in local slope, geology, and hillslope modifications of this area and the northern part of the Sherwood Hills subdivision, suggest some potential for similar landsliding in the subdivision.

GEOLOGY

The horse ranch is underlain by prehistoric landslide deposits that comprise the northern part of the Sherwood Hills landslide complex (Machette, 1992; Ashland, 2003). Figure 3 shows the local geology and younger pre-existing landslides within the prehistoric older landslide deposits. The younger pre-existing landslides with well-defined boundaries indicate local partial reactivation of the prehistoric landslide deposits prior to the area's use as a horse ranch. Landslide deposits consist of clay-rich debris with angular cobble and boulder clasts supported in a clay-rich soil matrix. The debris is likely derived, in part, from residual and colluvial deposits formed on the Mississippian Manning Canyon Shale, a formation that underlies the eastern part of the Sherwood Hills landslide complex.

Some hillslope modification accompanied building and road construction on the horse ranch property, including site regrading that locally flattened the ridgetop. Locally derived fill was likely placed on the upper parts of the slopes during this regrading. Field observations suggest a considerable amount of fill likely existed near the west corner of the corral prior to the landslide. A second large fill area exists upslope and northeast of the main landslide in the upper part of the drainage that bounds the ridge and the slide on the north.

LANDSLIDE DESCRIPTIONS

Four separate landslides were active in 2005 on the horse ranch (figure 4). The main landslide is a reactivation of younger pre-existing landslides in the underlying prehistoric landslide deposits. The other three landslides occurred in either cut or fill slopes. Fill materials were likely locally derived, making distinguishing fill from native landslide deposits difficult.

Main Landslide

The main landslide is on the southwest-trending ridge occupied in part by the corral (figure 4). The landslide consists of two slides that overlap at the ridge crest, one on the northern slope of the ridge and one on the southern slope, that have divergent movement directions. Our mapping indicates that the northern part of the landslide moved first and that the southern part expanded upslope, capturing part of the northern part of the slide. Evidence for this includes a severed toe thrust on the western edge of the landslide that initially was in the northern part of the slide before it was cut off by the main scarp of the southern part of the slide. Figure 5 is a detailed map of the main landslide showing the major internal deformation features, movement directions, scarp heights, and deposit thicknesses. By June 23, the main landslide was about 2.4 acres in size.

The northern part of the main landslide (figure 2A) consisted of an earth flow in the lower western part, and an earth slide in the upper eastern part that together form a complex earth slide-earth flow. Figure 5 shows that movement in the earth flow was to the southwest. Scarp orientation indicates movement in the upper earth slide was generally westward and locally west-northwest. The entire northern part of the main landslide was about 490 feet long. Local relief between the toe of the earth flow and main scarp of the earth slide was about 165 feet, indicating an average slope of the complex earth slide-earth flow of about 34 percent. The average slope of the lower earth flow was slightly steeper, about 41 percent. Several internal (minor) scarps cut the upper earth slide, including two with large offsets. The lower of these two scarps was about 70 feet upslope of the top of the earth flow, arcuate in plan view, and between 3.5 and 7 feet high on June 23. The second large-offset scarp (figure 6D) crossed the middle of the corral and reached a maximum height of about 6 feet near the southeastern edge of the corral. Observations between March and June suggest that the northern part of the landslide remained active during this period and enlarged upslope of the tack shed. On June 23, the main scarp east of the large-offset internal scarps reached a maximum height of only about a foot and crossed a cut slope above a tack shed northeast of the corral.

The southern part of the main landslide consisted of an earth slide about 340 feet wide and between 160 and 200 feet long. Figure 5 shows the movement direction of the southern part of the slide was generally to the south-southwest. In the east, the southern part of the slide abutted the northern earth slide, but in the west the southern part of the slide overlapped the northern part. The northern boundary of the southern part of the landslide extended into the southern corner of the corral and about 80 feet of the northern part of the slide was captured by the southern part. Local relief in the southern part of the landslide ranged between about 50 and 95 feet, with an average slope between about 32 and 46 percent. The main scarp of the southern part of the slide consisted of two separate arcuate scarp areas divided by a narrow south-trending ridge (figure 5). The scarps locally reached a maximum height of about 6 feet on June 23. Figure 6F shows damage to a wooden fence caused by ground deformation in the upper part of the southern part of the main landslide. A well-defined landslide toe exists along the bank of a drainage in the east and near the base of the slope in the west (figures 4 and 5).

Small Landslides

Three other small landslides were also active in 2005 on the property (figures 2B through 2D and 4), all of which formed in cut and/or fill slopes. Because of the use of local landslide debris as fill, differentiating cut and fill slopes was not possible. The topography suggests that the slopes may be cuts in their lower parts and fills in their upper parts. Table 1 summarizes the dimensions of these landslides.

Table 1. *Summary of dimensions and slope of small landslides.*

Location of slide	Length (ft)	Width (ft)	Area (sq yds)	Slope (percent)
Near tack shed	45	59	308	47
East of barn	59	64	377	79
Northeast of arena	26	50	108	93

The closest small slide to the main landslide was in a steep southwest-facing slope below a paved access road to a large barn on the property, a short distance southeast of the tack shed. Offset on the main scarp caused minor damage to a wooden fence and to the edge of the pavement atop the slope (figure 2B). Based on its proximity to ground deformation features in the crown of the main landslide, the small slide may actually be within the limits of the main landslide, although it is mapped as a separate slide on figures 4 and 5.

The two other small slides were upslope of a large barn and riding arena (figure 4). One was on a southeast-facing slope east of the large barn (figure 2D). Offset on the main scarp severed a buried drain or water pipe. The other small slide (figure 2C) was in a cut slope directly northeast of a riding arena. The landslide was localized in a weathered block of Manning Canyon Shale or homogenous debris derived from the shale.

CAUSES AND IMPLICATIONS

Movement of the 2005 landslides initiated during a wetter than normal period and after most, if any, snowpack at this elevation (approximately 5,200 to 5,450 feet) had melted. Thus, rising ground-water levels in the underlying prehistoric landslide deposits likely triggered the movement. However, ground-water levels declined between February and March in most of the nearby monitoring wells in the Sherwood Hills subdivision to the south. Only two of the Sherwood Hills wells, both at about elevation 5,200 feet, had rising ground-water levels in March, suggesting the possibility that ground-water levels were rising at least in the lower part of the main landslide when movement triggered. Rising ground-water levels in the lower parts of the underlying younger pre-existing landslides may have reduced the resisting forces sufficiently, possibly in combination with a wetting-induced rise in soil weight that increased driving forces in the upper parts of these slides, to trigger movement.

The property owner of the affected part of the horse ranch indicated that minor ground deformation was noticed in 2004 in the corral area, suggesting movement in the previous year. Thus, another possibility is that movement in 2004 never suspended, but only fell to an extremely slow rate in the summer of 2004. The onset of rising ground-water levels and soil wetting in March 2005 may have caused a rapid acceleration in the rate of movement and the resulting ground deformation.

Grading and fill placement at the top of the younger pre-existing landslides ($Qmsy_1$ in figure 3) were also likely contributing causes of the landsliding. The additional load of the fill in the upper part of these landslides increased driving forces and likely left the pre-existing slides marginally stable prior to the rising ground-water levels in 2005 or the onset of movement in previous years.

The large amount of displacement and ground deformation of the main landslide in 2005 is notably different from that which occurred during the same time period in the remainder of the Sherwood Hills landslide complex directly to the south. Scarp heights on the horse property reached a maximum height of about 7 feet in the northern earth slide whereas the highest scarp in the Sherwood Hills subdivision part of the complex, caused by movement in 2005, measured only several inches in height. The amount and extent of displacement and ground deformation at the horse ranch landslide is likely due to both the local steep slopes (average slopes in the main landslide ranged typically between 30 and 45 percent with locally steeper slopes), and the type of movement (flow) in the northern part of the slide. Earth-flow displacement likely exceeded 50 feet in the northern part of the landslide and accommodated considerable stretching in the upslope earth slide, as indicated by the numerous scarps. Rapid failure of the fill slope and disruption of fill soils at the west corner of the corral during a time when the soil was wet or even locally saturated may have accelerated the transition to earth flow. However, scarp height and upslope enlargement of the landslide also suggests deeper seated movement of the underlying landslide deposits. Initial landslide boundary mapping in late March showed close conformity between the 2005 boundaries of the northern part of the landslide and the northern younger pre-existing landslide ($Qmsy_1$ in figure 3).

FIELD METHODS

Landslide boundaries were mapped using a handheld global positioning system device with an approximate accuracy range of between 10 and 30 feet at the time of the fieldwork. Maps of the 2005 landslides and dimensions listed in this report were derived using this method. Short-term variation in location was tested using duplicate measurements from the same device and was less than 2 feet. Duplicate measurements using two devices were also used to improve accuracy. Some measurements of landslide dimensions were checked in the field using a fiberglass tape.

ACKNOWLEDGMENTS

Michael Kirschbaum (formerly UGS) conducted the initial reconnaissance of the landslide and subsequent photographic documentation of the progression of landsliding. He also assisted with fieldwork for this study. Lucas Shaw (UGS) provided assistance in creating several of the figures in this report.

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, UGS, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, UGS, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCES

Ashland, F.X., 2003, Characteristics, causes, and implications of the 1998 Wasatch Front landslides, Utah: Utah Geological Survey Special Study 105, 49 p.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, 26 p. pamphlet, scale 1:50,000.

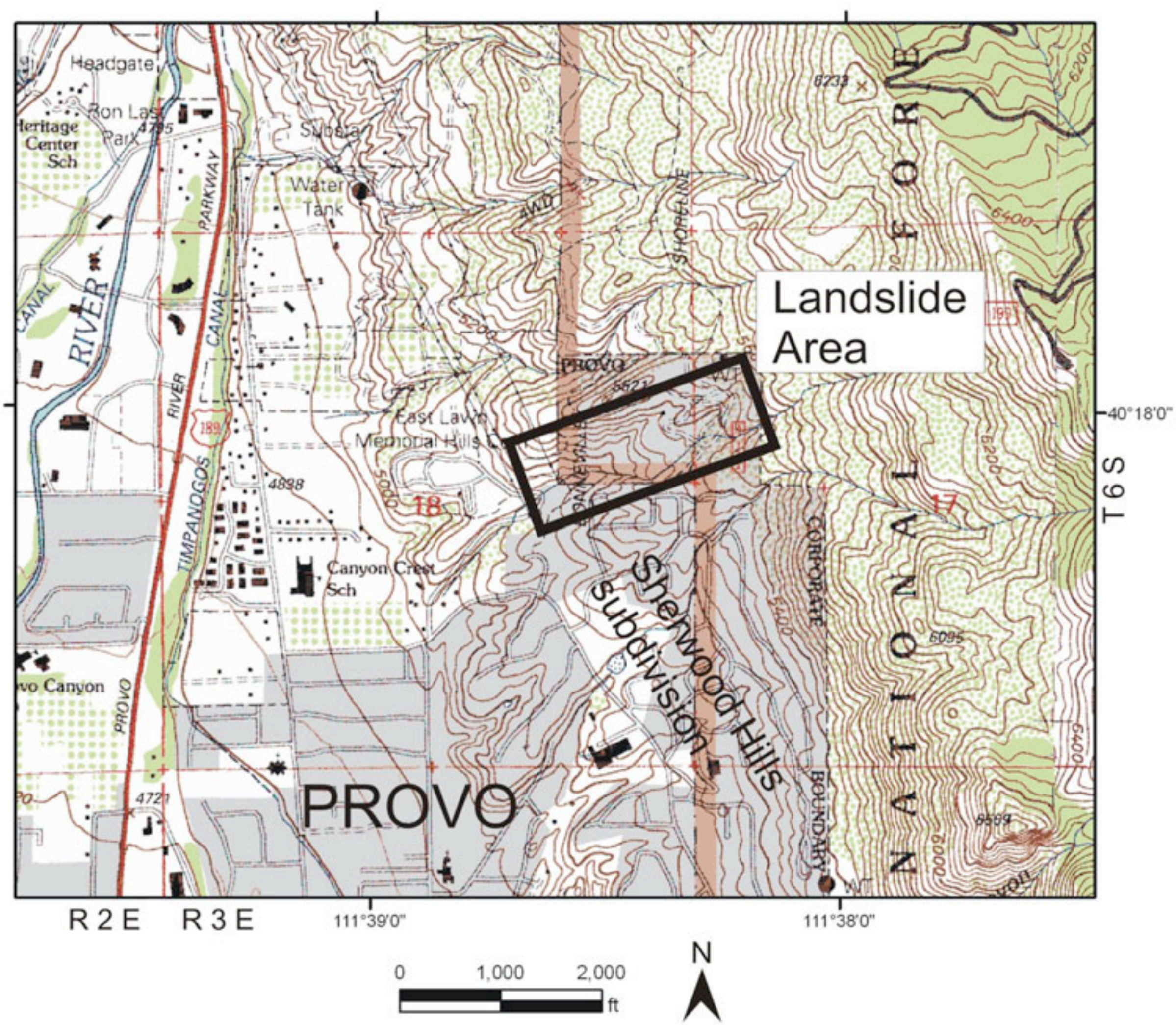


Figure 1. Location map of landslide area on horse ranch east of East Lawn Memorial Hills Cemetery in northern Provo. Topographic base from the Orem 7.5-minute quadrangle.

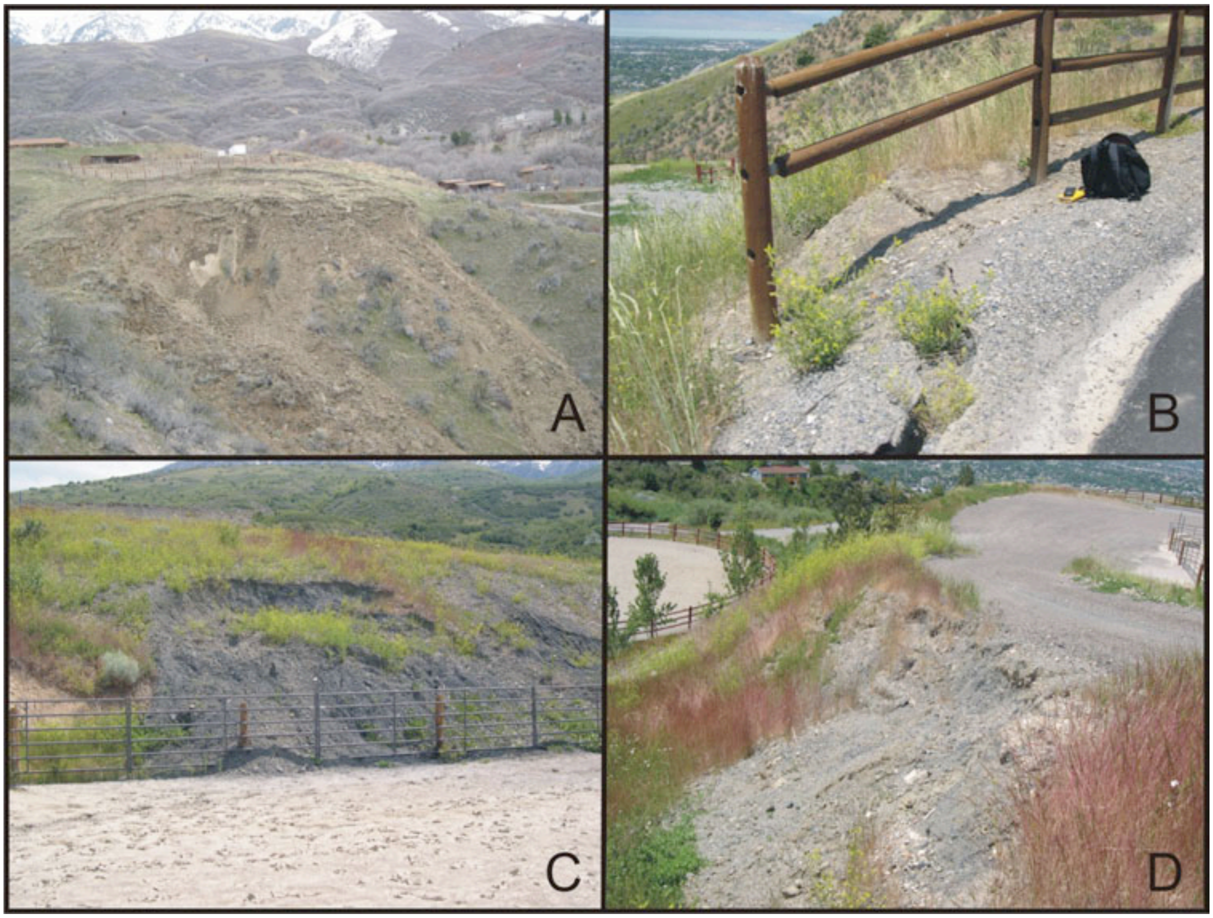


Figure 2. *Landslides in 2005 on horse ranch east of East Lawn Memorial Hills Cemetery, Provo. (A) View to the east of north part of main landslide on March 17. (B) Minor offset on main scarp of small companion slide to main landslide southeast of tack shed that caused minor damage to fence. View is to the west. (C) View to the east of small landslide northeast of riding arena in highly weathered Manning Canyon Shale or debris derived from the shale. Movement direction is to the west-southwest. (D) View to the west-southwest of main scarp of small landslide east of barn. Movement direction is to the southeast. Photographs of small landslides (B, C, and D) taken on June 23.*

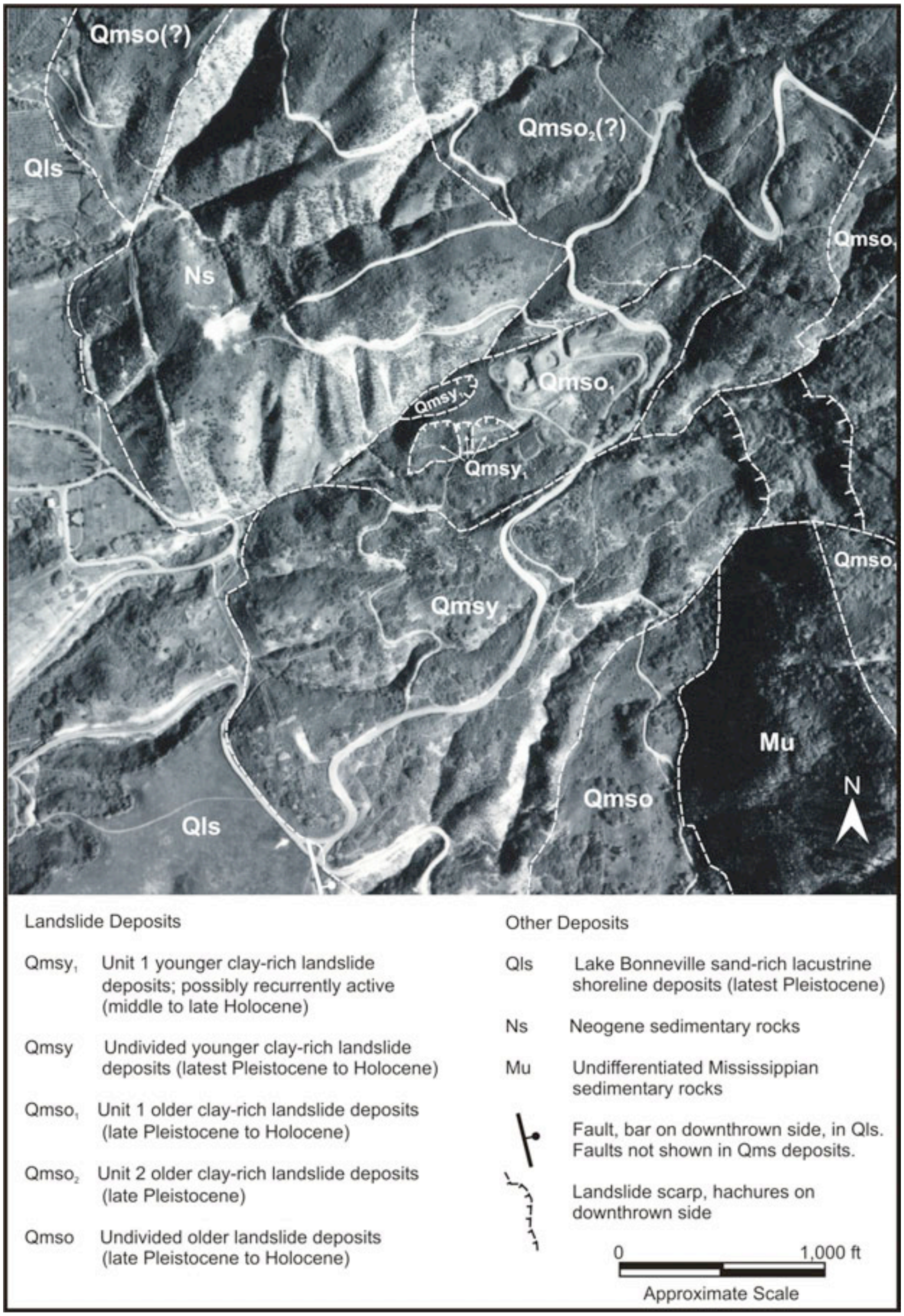


***Figure 3**. Aerial photograph geologic map of the northern part of the Sherwood Hills landslide complex showing prehistoric landslides and landslide deposits prior to development. Unit 1 younger landslides ($Qmsy_1$) and unit 1 older landslide deposits ($Qmso_1$) underlie site of 2005 landslides on horse ranch property.*

Figure 4. *Map showing 2005 landslides on horse ranch property. The main landslide consists of two parts that overlap near a southwest-trending ridge crest, a northern complex earth slide-earth flow that moved west-southwest and a southern earth slide that moved south-southwest. The other three small landslides occurred in either cut or fill slopes.*

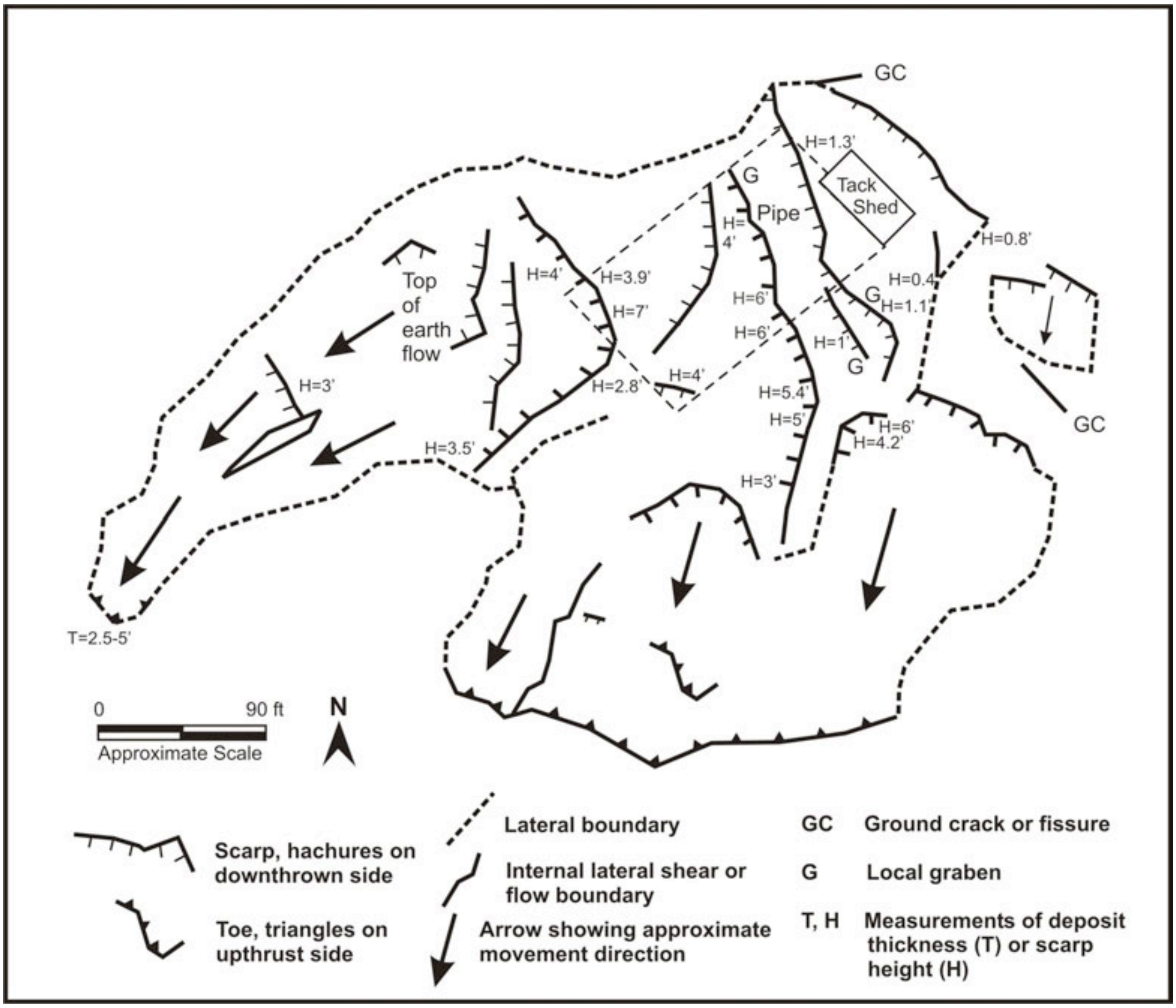


Figure 5. *Detailed map of main landslide. Height of scarps or deposit thicknesses in feet on June 23 also shown. Dashed rectangular area is approximate boundary of corral. Pipe indicates drainpipe exposed in scarp.*

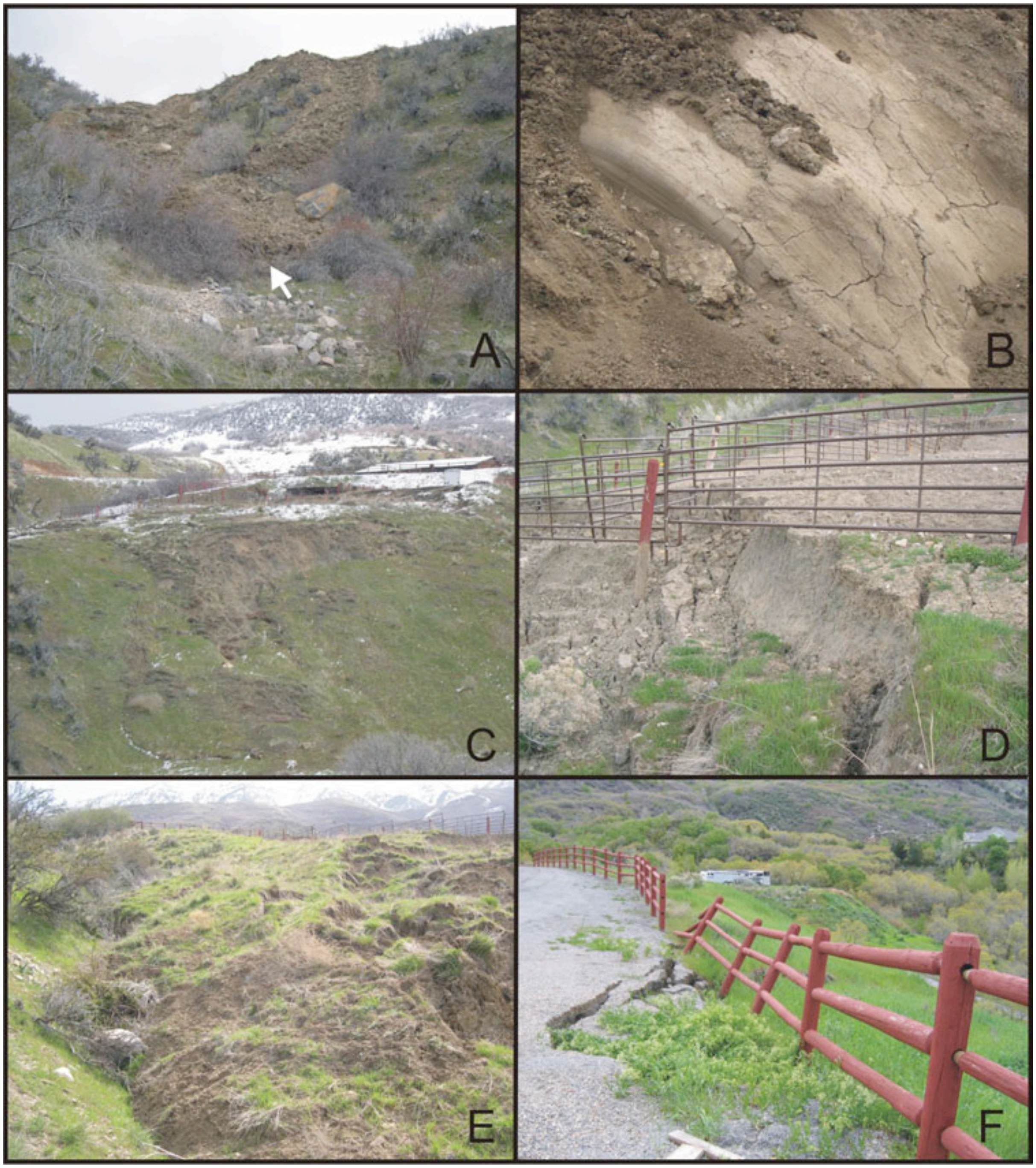


Figure 6. *Ground deformation in the main landslide, March 17 to May 12, 2005. (A) View to the northeast of earth-flow toe (arrow) on March 17. (B) Slickensided clay in north part of landslide on March 17. (C) View to the north of south part of landslide on March 29. (D) View to the northwest of large internal scarp that crossed horse corral on April 18. (E) View to the northeast of north edge of landslide on April 18. (F) View to the east of damage to fence due to offset of main scarp of south part of landslide on May 12.*

Utah Geological Survey Technical Report

Project: Investigation of the 2005 Uinta Canyon snowmelt debris flows, Duchesne County, Utah			
By: Richard E. Giraud, P.G.	Date: 01-27-06	County: Duchesne	
USGS Quadrangles: Bollie Lake (1199)	Section/Township/Range: Sections 18 and 19, T. 3 N., R. 2 W., Sections 13 and 24, T. 3 N., R. 3 W., Uinta Baseline and Meridian		
Requested by: Incident Investigation			Technical report number: 06-03 (GH-11)

INTRODUCTION

On the evening of May 25, 2005, a debris flow occurred on the U-Bar Dude Ranch, destroying one guest cabin and partially burying another cabin (Uinta Basin Standard, 2005). U-Bar Ranch lies at the north of Ashley National Forest Service Road 118 in Uinta Canyon on the south flank of the Uinta Mountains about 25 miles north of Roosevelt, Utah. The cabins were unoccupied because the U-Bar Ranch was not yet open for the summer season but ranch personnel evacuated the premises following the debris flow. U-Bar Ranch personnel returned the following morning and found a second debris-flow deposit blocking the road at the Wandin Campground (Uinta Basin Standard, 2005) about 0.2 mile south of the ranch. U-Bar Ranch personnel later discovered a third debris flow that crossed a wilderness trail about 0.8 mile north of the ranch.

For this report, the Uinta Canyon debris flows from north to south are referred to as U-Bar Ranch North, U-Bar Ranch, and Wandin Campground debris flows (figure 1). All three debris flows occurred near the end of snowmelt of an above average snowpack. The U-Bar Ranch and Wandin Campground debris flows initiated as debris slides that transformed into debris flows as they traveled downslope.

The purpose of my investigation was to determine the geologic characteristics of these snowmelt debris flows and evaluate the future hazard potential. U.S. Forest Service Ashley National Forest geologist Dave Herron visited the site on June 2, 2005, and prepared a report describing the Wandin Campground and U-Bar Ranch debris flows (Herron, 2005). On July 12, 2005, Dave Herron and I measured the volumes of channel erosion and mapped the source debris slides for the U-Bar Ranch and Wandin Campground debris flows. On July 13, 2005, I mapped the deposits of the U-Bar Ranch North, U-Bar Ranch, and Wandin Campground debris flows. A field traverse up the channel to the start of the U-Bar Ranch North debris flow was not made. I discussed the damages and timing of the three debris flows with U-Bar Ranch personnel. I also reviewed 1:60,000 scale 1953 aerial photos, U.S. Geological Survey 1993 aerial photos at various scales (TerraServer USA, 2005), National Agriculture Imagery Program aerial photos at various scales (Utah Automated Geographic Reference Center, 2005), 1:125,000-scale geologic maps, and regional geologic reports of the area.

CONCLUSIONS AND RECOMMENDATIONS

Based on this geologic investigation and hazard assessment of the Uinta Canyon debris flows, the Utah Geological Survey (UGS) concludes the following:

- The U-Bar Ranch and Wandin Campground debris flows triggered as shallow debris slides near the end of the spring snowmelt. The flows traveled down the channels, bulking additional sediment until they flowed out onto alluvial fans and deposited the sediment. Ample material is available in the debris-slide-source areas and in channels for future debris flows. Future debris flows could produce volumes similar to or larger than the 2005 events.

- The debris flows occurred near the end of a period of rapid snowmelt of an above-normal snowpack.

- Infiltrating snowmelt water likely perched on shale bedrock, increased the pore-water pressure in overlying materials, and triggered the debris slides that transformed into debris flows.

- The U-Bar Ranch and Wandin Campground debris flows fall within the Chleborad (1997) temperature threshold and anticipated landslide movement window, indicating Chleborad's methods could be used to anticipate the timing of future snowmelt debris flows in this area.

- Based on the debris slides and scoured channels observed in the field and on aerial photographs, debris slides are a common mechanism for the initiation of debris flows in this area.

- The U-Bar Dude Ranch and Wandin Campground lie on alluvial fans where debris flows run out and deposit sediment. Debris flows will continue to run out on these alluvial fans and may damage facilities built on these fans. Because debris flows travel fast and often strike without warning, the potential also exists for loss of life. I recommend a site-specific debris-flow investigation be performed to evaluate the risk to individual structures and possible risk-reduction measures and their cost. Alluvial-fan flooding is also a hazard on these fans that should be addressed along with the debris-flow hazard.

- The source area of the U-Bar Ranch North debris flow was not investigated but it likely followed similar timing and trigger patterns as the U-Bar Ranch and Wandin Campground debris flows.

DESCRIPTION AND GEOLOGIC SETTING

The U-Bar Ranch North, U-Bar Ranch, and Wandin Campground debris flows initiated along the steep east valley wall of Uinta Canyon (figure 1). The Uinta River flows south in a large glacial valley with oversteepened valley sides. Valley glaciers filled the canyons on the south side of the Uinta Mountains during the middle and late Quaternary (Laabs and Carson, 2005). The most recent glaciation in the area was the Smith Fork glaciation that reached a maximum prior to 17.6 ka in the Lake Fork and Yellowstone Canyons to the west (Laabs and Carson, 2005). The Smith Fork glaciation is equivalent to the Pinedale glaciation used by earlier workers to describe the latest glacial advance in this area.

The general geology in the area was mapped by Bryant (1992). Bedrock in the area consists of two Middle Proterozoic units. The Hades Pass unit consists of sandstone, arkose, and shale. The Red Pine Shale consists of siltstone and shale with thin discontinuous beds of quartzite and arkose. The Red Pine Shale is a unit commonly involved in landsliding in northeastern Utah (Harty, 1991). Bryant (1992) mapped several landslides within and adjacent to the Red Pine Shale along the east wall of Uinta River Canyon. The most widespread surficial deposit is glacial till associated with the Smith Fork glaciation. Post-glacial deposits consist of talus, colluvium, landslides, alluvial fans, and stream alluvium. East of Wandin Campground, a large, deep-seated landslide is mapped within and adjacent to the Hades Pass unit and the Red Pine Shale (Bryant, 1992). This large landslide extends into the glacial valley indicating post-glacial movement (Herron, 2005). Different ages of historical debris slides along the east valley wall are evident on aerial photographs. These debris slides have a similar elevation and aspect to the 2005 debris slides. Post-glacial alluvial fans prograde out onto glacial till deposits on the valley floor. These fans are sites of active deposition and show evidence of recent debris flows. Stream alluvium is deposited along the channels and flood plain of the Uinta River and tributary streams.

All three debris flows traveled down small, steep drainage basins onto alluvial fans. The drainage basins ranged in size from 21 to 79 acres and have relief ratios ranging from 44 to 53% indicating that these small basins are very steep (table 1). The alluvial fans also have steep average gradients that range from 8.5 to 11.6°. Easily erodible sediment is stored in these drainage basin channels and is a source for future debris flows. A wildfire during the mid-1980s burned the slopes in the small, steep drainage basins above U-Bar Ranch and Wandin Campground. Standing dead tree trunks from the fire are present within and around the 2005 debris slides. The dead tree trunks show significant decay and likely have little root strength from a slope stability standpoint. However, the 2005 debris slides are likely not related to the wildfire because numerous young aspen trees within and around the debris slides provide increase in root strength.

U-BAR RANCH NORTH DEBRIS FLOW

The exact timing of the U-Bar Ranch North flow is unknown. However, U-Bar Ranch personnel discovered the deposit in mid-June about 3 weeks after the other flows. The deposit was dried out, suggesting the flow likely occurred in late May. The drainage basin for this flow has a similar aspect and elevation as the other basins (table 1). West-facing debris slides are also evident on 1953 aerial photos at the head of this drainage. The U-Bar Ranch North flow exhibits characteristics of a hyperconcentrated flow that deposited a 0.1- to 0.5-foot-thick layer of sand, gravel, and cobbles on the alluvial fan. Hyperconcentrated flows have 20 to 60% sediment by volume (Pierson and Costa, 1987) and are more fluid than debris flows that have greater than 60% sediment by volume. For this report, the term debris flow is used in a general way to include all flows within the hyperconcentrated- and debris-flow sediment-water concentration range. The flow has a relatively long runout (960 feet) and large deposit area given the small flow volume (500 cubic yards [yd^3], table 1). The long runout distance and large deposit area are likely the result of the fluid nature of this hyperconcentrated flow and its ability to spread laterally. The distal end of the deposit extends off the alluvial fan and onto the Uinta River flood plain. Damages from this flow include sediment deposited on a wilderness trail and some sediment that flowed into the Uinta River.

U-BAR RANCH DEBRIS FLOW

According to personnel at the U-Bar Ranch, the U-Bar Ranch debris flow occurred about 10:15 p.m. and was recognized by loud sounds as the flow advanced down the channel (Uinta Basin Standard, 2005). The flow destroyed the Chepta cabin that was built in the 1930s (figure 2). The flow also deposited sediment 4 feet deep on the upslope side of the nearby Atwood cabin and 4-5 feet deep on the road leading into the ranch (figure 3). Above-ground water lines at the ranch were also damaged.

The U-Bar Ranch debris flow initiated as a debris slide 190 feet long and 90 feet wide at an elevation of 9280 feet (figures 1, 4). The debris slide consists mostly of weathered shale and had an estimated volume of 5500 yd^3. Detached blocks of weathered shale within the slide and weathered shale adjacent to the slide are prone to future movement (figure 4). The shale likely played a key role in perching infiltrating snowmelt water, increasing the pore-water pressure in the weathered shale and hillslope till and colluvium, and eventually triggering the debris slide. A small amount of water was draining from the area evacuated by the debris slide on July 12, 2005. This drainage probably has not experienced historical debris slides because none are apparent on 1953, 1993, and 2004 aerial photographs. The debris slide transformed into a viscous debris flow as it traveled downslope.

Two types of debris-flow behavior are present downslope of the debris slide. From the toe of the debris slide at elevation 9160 feet to a quartzite cliff band at elevation 8320 feet, the debris flow was a viscous mass flowing down the channel, depositing levees on steep slopes ranging from 27 to 30° (figure 5). Deposition of channel levees (some up to 50 feet wide and 4 feet thick) indicate the peak flow greatly exceeded the channel capacity. Below the quartzite cliff band, the flow eroded the pre-existing channel 5 to 12 feet deep and did not deposit levees. Field measurements show that between the toe of the debris slide and the quartzite cliff band approximately 3600 yd^3 of sediment were deposited as channel levees and 200 cubic yards were eroded from the channel. Below the quartzite cliff band 3500 yd^3 were eroded from the channel. The average sediment bulking rate along the entire channel length is 2.5 yd^3 per liner foot of channel.

The debris-flow deposit forms a large lobe on the alluvial fan (figures 1, 6). Some sediment was also deposited along and within the feeder channel above the fan. The deposit area is 1.2 acres and consists of 7000 yd^3 of sediment (table 1). Locally the deposit is up to 6 feet thick. Runout on the alluvial fan is 750 feet and the distal end of the flow nearly reached the lodge (figure 2).

WANDIN CAMPGROUND DEBRIS FLOW

The Wandin Campground debris flow occurred late on May 25 or early on May 26, 2005, because the flow had blocked Forest Service Road 118 (figure 7) when U-Bar Ranch personnel returned on May 26 (Uinta Basin Standard, 2005). The flow plugged a culvert and then flowed over the road and down the alluvial fan into the campground, damaging several camp sites. Stream flow following the debris flow reworked sediment originally deposited in the campground farther downslope (Herron, 2005).

The Wandin Campground debris flow initiated as a debris slide (figures 1, 8) measuring 90 feet long and 60 feet wide at an elevation of 9320 feet. The debris slide had an estimated volume of 1000 yd^3 but the volume is difficult to estimate based on evacuated material because of a previous debris slide in the same location, which aerial photographs indicate occurred between 1993 and 2004. The debris slide(s) have produced a 20 to 25-foot-high main scarp that exposes glacial till and colluvium above shale bedrock (figure 8). On July 12, 2005, a spring was flowing out of the landslide scar on the shale (figure 8). Similar to the U-Bar Ranch flow, the shale likely played a key role in perching infiltrating snowmelt water, increasing the pore-water pressure in the overlying till, and eventually triggering the debris slide. The debris slide transformed into a debris flow as it traveled downslope.

The debris flow likely traveled in pulses because channel-plug deposits are present below the debris slide at elevation 8840 feet (figure 9) and at elevation 8000 feet above the alluvial fan. These channel-plug deposits are a source of sediment for future debris flows. The volume of material eroded by the debris flow varied along the channel. Channel erosion depths ranged from 0.1 to 3 feet and the estimated average sediment bulking rate is 0.2 yd^3 per linear foot of channel.

Two channel profiles at elevations 7920 and 7980 feet were measured along straight reaches to get rough estimates of peak flow. Using relatively low debris-flow velocities of 5 to 10 feet per second (Costa, 1984), peak-flow estimates range from 555 to 1110 cubic feet per second at elevation 7980 feet, and 680 to 1360 cubic feet per second at elevation 7920 feet.

The Wandin Campground debris flow was deposited in three thin lobes (figure 1). Two lobes were deposited on the upper fan and a third lobe was deposited on the lower fan in the campground. On the fan head the flow exceeded the alluvial-fan-channel capacity and avulsed part of the flow south out of the channel. The remaining flow continued down the channel, blocked the culvert under the road (figure 7), and then flowed through the campground. The three lobes have a combined volume of 1700 yd^3 and an area of 1.1 acres (table 1). All deposits are 1 foot or less in thickness. The west edge of the farthest downslope lobe extends off the alluvial fan toe onto a small stream terrace. The flow has a runout distance of 900 feet.

PROBABLE LANDSLIDE CAUSES

Based on conversations with U-Bar Ranch personnel, the debris flows occurred near the end of the spring snowmelt. Rapid snowmelt of an above-normal snowpack in late May and early June of 1983 triggered numerous shallow landslides that mobilized into debris flows in northern Utah (Anderson and others, 1984). Many of the 1983 flows were triggered near the end of the snowmelt, similar to the U-Bar Ranch and Wandin Campground debris flows.

Snowmelt seeps into the soils and is a major factor contributing to spring landslides (Chleborad, 1997). Mathewson and others (1990) found that snowmelt may also recharge shallow fractured bedrock aquifers and raise pore-water pressures beneath shallow soils, triggering landslides. Snowmelt also provides a more continuous supply of water over longer time periods than infiltration from rainfall (Wieczorek and Glade, 2005). The U-Bar Ranch and Wandin Campground debris flows likely triggered when snowmelt water infiltrated into the subsurface, perched on shale bedrock, raised the pore-water pressures in material overlying the shale, and triggered debris slides.

The south flank of the Uinta Mountains had an above-average snowpack at the onset of the 2005 snowmelt. The nearest snowpack, snowmelt, and temperature measurement site is at the Natural Resources Conservation Service (NRCS) Utah Snow Survey Mosby Mountain snotel site (NRCS, 2005a), 15 miles to the east. Even though the snotel site is east of the debris flows, the data can be used to evaluate the 2005 snowmelt pattern. Regional spring snowmelt air temperatures are broadly the same for a given elevation. The Mosby Mountain snotel site is at 9500 feet and similar in elevation to the U-Bar Ranch (9280 feet) and Wandin Campground (9320 feet) debris slides. On April 1, 2005, the Mosby Mountain snotel site had a snow-water equivalent of 25.7 inches, which is 212% of the 1977-2000 average (NRCS, 2005b).

The rate of snowmelt depends primarily on air temperature, which in turn relates to the timing of debris flows (Chleborad, 1997, 1998). A strong relationship exists between snowmelt landslide events and rising spring temperatures in the central Rocky Mountains (Chleborad, 1997; Chleborad and others, 1997). Figure 10 is a plot of daily snowmelt and average daily temperature at the Mosby Mountain snotel site. An average of 1.5 inches of water per day melted from May 16 through 27, 2005, a 12-day period of rapid snowmelt. This melt period also corresponds to a significant increase in average daily temperature. The site melted out on May 27, 2005.

Chleborad and others (1997) used a 6-day moving average of daily maximum air temperature with an optimum threshold of 58°F or higher for anticipating the onset of snowmelt-generated landslides. Their study concluded that most snowmelt-triggered landslides occur within two weeks after the first yearly exceedance of this threshold. Figure 11 shows the 6-day moving average of daily maximum temperature at the Mosby Mountain snotel site. The first occurrence of the 6-day moving average of daily maximum temperature at or greater than 58°F is on May 22, 2005. The U-Bar Ranch and Wandin Campground debris flows triggered on May 25 and 26, 2005, three to four days after reaching the threshold, suggesting that these landslides triggered in a similar manner to other snowmelt-generated landslides studied by Chleborad. Since these landslides fall within the Chleborad (1997) temperature threshold and anticipated landslide movement window, this method could be used to anticipate timing of future snowmelt-generated debris flows in the area.

HAZARD ASSESSMENT

Debris flows are fast-moving slurries of mud, rocks, and debris that travel down drainage channels. Debris flows are particularly dangerous to life and property because they travel fast, destroy and bury objects in their paths, and often strike without warning. On June 10, 1965, seven people died in Palisade Campground at night in their trailer when a debris flow in Sheep Creek destroyed the campground (Sprinkel and others, 2000). Sheep Creek is about 35 miles northeast of the Uinta Canyon debris flows. This case illustrates that debris flows can travel fast and people sleeping in campgrounds have little chance to evacuate. The demolished guest cabin at U-Bar Ranch also demonstrates the destructive power of debris flows.

Based on findings in this investigation, future debris flows will continue to run out and deposit sediment on the alluvial fans occupied by U-Bar Ranch and Wandin Campground. Both snowmelt or intense rainfall could trigger future debris flows. Ample sediment is present both in debris slide areas and in drainage channels to produce debris flows as large as or larger than the 2005 flows. Field and aerial-photograph observations of debris-slide-source areas and scoured channels indicate debris flows are frequent, as do young debris-flow deposits on the alluvial fans. The primary hazards associated with debris-flow processes on these fans are direct impact, sediment burial, and water damage. A site-specific debris-flow investigation is needed to understand the hazard and risk to individual structures at U-Bar Ranch and Wandin Campground and to assess possible risk-reduction measures and their costs. Giraud (2005) outlined methods for the geologic evaluation of debris-flow hazards on alluvial fans.

SUMMARY

The U-Bar Ranch and Wandin Campground debris flows triggered as shallow debris slides, transformed into debris flows, and traveled down channels bulking additional sediment until they flowed out onto alluvial fans and deposited the sediment. The U-Bar Ranch flow destroyed a cabin, partially buried another cabin, buried the ranch access road, and damaged water lines. The Wandin Campground flow blocked Forest Service Road 118, plugged a culvert, and damaged several campsites. These debris slides and debris flows are related to a period of rapid snowmelt of an above-average snowpack. The infiltrating of snowmelt water perched on shale bedrock, increased the pore-water pressure in overlying materials, and triggered the debris slides. These debris flows fall within the Chleborad (1997) temperature threshold and anticipated landslide movement window, indicating Chleborad's methods could be used to anticipate the timing of future snowmelt debris flows in the area. Future debris flows will continue to run out and deposit sediment on the alluvial fans occupied by U-Bar Ranch and

Wandin Campground. I recommend a debris-flow investigation to understand the hazard and the risk to individual structures at these sites and to evaluate potential risk-reduction measures.

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, UGS, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, UGS, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCES

Anderson, L.R., Keaton, J.R., Saarinen, T.F., and Wells, W.G., II, 1984, The Utah landslides, debris flows, and floods of May and June 1983: Washington, D.C., National Academy Press, 96 p.

Bryant, B., 1992, Geologic and structure maps of the Salt Lake City 1° x 2° quadrangle, Utah and Wyoming: U.S. Geological Survey Map I-1997, scale 1:125,000, 3 sheets.

Chleborad, A.F., 1997, Temperature, snowmelt, and onset of spring season landslides in the central Rocky Mountains: U.S. Geological Survey Open-File Report 97-27, 10 p.

—1998, Use of air temperature data to anticipate the onset of snowmelt-season landslides: U.S. Geological Survey Open-File Report 98-124, 16 p.

Chleborad, A.F., Ellis, W.L., and Kebler, D., 1997, Results of site investigation and instrumentation of the Keno Gulch landslide/debris-flow source area, Aspen, Colorado: U.S. Geological Survey Open-File Report 97-717, 17 p.

Costa, J.E., 1984, Physical geomorphology of debris flows, *in* Costa, J.E. and Fleisher, P.J., editors, Developments and applications of geomorphology: New York, Springer-Verlag, p. 268-317.

Giraud, R.E., 2005, Guidelines of the geologic evaluation of debris-flow hazards on alluvial fans in Utah: Utah Geological Survey Miscellaneous Publication 05-06, 16 p.

Harty, K.M., 1991, Landslide map of Utah: Utah Geological and Mineral Survey Map 133, 28 p. pamphlet, scale 1:500,000.

Herron, D., 2005, Field report – Uinta Canyon slope stability: Roosevelt, Utah, unpublished Ashley National Forest, Duchesne Ranger District report, 3 p.

Laabs, B.J.C., and Carson, E.C., 2005, Glacial geology of the southern Uinta Mountains, *in* Dehler, C.M., Pederson, J.L., Sprinkel, D.A., and Kowallis, B.J., editors, Uinta Mountain geology: Utah Geological Association Publication 33, p. 235-253.

Mathewson, C.C., Keaton, J.R., and Santi, P.M., 1990, Role of bedrock ground water in the initiation of debris flows and sustained post-flow stream discharge: Bulletin of the Association of Engineering Geologists, v. 27, no. 1, p. 73-83.

Natural Resources Conservation Service, 2005a, Current water year data: Online, http://www.ut.nrcs.usda.gov/snow/data/current.html, accessed September 7, 2005.

—2005b, Current water year data: Online, http://www.wcc.nrcs.usda.gov/cgibin/snow_rpt.pl?state=utah, accessed September 7, 2005.

Pierson, T.C., and Costa, J.E., 1987, A rheologic classification of subaerial sediment-water flows, *in* Costa, J.E., and Wiezorek, G.F., editors, Debris flows/avalanches: Geological Society of America, Reviews in Engineering Geology, Volume VII, p. 1-12.

Sprinkel, D.A., Park, B., and Stevens, M., 2000, Geology of Sheep Creek Canyon geological area, northeastern Utah, *in* Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson P.B., editors, Geology of Utah's parks and monuments: Utah Geological Association Publication 28, p. 517-528.

TerraServer USA, 2005, U.S. Geological Survey 1993 aerial photographs: Online, http://terraserver.microsoft.com/image.aspx?T=1&S=12&Z=12&X=714&Y=5624&W=3&qs=%7cvernal%7cut, accessed December 2, 2005.

Uinta Basin Standard, 2005, Mudslide destroys cabin: Roosevelt, Utah, newspaper article, v. 91, no. 22, p. 24.

Utah Automated Geographic Reference Center, 2005, National agriculture imagery program aerial photos: Online, http://agrc.utah.gov/agrc_sgid/naip.html, accessed December 2, 2005.

Wieczorek, G.F., and Glade, T., 2005, Climatic factors influencing occurrence of debris flows, *in* Jakob, M. and Hungr, O., editors, Debris-flow hazards and related phenomena: Chichester, UK, Springer-Praxis, p. 325-362.

Table 1. *Basin, landslide, fan, and deposit characteristics for the Uinta Canyon debris flows.*

Debris Flow	Basin Area mi^2 (acres)	Basin Relief ft	Longest Channel ft	Relief Ratio* %	Debris Slide Head Elevation ft	Debris Slide Volume yd^3	Average Fan Gradient degrees	Fan Head Elevation ft	Fan Runout Distance ft	Fan Deposit Volume yd^3	Fan Deposit Area acres
U-Bar Ranch north	0.12 (79)	2240	4200	53	na	na	10.1	8080	960	500	0.9
U-Bar Ranch	0.03 (21)	1520	2600	58	9280	5500	11.6	7920	750	7000	1.2
Wandin Campground	0.05 (29)	1280	2900	44	9320	1000	8.5	7880	900	1700	1.1

*Relief ratio is the basin relief divided the longest channel extended to the drainage divide

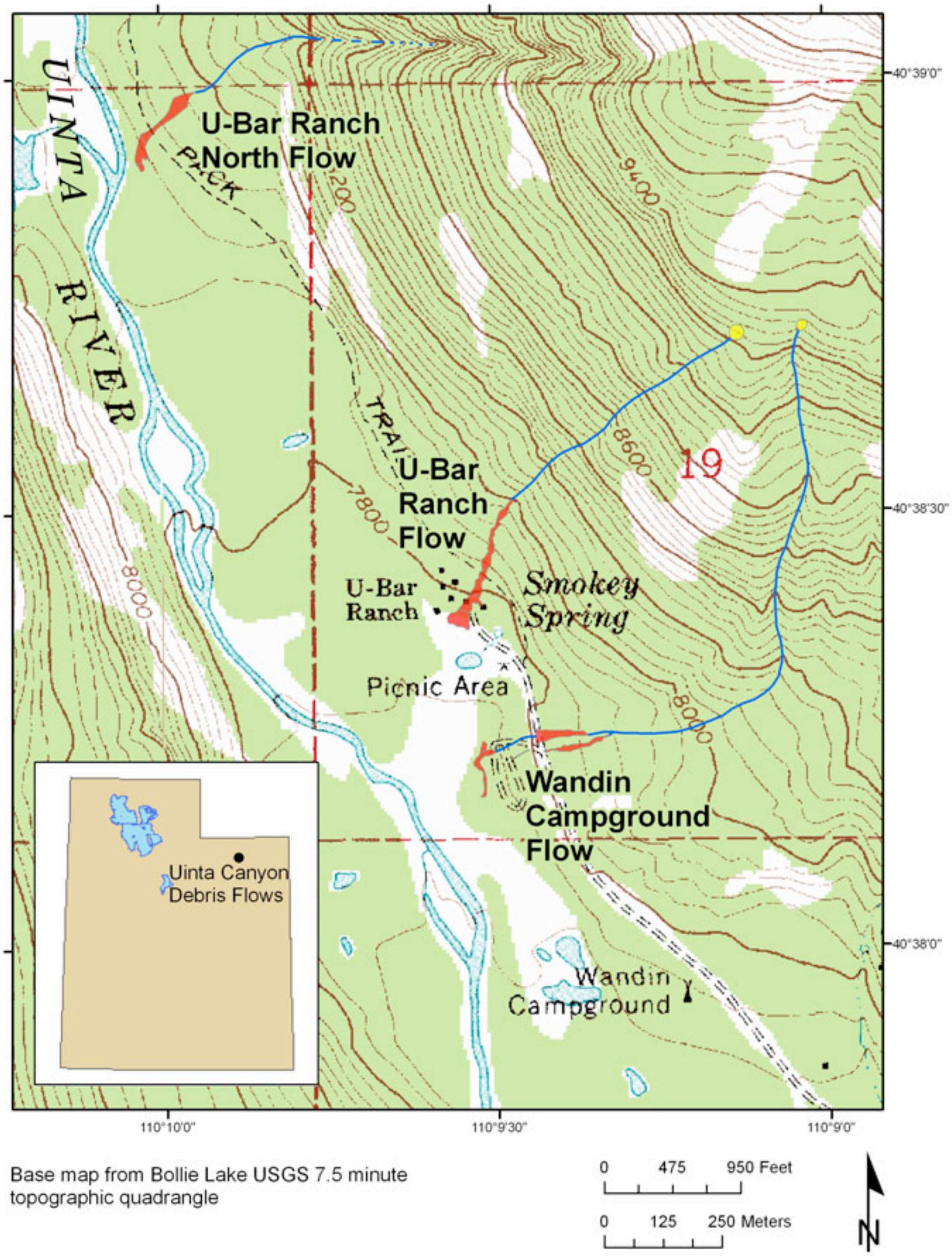


Figure 1. *Location of the Uinta Canyon debris flows: U-Bar Ranch North, U-Bar Ranch, and Wandin Campground. The debris slides are shown in yellow, debris-flow paths in blue, and debris-flow deposits in red.*

Figure 2. *The roof of the Chepta cabin lies on the toe of the U-Bar Ranch debris-flow deposit. The cabin roof is approximately 180 feet downslope of the original cabin position. The U-Bar Ranch lodge (building with green metal roof) is left of the deposit. Photo by Dave Herron, U.S. Forest Service.*

Figure 3. *The U-Bar Ranch debris-flow deposit. The deposit is 4 to 5 feet thick and is blocking the access road into the ranch. The mattress and cut logs on the road are from the demolished Chepta log cabin. Photo by Dave Herron, U.S. Forest Service.*

Figure 4. *View looking west down the U-Bar Ranch debris slide toward the Uinta River, showing smaller slide blocks within the slide and weathered shale adjacent to the slide. The travel angle from the debris slide to ranch lodge (building with green roof in center of photo) is 27°. Photo by Dave Herron, U.S. Forest Service.*

Figure 5. *Left-bank channel levee of U-Bar Ranch debris flow at 8800 feet elevation. The levee is deposited on a 27-30° slope indicating a viscous phase of the debris flow. Photo by Dave Herron, U.S. Forest Service.*

Figure 6. *View looking west down the lower U-Bar Ranch flow path. Maximum flow depth shown by mud lines and boulder impact on tree trunks is 4 to 5 feet. The deposit toe is just beyond the red car. Photo by Dave Herron, U.S. Forest Service.*

Figure 7. *Looking up the alluvial-fan channel from Forest Service Road 118 and Wandin Campground. The Wandin Campground flow plugged the culvert at the bottom of the photo and flowed across the road into the campground. The mud line on the large boulder indicates a maximum flow depth of 3.8 feet. This large boulder indicates the size of boulders transported by previous debris flows.*

Figure 8. *Wandin Campground debris-slide main scarp. The scarp is 20-25 feet high and exposes unconsolidated till and colluvium. A spring is flowing over shale bedrock in the lower part of the photo. Photo by Dave Herron, U.S. Forest Service.*

Figure 9. *Wandin Campground debris-flow channel plug at 8880 feet elevation. The two light-colored areas without vegetation in the upper part of the photo are debris slides. The debris slide on the left is the source of the 2005 Wandin Campground debris flow. The debris slide on the right occurred between 1993 and 2004.*

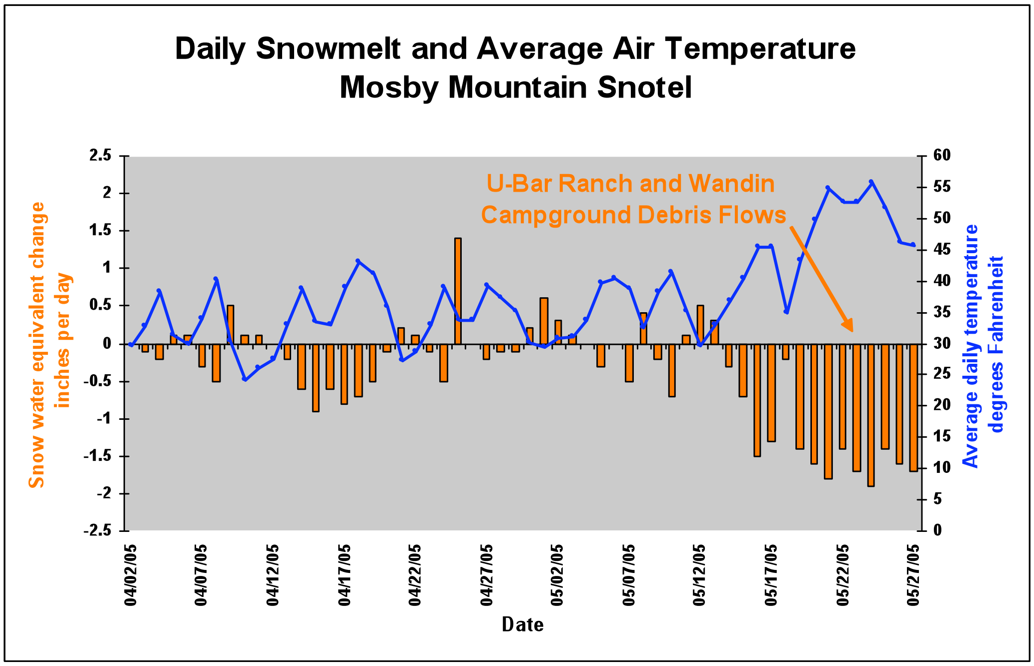


Figure 10. *Daily snowmelt and average daily temperature at the Mosby Mountain snotel site. From May 16 to May 27, 2005, an average of 1.5 inches of water per day melted from the snowpack.*

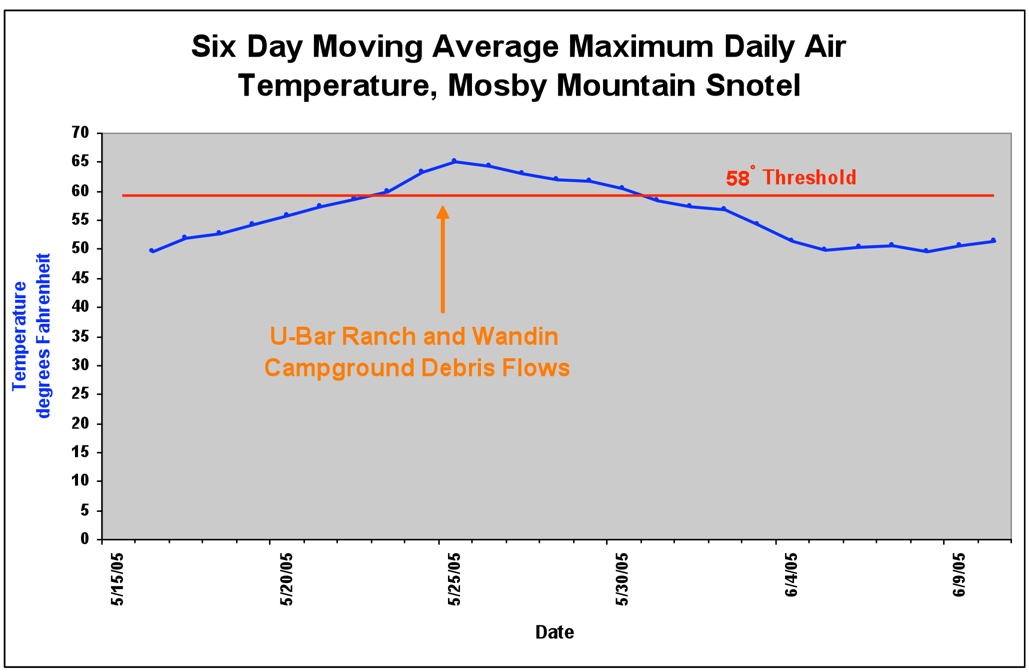


Figure 11. *Six day moving average maximum daily air temperature at the Mosby Mountain snotel site. The U-Bar Ranch and Wandin Campground debris flows occurred five days after the 58°F threshold was reached at the Mosby Mountain snotel.*

Utah Geological Survey Technical Report

Project: Preliminary assessment of two landslides in 2005 between a sewer line and Gordon Creek, Mountain Green, Morgan County, Utah			
By: F.X. Ashland, P.G.	Date: March 13, 2006	County: Morgan	
USGS Quadrangles: Snow Basin (1344)	Section/Township/Range: Secs. 22 and 27, T. 5 N., R. 1 E.		
Requested by: Incident Investigation	Date report received at UGS:		Technical Report number: 06-04 (GH-12)

INTRODUCTION

Beginning on June 8, 2005, Utah Geological Survey (UGS) geologists conducted an investigation of two landslides between a sewer line northeast of Creekside Drive and Gordon Creek in the Highlands West subdivision in Mountain Green (figures 1 and 2). The purpose of the investigation was to assess the potential hazard to the sewer line and creek and to determine the state of activity of the two landslides. This report presents the conclusions of this investigation. Our preliminary concerns and recommendations related to the potential threat posed by the two landslides to the sewer line were sent to Morgan County in a letter dated June 17, 2005. During this investigation, I provided periodic updates on movement monitoring results and field observations to Morgan County Engineer Austin Rowser. A representative of the Mountain Green Sewer Improvement District was informed of the landslides at a public meeting on June 30, 2005.

CONCLUSIONS AND RECOMMENDATIONS

The two small landslides pose a direct threat to the sewer line if upslope enlargement of the landslides occurs or if the main scarps of the landslides grow to sufficient height to initiate local failure. Damage to the sewer line poses an environmental hazard if sewage is discharged into Gordon Creek, a tributary of the Weber River. Upslope expansion of the southernmost landslide may also threaten Creekside Drive and part of a residential lot. Future downslope movement of debris, particularly in the southern of the two landslides, may divert Gordon Creek or create a small temporary blockage. Minor erosion and/or sedimentation may accompany diversion or blockage of the creek.

The UGS recommends that the sewer company regularly monitor the condition of the buried sewer line for potential leakage and develop a contingency plan if sewage is discharged from a break upslope of the creek. We also recommend that the sewer company hire a professional geotechnical engineering firm to assess potential landslide stabilization options.

Ideally, stabilization efforts should be conducted in the dry summer months of June through August, in the absence of an emergency situation that requires more immediate action.

GEOLOGY

The sewer line is underlain by a complex of late Holocene and older landslides in the underlying Tertiary Norwood Tuff (Kaliser, 1972; Coogan and King, 2001). The Norwood Tuff consists of tuffaceous sedimentary rocks and crops out along the northwest-trending ridge crest southwest of Creekside Drive. The ridge is flanked on three sides (north, east, and south) by landslides that formed in the tuff and Quaternary surficial deposits that formed on the tuff. To the west, the Norwood Tuff is in contact with the underlying (older) Tertiary Wasatch Formation that consists mostly of conglomerate and sandstone. The bedding in these formations dips moderately to the east in the Creekside Drive area. Soils developed in residual, colluvial, and landslide deposits derived from the Norwood Tuff are commonly expansive.

LANDSLIDE DESCRIPTIONS

The two small landslides occur at separate locations on the northeast-facing slope between the buried sewer line and Gordon Creek, north of Creekside Drive in the Highlands West subdivision in Mountain Green (figure 2). In this report we refer to the landslides as the Southern and Northern Sewer-Line landslides. Table 1 summarizes the approximate dimensions and average slope of the two landslides.

Table 1. *Summary of approximate dimensions and average slope of sewer-line landslides.*

Location of slide	Length (feet)	Width (feet)	Slope (percent)
Southern	250	47 head; 60 toe	25
Northern	150	139 head; 177 (lower slide)	32-39

The Southern Sewer-Line landslide (figure 3) is on a relatively flat slope (about 25 percent) between the sewer line and Gordon Creek. The head of the landslide included embankment fill from the sewer-line corridor, but most of the landslide occurred on a natural slope that had been partly disturbed by emplacement of a drainpipe between the sewer line and the creek. Broken pieces of the drainpipe were exposed on the upper north flank of the landslide and had been thrust to the surface in the lower part of the slide. However, most of the lower part of the landslide is in undisturbed native soils. On June 8, the main scarp exceeded seven feet (2 m) in height (figure 3A), but continued offset throughout the remainder of 2005 increased the scarp height slightly. The main scarp cut across the eastern half of the sewer-line corridor. Landsliding displaced the downslope side of the sewer-line embankment, but the sewer line had not been exposed in the main scarp face as of November 1. A house at 6110 N. Creekside Drive is to the west-northwest of the head of the landslide, but not directly upslope.

The toe of the landslide overrode the active flood plain of Gordon Creek. The downslope tip of the slide was as close as 3.4 feet (1 m) from the southwest edge of the incised creek on October 12, 2005 (figure 3B). A wooden bridge across the creek, used for a trail crossing, is directly downslope of the landslide. Internal deformation features include an east-trending graben in the lower part of the landslide (figure 3D). A broken and displaced drainpipe in the lower part of the landslide (figure 3E) indicated about 3.9 feet (1.2 m) of shortening as shown by the downslope distance the upper pipe was displaced at the break.

The Northern Sewer-Line landslide (figure 4) occurred in a location where Gordon Creek cuts into the base of a relatively steep slope below the sewer line. The landslide is crescent shaped, widening in a downslope (eastern) direction. On June 8, the main scarp zone of the landslide was within a few feet of the downslope edge of the sewer-line corridor. The main scarp zone (figure 4A) consisted of two parallel scarps separated by about 3 to 4 feet (1-1.2 m) with roughly equal amounts of offset. The maximum offset on the upper (main) scarp on June 8 was about 4 feet (1.2 m). The toe of the landslide was being directly eroded by Gordon Creek on June 8 (figure 4B). In the lower part of the landslide, shallow sliding into the creek had removed all surficial soils and vegetation. As in the Southern Sewer-Line landslide, a drainpipe was exposed in both the upper and lower parts of the slide. The pipe was broken in the lower part of the landslide.

LANDSLIDE MOVEMENT HISTORY AND POTENTIAL FOR FUTURE MOVEMENT

Most of the landslide movement in 2005 preceded our initial site visit on June 8. Local residents indicated that movement of the two slides initiated earlier in the year, roughly coincident with the end of the snowmelt in the area. In early June, the UGS installed survey stakes to measure landslide movement across the main scarp zone of each landslide (figure 5). At the Southern Sewer-Line landslide, movement continued throughout the latter part of the year (June 10, 2005, through January 13, 2006). The plot shows a gradual decrease in the rate of movement in the latter part of June and movement at a relatively steady rate subsequently. Total movement (stretching) during the measurement interval exceeded 4 inches (10 cm) and was accompanied by additional offset on the main scarp (figure 2F). At the Northern Sewer-Line landslide, the rate of movement slowed in the latter part of June in a similar manner as at the Southern Sewer-Line landslide, but movement suspended by the end of the month.

Given the excess precipitation in the area in 2005 (6.4 inches of excess precipitation between September 2004 and August 2005 at the National Weather Service Huntsville station), ground-water levels in landslide deposits in the slope below the sewer line likely remained high (shallow) at the end of 2005. Continued movement of the Southern Sewer-Line landslide throughout the latter part of 2005 also suggests sustained high ground-water levels. Thus, the necessary ground-water-level rise to reactivate the two landslides, or to cause a rapid increase in the rate of movement of continuously moving slides, may be possible even with a below-normal snowpack.

FIELD METHODS

Landslide boundaries and ground deformation features were mapped using handheld global positioning system devices with an approximate accuracy range of between 10 and 30 feet at the time of the fieldwork. Maps of the two landslides and dimensions listed in this report were derived using this method. Short-term variation in location was tested using duplicate measurements from the same device and was typically less than 2 feet.

ACKNOWLEDGMENTS

Michael Kirschbaum (formerly UGS), Greg McDonald, and Richard Giraud (both UGS) assisted with the fieldwork. Lucas Shaw (UGS) provided assistance in creating several of the figures in this report.

LIMITATIONS

REFERENCES

Coogan, J.C., and King, J.K., 2001, Geologic map of the Ogden 30' x 60' quadrangle: Utah Geological Survey Open-File Report 380, scale 1:100,000.

Kaliser, B.N., 1972, Geological hazards in Morgan County with applications to planning: Utah Geological and Mineralogical Survey Bulletin 93, 56 p.

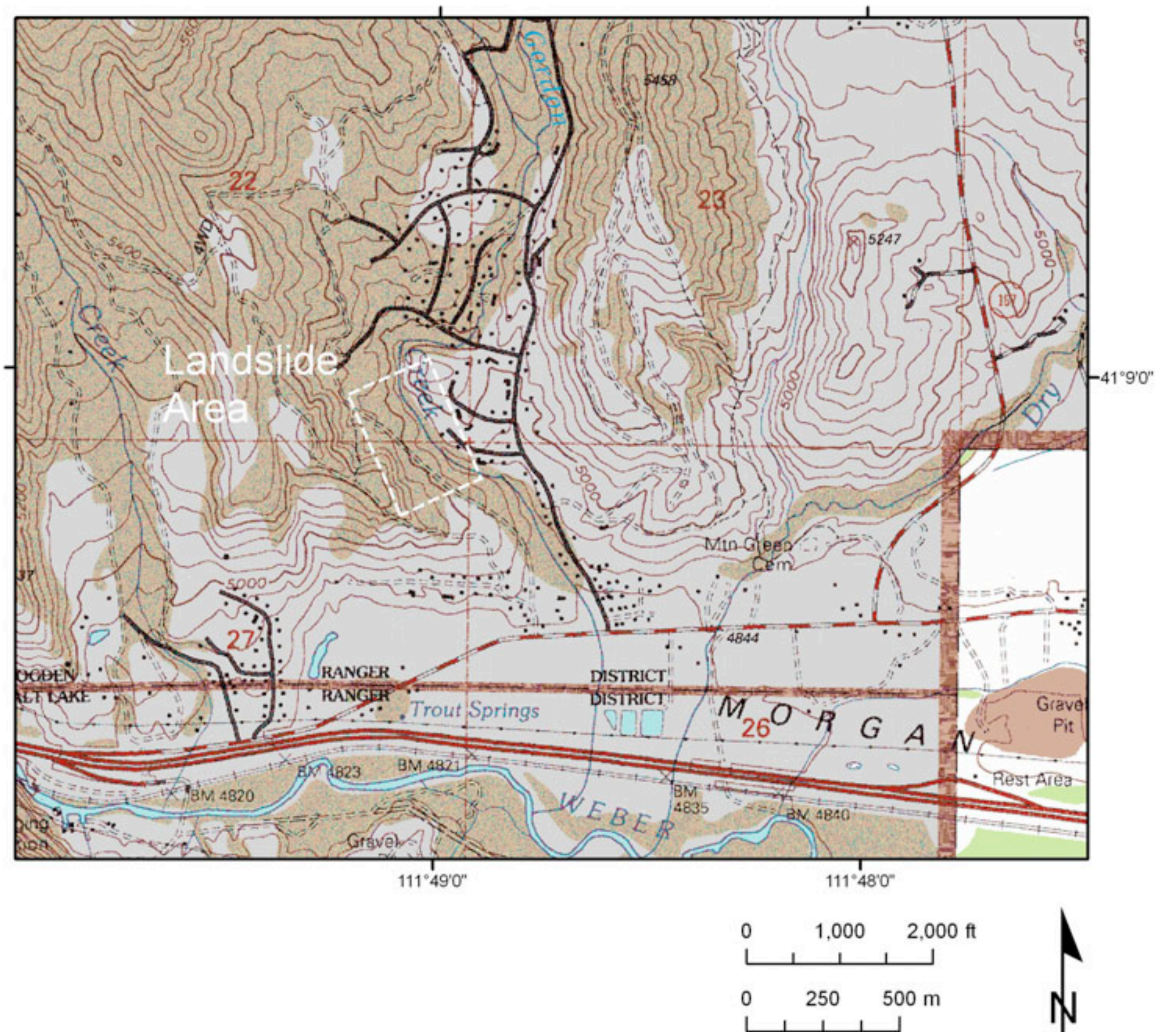


Figure 1. *Location map of landslide area abutting sewer line in the Highlands West subdivision northeast of Creekside Drive in Mountain Green. Base from U.S. Geological Survey Snow Basin 7-1/2' quadrangle map.*

***Figure 2**. Aerial photograph showing approximate locations of two small landslides between Gordon Creek and buried sewer line northeast of Creekside Drive in Mountain Green. Northern Sewer-Line (NSL) and Southern Sewer-Line (SSL) landslides shown. Locations and boundaries of landslides approximate.*

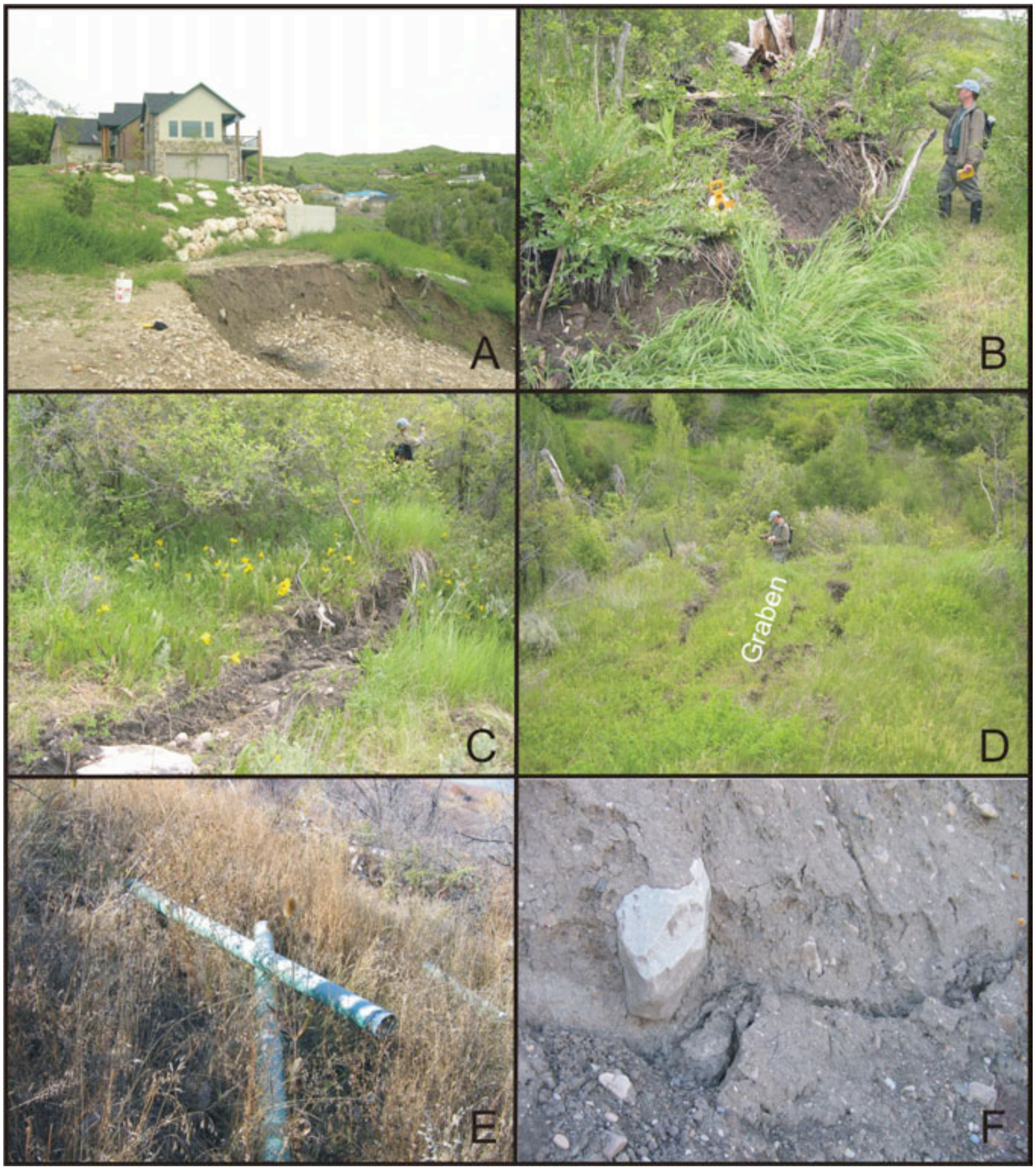


Figure 3. *Southern Sewer-Line landslide. (A) View to the northwest of main scarp of the Southern Sewer Line landslide. Landsliding destroyed the eastern part of the sewer corridor embankment, but had not exposed the sewer pipe as of January 13, 2006. House at 6110 N. Creekside Drive visible in background. (B) View to the northwest of toe of the landslide. Lower toe thrust/fold is approximately 5 feet high. West edge of Gordon Creek (not visible just to the right of the edge of the photograph) was only 3.4 feet from toe on October 12, 2005. (C) View downslope of right-flank shear cutting across natural slope. (D) View downslope of east-trending graben in lower part of slide. (E) Broken drainpipe in lower part of slide. Upslope pipe displaced about 3.9 feet downslope. (F) Recent offset of main scarp on November 1, 2005, due to continued movement of slide in latter part of 2005.*

Figure 4. *Northern Sewer-Line landslide. (A) View to the south-southwest of main scarp zone of the landslide. Top of main scarp was only a few feet from the east edge of the sewer-line corridor. (B) View to the south of toe of the landslide along Gordon Creek. Note drainpipe exposed along south flank of landslide.*

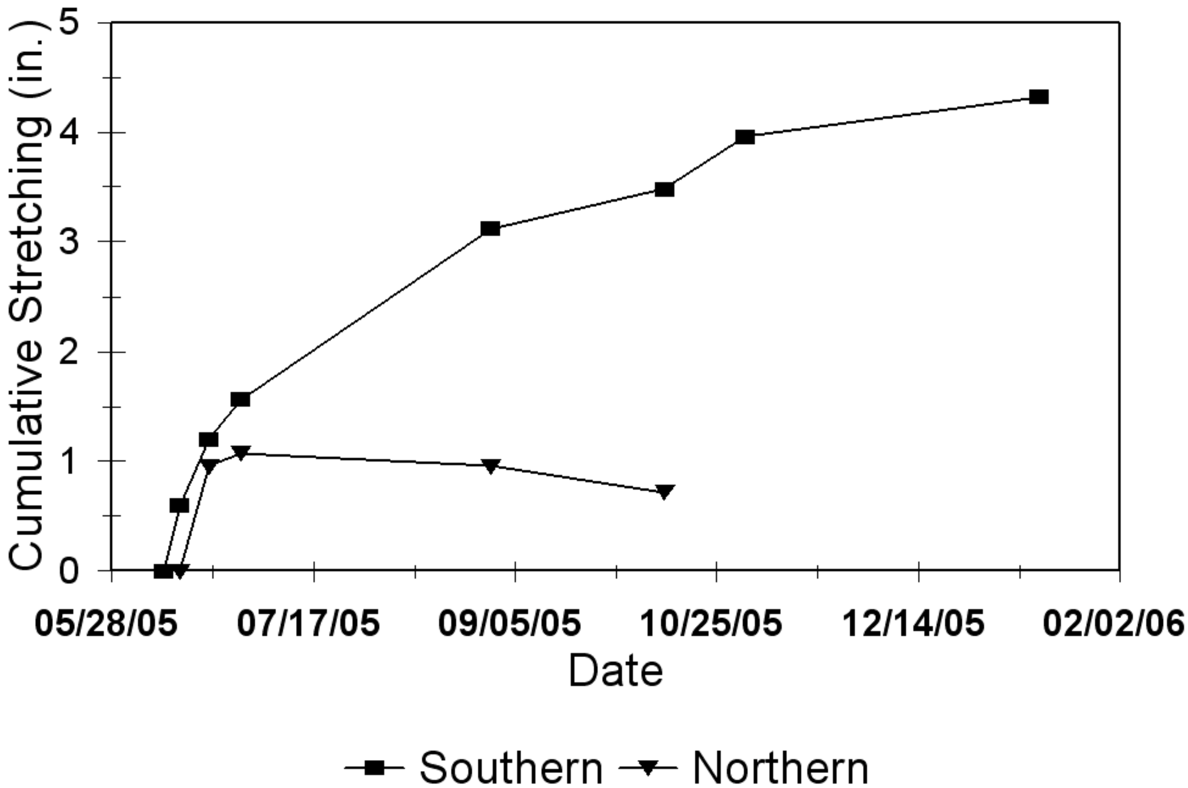


Figure 5. *Landslide movement and ground deformation between June 10, 2005 and January 13, 2006. Plot shows continuous movement (stretching) at survey stake station across main scarp of the Southern Sewer-Line landslide (squares). The rate of movement slowed in late June, but movement continued at a relatively steady rate through January 13, 2006. At the Northern Sewer-Line landslide (triangles), movement continued through most of June, but likely suspended by the end of the month. Subsequent minor shortening across main scarp zone is likely due to collapse of extensional fissures separating soil blocks in zone.*

Utah Geological Survey

Project: Investigation of the June 3, 2005, landslide-generated Black Mountain debris flow, Iron County, Utah			
By: Richard E. Giraud, P.G., & William R. Lund, P.G.	Date: 03-16-06	County: Iron	
USGS Quadrangles: Webster Flat (196)	Section/Township/Range: NE1/4NW1/4 section 24, T. 37 S., R. 10 W., SLBL&M		
Requested by: Incident Investigation			Job number: 06-05 (GH-13)

INTRODUCTION

On the morning of June 3, 2005, a pre-existing landslide on the north side of Black Mountain in southeastern Iron County reactivated and generated a large debris flow, which flowed approximately 1.6 miles down an unnamed stream drainage before encountering Utah State Route 14 (SR-14) and Crow Creek (figure 1). Lund and others (2005) made a reconnaissance on June 4, 2005, to document the event, determine its source, and evaluate the resulting damage. The debris flow buried a 100-foot-long section of SR-14 with mud, boulders, and large trees, and then continued down Crow Creek (Cedar Canyon) causing erosion and flood damage to SR-14 at several locations and blocking culverts with large tree trunks and gravel-to boulder-size debris (figure 1) (Lund and others, 2005). Water from Crow Creek and its tributaries eventually diluted the debris flow and transformed it into a sediment-laden stream flood. SR-14 was closed for a week for cleanup and repair. In this report, we designate the source landslide as the Black Mountain landslide, and the landslide-generated debris flow as the Black Mountain debris flow.

The purpose of this investigation was to examine the source landslide, determine its triggering mechanism, quantify the volume and geologic characteristics of the resulting debris-flow deposits, and evaluate the potential for future large debris flows. Other than the SR-14 right-of-way, the landslide and debris-flow deposits are on private land. Landowners selectively logged the north side of Black Mountain in the mid-1980s.

CONCLUSIONS AND RECOMMENDATIONS

Based on our investigation of the Black Mountain landslide and debris flow, we conclude the following:

- The lower part of a pre-existing landslide on the north side of Black Mountain reactivated and catastrophically released into a steep, narrow mountain channel. Rapid movement down the channel transformed the landslide into a debris flow. Upon exiting the channel, the debris flow quickly traveled down a low-gradient, unnamed stream valley where it scoured additional material from the stream channel and removed mature trees. Upon reaching SR-14, the debris flow overtopped the highway and then continued down Crow Creek and Cedar Canyon. Water from Crow Creek and its tributaries eventually transformed the debris flow into a sediment-rich flood that eroded the highway embankment and blocked culverts with tree trunks and sediment.

- Rapid melting of a 210%-of-average 2005 snowpack initiated landslide movement. Infiltration of snowmelt water increased pore-water pressure in the pre-existing landslide and triggered movement.

- The lower landslide released an estimated 50,000 to 60,000 cubic yards (yd^3) of material into the steep, narrow mountain channel. We estimate that the remaining upper landslide mass perched above the channel on Black Mountain contains an additional 155,000 to 160,000 yd^3 of material.

- Timber harvest on Black Mountain likely had little influence on the stability of the pre-existing landslide because of the deep rupture surface.

- Based on snow climate, steep gradient, and low-strength material along the landslide rupture surface, we believe that future downslope movement of the remaining Black Mountain landslide mass is highly probable. Release of additional landslide material into the steep, narrow mountain channel could generate future large debris flows. The 2005 landslide enlarged the pre-existing Black Mountain landslide, and future landslide movement could do the same, making even more material available to generate future debris flows.

- The Black Mountain debris-flow deposit has different characteristics in the upper and lower parts of the unnamed stream valley above SR-14. The upper valley deposit is wide, has distinct tree trim lines, and has a rough surface, whereas the lower valley deposit is narrow, lacks tree trim lines, and has a smooth surface.

- Based on the size of the trees removed along the upper part of the unnamed stream valley, a debris flow similar in size to the 2005 event has likely not occurred in that drainage for 100 years or longer. However, investigation and age determination of debris-flow deposits in the unnamed valley is needed to estimate the long-term debris-flow frequency.

- Based on pre-2005 debris-flow deposits observed in the field and on aerial photographs, small-volume debris flows in the upper part of the unnamed stream valley below the narrow mountain channel are relatively frequent.

- The triggering event for the Black Mountain landslide and debris flow follows a pattern similar to other snowmelt-generated landslides studied by Chleborad (1997). The 2005 snowmelt pattern can be used to anticipate reactivation of the Black Mountain landslide and possible future debris flows.

- The primary hazard associated with future large debris flows in the unnamed stream valley is damage to SR-14 caused by direct impact and sediment burial. Hazards along Crow Creek and Cedar Canyon (Coal Creek) include flooding, erosion, and creek and culvert blockage.

- Building structures in the bottom of the unnamed stream valley is not recommended unless the debris-flow hazard is reduced to an acceptable level.

- The short-term debris-flow hazard is controlled by reactivation of the Black Mountain landslide and its ability to release large volumes of material into the steep mountain channel.

- We recommend a detailed investigation to determine possible highway risk-reduction measures and their cost.

DESCRIPTION AND GEOLOGIC SETTING

Gregory (1950) mapped the bedrock geology on the north side of Black Mountain. Quaternary basalt caps the mountain, and Gregory (1950) showed the basalt is underlain, from youngest to oldest, by the Kaiparowits, Wahweap, and Straight Cliffs Formations. All three formations are of Cretaceous age. Gregory (1950) showed the area where the Black Mountain landslide occurred as underlain by the Kaiparowits Formation. Moore and Straub (2002) redefined the Upper Cretaceous bedrock units in Cedar Canyon, but they did not remap the north side of Black Mountain. Moore and others (2004) mapped the Navajo Lake quadrangle east of Black Mountain, and their stratigraphic column shows the informal "formation of Cedar Canyon" (Paleocene to Upper Cretaceous) above the Straight Cliffs, rather than the Wahweap and Kaiparowits Formations. Gregory (1950) and Moore and others (2004) described the Kaiparowits Formation and formation of Cedar Canyon, respectively, as mostly sandstone with interbeds of conglomerate, mudstone, and shale. Moore and others (2004) mapped numerous landslides within the formation of Cedar Canyon east of Black Mountain. Gregory (1950) showed the steep, narrow mountain channel (figure 2) directly below the Black Mountain landslide as underlain by the Straight Cliffs and Wahweap Formations.

Surficial geologic deposits on the north side of Black Mountain consist of old landslide deposits, debris-flow deposits, basalt talus, colluvium, and stream alluvium. Based on mapping by Moore and others (2004) in the Navajo Lake quadrangle, these surficial deposits generally range in age from late Pleistocene to Holocene. Colton and others (1986) mapped a landslide on the north side of Black Mountain; however, that landslide is much larger than the 2005 Black Mountain landslide because their mapping included the large basalt talus deposit that lies west of the Black Mountain landslide. The pre-2005 landslide is evident on the 1998 U.S. Geological Survey (USGS) (TerraServer USA, 2005) and 2004 National Agriculture Imagery Program

(NAIP) (Utah Automated Geographic Reference Center, 2005) aerial photos, as are young debris-flow deposits immediately below the steep, narrow mountain channel where it empties into the unnamed stream valley. We identified two small probable 2005 landslides near the top of the talus deposit.

BLACK MOUNTAIN LANDSLIDE

The Black Mountain landslide consists of two distinct parts, an upper and a lower landslide (figure 2). The upper landslide (figures 2, 3) is approximately 560 feet long, 370 feet wide, and covers an area of 5.6 acres. On June 3, 2005, the lower landslide catastrophically released into the steep, narrow mountain channel (figures 2, 4), and quickly transformed into the Black Mountain debris flow. The upper landslide moved downslope but did not release catastrophically and remains perched on the mountain slope. A large evacuated area now exists where the lower landslide was formerly located (figure 5). We estimate that the lower landslide was 450 feet long, 200 feet wide, and 1.6 acres in area, and the volume of landslide material released into the mountain channel was between 50,000 and 60,000 cubic yards (yd^3). An estimated 155,000 to 160,000 yd^3 of material remains in the upper landslide, which is now perched above the narrow channel (figure 6). Based on the position of the pre-existing landslide's main scarp as indicated on 2004 aerial photos, the main scarp of the upper 2005 landslide extended an additional 400 feet upslope and slightly to the west. Both the upper and lower landslides have steep gradients of 43% (23.3°) and 60% (30.9°), respectively. The physical characteristics of the 2005 landslide are shown in table 1.

The upper landslide has a very rough surface and consists of clay-rich debris with angular cobbles and boulders of basalt and sandstone (figures 3, 7). Where exposed downslope from the main scarp of the upper landslide, the rupture surface beneath the upper part of the upper landslide is shallow and movement only involved the upper few vertical feet of slope (figure 7). The rupture surface dipped from 30 to 34^{o}, and formed in weathered, soft, low strength, shale and mudstone. However the rupture surface becomes significantly deeper downslope, and we estimate it was 40 to 50 feet deep where the lower landslide catastrophically failed into the mountain channel (figures 5 and 6). Timber harvest and subsequent loss of root strength likely had little influence on landslide stability because of the deep rupture surface. Several springs were present in the evacuated area and were discharging from the exposed rupture surface.

Field observations and Utah Highway Patrol aerial reconnaissance photos taken a few hours after the landslide on June 3, 2005, indicate recent landslide movement. The photos show a fresh main scarp with slickensides lacking snow cover surrounded by an approximate 3-foot-thick snowpack (figure 3). At the top of the main scarp, the landslide pulled away leaving a sharp break in the snowpack that resembles a snow avalanche crown line. Early news reports stated that the debris flow may have been a snow avalanche, but the photos show that landslide movement created the crown line in the snowpack. Shearing along the landslide's left flank churned up talus blocks and landslide material onto the snow surface (figure 3), which also demonstrates recent movement.

BLACK MOUNTAIN DEBRIS FLOW

Once the lower landslide released into the steep, narrow mountain channel, rapid mixing of the landslide mass quickly transformed it into a debris flow. As it proceeded down the 1200-foot-long channel, the debris flow scoured additional debris from the channel bottom and sides before exiting into the more gently sloping unnamed tributary stream valley to Crow Creek. The debris flow continued down the valley, scouring additional sediment, taking out trees, and depositing large volumes of sediment (figure 2). The debris flow plugged the box culvert under SR-14 with sediment and then overtopped the road, depositing sediment and blocking the highway (figure 8). Lund and others (2005) discussed the damages downstream in Crow Creek and Cedar Canyon.

The steep, narrow mountain channel played an important role in the formation of the debris flow by promoting mixing and acceleration of landslide material released into the channel (figure 4). The channel is a distinct topographic feature at the head of the unnamed stream valley (figure 2). The channel has an average gradient of 45% (24°) but steeper parts have gradients up to 103% (46°). The channel also has several small, short vertical drops, which accelerated mixing of material moving down the channel. Snowmelt water in the narrow channel and in the unnamed stream valley below was incorporated into the flowing mass. Upon exiting the channel, the rapidly moving debris flow superelevated (climbed) up onto the east wall of the unnamed stream valley (figures 2 and 9). The debris flow then quickly traveled the 1.6 miles to SR-14 and Crow Creek. The long runout distance is due to the initial high flow velocity of the debris flow as it left the narrow mountain channel, and the V-shape of the unnamed valley which kept the flow confined as it moved down the relatively low gradient (12.5% [7°]) valley. If the debris flow had become unconfined, it likely would have quickly spread laterally, thinned, and deposited sediment, resulting in a shorter runout distance. The physical characteristics of the narrow channel and debris-flow deposits are shown in table 1.

The debris flow's behavior and depositional style were different in the upper and lower parts of the unnamed stream valley, and therefore, we mapped the deposits separately (figure 2). The upper valley deposit covers and obscures the pre-2005 flow topography and previous debris-flow deposits. The upper and lower valley debris-flow deposits are composed of gravel, sand, silt, and clay with boulders and cobbles of basalt and sandstone. The debris flow demolished a forest along the upper valley floor, and both upper and lower valley debris-flow deposits contain tree trunks and woody debris. Both matrix-supported and clast-supported textures were observed in the deposits.

The upper valley debris-flow deposit below the mountain channel is up to 550 feet wide and locally up to 10 feet thick (figure 9). Below an elevation of 8800 feet the deposit narrows and from 8440 to 8400 feet elevation a small lobe of material was deposited along the west edge of the valley (figure 2). The upper valley deposit has an average slope of 16% (9°), an estimated volume of 55,000 yd^3, and covers an area of 13.7 acres. The deposit thins downvalley and is only 1 to 2 feet thick immediately upstream from the lower valley deposit. The largest observed boulder in the deposit is 22 feet long (figure 10). The drainage channel along the upper deposit was locally scoured up to 30 feet deep; however, the original channel depth is unknown. Channel scouring incised into the 2005 debris-flow deposit, indicating that scouring was later in the debris-flow event. The upper deposit is wider and has a rougher surface than the lower deposit (figures 9, 11).

Along the upper-valley deposit margins, the debris flow removed mature, similar-aged conifer trees, and left distinct tree trim lines (figures 9, 10, 11). Based on their size, these trees were a minimum of 100 years old and likely were older (Burrows and Burrows, 1976), which suggests that a minimum of 100 years has passed since the last large debris flow in this drainage. We observed pre-2005 debris-flow deposits at an elevation of 8800 feet along the west margin of the 2005 deposit. Relatively young conifer trees 4 to 5 inches in diameter are growing on this deposit, which suggests that the deposit is relatively young and possibly related to a small-volume historical debris flow. On aerial photos, we observed young debris-flow deposits immediately below the steep, narrow mountain channel. These small-volume deposits likely represent relatively high frequency, low-volume flows that occur more frequently than large-volume flows.

The break between the upper and lower valley deposits is at an elevation of 8360 feet (figure 2). Compared to the upper valley deposit, the lower valley deposit is narrower, thinner, smoother, and lacks the demolished forest and tree trim lines (figure 12). The drainage channel was locally scoured up to 3 feet deep, but erosion from the lower valley did not add a significant volume of material to the debris flow. The lower valley deposit is generally 1 to 2 feet thick, has an average slope of 9% (5°), an estimated volume of 18,000 yd^3, and area of 12.9 acres.

A volume discrepancy exists between landslide volume that released into the mountain channel (50,000 to 60,000 yd^3), and the debris-flow deposit volume (73,000 yd^3) in the valley below. Part of this discrepancy is due to scouring of additional sediment from the steep, narrow mountain channel and from the stream channel in the upper part of the unnamed stream valley. A significant volume of tree trunks and woody material was also incorporated into the flow as it passed through the upper valley area. An undetermined amount of sediment was transported down Crow Creek, first as a debris flow and then, with the addition of more water, as a sediment-laden stream flood. Finally, the Utah Department of Transportation removed an estimated 20,000 yd^3 of sediment from various locations along the SR-14 right-of-way (Leslie Heppler, Utah Department of Transportation, verbal communication, 2005).

The Black Mountain debris flow differs from most other large historical landslide-generated Utah debris flows in topographic setting, sediment deposition, and origin of sediment. Most other debris flows started in short steep drainage basins, eroded sediment from steep drainage channels, and deposited sediment on alluvial fans. The Black Mountain debris flow started as a large landslide on a steep mountain flank, traveled a sort distance down a steep mountain channel, and then deposited sediment as it traveled a long distance down a low-gradient valley. About 80% of the Black Mountain debris-flow volume was from the landslide mass, which differs from most other historical debris flows where 80 to 90% of the debris-flow volume is scoured from the drainage channel (Croft, 1967; Santi, 1988; Keaton and Lowe, 1998).

PROBABLE LANDSLIDE CAUSES

Snowmelt infiltrating the subsurface is a major factor contributing to spring landslides (Chleborad, 1997). Snowmelt provides a more continuous supply of water over a longer period of time than does infiltration from rainfall (Wieczorek and Glade, 2005). The Black Mountain landslide likely reactivated when snowmelt water infiltrated the subsurface and raised the pore-water pressure in the landslide.

Black Mountain had an above average snowpack at the onset of the 2005 spring snowmelt. The nearest snowpack, snowmelt, and temperature measurement site is at the Natural Resources Conservation Service (NRCS) Utah Snow Survey Webster Flat SNOTEL site (NRCS, 2005a), 1.75 miles east of the landslide. The SNOTEL data are useful for evaluating the spring snowmelt pattern. Regional spring snowmelt air temperatures are broadly the same for a given elevation. The Webster Flat SNOTEL is at an elevation of 9200 feet, lower than the Black Mountain landslide which is between 9450 to 9900 feet in elevation. On April 1, 2005, the Webster Flat SNOTEL site had a snow-water equivalent of 33.4 inches, which is 210% of the 1977-2000 average (NRCS, 2005b).

The rate of snowmelt depends primarily on air temperature, which in turn relates to the timing of snowmelt-generated landslides (Chleborad, 1997, 1998). A strong relation exists between snowmelt landslides and rising spring temperatures in the central Rocky Mountains (Chleborad, 1997; Chleborad and others, 1997). Figure 13 is a plot of daily snowmelt and average daily temperature at the Webster Flat SNOTEL site, which melted out on May 27, 2005. Even though the SNOTEL site melted out six days before the landslide and debris flow occurred, the SNOTEL data can be used to infer temperatures and snowmelt patterns on Black Mountain. At the Webster Flat SNOTEL, snowmelt generated an average of 1.54 inches of water per day from May 14 through May 27, 2005. This period of rapid snowmelt corresponds to a significant increase in average daily temperature (figure 13). The snowmelt rate at the Black Mountain landslide was probably slightly less due to the area's north aspect and higher elevation. The average daily temperature remained high through June 3, 2005, (figure 14), which suggests rapid snowmelt preceding the landslide and debris-flow events.

Aerial photos and field observations indicate an approximate 3-foot-thick snowpack remained on Black Mountain on June 3, 2005 (figure 3). The remaining snowpack indicates that only partial snowpack melting was sufficient to trigger landslide movement. A rapid rate of snowmelt over several days may be a more critical parameter in triggering landslides than the total volume of snow melted and water added. Melting of an above average snowpack in 1983 triggered numerous landslides in Utah, and Wieczorek and others (1989) observed that most of those landslides triggered during the most rapid period of snowmelt.

Chleborad and others (1997) used a six-day moving average of daily maximum air temperature with an optimum threshold of 58° F for anticipating the onset of snowmelt-generated landslides. Their study concluded that most snowmelt-triggered landslides occur within two weeks after the first yearly occurrence of this threshold. Figure 14 shows the six-day moving average of daily maximum temperature at the Webster Flat SNOTEL site. The first occurrence of the 58° F threshold was on May 19, 2005. The Black Mountain debris flow occurred on June 3, 2005, 16 days after reaching the temperature threshold at Webster Flat. Sixteen days is longer than Chleboard's two-week period for most snowmelt-generated landslides, but Chleborad and others (1997) did observe some landslides triggering within three weeks. Also the longer than two-week period may be due to the higher elevation and north aspect of the landslide and therefore cooler temperatures as compared to the SNOTEL site. The landslide also has a deep surface of rupture, and the time required to increase the pore-water pressure at depth was likely longer.

HAZARD ASSESSMENT

Debris flows are fast-moving slurries of mud, rocks, and debris that travel down drainage channels. Debris flows are particularly dangerous to life and property because they travel fast, destroy and bury objects in their paths, and often strike with little or no warning. The demolished forest along the upper valley deposit demonstrates the destructive nature of debris flows.

Based on the results of our investigation, we conclude that future movement of the Black Mountain landslide downslope toward the steep, narrow mountain channel is likely, and that the release of additional landslide material into the channel could generate future large debris flows. An ample volume of material (155,000 to 160,000 yd^3) remains in the upper landslide to supply future debris flows. The landslide also has the potential to enlarge upslope and incorporate additional material as occurred in 2005. The steep average landslide slope (52% [27.5°]) and steeply dipping rupture surface (up to 34° [67%]) both promote additional landslide movement, and the north side of Black Mountain has an adequate climate for snow accumulation and subsequent rapid snowmelt to trigger future landslide movement.

The age of conifer trees removed by the Black Mountain debris flow along the upper stream valley shows that a minimum of 100 years has passed since the last large debris flow occurred in this drainage. Debris-flow deposits in the valley need to be investigated and dated to understand long-term debris-flow frequency. Debris-flow deposits in the upper valley and below the steep mountain channel indicate that smaller volume debris flows are more frequent than large events. Even though an understanding of long-term frequency could be obtained, the short-term debris-flow hazard is controlled by the remaining landslide mass poised above the mountain channel and its potential to reactivate and release large volumes on material into channel to generate debris flows.

The major structure at risk from future debris flows originating on the north side of Black Mountain is SR-14, which is subject to culvert blockage, overtopping, erosion, and sediment burial. The unnamed stream valley above SR-14 is presently undeveloped, and building structures in the bottom of the valley is not recommended unless the debris-flow hazard is reduced to an acceptable level. Downstream from the unnamed drainage, potential impacts along Crow Creek and Cedar Canyon include further erosion and damage to SR-14, blocked culverts, potential creek blockage, and influx of sediment. A site-specific, detailed investigation is needed to determine possible highway risk-reduction measures and their cost. Giraud (2005) outlined methods for the geologic evaluation of debris-flow hazards.

STUDY METHODS

We examined USGS 1998 aerial photos at various scales, NAIP 2004 aerial photos at various scales, and reviewed 1:63,360- and 1:24,000-scale geologic maps and regional geologic reports of the area. We performed field work on June 4; July 19, 20, 21; and August 20, 2005. We mapped landslide and debris-flow boundaries using a handheld global positioning system (GPS) unit with an approximate accuracy range of 20 to 100 feet. GPS points were checked with field measurements and photos and adjustments made where necessary. Our landslide volume estimates are based on methods outlined by Cruden and Varnes (1996, p. 42-43).

SUMMARY

The June 3, 2005, Black Mountain landslide and debris flow clearly demonstrate the ability of the terrain on the north side of Black Mountain to produce large, destructive debris flows. The landslide and debris flow were initiated by a combination of rapid snowmelt, weak geologic materials, pre-existing landslide deposits, and steep terrain. The remaining Black Mountain landslide contains an estimated 155,000 to 160,000 yd^3 of material, which can catastrophically release into the mountain channel on the north side of Black Mountain. The channel provides a mechanism to mix and transform the landslide material into a debris flow, and also accelerates the flow, which can then runout long distances in the low-gradient stream valley and reach Crow Creek.

Rapid melting of an above average snowpack and infiltration of the meltwater into the landslide increased the pore-water pressures in the landslide and triggered landslide movement. Only partial melting of the 2005 snowpack was necessary to initiate movement. The 2005 snowmelt pattern can be used to anticipate future reactivation of the remaining Black Mountain landslide and possible future debris flows. The remaining landslide and its potential to reactivate and release large volumes of material into the steep mountain channel controls the short-term debris-flow hazard.

Future large debris flows will likely reach and damage SR-14. Building structures in the presently undeveloped stream valley bottom is not recommended unless the debris-flow hazard is reduced to an acceptable level. A detailed investigation is recommended to determine the best methods to mitigate future debris-flow damage to SR-14.

ACKNOWLEDGMENTS

Lt. David Excel, Utah Highway Patrol, provided the June 3, 2005, aerial reconnaissance photographs of the landslide and the debris flow. Leslie Heppler, Utah Department of Transportation (UDOT), provided information on the volume of material cleaned from SR-14. Jim McConnell, UDOT, provided photographs and video clips of plugged culverts and highway cleanup. Mike Hozik and Joe Buckley provided valuable field assistance.

LIMITATIONS

REFERENCES

Burrows, C.J., and Burrows, V.L., 1976, Procedures for the study of snow avalanche chronology using growth layers of woody plants: Institute of Arctic and Alpine Research Occasional Paper no. 23, 54 p.

Chleborad, A.F., 1997, Temperature, snowmelt, and onset of spring season landslides in the central Rocky Mountains: U.S. Geological Survey Open-File Report 97-27, 10 p.

—1998, Use of air temperature data to anticipate the onset of snowmelt-season landslides: U.S. Geological Survey Open-File Report 98-124, 16 p.

Chleborad, A.F., Ellis, W.L., and Kebler, D., 1997, Results of site investigation and instrumentation of the Keno Gulch landslide/debris-flow source area, Aspen, Colorado: U.S. Geological Survey Open-File Report 97-717, 17 p.

Colton, R.B., Holligan, J.A., and Anderson, L.W., 1986, Preliminary map of landslide deposits and rock fall areas in the Panguitch 30’ x 60’ quadrangle, Utah: U.S. Geological Survey unpublished map, scale 1:100,000.

Croft, A.R., 1967, Rainstorm debris floods, a problem in public welfare: University of Arizona, Agricultural Experiment Station Report 248, 35 p.

Cruden, D.M., and Varnes, D.J., 1996, Landslides, types and processes, *in* Turner, A.K., and Schuster, R.L., editors, Landslides, investigation and mitigation: Washington, D.C., National Academy Press, Transportation Research Board Special Report 247, p. 36-75.

Giraud, R.E., 2005, Guidelines for the geologic evaluation of debris-flow hazards on alluvial fans in Utah: Utah Geological Survey Miscellaneous Publication 05-06, 16 p.

Gregory, H.E., 1950, Geology of eastern Iron County, Utah: Utah Geological and Mineralogical Survey Bulletin 37, 153 p., scale 1:63,360.

Keaton, J.R., and Lowe, M., 1998, Evaluating debris-flow hazards in Davis County, Utah - engineering versus geological approaches, *in* Welby, C.W., and Gowan, M.E., editors, A paradox of power - voices of warning and reason in the geosciences: Geological Society of America Reviews in Engineering Geology, Volume XII, p. 97-121.

Lund, W.R., Vice, G. and Buckley, J., 2005, June 3, 2005, Black Mountain debris flow, Iron County, Utah: Salt Lake City, Utah, unpublished Utah Geological Survey Technical Report 05-07, 11 p.

Moore, D.W., and Straub, A.W., 2002, Correlation of Upper Cretaceous and Paleogene (?) rocks beneath the Claron Formation, Crow Creek, western Markagunt Plateau, southwestern Utah, *in* Erskine, M.C., and others, editors, The geologic transition, High Plateaus to Great Basin – A symposium and field guide – The Mackin Volume: Utah Geological Association Publication 30 and Pacific Section American Association of Petroleum Geologists Publication GB-78, p. 75-96.

Moore, D.W., Nealey, L.D., Rowley, P. D., Hatfield, S.C., Maxwell, D.J., and Mitchell E., 2004, Geologic map of the Navajo Lake quadrangle, Kane and Iron Counties, Utah: Utah Geological Survey Map 199, 2 plates, scale 1:24,000.

Natural Resources Conservation Service, 2005a, Current water year data: Online, http://www.ut.nrcs.usda.gov/snow/data/current.html, accessed December 20, 2005.

—2005b, Current water year data: Online, http://www.wcc.nrcs.usda.gov/cgibin/snow_rpt.pl?state=utah, accessed December 7, 2005.

Santi, P.M., 1988, The kinematics of debris flow transport down a canyon: College Station, Texas A&M University, M.S. thesis, 85 p.

TerraServer USA, 2005, U.S. Geological Survey 1998 aerial photographs: Online, http://terraserver.microsoft.com/image.aspx?T=1&S=12&Z=12&X=714&Y=5624&W=3&qs=%7cvernal%7cut, accessed December 29, 2005.

Utah Automated Geographic Reference Center, 2005, National agriculture imagery program aerial photos: Online, http://agrc.utah.gov/agrc_sgid/naip.html, accessed December 29, 2005.

Wieczorek, G.F., Lips, E.W., and Ellen, S., 1989, Debris flows and hyperconcentrated floods along the Wasatch Front, Utah, 1983 and 1984: Bulletin of the Association of Engineering Geologists, v. 26, no. 2, p. 191-208.

Wieczorek, G.F., and Glade, T., 2005, Climatic factors influencing occurrence of debris flows, *in* Jakob, M. and Hungr, O., editors, Debris-flow hazards and related phenomena: Chichester, UK, Springer-Praxis, p. 325-362.

Table 1. *Physical characteristics of the Black Mountain landslide, narrow channel, and upper and lower valley debris-flow deposits.*

Geologic Feature	**Average slope % (degrees)**	**Area acres**	**Volume yd^3**	**Slope Length feet**
Upper Landslide	43 (23.3°)	5.6	155,000 to 160,000	550
Lower Landslide	60 (30.9°)	1.6	50,000 to 60,000	450
Narrow Channel	45 (24°)	-	-	1200
Upper and Lower Valley Debris-Flow Deposit	12.5 (7°)	26.6	73,000	8500 (1.6 miles)
Upper Valley Deposit	16 (9°)	13.7	55,000	3800
Lower Valley Deposit	9 (5°)	12.9	18,000	4700

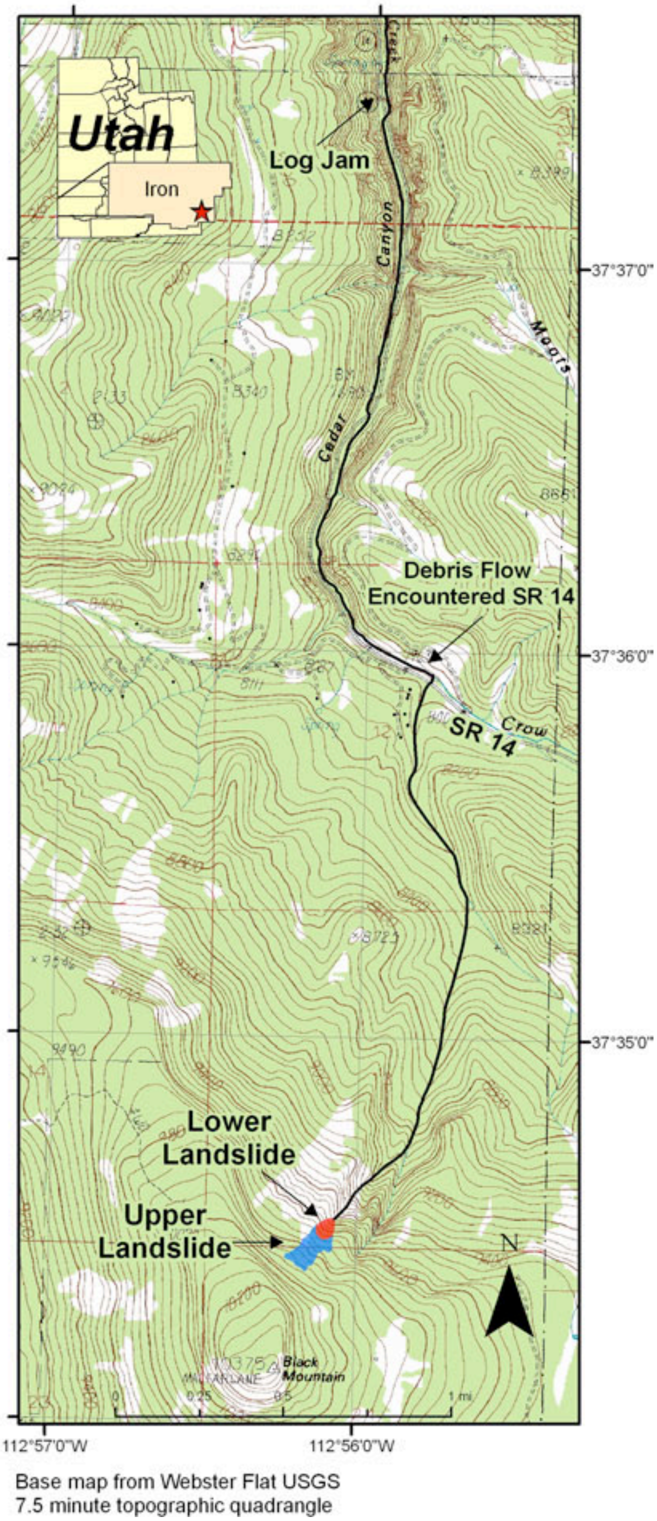


Figure 1. *Map showing upper and lower landslide and flow path (black heavy line) of the Black Mountain debris flow and related flooding in Cedar Canyon.*

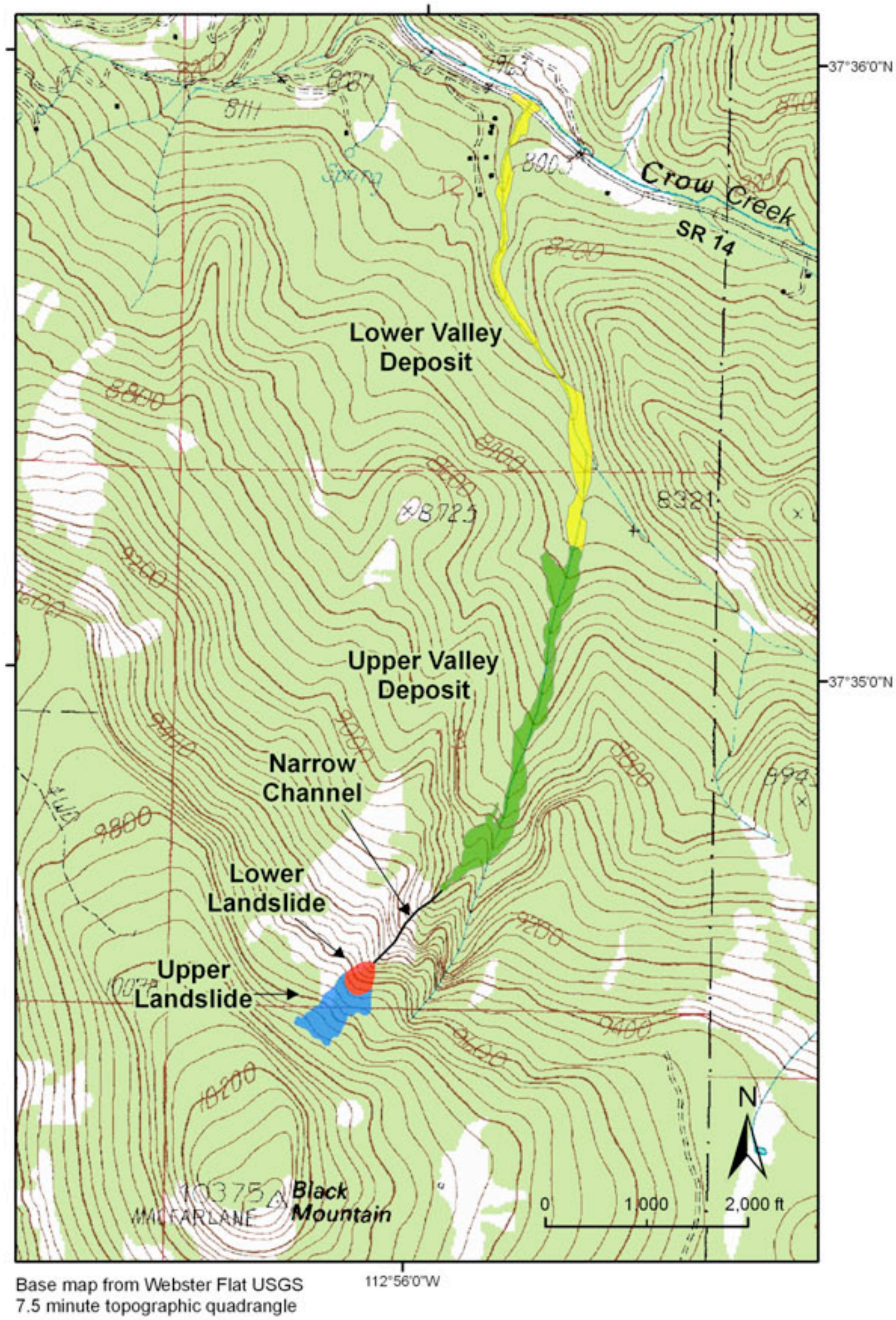


Figure 2. *Map showing upper and lower landslide, narrow channel, and upper and lower valley debris-flow deposits.*

Figure 3. *The remaining upper landslide on the north side of Black Mountain. The upper landslide is perched above the narrow mountain channel (figure 4) that is out of view and below the photo. Photo taken on June 3, 2005, by Lt. David Excel, Utah Highway Patrol.*

Figure 4. *View down the steep, narrow mountain channel. The lower part of the landslide released into the channel and was transformed into a rapidly moving debris flow. Part of the debris-flow path is evident below the channel.*

Figure 5. *View west into the evacuated area of the lower landslide. The estimated evacuated volume is 50,000 to 60,000 yd*^{3}. *The landslide left flank (upper part of photo) exposes basalt talus. The reddish colored material is weathered shale and mudstone and is the landslide rupture surface.*

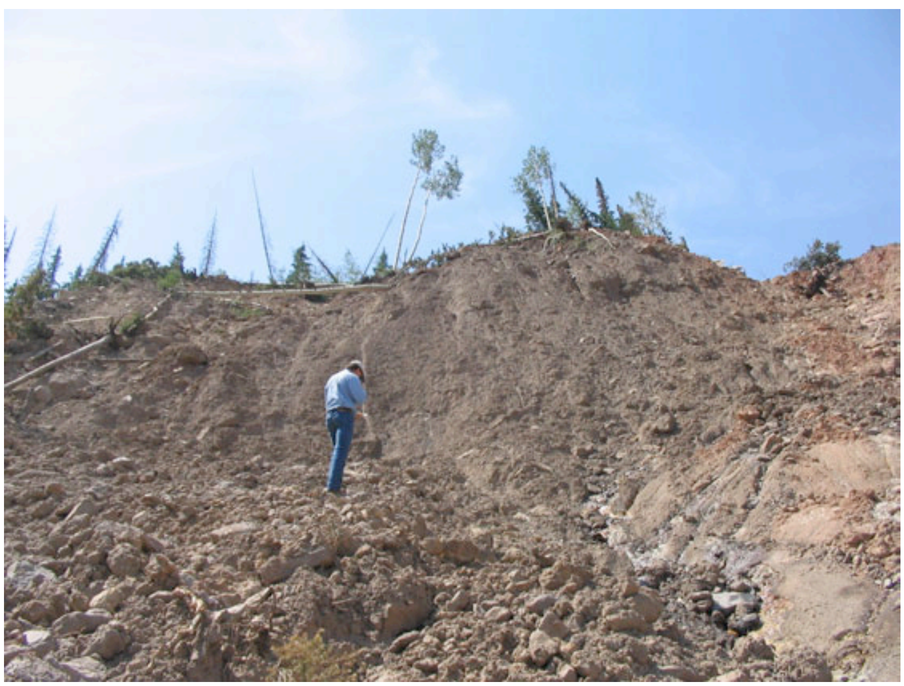


Figure 6. *View is from the evacuated area of the lower landslide toward the remaining upper landslide. The upper landslide lies on a steep rupture surface.*

Figure 7. *View from the landslide main scarp toward Crow Creek and SR-14. The main scarp is covered with slickensides. The debris-flow path and deposits are evident in the unnamed tributary stream valley to Crow Creek.*

Figure 8. *View northwest of SR-14 blocked by sediment from the Black Mountain debris flow. Crow Creek is on the right. Photo taken on June 3, 2005, by Lt. David Excel, Utah Highway Patrol.*

Figure 9. *Northeast view down the upper stream valley at the debris-flow deposit below the narrow mountain channel. The debris flow had sufficient velocity to superelevate up onto the valley side below the sandstone cliff.*

Figure 10. *Large boulder transported by the debris flow now part of the upper valley deposit. The boulder measures 22 feet long, 9.5 feet wide, and 6.5 feet high. The tree trim line is evident in the background.*

Figure 11. *Upper valley debris-flow deposit showing the rough, wide, and thick deposit and distinct tree trim lines along the deposit flanks.*

Figure 12. *Lower valley deposit showing the relatively smooth, narrow, thin deposit compared to the upper valley deposit.*

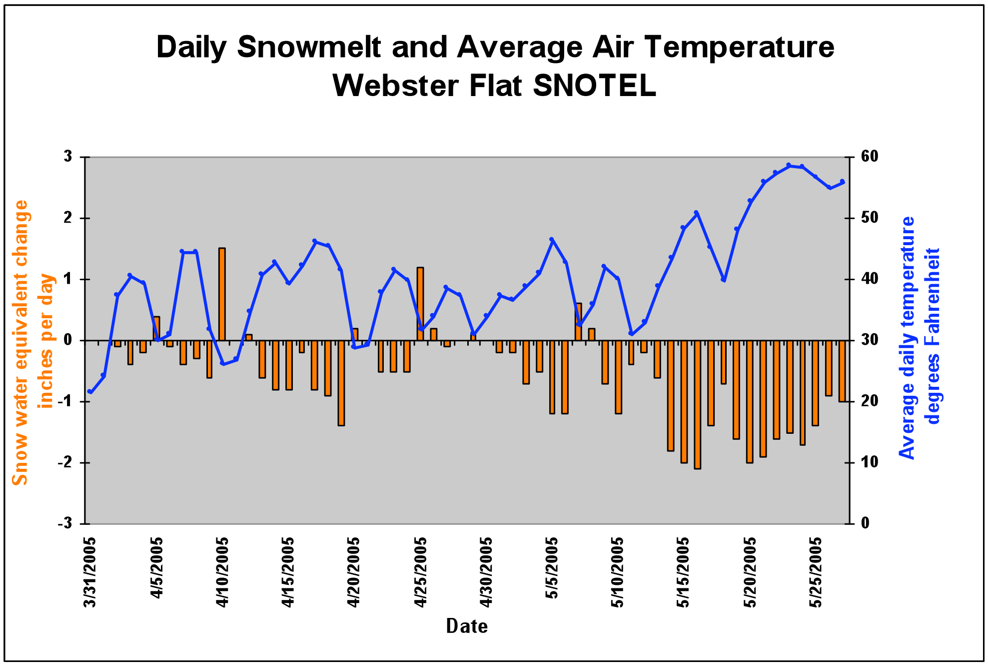


Figure 13. *Daily snowmelt and average daily temperature at the Webster Flat SNOTEL site. From May 14 to May 27, 2005, an average of 1.5 inches of water per day melted from the snowpack.*

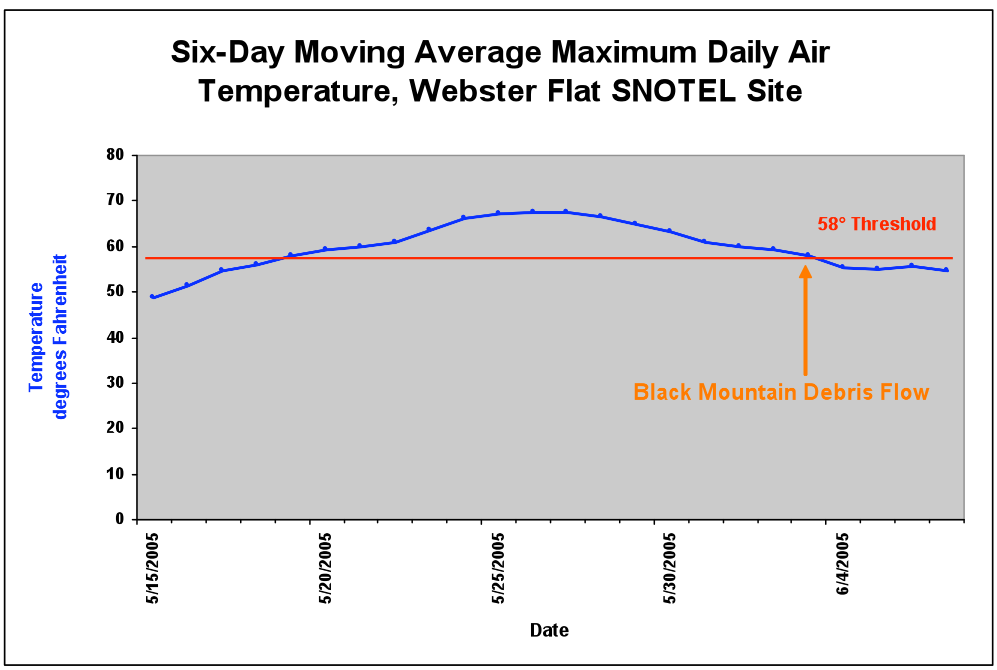


Figure 14. *Six-day moving average maximum daily air temperature at the Webster Flat SNOTEL site. The Black Mountain debris flow occurred 16 days after the 58° F threshold was reached at the Webster Flat SNOTEL.*

Utah Geological Survey

Project: Reconnaissance of the April 9, 2006, 1650 East landslide, South Weber, Utah			
By: Richard E. Giraud, P.G. and Greg N. McDonald, P.G.	Date: 07-26-06	County: Davis	
USGS Quadrangles: Ogden (1345)	Section/Township/Range: SW¼NE¼ section 34, T. 5 N., R. 1 W., SLBLM		
Requested by: Ron Chandler, South Weber City Manager			Job number: 06-10 (GH-14)

INTRODUCTION

At the request of Ron Chandler, the Utah Geological Survey (UGS) conducted a reconnaissance of the 1650 East landslide in the Highland View Estates subdivision, South Weber, Davis County, Utah (figures 1 and 2) on April 10, 2006. Rick Chesnut (Terracon) and Lee Cammack (JUB Engineers) were also conducting a field study of the landslide and damage to the Davis-Weber Canal for the Davis-Weber Canal Company at the time of our visit. On April 11, 2006, Richard Giraud discussed the landslide hazard with city officials and homeowners in a public meeting and on April 14, 2006, provided a letter (Giraud, 2006) to South Weber City outlining recommendations for managing the landslide hazard.

The landslide occurred around 9:30 p.m. on the evening of April 9, 2006. It flowed over and damaged the Davis-Weber Canal at the base of the slope, and impacted the back of the house at 1650 East 7687 South below the canal (figures 3 and 4). The landslide caused significant damage to the house, injured a child inside the house, and prompted evacuation of nearby houses. The purpose of our investigation was to determine the cause of the landslide, document physical characteristics of the landslide, and evaluate the remaining landslide hazard to aid South Weber City in determining when to allow evacuated residents to return and in assessing the long-term risk to development at the base of the bluff.

For this study, we reviewed relevant geologic maps and reports of geology, geologic-hazard, and landslide investigations in the area. We also reviewed 1:20,000-scale (1937), 1:10,000-scale (1958), and 1:24,000-scale (1985) stereo aerial photographs; U.S. Geological Survey 1997 and 2003 orthophotos at various scales (TerraServer USA, 2006); and National Agriculture Imagery Program orthophotos at various scales (Utah Automated Geographic Reference Center, 2006).

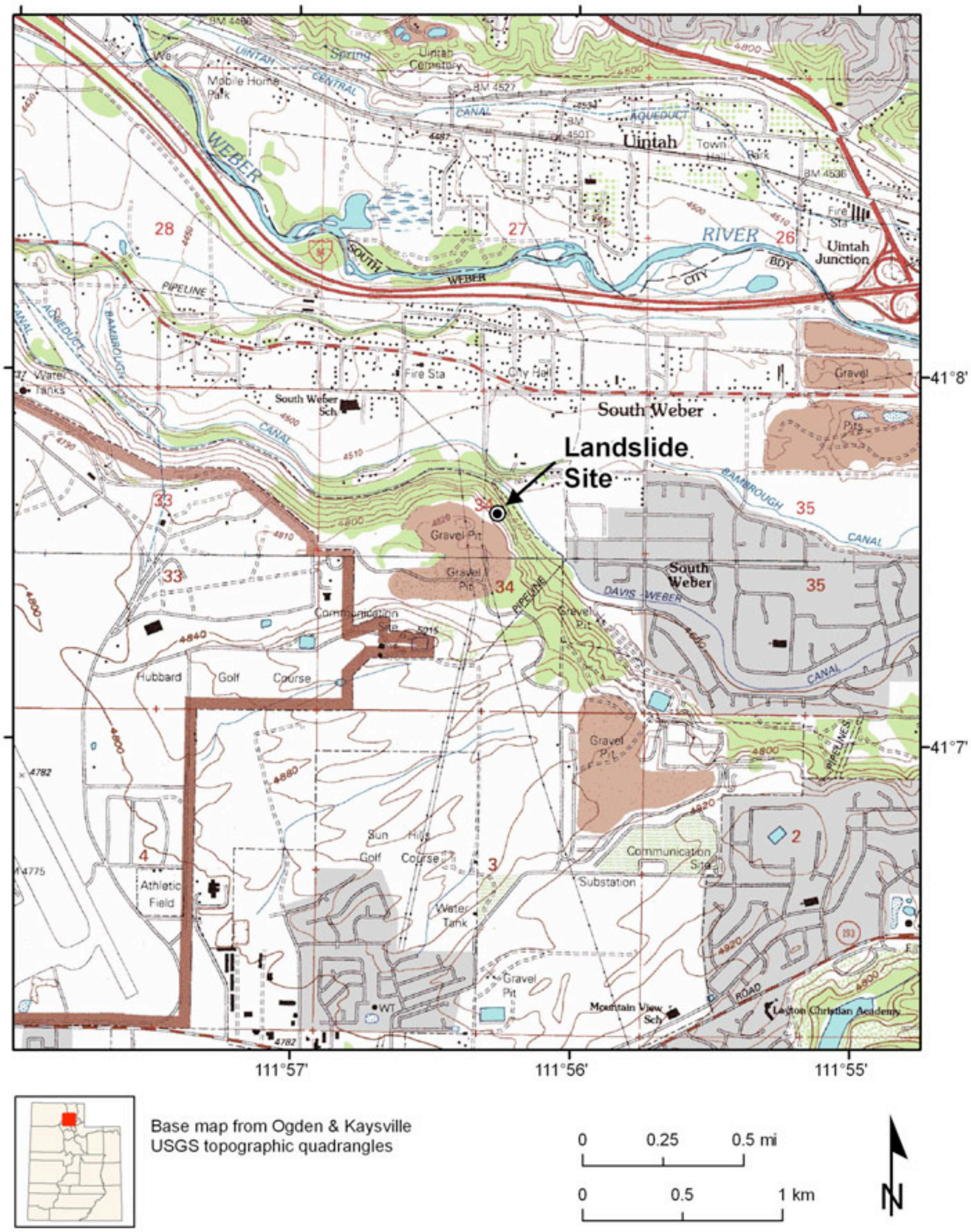


Figure 1. *Location of the 1650 East landslide in South Weber, Utah.*

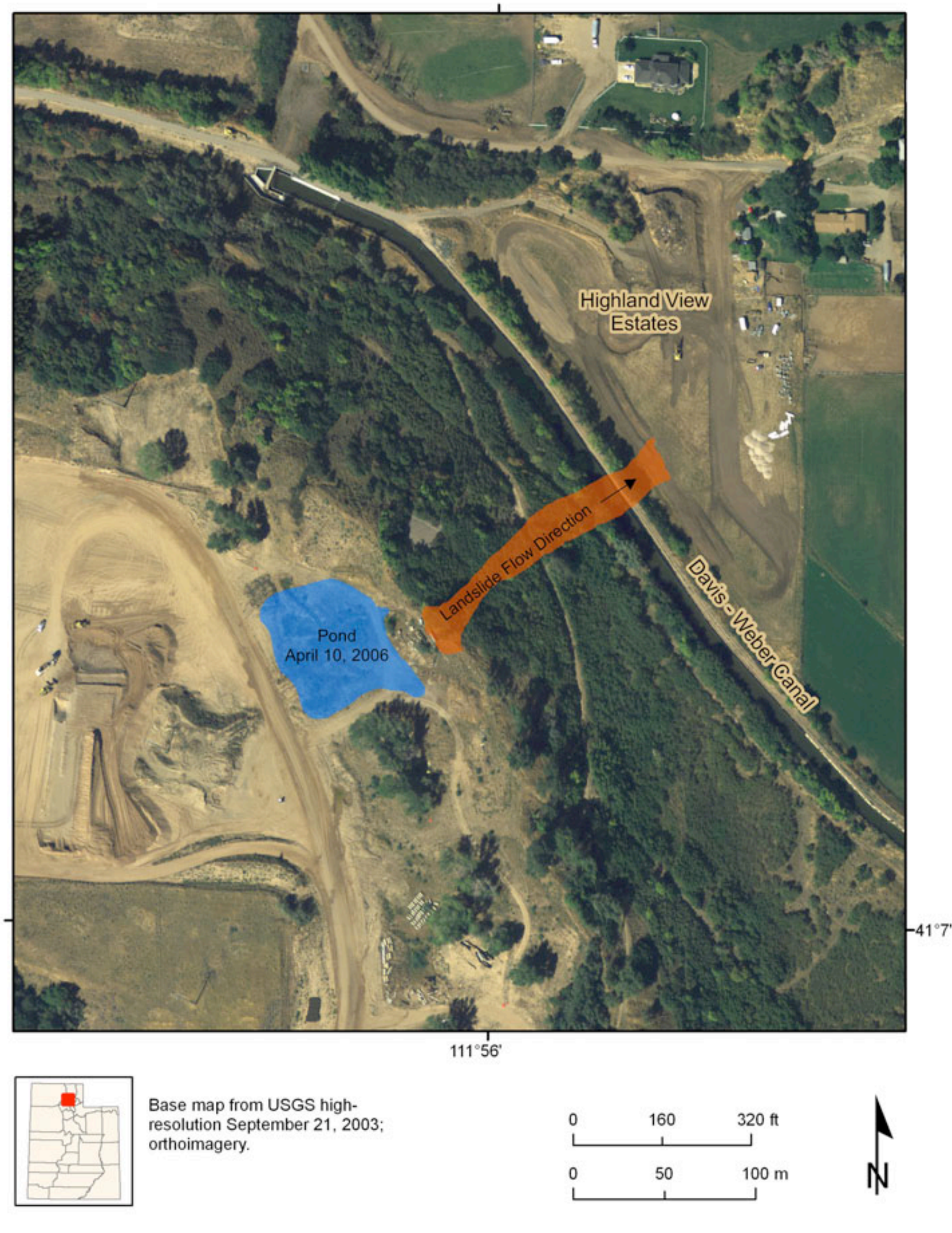


Figure 2. *Image showing landslide flow direction, Highland View Estates subdivision, gravel pit pond, and the Davis-Weber Canal. The pond boundary is approximate and is based on oblique aerial photographs taken by Davis County Sheriff's Office personnel on the morning of April 10, 2006.*

Figure 3. *Landslide damage to the house at 1650 East 7687 South.*

Figure 4. *Damage to the house and garage at 1650 East 7687 South.*

CONCLUSIONS AND RECOMMENDATIONS

Based on this geologic investigation and hazard assessment of the 1650 East landslide, the UGS concludes the following:

- The 1650 East landslide was a rapid earth flow that damaged the Davis-Weber Canal and the house at 1650 East 7687 South, and injured a child inside the house.

- Piping holes near the head of the landslide below the slope crest indicate a pond and shallow ground water in the gravel pit atop the bluff saturated a zone in material along the slope crest and triggered the landslide. The steep slope, runoff of snowmelt into the pond, shallow ground water in the gravel pit, weight of embankment fill at the slope crest, and weak underlying geologic materials probably all contributed to the landslide.

- The houses along the base of the slope are in a runout zone for shallow rapidly moving landslides and may also be at risk from deep-seated rotational landslides.

- For potential deeper seated rotational landslides in the slope above the subdivision, Terracon's (2005) slope-stability investigation estimated a static factor of safety of 1.2, which is well below the normally accepted 1.5 factor of safety. Terracon's analysis indicates the slope will likely fail during an earthquake.

- Deep-seated landslides can impact the canal, and if the canal is conveying water and a landslide caused a canal breach, widespread flooding and sedimentation could occur at the base of the slope.

To reduce the potential impacts of landslide movement and manage the landslide hazard in this area, the UGS recommends the following:

- Implement surface- and ground-water control measures to ensure conditions at the slope crest that caused the 1650 East landslide do not reoccur.

- Because houses already exist along the base of the slope and are potentially impacted by both shallow and deep-seated landslides, a study should evaluate the landslide hazard, potential impacts to houses, and possible risk-reduction measures.

- Monitoring should continue of slope movement and ground-water levels in inclinometers and piezometers, respectively, installed by Terracon for the Davis-Weber, to assess potential movement of deep-seated landslides.

- South Weber City should consider both shallow and deep landslide hazards and hazards related to a possible canal breach when evaluating existing or future development and setbacks at the base of the slope along the city's entire south side.

- Disclose the existence of hazards reports and information to existing and future homeowners.

GEOLOGIC SETTING

The 1650 East landslide is in a steep northeast-facing slope forming the south side of the Weber River Valley (figure 1). The slope formed as the Weber River cut down into its former delta as Lake Bonneville receded from the Provo shoreline after 14,500 years ago to the present level of Great Salt Lake. The slope is approximately 220 feet high and has an average gradient of 45% (24°). The Davis-Weber Canal is in the lower slope just above houses built along the slope base.

Geologic evidence and historical records indicate relatively frequent landsliding in slopes in the area. Yonkee and Lowe (2004) mapped the northeast-facing slope as "older Holocene landslide deposits" that include widespread landslides developed within generally fine-grained lacustrine and deltaic sediments. The older Holocene landslide deposits are mainly slumps and earth flows. Lowe (1988) shows historically active landslides (LSa 331-334) near the 1650 East landslide and along the entire northeast-facing bluff, which he mapped as an older landslide complex (LS 335). Yonkee and Lowe (2004) mapped these historically active landslides as younger Holocene landslide deposits. Earthtec (2002) completed a geotechnical study for Highland View Estates subdivision and identified a landslide near the subdivision but did not show the landslide relative to the subdivision on a map. Other authors have documented numerous historical landslides in the slope east and west of the 1650 East landslide (Pashley and Wiggins, 1972; Lund, 1984; Black, 1999; Solomon, 1999). These landslide deposits are also derived from Lake Bonneville fine-grained lacustrine and deltaic deposits.

The 1650 East landslide is similar to the February 20, 2005, 425 East South Weber Drive landslide (Giraud, 2005). The 425 East South Weber Drive landslide threatened the Davis-Weber Canal, demolished a barn, blocked State Route 60 (South Weber Drive), and had a 150 foot runout beyond the slope toe onto flat ground. The Davis-Weber Canal Company installed drains and buttressed the slope to reduce the risk of future landslides.

LANDSLIDE DESCRIPTION

The 1650 East landslide was a rapid earth flow that started as a slide at the slope crest adjacent to a pond in a gravel pit (figures 2 and 5). The landslide main scarp extends a short distance back from the slope crest onto flat ground toward the pond in the gravel pit. The landslide is mostly a failure of fill pushed out of the gravel pit onto the upper slope to form a berm along the slope crest (figure 6). The landslide also involved native materials underlying and downslope of the fill. The slide at the crest mobilized into a flow that accelerated rapidly downslope, removing trees and crossing dirt roads, the canal, and a rock wall at the back of the lot before impacting the house at 7687 South 1650 East (figures 2 and 7). The landslide impact

Figure 5. *View looking northwest at the pond in the gravel pit and the landslide head (arrow). A berm was placed between the pond and the landslide to prevent water from flowing onto the landslide. Photo taken on the morning of April 10, 2005, by Davis County Sheriff's Office personnel.*

Figure 6. *View to the southeast showing landslide main scarp and fill placed on the upper slope. Near the left edge of the photo, black top soil at the base of the scarp (arrow) underlying the brown fill is evident and indicates the original slope surface.*

Figure 7. *View looking down the landslide flow path at the damaged house at 1650 East 7687 South. The culvert in the lower slide path above the house was originally in the gravel pit. Subsequent water flow eroded the right side of the landslide.*

broke through the house and garage walls and a small volume of sediment and tree debris was deposited in the house. A child inside the house was injured and the landslide impacted with sufficient force to break part of the house foundation wall (figure 8). The impact to the back of the garage pushed a car and pickup out through the garage doors. The landslide broke windows at the adjacent house to the southwest at 1650 East 7701 South. The landslide also damaged the Davis-Weber Canal which had recently been enclosed in a concrete box culvert but was not yet covered with backfill (Ray, 2006) (figure 9). Water had not yet been turned into the canal for the irrigation season so obstruction to flow in the canal by the landslide was not an issue.

The landslide likely moved initially as a shallow translational landslide but quickly transformed downslope into a rapidly moving earth flow. The landslide was about 80 feet wide and 600 feet long (figure 2). It initiated in the upper slope on gradients of as much as 60% (31°). The average gradient from the landslide main scarp to the impacted house is 45% (24°). The steep slopes accelerated the landslide downslope toward the subdivision. Some landslide material was deposited on the canal and canal access road (figure 9) and on dirt roads above the canal (figure 10), which reduced the landslide volume before impacting the house and likely reduced damage to the house. Following the landslide, water draining from the landslide crown and head eroded the right side of the landslide and flowed into the canal (figures 7 and 9).

The pond in the gravel pit collects surface-water runoff and also reflects the local shallow water table. Test pits excavated by the Davis County Public Works Department on April 10, 2006, near the landslide crown in the gravel pit showed shallow ground water perched at depths of 4 to 6 feet on clay beds. Cottonwood trees in the gravel pit and wetland vegetation in and near

Figure 8. *Basement at 1650 East 7687 South showing upper foundation wall (right side of photo) broken by landslide impact.*

Figure 9. *View looking northwest of Davis-Weber Canal showing landslide material deposited on the box culvert and canal access road. Following the landslide water and sediment flowed into the canal left of the box culvert.*

Figure 10. *Landslide material deposited on a dirt road midslope above the Davis-Weber Canal*.

the pond (figure 5) also indicate the presence of perennial shallow ground water since surface-water runoff alone would not sustain this vegetation. Cottonwood trees growing along the slope crest also indicate shallow ground water (figure 6). Following the landslide, a soil berm was placed between the pond and the landslide to prevent pond water from flowing onto the landslide head (figure 5).

CANAL SLOPE-STABILITY INVESTIGATION

Prior to construction of the Highland View Estates subdivision, Terracon (2000) completed an initial geotechnical-engineering investigation along the bluff to identify areas along the Davis-Weber Canal that are prone to landsliding. This investigation indicated that the slope above the Highland View Estates subdivision and the canal is marginally stable. To address the landslide hazard, Terracon (2005) completed a follow-up slope-stability investigation, which included installation of piezometers and inclinometers and a subsequent slope-stability analysis. The boreholes encountered interbedded clay, sand, silty sand, sandy silt, and gravel. For the slope above the canal and subdivision, Terracon (2005) estimated a factor of safety of 1.2 under static conditions for deep rotational landsliding. For earthquake ground-shaking conditions, Terracon (2005) estimated the factor of safety to be well below 1.0, meaning the slope would fail during an earthquake. Terracon (2005) states that lot grading for the subdivision cut the slope toe and canal embankment which may decrease the stability of the slope. Terracon (2005) provides recommendations to reduce the landslide hazard and potential impacts to the canal but did not address the potential for shallow landsliding and rapid earth-flow landslides.

PROBABLE CAUSES OF MOVEMENT

Several factors likely contributed to landslide movement. The fill placed along the slope crest added weight, loading the underlying weak native slope materials and promoting slope failure. The elevated pond level and related shallow ground water saturated part of the fill and native material in the upper part of the slope and triggered the April 9, 2006, landslide. Piping holes along the landslide flanks (figure 11) near the landslide head indicate active subsurface flow through the fill on the slope crest prior to the landslide. A major spring storm on April 4 through 6, 2006, resulted in 10 inches of snow (2.12 inches water) in South Ogden and 8 inches of snow (1.95 inches water) in Layton (National Weather Service, 2006). The subsequent snowmelt and runoff likely increased the pond-water level and ground-water level and saturated part of the fill along the slope crest. The steep slope, runoff of snowmelt water into the pond, shallow ground water, weight of embankment fill, and weak underlying materials probably all contributed to the landslide.

(a)

(b)

Figure 11. *Piping holes in the upper slope near the landslide flanks. (a) Small piping hole near the landslide right flank. (b) Large piping hole adjacent to the landslide left flank.*

FUTURE LANDSLIDE HAZARD POTENTIAL

The April 9, 2006, and February 20, 2005, landslides clearly demonstrate the potential for shallow, rapidly moving, earth-flow-type landslides with significant runout distances on similar slopes in South Weber. Flow-type landslides are destructive and a threat to life safety due to their velocity and impact. When such landslides occur above subdivisions built within the landslide runout zone, the potential exists for loss of life in addition to property damage. Both the April 9, 2006, and February 20, 2005, landslides demonstrate the distance small earth flows can travel beyond the base of a slope.

Both shallow- and deep-seated landslides have potential to damage the Highland View Estates subdivision. Controlling the pond- and ground-water levels in the gravel pit, as discussed in the April 11, 2006, meeting and April 14, 2006, letter (Giraud, 2006), manages one landslide triggering mechanism but does not eliminate all risk from shallow landslides. Shallow landslides can be triggered by rapid snowmelt, prolonged rainfall, or periods of above-normal precipitation. The February 20, 2005, 425 East South Weber landslide (Giraud, 2005) was triggered in a year that had above-normal precipitation. For deep-seated landslides, Terracon (2005) estimated a static factor of safety of 1.2 for the slope and emphasized that 1.2 is below the normally accepted 1.5 factor of safety. Deep-seated landslides have the potential to damage both the subdivision and the canal. Earthquakes could trigger both shallow and deep landslides.

Because houses have been constructed along the base of the slope and can potentially be impacted by both shallow and deep-seated landslides, a study should evaluate the landslide hazard, potential impacts to houses and lots, and possible risk-reduction measures. The study should include an assessment of drainage and ground-water conditions in the gravel pit at the top of the slope, the extent of fill placed at the slope crest, and thickness and nature of shallow colluvial deposits on the face of the slope as they relate to shallow landslides and the potential to transform into rapid earth flows. The study should evaluate rapid snowmelt, prolonged rainfall, and periods of above-normal precipitation as potential landslide triggers. The landslide study should also evaluate global stability of the slope with respect to deep-seated rotational landslides and the stability effects of undercutting the base of the slope to enlarge back-yard areas in lots below the canal.

Because the canal is now buried in a concrete box culvert, rapid earth flows may travel over the canal but deep-seated landslides may still damage the canal. If deep-seated landslides impact the Davis-Weber Canal when the canal is conveying water, the potential exists for the canal to breach and cause widespread flooding and sediment deposition. The Davis-Weber Canal Company has studied the deep-seated landslide hazard relative to their canal and Terracon (2005) provided recommendations to reduce the potential impacts to the canal.

SUMMARY

The 1650 East landslide was a rapid earth flow that damaged the Davis-Weber Canal and a house at 1650 East 7687 South. The landslide also injured a child inside the house. Piping holes in the upper slope adjacent to the landslide head indicate saturation of part of the fill along the slope crest from a pond and shallow ground water and triggered the landslide. The steep slope, runoff of snowmelt into the pond, shallow ground water, weight of embankment fill, and weak underlying geologic materials probably all contributed to the landslide.

The Terracon study of deep-seated landsliding indicated the slope has a static factor of safety of 1.2, which is below the normally accepted factor of safety of 1.5. Both shallow and deep-seated landslides have the potential to damage houses constructed along the base of the slope. Deep-seated landslides may also damage the canal and cause widespread flooding and sediment deposition. We recommend a landslide study to evaluate shallow and deep-seated landslide hazards, potential impacts to houses, and possible risk-reduction measures. For existing and future development in South Weber near the base of the slope along the city's south side, South Weber should consider the potential impacts of shallow and deep-seated landslides and the possibility of a breach of the Davis-Weber Canal.

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCES

Black, B.D., 1999, Reconnaissance of a landslide along the Davis-Weber Canal near 1250 East South Weber Drive, South Weber, Davis County, Utah, *in* McDonald, G.N., compiler, Technical reports for 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 36-41.

Earthtec Testing and Engineering, P.C., 2002, Geotechnical study, Highland View Estates subdivision, South Weber, Utah: Ogden, Utah, unpublished consultant's report, 13 p.

Giraud, R.E., 2005, Reconnaissance of the 425 East South Weber Drive landslide, South Weber, Utah: Unpublished Utah Geological Survey Technical Report 05-03, 10 p.

—2006, April 9, 2006, landslide at 1650 East 7687 South, South Weber, Utah: Unpublished Utah Geological Survey letter to Joseph E. Gertge, South Weber City Mayor, April 14, 2006, 3 p.

Lowe, M., 1988, Natural hazards overlay zone - slope-failure inventory map, Ogden quadrangle: Weber County Planning Department unpublished map, scale 1:24,000.

Lund, W.R., 1984, Inspection of landslides adjacent to Hill Air Force Base in Davis County, Utah: Unpublished Utah Geological and Mineral Survey Technical Memorandum, Job Number 84-09, 1 p.

National Weather Service, 2006, Observed weather reports: Online,

<http://www.wrh.noaa.gov/slc/forecast/textproduct.php?pil=CLM&sid=SLC&version=0>, accessed May 8, 2006.

Pashley, E.F., Jr., and Wiggins, R.A., 1972, Landslides of the northern Wasatch Front, *in* Hilpert, L.S., editor, Environmental geology of the Wasatch Front, 1971: Utah Geological Association Publication 1, p. K1-K16.

Ray, I.J., 2006, April 9, 2006, mudslide in South Weber: Sunset, Utah, unpublished Davis and Weber Counties Canal Company letter to Haven J. Barlow, Barlow Corporation, April 28, 2006, 2 p.

Solomon, B.J., 1999, Reconnaissance of a landslide near the Cedar Bench subdivision, South Weber, Davis County, Utah, *in* McDonald, G.N., compiler, Technical reports for 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 42-49.

Terracon, 2000, Geotechnical engineering report, evaluation of Davis and Weber Canal stations 160 to 470, Davis County, Utah: Draper, Utah, unpublished consultant's report, 24 p., 3 appendices.

—2005, Slope stability evaluation, Davis and Weber Canal at Highland View Estates, South Weber, Utah: Draper, Utah, unpublished consultant's report, 13 p., 4 appendices.

TerraServer USA, 2006, U.S. Geological Survey 1997 and 2003 aerial photographs: Online, <http://terraserver.microsoft.com/image.aspx?T=4&S=11&Z=12&X=1054&Y=11365&W=1&qs=%7clayton%7cut>, accessed May 5, 2006.

Utah Automated Geographic Reference Center, 2006, National Agriculture Imagery Program aerial photos: Online, <http://agrc.utah.gov/agrc_sgid/naip.html>, accessed May 5, 2006.

Yonkee, A., and Lowe, M., 2004, Geologic map of the Ogden 7.5-minute quadrangle, Weber and Davis Counties, Utah: Utah Geological Survey Map 200, 42 p. pamphlet, scale 1:24,000.

Utah Geological Survey Technical Report

Project: Reconnaissance of a large landslide upslope of the Mill Hollow Dam, Wasatch County, Utah			
By: F.X. Ashland, P.G.	Date: December 11, 2006	County: Wasatch	
USGS Quadrangles: Wolf Creek Summit (1124)	Section/Township/Range: Sec. 12, T. 4 S., R. 7 E.		
Requested by: Ed Fall, Utah Division of Water Resources	Dates reports received at UGS: na		Job number: 06-12 (GH-15)

INTRODUCTION

The right (south) abutment of the Mill Hollow Dam was constructed at the foot of a large pre-existing landslide (figure 1). Geological and geotechnical investigations by the Utah Division of Water Resources for the design of proposed improvements to the dam included additional assessment of the potential hazard posed by the landslide. A brief reconnaissance of the landslide on October 13, 2006, by the Utah Geological Survey (UGS) was conducted as part of the assessment at the request of the Utah Division of Water Resources. The purpose of the reconnaissance was to help assess the state of activity of the landslide and characterize its probable stability. The scope of work included analysis of topographic information and aerial photographs and a field reconnaissance by Francis Ashland and Ashley Elliott, UGS. This report summarizes our preliminary findings.

CONCLUSIONS AND RECOMMENDATIONS

Field observations indicate the landslide has experienced a recent, and possibly historical, movement episode, and suggest the potential for future movement is likely high. Tilted tree stumps on the upper part of the landslide suggest significant movement occurred in the last several hundred years. Whereas field observations revealed no evidence for recent movement sufficient to cause visible ground deformation, ongoing or recent movement of the slide at a very slow rate cannot be ruled out. Based on these conclusions we recommend the following:

- The potential for future movement of the landslide should be considered in the hazard assessment for the dam.
- Landslide movement monitoring of the entire slide using Global Positioning System survey techniques may reveal ongoing local or global movement or provide a basis for detecting and measuring future movement.

LANDSLIDE DESCRIPTION

The landslide has a north aspect and is bounded on the east by a steep slope that includes a cliff face and on the south by a northeast-trending ridge (figure 1). The lower part of the north slope of the ridge is the main scarp of the slide. An unnamed drainage bounds the slide on the west upslope of its intersection with the Mill Hollow reservoir. The reservoir abuts the lower left flank of the slide. A U.S. Forest Service campground occupies the lower slide and water-supply infrastructure is located upslope of the campground on the upper part of the slide.

Vegetation on the landslide includes clusters of conifers (Engelmann spruce?) and grasses in open meadows. Cut tree stumps on the upper part of the slide are tilted (figure 2) whereas living trees are mostly vertical. Some of the tallest, and presumably oldest, living conifers are on the lower part of the slide in and near the campground.

The upper part of the landslide consists of numerous geomorphically young-looking back-tilted surfaces, some with sag ponds on the upslope edges. The lowermost back-tilted surfaces are relatively narrow and occur on steep slopes. The head of the slide is occupied by three separate sag ponds; the central one was dry at the time of our reconnaissance. The other two sag ponds in the head of the slide drain to the edges of the slide. An abandoned natural spillway channel extends downslope of the western sag pond on the head of the slide. Several other sag ponds exist downslope, including near a right step in the right-flank shear zone (figure 3).

Geology

The landslide material consists, at least in part, of debris derived from the surrounding Tertiary Keetley Volcanics in the cliff and ridge bounding the slide. Boulders of volcanic rocks occur in the slide debris. Glacial debris, also likely derived mostly from the Keetley Volcanics, is present to the west of the slide and the reservoir, and make up some of the landslide mass. Colluvium covers the main scarp of the slide.

Dimensions and Slope

The landslide is about 3,400 feet long and about 1,100 feet wide near the campground (table 1). Overall, the slide is relatively flat with an average slope of less than 20 percent. The lower part of the slide has a flat slope (about 10 percent average slope), but the slope steepens (to about 18 percent average slope) in the upper part of the slide above elevation 9,000 feet (figure 1). The main-scarp slope exceeds 50 percent. The local slope along the foot of the slide is also steep.

Currently, the lower part of the landslide forms a constriction in Mill Hollow, suggesting a total displacement of about 570 feet. Reconstruction of the estimated pre-failure slide geometry suggests the original slide was about 2,900 feet long and had an average slope slightly over 20 percent (figure 4).

Table 1. *Summary of approximate dimensions and average slope.*

Description	Current (toe to head)	Current (toe to crown)	Pre-Failure (estimated)
Relief (feet)	520	640	600
Length (slope)	3,350	3,550	2,920
Average Slope (percent)	16	18	21

EVIDENCE FOR RECENT OR ONGOING MOVEMENT

Field observations revealed no evidence for recent or ongoing global movement resulting in displacement sufficient to cause visible ground deformation, but movement at a very slow rate resulting in only minor displacement and ground deformation cannot be ruled out. A trail crossing the right flank of the landslide was intact and no ground cracks were observed. Near the south edge of the campground, a buried pipe was broken, and a small sinkhole had formed, but the cause of the damage to the pipe was uncertain. Near the west side of the landslide, well casings appeared tilted and possibly displaced toward the left-flank drainage. New wells had been completed upslope of the older ones. Some, but not all, of the living trees in the southeastern corner (head) of the landslide were tilted, suggesting that landsliding is not the most probable cause of the tilting.

PROBABLE AGE OF MOST RECENT MAJOR MOVEMENT EPISODE

Tree stumps on back-tilted surfaces are tilted, but living trees are vertical, bracketing the age of the most recent major movement episode (figures 2 and 3). This episode likely occurred in the latter part of the life of the cut trees, suggesting the episode occurred in the past several hundred years. The ages of the tallest vertical living trees on the upper part of the slide provide a constraint on the minimum age of the most recent major movement episode. Figure 5 shows a conceptual model explaining the tilting of trees on the upper part of the landslide. Some of the oldest living trees in the campground areas are in the flat lower part of the slide where displacement may not have been accompanied by any rotation. These trees may be the same age as the tilted cut trees, and may have been displaced and survived the most recent major movement episode with little tilting or disruption. Thus, their age may constrain the maximum age for the most recent movement episode. Close examination of tree rings from both large living trees and tilted cut stumps (dendrochronology) may allow for dating of the movement episode.

CONCLUSIONS

Field observations suggest the most recent major movement episode of the landslide occurred in the past several hundred years, and possibly during the lifetime of the oldest living trees in the lower part of the slide. The stability of the landslide and its potential for reactivating and affecting the Mill Hollow Dam is of concern. Whereas field observations revealed no evidence for recent movement sufficient to cause ground deformation, ongoing or recent movement of the slide at a very slow rate cannot be ruled out.

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for any particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

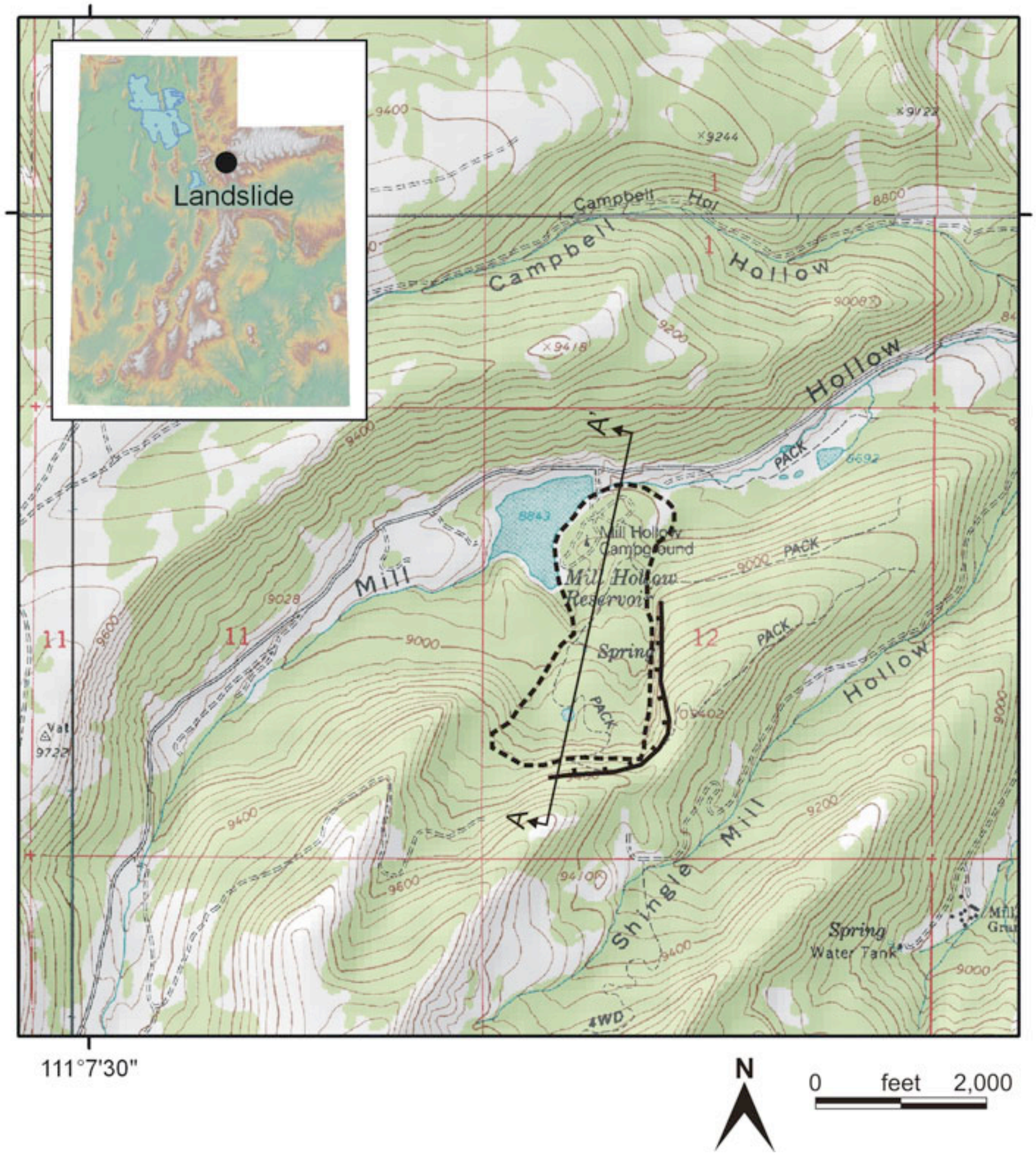


Figure 1. *Location map of the landslide abutting the Mill Hollow Dam in Wasatch County. Base from U.S. Geological Survey Wolf Creek Summit 7-1/2' quadrangle map. Profile line A-A' (figure 4) shown; dashed line is approximate landslide boundary, hachured line indicates main and right-flank scarps.*

Figure 2. *View toward the west of back-tilted surface in upper part of landslide. Note that whereas the living trees are vertical, the tree stump is tilted, suggesting back-tilting occurred during lifetime of tree.*

Figure 3. *View toward the west from right flank of landslide showing back-tilted surface (right) at right step in right-flank shear zone. Note that the tree stumps are tilted, but the living trees are vertical.*

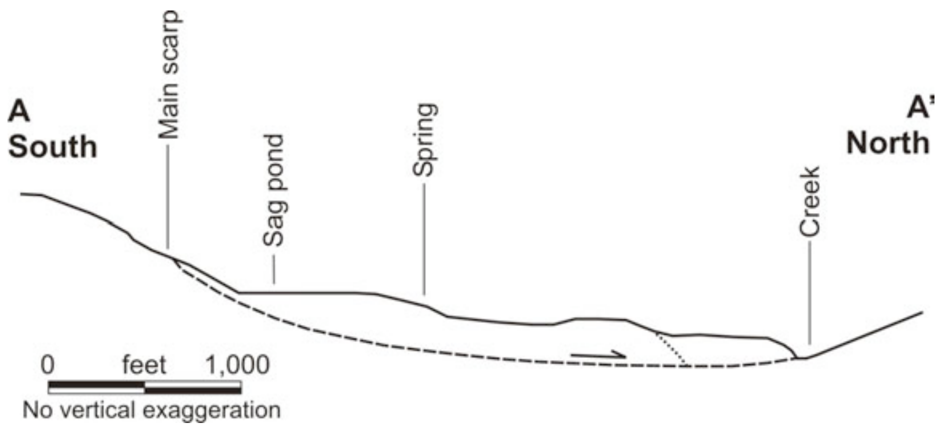


Figure 4. *Profile A-A' across landslide showing approximate geometry. Dotted line is estimated pre-failure location of incipient toe. See figure 1 for profile-line location.*

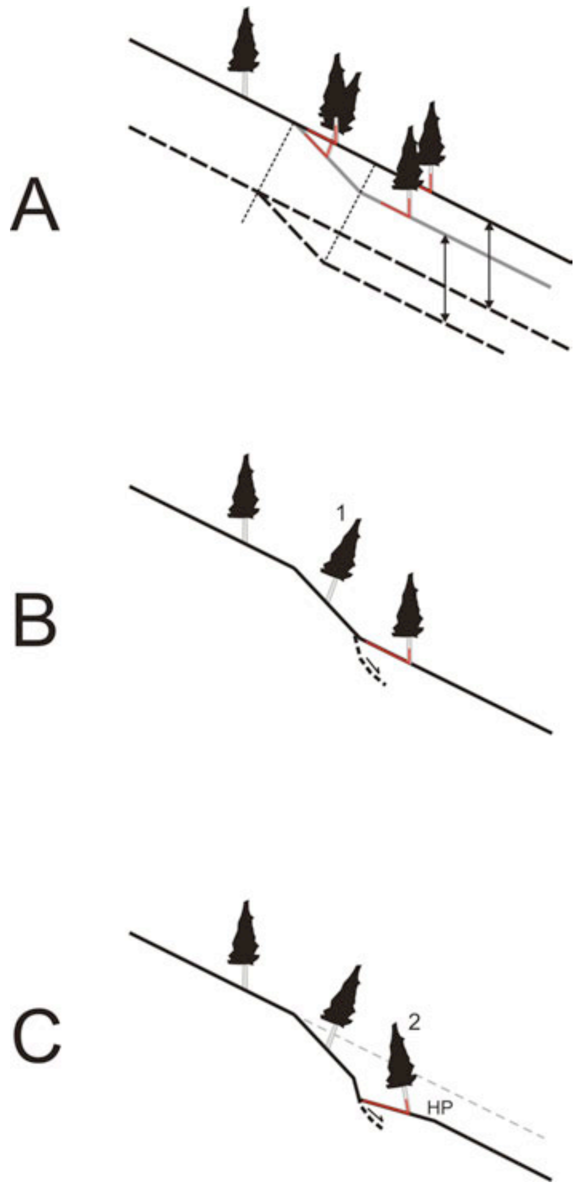


Figure 5. *Conceptual diagram showing the development of back-tilted surfaces and tilted trees on the upper part of the landslide. (A) Monoclinal folding of slope with vertical trees (solid black line) initiates above incipient scarp on the landslide. Dashed black lines show hypothetical lower surface used to draw monocline using the kink method. Solid gray lines show future displaced ground surface due to folding. Arrows show preserved layer thickness. Thin dashed black lines are traces of hinge planes that divide dip domains of monocline. Red elbows used to preserve angle between ground surface and tree trunks. (B) Slope geometry following monoclinal folding showing downslope-tilted tree (1). Dashed black line shows incipient scarp. (C) Ground surface offset by scarp causes back-tilting directly downslope of scarp and rotates tree (2). A hinge point (HP) defines the downslope extent of back-tilting where ground-surface tilt remains unchanged. Gray dashed line shows net vertical offset of ground surface.*

Utah Geological Survey Technical Report

Project: Update on conditions through 2008 at the Springhill landslide, North Salt Lake, Utah			
By: F.X. Ashland and A.H. Elliott	Date: March 23, 2009	County: Davis	
USGS Quadrangles: Salt Lake City North (1254)	Section/Township/Range: Sec. 12, T. 1 N., R. 1 W., Salt Lake Base Line and Meridian		
Requested by: NA	Dates reports received at UGS: NA		Job number: 09-01 (GH-16)

INTRODUCTION

The Utah Geological Survey (UGS) has been monitoring conditions at the Springhill landslide in North Salt Lake (figures 1 and 2) since 1998. This report summarizes and updates some of the technical information on the landslide including the current boundary based on recent UGS mapping, movement history, and ground-water levels affecting stability. The report is intended to provide the affected residents, city officials, and utility providers with information on landslide conditions through 2008 and possible trends (what might happen in the future).

BACKGROUND

In the late 1990s, residents in the Springhill area of North Salt Lake began noticing building and pavement cracking and other distress related to relatively minor movement of the landslide. By 1998, a house at 160 Springhill Drive that straddled the northeastern boundary of the landslide was severely damaged and condemned (Giraud, 1999; Ashland, 2003). Relatively severe distress also occurred to several houses along Valley View Drive (formerly 350 E) and Springhill Circle. Little movement or damage occurred during a dry period between 1999 and 2004, but the rate of movement accelerated during the 2005 wet year. Since 2005, the amount of movement each year has increased, except in 2007 (a dry year), resulting in an increased amount of damage and distress, particularly to houses in the upper and lower parts of the landslide (figure 3) and to Springhill Drive (figure 4).

Monitoring of the landslide movement began in late 1998, with the installation of inclinometers by the geotechnical consulting firm Terracon, which was hired by North Salt Lake City to conduct a subsurface investigation. Inclinometers are sensitive movement-detection devices used to determine the depth of landslides and the amount of movement. The initial inclinometer readings were made in five locations in September 1998 (Terracon, 1998).

Subsequent measurements have provided data on the depth and amount of movement at three of the locations (Terracon, 2000, 2005). However, the best data (in quality and duration of record) was obtained from inclinometer I-1 installed on the north side of Springhill Circle (figure 2).

Subsequent to Terracon's inclinometer measurements in 2005, the UGS began monitoring ground deformation at various locations on the landslide, providing some basis to assess changes in the rate of movement. In 2006, the UGS began monitoring ground deformation across scarps that had formed in the uppermost part of the landslide. In 2008, the UGS also began monitoring ground deformation at the toe of the landslide following demolition of a condemned house at 157 South Valley View Drive.

GEOLOGY

The Springhill landslide formed in weak, poorly drained clay soils and underlying weathered Tertiary tuffaceous deposits and volcanic breccia (Van Horn, 1981). The weathering of the underlying volcanic rocks may be due, in part, to the proximity of the Wasatch fault zone, which crosses the lowermost part of the landslide near the modified slope between Valley View Drive and Springhill Drive (Nelson and Personius, 1993) (figure 5). Prehistoric faulting and intense ground shaking may have fractured the nearby rocks and provided a path for ground-water flow that promoted hydrothermal alteration and weathering. The numerous springs in the area are likely the result of the inability of ground water to flow downward through the clay soils and weathered rocks.

LANDSLIDE DESCRIPTION

In 1998, the total cumulative movement of the landslide was insufficient for the development of well-defined ground deformation features along the boundary of the landslide. Thus, the exact boundary of the landslide was difficult to map (Terracon, 1998; Giraud, 1999). Following the increased movement in 2005, ground deformation features began to develop along much of the landslide. Our map (figure 2) shows the current landslide boundary and deformation features in the head (uppermost part) and toe (lowermost part) of the landslide.

The landslide (figures 2 and 5) is about 720 feet (220 m) long and reaches a maximum width of about 290 feet (90 m) where it crosses Springhill Drive. The local relief is about 150 feet (46 m) and the average slope is about 21 percent. The landslide is about 48 feet (15 m) deep beneath Springhill Circle (at inclinometer I-1) (figure 6) and probably deeper than 70 feet (21 m) near Springhill Drive (at inclinometer I-3). At inclinometer I-2, near the southern boundary, the landslide is only between about 10 and 14 feet (3-4 m) deep (Terracon, 2000). At inclinometer I-5, near the toe of the landslide, the depth of the landslide may be between about 6 and 18 feet (2-6 m) (Terracon, 2000, 2005). The inclinometer plot for I-5 suggests that perhaps three separate slide surfaces intercept the casing within that depth range. These slide surfaces may be developing below ground downslope of the mapped toe and have not yet intercepted the ground surface. The landslide is moving slowly toward the northwest (toward Valley View Drive).

The northern boundary of the landslide is presently well defined by scarps, linear troughs, road cracks and pavement distress, and deflections of linear elements such as fences. The southern boundary of the landslide is less well defined because it crosses a wetland area south of Springhill Circle, but a set of recurrent road cracks indicates its location in the southern part of Springhill Drive. Since 2006, scarps have formed in the head of the landslide, southeast of Springhill Circle. These scarps locally reached a maximum height of about 3 feet (1 m) by December 2008 (figure 7).

The toe of the landslide is characterized by several step-like features between Valley View Drive and the steep slope at the back of the lots along the southeast side of the road. UGS mapping suggests that the main basal slide plane, which is about 48 feet (15 m) deep at inclinometer I-1, splays and intersects the ground surface in at least four locations, each coinciding with one of the steps (figure 5). Each of the slide-plane intersections is referred to as a toe thrust, and collectively they form a toe thrust system. As landslide movement occurs upslope, a portion of the total movement is distributed among each splay. Due to the relatively small differential movement amounts at each toe thrust, the ground bends or flexes. Eventually, with sufficient cumulative movement of the landslide, differential movement at each toe thrust will cause the ground on the upslope side of the thrust to override the ground surface directly downslope.

MOVEMENT HISTORY

The Springhill landslide has been persistently moving since the late 1990s, but movement may have suspended during dry years such as in 2003 and 2007. Figure 8 shows the general movement history in relation to precipitation during the landslide water years (LWY; Ashland, 2003) between 1997-98 and 2007-08. Damaging movement occurred or initiated in two wet years of 1998 and 2005. Since January 2008, the landslide has been continuously moving at a very slow rate. The total movement of the landslide since September 1998, likely exceeds 18 inches (46 cm).

Inclinometer Data

Measurements from inclinometer I-1 showed that the landslide persistently moved between September 1998 and April 2000 (figure 6). However, the data also indicated that the rate of movement dramatically slowed between late 1999 and early 2000, coincident with the onset of a prolonged dry period from 1999 through 2003. Two subsequent measurements in 2001 and 2002 showed only very minor movement, confirming that the rate of movement had slowed by the year 2000. A final measurement in July 2005 indicated a dramatic increase in both the amount and rate of movement (Terracon, 2005). Between September 1998 and July 2002, only about an inch (2.5 cm) of movement had occurred at inclinometer I-1. However, by July 2005, nearly 4 additional inches (10 cm) of movement had occurred, indicating a dramatic increase in the rate of movement with the return of wet conditions in 2005.

Measurements from inclinometer I-2 near the southern boundary of the landslide showed that the landslide moved about 1.25 inches (3.2 cm) between September 1998 and April 2000 (Terracon, 2000). By July 2005, the casing had sheared off, indicating (as at I-1) a dramatic increase in the amount and rate of movement in 2005.

Measurements from inclinometer I-5 at the toe of the landslide indicated the landslide moved about 1.25 inches (3.2 cm) by July 2005, considerably less than the movement in the upslope inclinometers. By late 2008, the inclinometer and adjacent observation well casings had not yet sheared off, suggesting most of the landslide movement was occurring on the daylighting toe thrusts upslope of the inclinometer and not the buried slide planes that intercept the inclinometer.

UGS Ground-Deformation Measurements

Measurements of ground deformation across the main scarp zone and toe in 2008 indicated continuous movement throughout the year (figures 9 and 10). The rate of deformation (movement) across the main scarp zone (figure 9) increased by around late February coincident with the snowmelt and was relatively constant through early May. By around mid-May, the rate of movement slowed, but movement continued at a nearly constant rate through at least late summer. An increase in the rate of movement occurred in September 2008. By December, about 8.9 inches (23 cm) of stretching had occurred in 2008.

Monitoring at the toe of the landslide showed how upslope movement was distributed among the step-like toe thrusts southeast of Valley View Drive (figure 10). Most of the movement occurred on the westernmost toe thrust directly southeast of inclinometer I-5, but each of the other toe thrusts was also active, accommodating some of the upslope movement. Between April and June 2008, about 2 inches (5 cm) of shortening occurred across the toe thrust system due to movement upslope. Based on measurements through December 2008, an estimated 3.4 inches (9 cm) of shortening occurred over the entire system in an eight-month period.

The extended duration of movement resulting from continuous movement throughout the calendar year may be a partial cause of the higher total annual movement amounts since 2005 (about 4 to 9 inches [10-23 cm]). One significant implication of continuous movement is the potential additional reduction in the strength of the clay along the slide plane. The weakening of the clay combined with more efficient infiltration of water into the landslide as new ground deformation features form may cause the rate of movement to accelerate, resulting in an increase in the total annual movement.

GROUND-WATER CONDITIONS

Terracon installed six observation wells in the landslide in 1998 to monitor ground-water levels in the landslide (Terracon, 1998). Since August 1998, the UGS has been monitoring ground-water levels each month to better understand the relationship between ground-water levels and landslide movement.

Ground-water levels in each observation well fluctuate seasonally (throughout the year) and generally are at their highest level during or shortly following the snowmelt (in the first half of the year) or later in the year (possibly as a result of local landscape irrigation) (figure 11). Between 1999 and 2004, the seasonal peak ground-water levels in the four wells in Springhill Drive typically occurred in the first six months of the year (figure 12), suggesting the ground-water levels rise in response to snowmelt and spring precipitation (generally the wettest months of the year are March through May). In the dry years between 2001 and 2004, the seasonal peak ground-water level in observation well P-1 in Springhill Circle occurred in either August or September, possibly in response to summertime landscape irrigation. Notably, lawns surround the observation well in every direction. The peak ground-water level in two of the Springhill Drive wells, P-3 and P-4, occurred three times, collectively, in the last two months of the year, possibly due to landscape irrigation in the summer or extreme (record) monthly precipitation in the fall.

The possible impact on ground-water levels from extreme monthly precipitation is illustrated by the ground-water fluctuations preceding the late-in-the-year seasonal peak ground-water level in observation well P-3 in 2004. The seasonal peak ground-water level in observation well P-3 in December 2004 was preceded by extreme monthly precipitation in October during which 6.0 inches (15 cm) of precipitation fell in nearby Bountiful. The monthly total in October was 267 percent of the normal monthly precipitation and equivalent to 22 percent of the annual precipitation (versus 8 percent for normal October precipitation). Between October and December 2004, the ground-water level in the observation well rose nearly 5 inches (13 cm) (roughly 80 percent of the total seasonal fluctuation in 2004 of 6 inches [15 cm]). Interestingly, the rise in ground-water level subsequent to extreme October precipitation reversed a gradual decline in ground-water level over the summer and early fall from a previous peak level associated with snowmelt.

Beginning in 2001, the ground-water level in observation well P-5, near the toe of the landslide, began to rise (figure 13). By 2005, seasonal fluctuations in ground-water level were observed with the highest level occurring in the early part of the year likely the result of the infiltration of snowmelt. The ground-water level rose at least 20 feet (6 m) by April 2006, a significant rise for which the cause remains unknown, and in 2008 was sustained within a foot of this peak level throughout the year. By November 2008, the ground-water level had risen to its highest level, rising a total of 21 feet (6.4 m) since 2001. The rising ground-water level in observation well P-5 is a concern if it also indicates a similar rise in ground-water levels in the toe of the landslide because such a rise results in a reduction in the frictional forces acting to resist downslope movement. The sustained high seasonal peak ground-water level near (and possibly in) the toe of the landslide since at least 2006 may be the primary cause of the increase in annual movement, and the sustained high ground-water level near the toe in 2008 may explain the continuous movement throughout the year.

FUTURE MOVEMENT POTENTIAL

Persistent movement of the Springhill landslide is likely in the future, except perhaps in the driest of years. Future movement amounts may exceed those since 2005 (4-9 inches [10-23 cm] per year). A 20-foot (6-m) rise in the ground-water levels near the toe of the landslide between 2001 and 2006 may be the cause of the increase in annual movement. If future annual movement amounts continue to exceed 6 inches (15 cm) per year, damage to houses, roads, and buried utilities will become more severe and recurrent, and new damage may occur to structures on parts of the landslide where damage was previously minor or tolerable.

ACKNOWLEDGMENTS

Richard Giraud, Michael Kirschbaum, and Keith Beisner assisted with various aspects of data collection and compilation. North Salt Lake City Engineer Paul Ottoson provided copies of the Terracon reports. Review comments from Steve Bowman and Mike Hylland (Utah Geological Survey) improved this report.

LIMITATIONS

REFERENCES

Ashland, F.X., 2003, Characteristics, causes, and implications of the 1998 Wasatch Front landslides: Utah Geological Survey Special Study 105, 49 p.

Giraud, R.E., 1999, Reconnaissance of building distress and ground movement in the Springhill Circle area, North Salt Lake, Davis County, Utah, in McDonald, G.N., compiler, Technical reports for 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 60-75.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2199, 22 p. pamphlet, scale 1:50,000.

Terracon, 1998, Geotechnical report, Springhill landslide, City of North Salt Lake, Utah: Salt Lake City, unpublished consultant's report, 23 p.

Terracon, 2000, Inclinometer and piezometer readings, Springhill subdivision, North Salt Lake, Utah: Salt Lake City, unpublished consultant's report, 2 p.

Terracon, 2005, Inclinometer and piezometer readings, Springhill subdivision, North Salt Lake, Utah: Draper, Utah, unpublished consultant's report, 2 p.

Van Horn, R., 1981, Geologic map of pre-Quaternary rocks of the Salt Lake City North quadrangle, Davis and Salt Lake Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1330, scale 1:24,000.

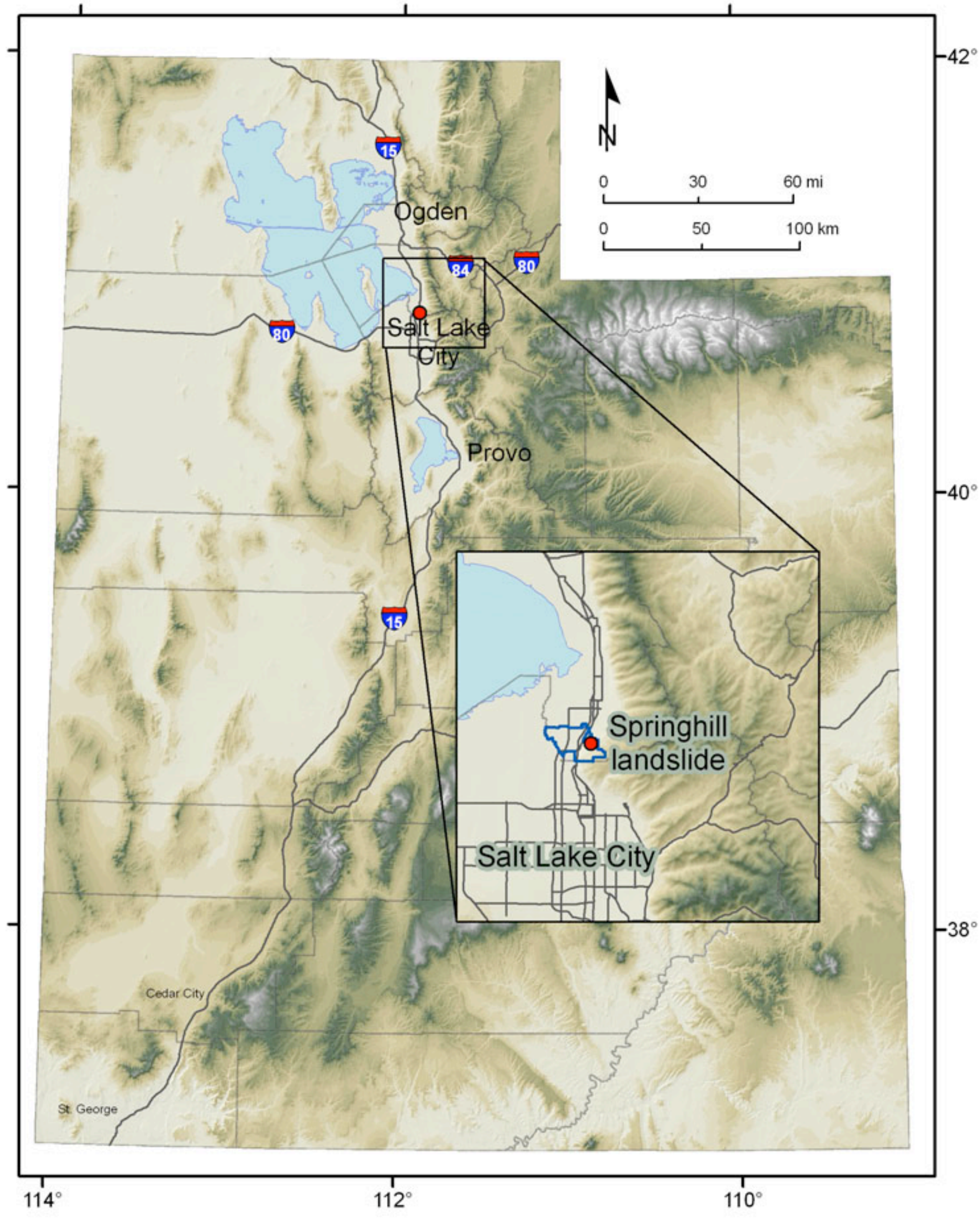


Figure 1. *General location of the Springhill landslide in North Salt Lake. Boundary of North Salt Lake shown in inset map (blue line).*

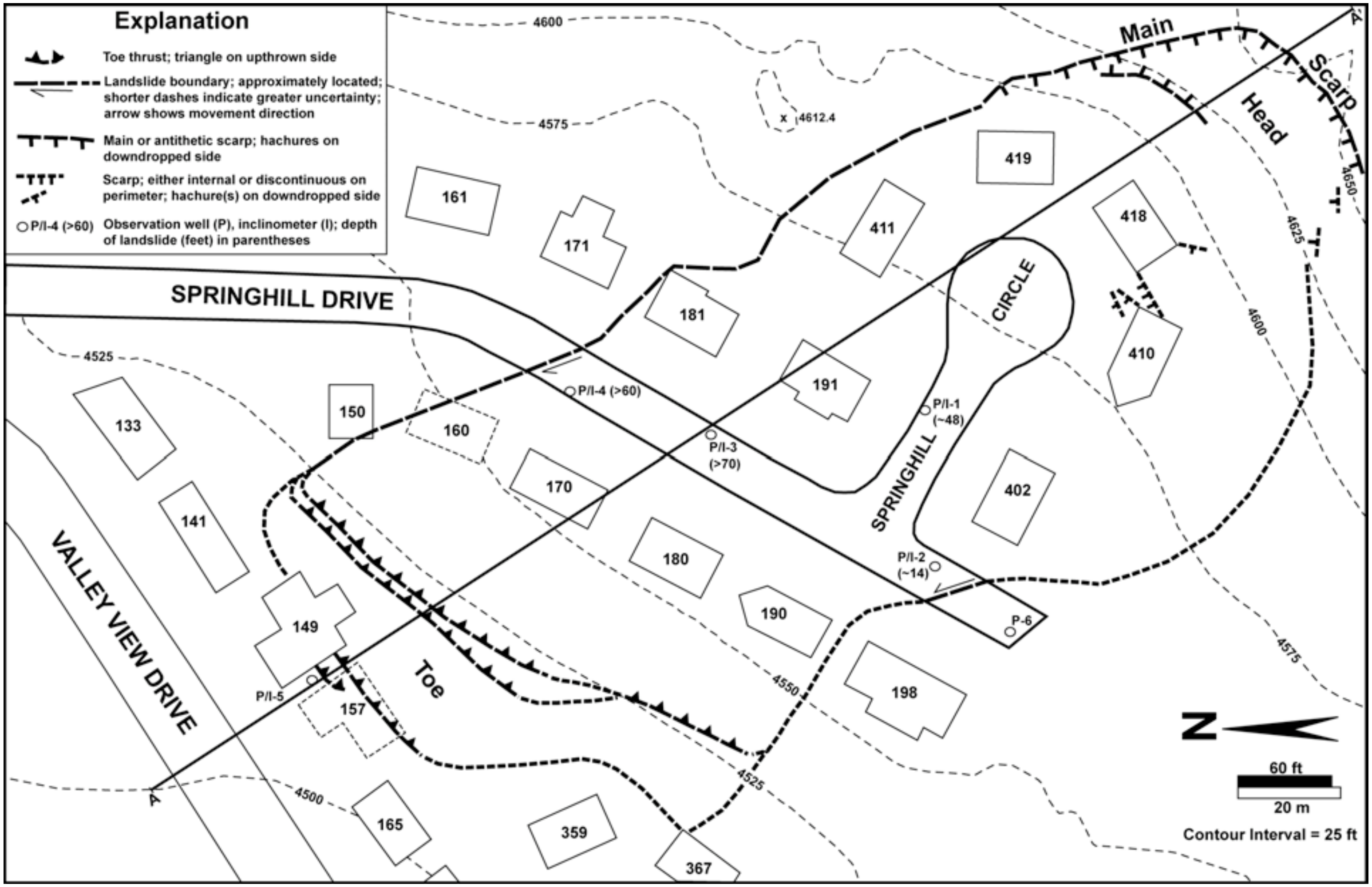


Figure 2. *Map of the Springhill landslide. Base map modified from Terracon (1998). A trace of the Wasatch fault zone (not shown on map, see figure 5 for approximate location) is inferred to cross the landslide in the backyards of the lots immediately southeast of Valley View Drive. Geologic cross section A-A' is shown on figure 5. Dashed lines indicate houses that have been demolished.*

Figure 3. *Damage to garage attached to a house at 157 South Valley View Drive. House was subsequently demolished. Photograph taken in June 2006.*

Figure 4. *Road damage to south end of Springhill Drive along south-flank shear zone. View is upslope and to the southeast. Tilted and displaced curb and gutter visible on opposite side of road. Ground on left side of photograph is moving downslope (toward bottom-left edge of photograph). Photograph taken in May 2008.*

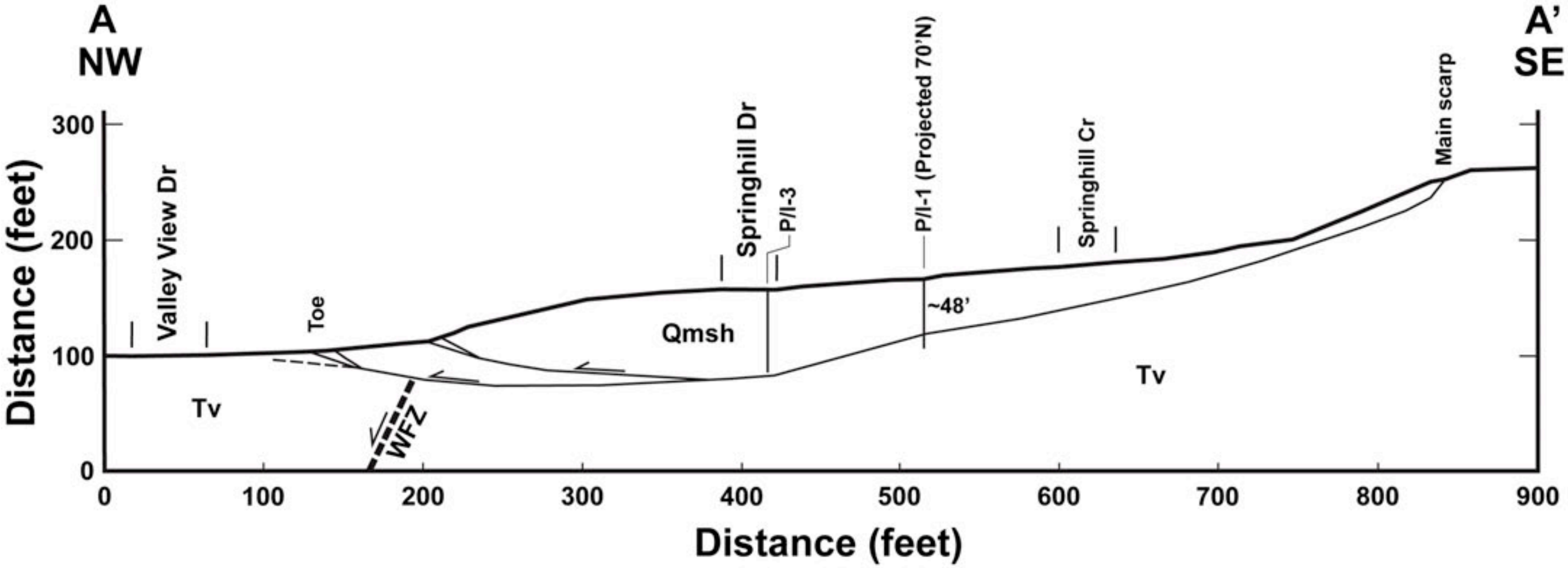


Figure 5. *Geologic cross section of Springhill landslide based on depths from inclinometers and slope-stability analysis. Landslide (Qmsh) overlies weathered Tertiary volcanic rocks (Tv). Basal slide-plane splays intersect the ground surface at four locations (see figure 2). Approximate location of trace of Wasatch fault zone (WFZ) shown beneath toe of landslide. Inclinometer I-5 near northwestern edge of toe not shown for clarity because of its location immediately downslope of frontal toe thrust. See figure 2 for section line location.*

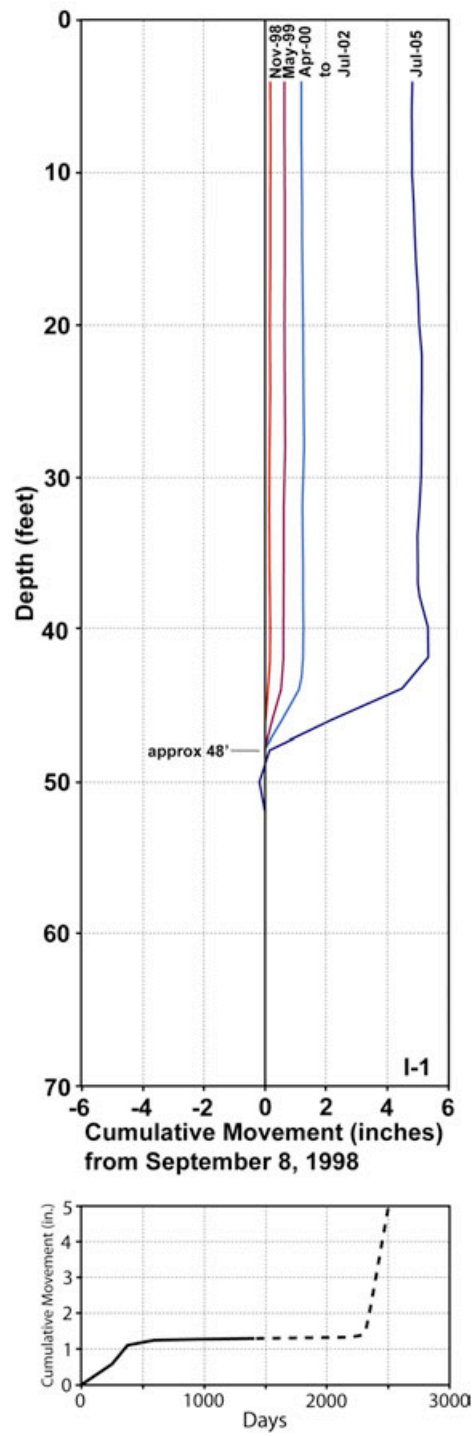


Figure 6. *Plots for inclinometer I-1 in Springhill Circle. Upper plot shows cumulative movement versus depth between September 1998 and July 2005. Landslide depth is about 48 feet (15 m.) Lower plot shows cumulative movement versus time. Dashed part of curve is inferred based on surface observations between July 2002 and July 2005. Plots modified from Terracon (2005).*

Figure 7. *View downslope and to the west of lowermost antithetic (uphill-facing) scarp in the main scarp zone. Photograph taken in December 2008.*

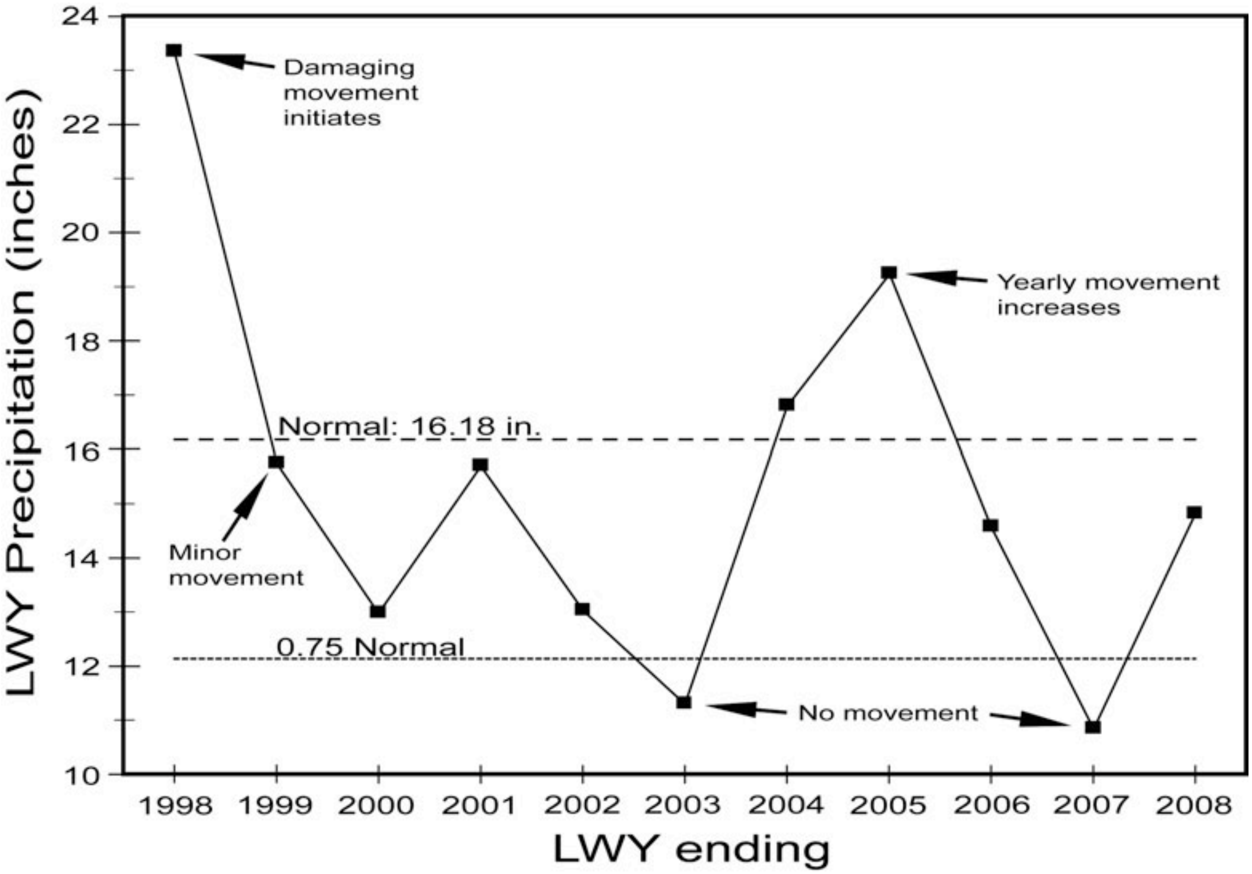


Figure 8. *Salt Lake City precipitation for landslide water years (LWY) ending between 1998 and 2008 annotated with movement history of the Springhill landslide. Damaging movement initiated in 1998 during the second-wettest LWY on record dating back to 1875 in Salt Lake City. Minor movement of landslide occurred during drier-than-normal period between 1999 and 2002. By 2003, movement may have suspended during exceptional dry conditions (LWY precipitation was less than 75 percent of normal). Damaging movement started again in 2005 during the second-wettest LWY in the measurement period. Beginning in 2005, annual movement amounts reached 4 inches (10 cm) or more. Despite drier-than-normal conditions in the following years, movement continued and annual movement amounts increased, except in exceptionally dry 2007. Annual movement amounts reached as high as 9 inches (23 cm) by 2008. LWY precipitation data compiled from provisional data in monthly National Weather Service climatological reports. Normal precipitation for Salt Lake City from Ashland (2003).*

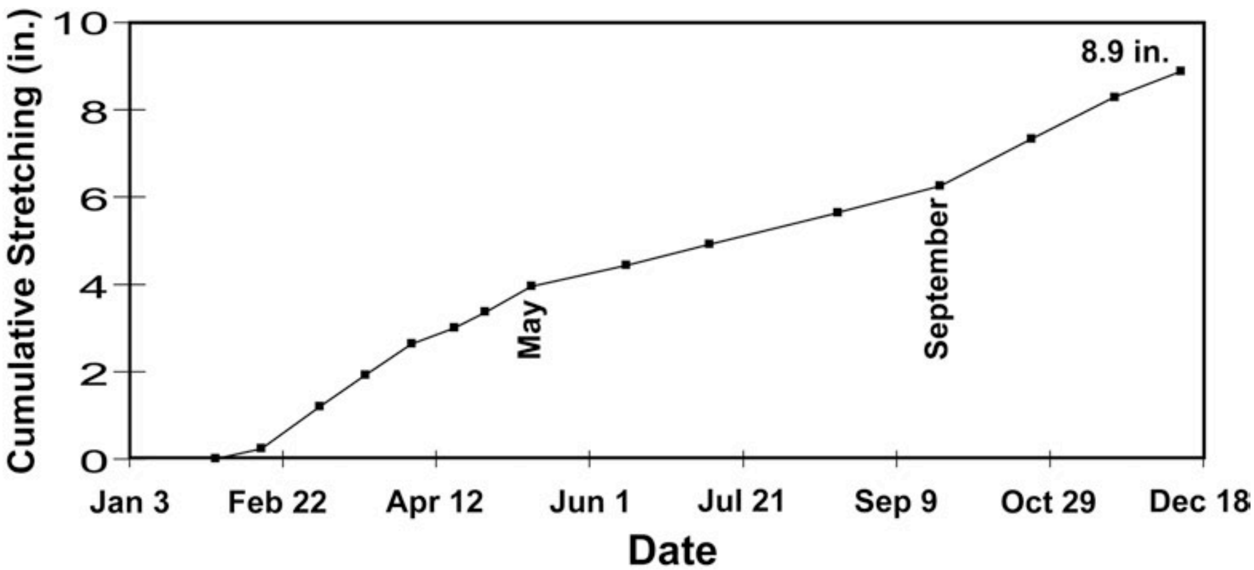


Figure 9. *Cumulative stretching across main scarp zone in 2008. Total stretching was about 8.9 inches (23 cm). Changes in the rate of movement occurred in May and September, separated by periods during which movement occurred at a nearly constant rate. A gradual increase in the rate of movement also occurred in early February. Ground deformation measurements were taken between January 31 and December 11.*

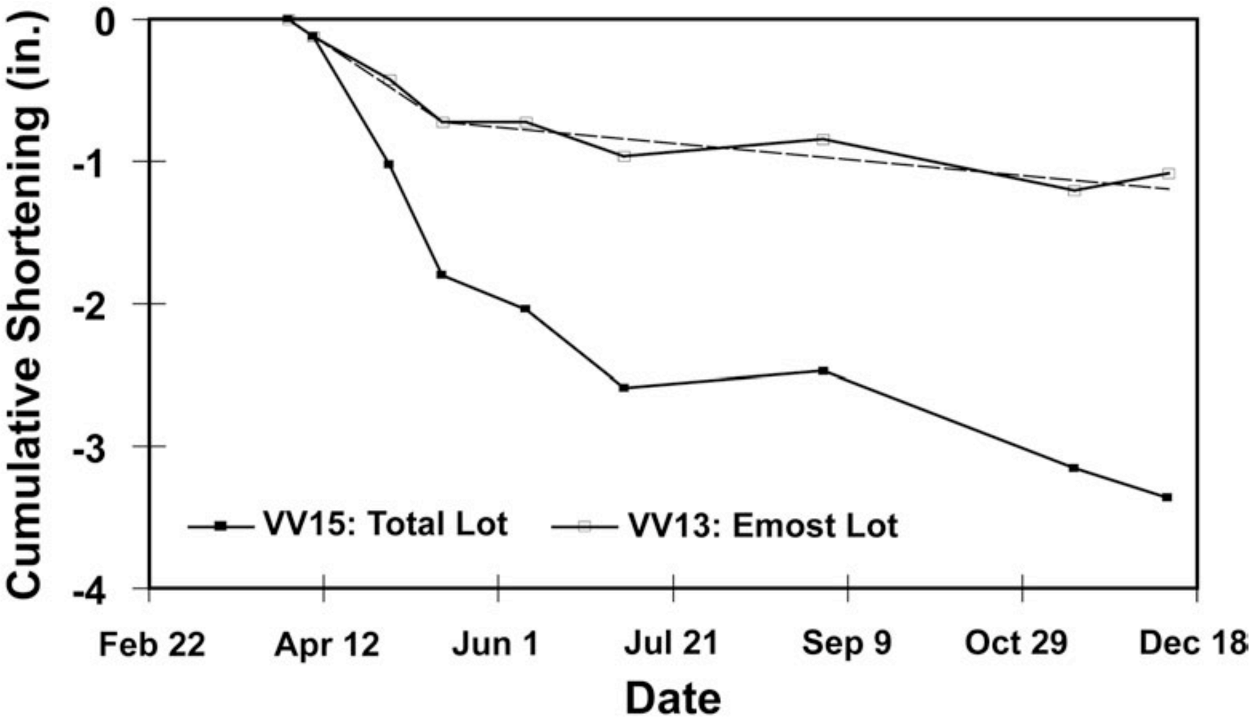


Figure 10. *Cumulative shortening across the toe thrust system at lot 157 Valley View Drive between April and December 2008. Upper curve shows cumulative shortening across southeasternmost two toe thrusts (figure 2). Lower curve shows cumulative shortening across entire toe thrust system, which was about 3.4 inches (9 cm) over the eight-month measurement period between April 2 and December 10. A decrease in the rate of movement occurred in May, similar to that observed in the upper part of the landslide, likely in response to declining ground-water levels in the dry period between March and July 2008. Dashed line shows probable deformation curve removing measurement error.*

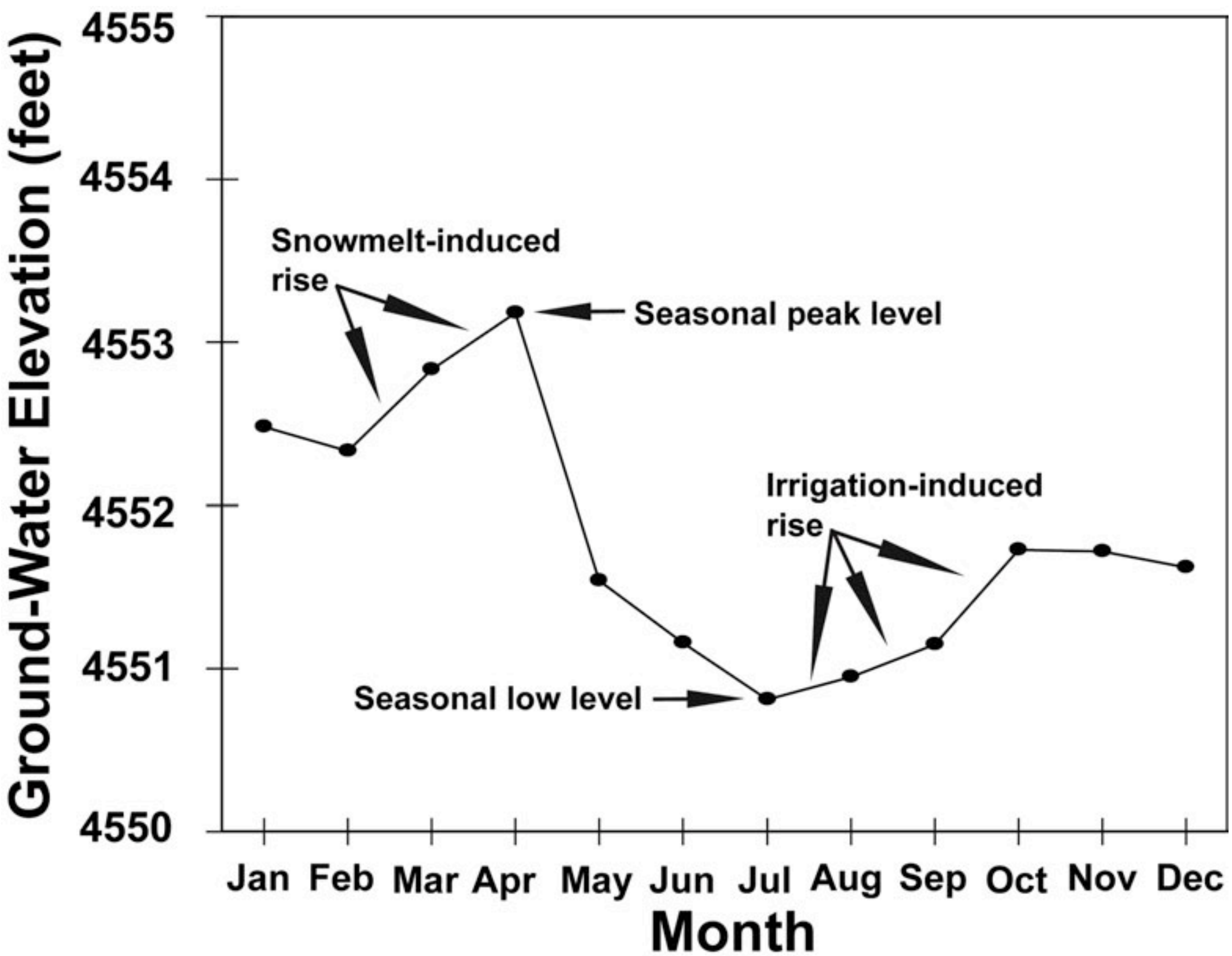


Figure 11. *Seasonal fluctuation in ground-water level in observation well P-4 in 2006. Rise in ground-water level between February and April to seasonal peak level is due mostly to infiltration of snowmelt. Seasonal low ground-water level occurs in response to dry hot weather and evapotranspiration. The rise in ground-water level between July and October is likely due to local landscape irrigation. Subsequently, the ground-water level declines in the fall and early winter. The rate of landslide movement typically increases with rising ground-water levels in the early part of the year and decreases as ground-water levels decline from the seasonal peak levels.*

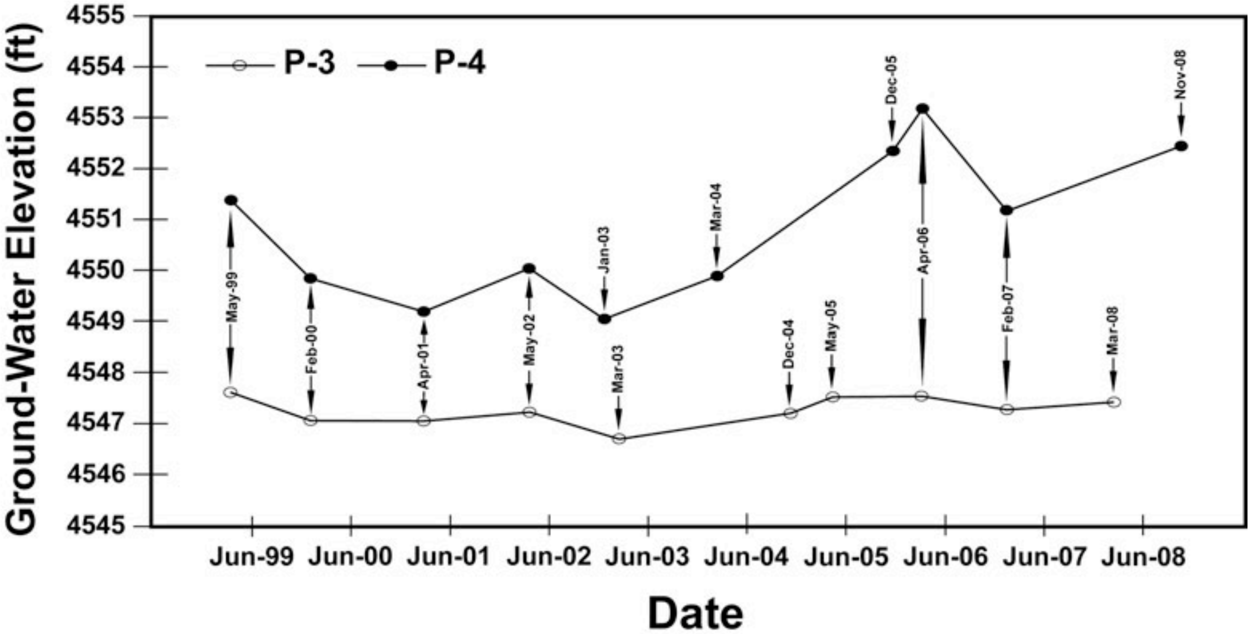


Figure 12. *Fluctuations in seasonal peak ground-water levels (SPGWL) in observation wells P-3 and P-4 between 1999 and 2008. The SPGWL coincides with the lowest stability of the landslide during the year, and thus is a basis for assessing the relative stability of the landslide. High SPGWLs since 2005, most evident in P-4, coincide with increased annual movement amounts, except in 2007.*

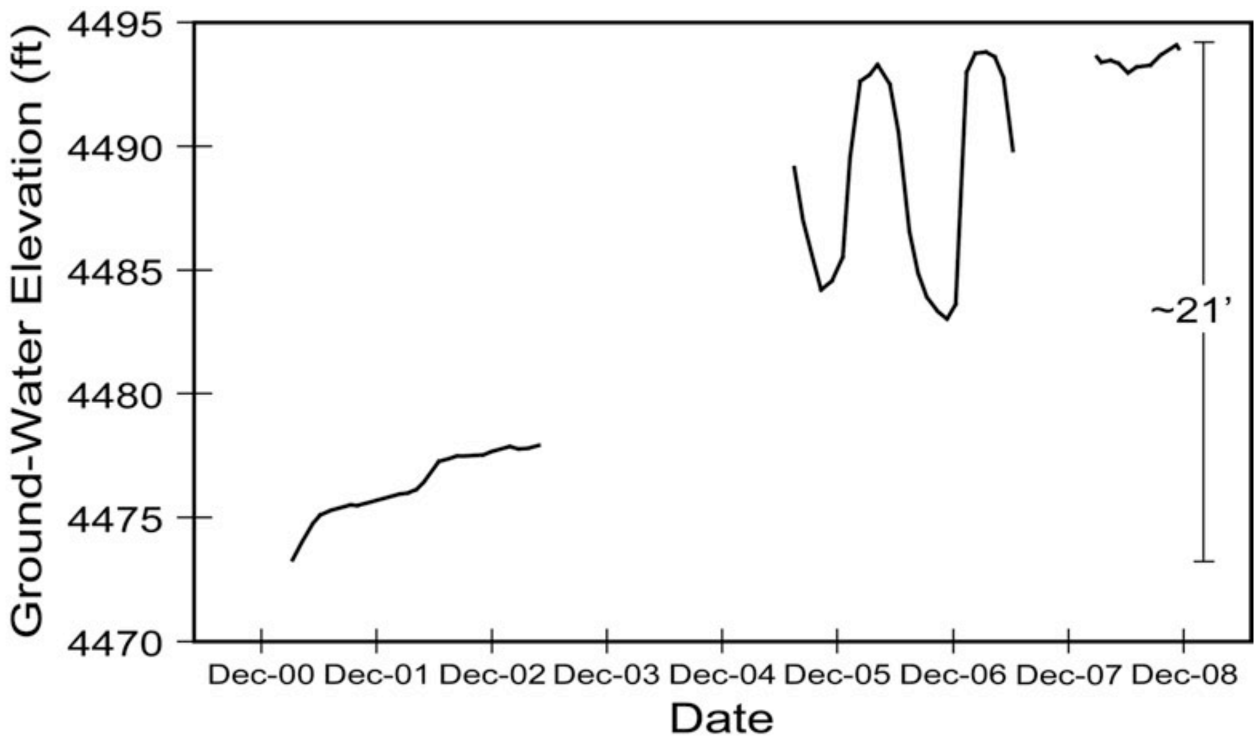


Figure 13. *Rise in ground-water level in observation well P-5 near toe of the landslide since 2001. Observation well was dry when initially installed in 1998 until March 2001. Between March 2001 and April 2006 the ground-water level rose nearly 20 feet (6 m). Ground-water levels between 2005 and early 2007 fluctuated seasonally, with the peak levels following snowmelt. By November 2008, the ground-water level had risen to its highest level, rising a total of 21 feet (6.4 m) since 2001. Gaps indicate periods when observation well was not accessible.*

Utah Geological Survey

Project: Investigation of the April 11, 2009, 1550 East Provo rock fall, Provo, Utah			
By: Richard E. Giraud, P.G., Ashley H. Elliott, and Jessica J. Castleton	Date: 07-2-09	County: Utah	
USGS Quadrangles: Orem (1088), Bridal Veil Falls (1087)	Section/Township/Range: Sections 32 and 33, R. 3 E., T. 6 S., SLBM		
Requested by: Lewis Billings, Mayor, Provo City			Job number: 09-02 (GH-17)

INTRODUCTION

On April 11, 2009, around 11:30 a.m., rock detached from a cliff band producing a rock fall on the upper part of Y Mountain (figures 1 and 2) above Provo, Utah. Rock debris traveled down the west side of Y Mountain into a subdivision. One rock impacted and severely damaged a vacant house at 1496 North 1550 East (figure 3). Another rock damaged a fence and playhouse at 1522 North 1550 East (figure 4). The damaged house at 1496 North 1550 East is one lot north of 1468 North 1550 East, where a guest house was destroyed by a rock fall on May 12, 2005 (Christenson and Giraud, 2005). The 2005 and 2009 rock-fall paths are shown in figure 2.

Provo City Mayor Lewis Billings requested that the Utah Geological Survey (UGS) investigate the rock fall. On April 15, 2009, we provided Mayor Billings a letter with our initial conclusions and recommendations. This report provides supplemental information on the rock-fall hazard and restates our conclusions and recommendations. The purpose of our investigation was to determine the geologic characteristics of the rock fall and evaluate future-hazard potential to aid Provo City in assessing the risk to houses and city infrastructure in the area. We focused on the relative susceptibility of rock outcrops to initiate rock fall, the rock-fall travel paths to houses, and rock-fall runout distance.

Ashley Elliott and Jessica Castleton, UGS, visited the site on April 13, 2009. On April 20, 2009, Ashley Elliott, Greg McDonald, and Steve Bowman, UGS, visually inspected and photographed the rock fall cliff area on Y Mountain during a helicopter flight. For this investigation, we studied relevant geologic literature and maps. We also reviewed early 1970s 1:15,000-scale stereo aerial photographs (Bowman and others, 2009); U.S. Geological Survey 1997 orthophotography at various scales (Utah Automated Geographic Reference Center, 2009a); and 2004 and 2006 National Agriculture Imagery Program (NAIP) orthophotography at various scales (Utah Automated Geographic Reference Center, 2009b).

APRIL 11, 2009 ROCK FALL

On April 11, 2009, rock-fall debris bounced and rolled downslope and damaged a vacant house and playhouse (figures 3 and 4). The rock that damaged the vacant house at 1496 North 1550 East traveled through the house and into the garage. Figure 3 shows house damage and figure captions describe the rock's travel path through the house. We estimate the rock's dimensions to be 4 x 5 x 4 feet (figure 3D) and weight to be about 6 tons. The dimensions of this rock are similar to other equidimensional to rectangular rock-fall boulders deposited on the alluvial fan to the south. The rock that damaged the playhouse at 1522 North 1550 East (figure 4) bounced into a chain link fence, pushing the fence into the playhouse. We estimate the rock's dimensions to be 2 x 4 x 3 feet and weight to be about 1.8 tons.

PHYSIOGRAPHIC AND GEOLOGIC SETTING OF Y MOUNTAIN

Y Mountain is a steep west-facing mountain front along the Wasatch Range above Provo. The cliff bands on the upper part of Y Mountain are divided into three Mississippian formations (Baker, 1972; Hintze, 1978), the Gardison Limestone, Deseret Limestone, and Humbug Formation (listed from oldest to youngest). The Gardison consists mostly of thin-bedded to massive limestone with abundant chert. The Deseret is primarily interbedded limestone and dolomite in thick beds with light- and dark-gray banding. The Humbug is composed of a thin- to thick-bedded limestone with interbeds of sandstone. These bedrock formations form a series of continuous and discontinuous cliff bands near the top of Y Mountain (figure 5).

Steep mountain slopes below the cliff bands extend downslope into a small drainage basin. The upper mountain slopes below the cliff are composed of talus that grades downslope into colluvium. The colluvium is a firm slope substrate. The mountain slopes are covered with oak brush and grass. A small alluvial fan mapped by Machette (1992) lies at the mouth of the small drainage basin. Houses damaged by the 2005 and 2009 rock falls are on the north side of this alluvial fan.

ROCK-FALL SOURCES, PATHS, AND DEPOSITION

The rock fall initiated in Deseret Limestone (figures 5 and 6) at approximately 7,700 feet elevation. The limestone cliffs are massive beds broken by discontinuities or cracks that consist of joints, fractures, and bedding planes (figure 6). Weathering along these discontinuities weakens the rock mass and creates opportunities for triggering mechanisms such as frost and root wedging, rainfall, snowmelt, or earthquakes to initiate rock fall. The orientation and spacing of discontinuities determine the overall stability and generally the initial size and shape of rock fall produced. The limestone bedding planes are flat to gently dipping and joints are near vertical, widely spaced, and perpendicular to bedding planes. The orientation, spacing, and intersection of bedding planes and joints produce large, roughly equidimensional to rectangular rock-fall blocks. The rock-fall-detachment surface is above an undercut cliff face that likely results from preferential weathering of thin bedded rock below massive thick-bedded rock (figure 6).

The cliff bands on Y Mountain are extensive and an obvious rock-fall source. The number of cliff bands and their area (length and height) represent a large area of bedrock (figure 5) exposed to rock-fall triggering mechanisms that will continue to generate rock falls. These cliff bands are the source of prehistoric and historical rock falls.

Following April 11, 2009, multiple fresh rock-fall paths were present on Y Mountain (figure 7, 8C, 8D). After detaching from the cliff face, rocks dropped vertically and then impacted the steep talus slope below, churning up talus, soil, and vegetation (figure 6). The rock debris then traveled down a small talus-lined gully. Freshly deposited rock was observed on the talus slope and in the gully. Rock debris continued rolling and bouncing down the mountain flank creating multiple linear rock-fall paths, shown by fresh bounce marks, or impact craters, and damaged vegetation (figures 7 and 8). The vertical drop along the cliff face and the steep 37º talus slope and gully likely provided a high initial velocity to rock debris. The firm mountain slopes that range from 27º to 35º maintained rock debris momentum, promoting the long runout distance into the subdivision. The rock debris traveled approximately 2,500 vertical feet and 5,000 feet slope distance to reach the affected structures. The mountain slopes are part of a small drainage basin that funnels rock-fall debris onto the alluvial fan below (figure 7).

A rock larger than those shown in figures 3D and 4 stopped about 650 feet slope distance above the damaged house and playhouse. Rock-fall paths suggest the rock that damaged the playhouse broke from a corner of the rock that damaged the house about 400 feet slope distance above the affected structures. If the larger rock had stayed intact, the house may have sustained more damage and the rock may have had enough momentum to exit the garage and continue farther into the subdivision.

Many large boulders are present on the alluvial fan to the south and the slope above houses damaged in 2005 and 2009 (figure 9). Some of the boulders on the alluvial fan may have a debris-flow origin, but we believe most of these boulders have a rock-fall origin because they lie directly on the fan surface in a random pattern, rather than in a debris-flow-deposition pattern, where boulders are partially buried or concentrated along levees or lobe fronts. Many of the large boulders are equidimensional to rectangular and reflect the orientation and spacing of bedding planes and joints in the cliff bands above.

The average slope from the apex of the talus slope to the rock's resting place, known as the "shadow angle" (Evans and Hungr, 1993), is about 29° for the 2009 event, similar to the 28.5° shadow angle for the 2005 event (Christenson and Giraud, 2005). Minimum shadow angles are used to estimate maximum rock-fall runout distances, and typical minimum shadow angles for rock falls measured elsewhere are about 22° (Wieczorek and others, 1998). This indicates that rocks may potentially travel farther downslope than houses damaged in 2005 and 2009, and that the rock-fall hazard area includes parts of the subdivision to the west, as shown by Robison (1990). The runout distances and size of these large rocks on the alluvial fan and the slope above houses damaged in 2005 and 2009 events show the proximity of houses to the rock-fall hazard.

PROBABLE CAUSES

Rock-fall initiation can sometimes be attributed to a specific cause or mechanism, but not always. Rock falls are generally the result of the cumulative effects of weathering and other geologic processes, but may be initiated by discrete events like earthquakes or meteorological events. In this particular case, the rock fall occurred approximately 47 hours after a storm on April 8-9, 2009, delivered 1.3 inches of precipitation as snow at the Cascade Mountain Snotel site (MesoWest, 2009), about 3 miles southeast of Y Mountain. The storm was followed by above-freezing temperatures at the Snotel site and air temperatures were above freezing at the time of the rock fall. Valley precipitation at the Provo Brigham Young University National Weather Service reporting station totaled 0.63 inches of precipitation as rain for the April 8-9 storm (National Weather Service Forecast Office, Salt Lake City, 2009). A specific triggering mechanism is not apparent, but the April 11, 2009 rock fall may be related to snowmelt following the April 8-9 storm and water infiltrating into fractures may have increased pore pressures and the potential for rock fall. Undercutting of the cliff face (figure 6) is an on-going process that contributes to rock-fall potential.

SUMMARY AND FUTURE HAZARD POTENTIAL

On April 11, 2009, rock detached from a cliff band on Y Mountain producing a rock fall that severely damaged a vacant house and slightly damaged a playhouse. The damaged vacant house is one lot north of a guest house destroyed by 2005 rock fall. Snowmelt from a storm on April 8-9, 2009 and an undercut part of the cliff band likely increased the rock-fall potential but a specific triggering mechanism is not apparent.

The continuous and discontinuous cliff bands on Y Mountain are extensive and have produced prehistoric and historical rock falls. Numerous potential rock detachment sites exist throughout the cliff bands and rock-fall initiation mechanisms will trigger future rock falls. The combination of rock size, cliff and mountain slope steepness, firm slope substrate, and lack of inhibiting dense vegetation promote a high momentum to rock fall resulting in long runout distances. The presence of large rock-fall boulders on the slopes above the subdivision and the alluvial fan clearly show that houses damaged by the 2005 and 2009 rock-fall events and adjacent houses are in a rock-fall-hazard area.

The timing of rock falls cannot be predicted, but they are most common during and following storms and earthquakes, and during periods of freeze-thaw such as spring and fall. However, rock falls are possible at any time and typically occur with no warning. Residents should be informed they are in a rock-fall-hazard area, and that they may wish to hire a geological consultant to investigate the risk from rock falls to the neighborhood or to individual homes and the feasibility of rock-fall risk-reduction measures.

LIMITATIONS

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, UGS, makes no warranty, express or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, UGS, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

REFERENCES

Baker, A.A., 1972, Geology of the Bridal Veil Falls quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-998, scale 1:24,000.

Bowman, S.D., Beisner, K., and Unger, C., 2009, Compilation of 1970s Woodward-Lundgren & Associates Wasatch fault investigation reports and oblique aerial photography, Wasatch Front and Cache Valley, Utah and Idaho: Utah Geological Survey Open-File Report 548, 3 p., 6 plates, DVD.

Christenson, G.E. and Giraud, R.E., 2005, Investigation of the May 12, 2005, 1550 East Provo rock fall, Provo, Utah: Salt Lake City, unpublished Utah Geological Survey Technical Report 05-06 for Provo City, 4 p.

Evans, S.G., and Hungr, O., 1993, The assessment of rockfall hazard at the base of talus slopes: Canadian Geotechnical Journal, v. 31, p. 620-636.

Hintze, L.F., 1978, Geologic map of the Y Mountain area, east of Provo, Utah: Brigham Young University Geology Series Special Publication, no. 5, scale 1:24,000.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, 26 p. pamphlet, scale 1:50,000.

MesoWest, 2009, Current weather summary for Utah: Online, <http://www.met.utah.edu/cgi-bin/droman/meso_base.cgi?stn=CAMU1>, accessed May 19, 2009.

National Weather Service Forecast Office Salt Lake City, Utah, 2009, April 2009 monthly weather summary: Online, <http://www.weather.gov/climate/index.php?wfo=slc>, accessed May 19, 2009.

Robison, R.M., 1990, Utah County natural hazards overlay (NHO) zone: Unpublished Utah County Planning Department maps, scale 1:50,000 and 1:24,000.

Utah Automated Geographic Reference Center, 2009a, U.S. Geological Survey 1997 aerial photos: Online, <http://gis.utah.gov/aerial-photography/mid-1990s-1-meter-b-w-ortho photography>, accessed May 19, 2009.

Utah Automated Geographic Reference Center, 2009b, National agriculture imagery program aerial photos: Online, <http://agrc.utah.gov/agrc_sgid/naip.html>, accessed May 19, 2009.

Wieczorek, C.F., Morrissey, M.M., Iovine, G., and Godt, J., 1998, Rock-fall hazard in the Yosemite Valley, California: U.S. Geological Survey Open-File Report 98-467, map scale 1:12,000.

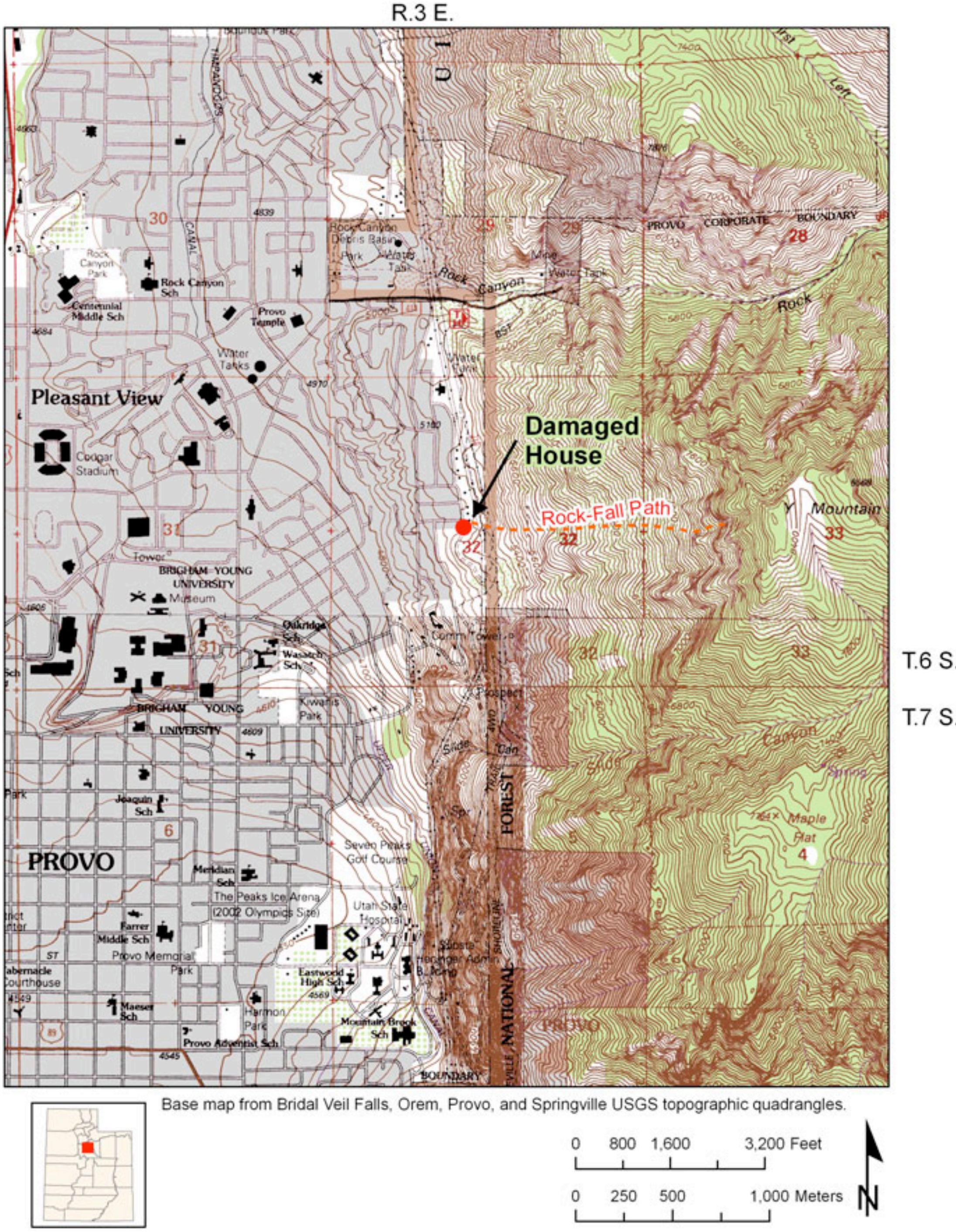


Figure 1. *Location of the April 11, 2009, 1550 East Provo rock fall showing generalized rock-fall path.*

Figure 2. *2006 NAIP orthophoto showing Y Mountain, the 2005 (blue) and 2009 (yellow) rock-fall paths, and damaged houses.*

(A)

(B)

(C)

(D)

Figure 3. *Rock-fall damage to a vacant house at 1496 North 1550 East (Provo Fire Department photos).* ***A.*** *The rock bounced downslope, impacted and bent the red steel post, traveled over the chain link fence, impacted the lawn leaving a bounce mark, and entered through the back wall with an upward bounce trajectory.* ***B.*** *Looking through the back wall into the house. Once inside with an upward trajectory, the rock impacted the ceiling and traveled downward through an interior wall and then down through the floor into the garage below.* ***C.*** *Hole in the floor where the rock traveled into the garage below. As the rock traveled through the floor it pulled carpet into the garage below.* ***D.*** *The rock stopped inside the garage. The rock size is estimated to be 4 x 5 x 4 feet and broke through part of a garage door.*

Figure 4. *Rock-fall damage to chain link fence and playhouse at 1522 North 1550 East (Provo Fire Department photo). The rock size is estimated to be 2 x 4 x 3 feet.*

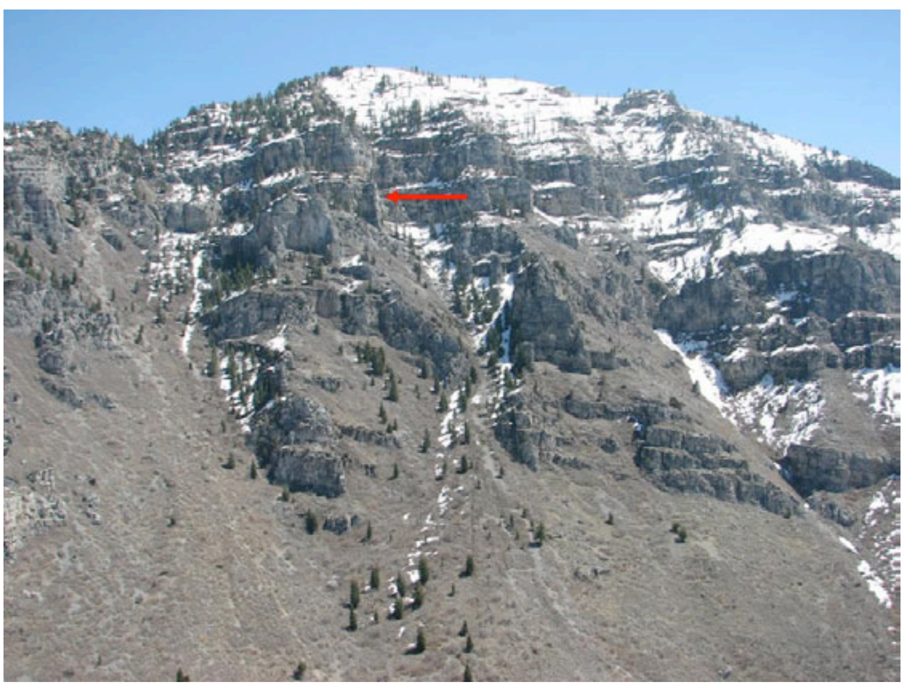


Figure 5. *West side of Y Mountain and extensive rock-fall source cliff bands. Steep, smooth mountain slopes below the cliff bands promote high rock-fall velocity and long runout distance. Red arrow points to the 2009 rock-fall detachment location.*

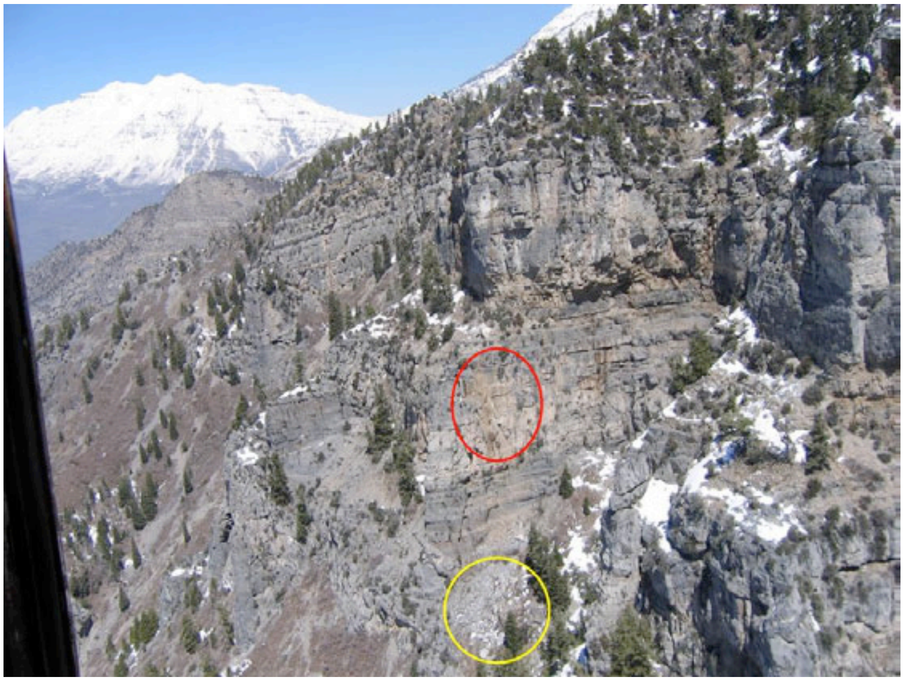


Figure 6. *Rock-fall detachment surface (red circle), photo taken 9 days after April 11, 2009. Rock debris impacted the talus slope below the cliff band (yellow circle). Cliff face undercutting is apparent below the detachment surface.*

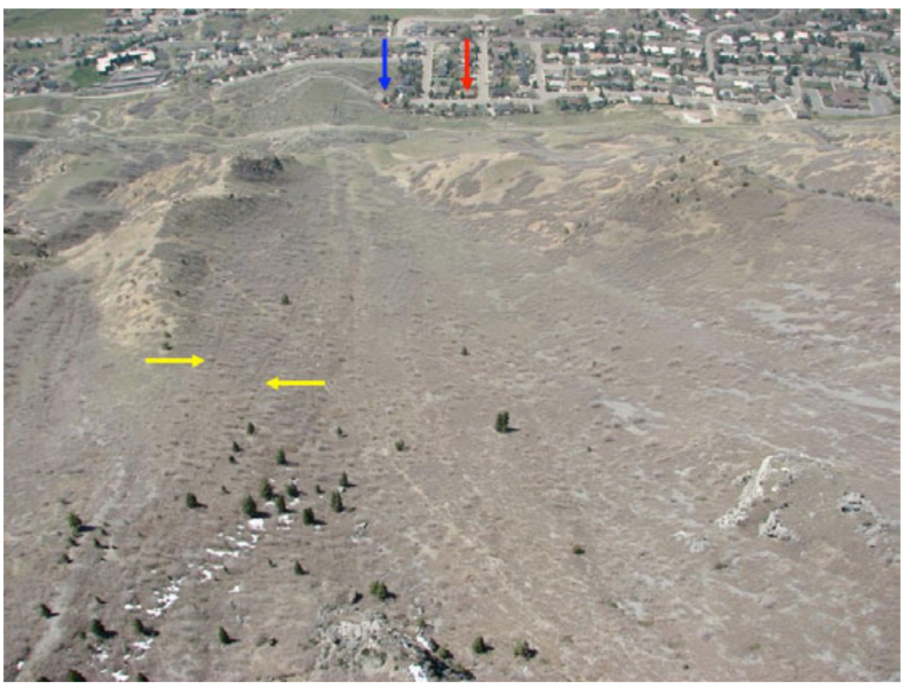


Figure 7. *View downslope showing rock-fall paths on Y Mountain above the subdivision. Yellow arrows point to two of multiple April 11, 2009, rock-fall paths. Older rock-fall paths are also evident. Blue and red arrows point to houses impacted in 2005 and 2009 respectively (also see figure 9).*

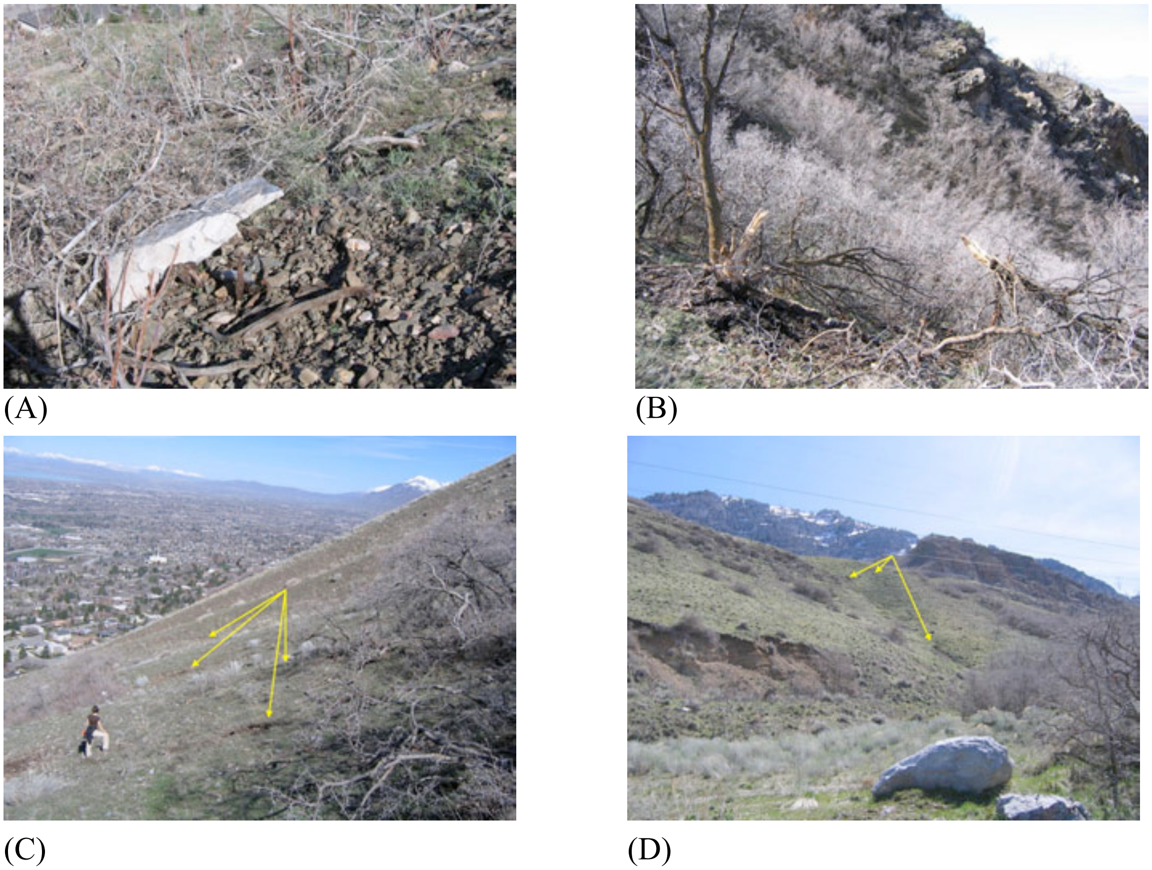


__Figure 8.__ Rock-fall travel paths. __A.__ A smaller rock that broke off a larger piece as it traveled downslope. __B.__ Rock fall damaged oak brush. __C.__ Multiple travel paths (yellow arrows). __D.__ Multiple travel paths (yellow arrows) evident directly above the damaged house and playhouse.

Figure 9. *Previous guest house location destroyed by the 2005 rock fall (blue arrow) and the house damaged by the 2009 rock fall (red arrow). Rock-fall boulders on the alluvial fan left of the blue arrow and the slope above the impacted houses show the distribution and size of historical and prehistorical rock fall and the proximity of houses to the hazard.*

REVIEWS

Project: Review of two geologic reports for the Paramount subdivision, Ogden, Utah			Requested by: John Mayer, Ogden City Planning
By: Greg N. McDonald Gary E. Christenson	Date: 2-6-02	County: Weber	Date report received at UGS: 1-15-02
USGS Quadrangle: North Ogden	Section/Township/Range: SE ¼ section 15, T.6 N., R.1W., SLBM		Job number: 02-01 (R-01)

We reviewed a geologic hazards report and portions of a geotechnical report for the proposed Paramount subdivision in northeast Ogden by Applied Geotechnical Engineering Consultants, Inc. (AGEC, 2000a, 2000b). For the review, we conducted a literature review and examined 1952 and 1972 1:12,000-scale aerial photos. The purpose of the review is to determine whether geologic hazards at the site are adequately addressed in the reports. We conclude that further study is needed and recommend the following:

- Further investigation of the feature observed in trench 1 at 3+50 feet is needed to determine if it is a fault. Eastward extension of trench 2 and additional trenching along the scarp apparent on the 1952 photos may be needed.

- If subsequent study indicates the feature in trench 1 at 3+50 feet is not a fault, an alternate explanation must be presented and related hazard implications investigated.

- The assumption that 50% of the debris in a debris flow from the canyon above the reservoir would be deposited north of the site should be re-evaluated.

- The debris flooding/sedimentation hazard associated with the small alluvial fan on the southern portion of the site should be evaluated.

- AGEC recommends considering rock-fall hazard mitigation in subdivision design and presents various options. A specific design still must be recommended.

We believe AGEC has not adequately evaluated the feature in trench 1 at about 3+50 feet which corresponds to a lineament on the aerial photos. The lineament is apparent on the 1972 photos and a graben at the head of the fan with a pronounced antithetic fault scarp at this location is clearly visible on 1952 (pre-reservoir) photos. The scarp may be an extension of the east-dipping fault mapped by Nelson and Personius (1993) on the right (north) flank of the fan. The feature in trench 1, as logged, could be interpreted as an antithetic fault associated with the main trace of the Wasatch fault to the east. In the trench log, the contact between units 1 and 2 has a vertical offset (down to the east) of about 2 feet, likely due to faulting, although the fault apparently was not discrete or obvious given the coarse nature of the deposits. The ground surface as shown in the trench log also exhibits an east-facing scarp about 2 feet high, consistent with an antithetic fault. AGEC further investigated this feature in trench 1 by excavating a pothole north and two short trenches north and south (trench 2 and an unlogged trench) of trench 1 along a projection of the feature and found no similar features. However, trench 2 may not have extended eastward far enough to intercept the feature, as the scarp appears to bend eastward toward the reservoir. The location of the pothole and the unlogged trench are not shown. Therefore, because the evidence for faulting is strong, we believe additional documentation or further investigation is necessary to determine if an antithetic fault is present at this location. If the scarp and feature in trench 1 are not interpreted to be fault-related, an alternate explanation is needed and related hazard implications must be assessed.

AGEC has identified a debris flow/flooding hazard at the proposed development and we concur. AGEC's assessment of the drainage basin east of the site and estimated total volume of debris from a debris flow are adequate. However, AGEC assumes that over half of the potential debris-flow volume would be routed to the north side of the fan or deposited above the site, but did not present supporting evidence. Most of the prehistoric debris flow mapped by Nelson and Personious (1993) was deposited on the south-central portion of the fan. The reservoir and canal will likely affect debris-flow paths and should be considered in any mitigation design. If a basin is planned, a location and design are still needed. Similarly, AGEC identifies a small alluvial fan on the southern portion of the site. The alluvial-fan-flooding/sedimentation hazard of this fan should be assessed. In addition, the possibility of collapsible soils should be considered if any of the alluvial-fan/debris-flow deposits are matrix-supported.

AGEC also concludes that a rock-fall hazard exists, recommends mitigation, and discusses several options. A preferred option still needs to be selected and designs provided and reviewed.

In conclusion, we believe additional investigation of surface-faulting and collapsible-soil hazards is needed. In addition, the debris-flow hazard must be reassessed and specific mitigation designs need to be presented for the debris-flow and rock-fall hazards.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc., 2000a, Geologic hazards investigation, Paramount subdivision, southeast quarter section 15, Township 6 North, Range 1 West, Ogden, Utah: Salt Lake City, unpublished consultant's report, 15 p.

--- 2000b, Geotechnical investigation, Paramount subdivision, southeast quarter section 15, Township 6 North, Range 1 West, Ogden, Utah: Salt Lake City, unpublished consultant's report, 16 p.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Map I-2199, 22 p. pamphlet, scale 1:50,000.

<table>
<tr><td colspan="3">Project:
Review of slope-stability-analyses reports for the proposed Hidden Hideaway Unit No.1 residential subdivision, Layton, Utah</td><td>Requested by:
Chelse Maughan, Layton City</td></tr>
<tr><td>By:
Francis X. Ashland</td><td>Date:
2-22-02</td><td>County:
Davis</td><td>Date reports received at UGS:
10-18-01 and 1-18-02</td></tr>
<tr><td>USGS Quadrangle:
Kaysville (1320)</td><td colspan="2">Section/Township/Range:
Section 10, T.4 N., R.1W., SLBM</td><td>Job number:
02-02 (R-02)</td></tr>
</table>

INTRODUCTION AND PURPOSE

I have completed my review of two slope-stability-analyses reports (Toland, 2001, 2002) for the proposed Hidden Hideaway Unit No. 1 (Hidden Hollow Unit 2 PRUD) residential subdivision in Layton, Utah. Included in the Toland (2001) report as appendices are older geotechnical reports (Toland, 1986, 2000), laboratory shear-strength-test results (Intermountain Geoenvironmental Services [IGES], 2001), and a slope-stability-analyses report (Applied Geotechnical Engineering Consultants, Inc. [AGEC], 2001). The Toland (2002) report included a geologic (geotechnical) investigation report (Jones, 2002). The purpose of my review is to determine whether slope stability has been adequately addressed to allow for safe site development. In a previous UGS letter to Layton City, dated November 21, 2001, we recommended additional subsurface investigations to document conditions at depth that had been assumed or estimated in the Toland (2001) analyses and to evaluate whether previous landsliding had occurred at the site.

CONCLUSIONS

The Toland (2001, 2002) reports conclude that the slope at the site is stable and Jones (2002) concludes the site has not been affected by previous landsliding. However, significant uncertainty exists regarding previous landsliding at the site because of the poor documentation of geologic conditions in these reports. Based on my review of aerial photographs and a site reconnaissance, I believe the site exhibits evidence of previous landsliding including a possible arcuate main scarp upslope of the site, a lateral ridge, and an area that resembles a landslide foot characterized by a curved, steeply sloped margin along which the creek is deflected. Further geologic investigation (trenching of the lower slope by an engineering geologist) is necessary to conclusively assess whether the site has been affected by previous landsliding and validate the slope-stability conclusions in the Toland (2001) report.

Based on my slope-stability analyses using data in the Toland (2001) reports, the actual factor of safety of the slope, while adequate if the site has not been affected by previous landsliding, is likely lower than described in the Toland (2001) report. The values in the Toland (2001) report likely are near the upper bound of the possible range in the factors of safety for the slope.

The UGS does not concur with the conclusion in the Toland (2001) report that the slope will remain stable during an earthquake. My slope-stability analyses suggest that landsliding is possible during earthquake ground shaking if the lower-bound soil shear strength controls slope stability.

DISCUSSION

Overall, the Toland (2001, 2002) and attached reports do not adequately document geologic conditions at the site or represent the preferred standard of care for landslide/slope-stability investigations in Layton. In order to adequately evaluate slope stability at a site, geologic conditions including evidence of previous landsliding must be carefully characterized. The results of a slope-stability analysis may be inaccurate if previous landsliding is overlooked because the geotechnical properties of the landslide mass may differ significantly from the properties of the surface of rupture zone along which sliding occurred. In some cases, evidence of a pre-existing landslide may be difficult to recognize if landslide movement was less than a few feet. Jones (2002) describes generally horizontal bedding in his test pits near the center of the site, but the Toland (1986, 2000, 2001, 2002) reports either lack test-pit logs or include logs that do not give bedding attitudes and details of the surficial soils at the remainder of the site. Based on verbal communication with Mr. Toland and photographs shown to me at one of our meetings, I am aware that possible deformation features encountered in the subsurface explorations were not documented in the reports.

In addition to the lack of documentation of bedding attitudes and evidence of deformation (or the lack thereof), the nature and age of the deposits at the site are not described. The bedded deposits could be either Lake Bonneville sediments or younger creek alluvium, or a combination of both, and each (if undeformed) has different implications as evidence of longer term slope stability. Also, shear-strength-test results on shallow soils in the Toland (2001) report may be in slope colluvium, and thus would not be useful in assessing the stability of deeper lacustrine soils. In general, insufficient attention was given to mapping and evaluating the surficial geology at the site, given the proximity to nearby prehistoric and historical landslides and the apparent landslide morphology of the site.

The inadequate characterization of geologic conditions made it difficult to review the slope-stability analyses and concur with the consultant's conclusions. Additional information needed to complete the review was presented to me by Mr. Toland in two meetings and in a telephone conversation with Mr. Walter Jones. In addition, I had to perform considerable slope-stability analyses in order to understand the limitations of the AGEC (2001) slope-stability analyses in the Toland (2001) report. The lack of adequate documentation of geologic conditions at the site increases the uncertainty associated with the consultant's conclusions regarding the stability of the slope.

Jones (2002) concludes the site is stable based on the historical stability of shallow soils that became saturated due to a leaking irrigation pipe between 1986 and 2000 (Toland, 2000). My slope-stability analysis of this condition confirms that the weakest soils identified at the site (IGES, 2001) would likely remain stable if saturated, although minimum factors of safety are near 1.0, and supports the Jones (2002) conclusion. However, the nature of the shallow ground water (perched or unconfined) described in the Toland (2000) report and its possible effect on ground-water levels (pore pressures) in deeper soils is undocumented. Thus, the likely impact on the overall stability of the site caused by the localized, shallow, leakage-induced wet condition is difficult to assess.

The factors of safety in the Toland (2001) report are applicable only in the absence of previous landsliding, but likely overestimate slope stability even if the site is not underlain by a pre-existing landslide. Several limitations exist in the slope-stability analyses by AGEC (2001) included in the Toland (2001) report that result in a higher factor of safety for the slope. A higher factor of safety results because the AGEC (2001) analyses:

- do not use all the new geologic and geotechnical information in the Toland (2002) report to create a realistic geologic cross section as the basis of the slope-stability modeling,
- do not calculate the factors of safety for the range in measured geotechnical properties and probable landslide geometries, and
- use a relatively high value of cohesion, above the mean for the test results, that would not be conservative if previous landsliding has occurred at the site.

The results of my slope-stability analyses suggest the actual factors of safety are likely lower than the values reported in the Toland (2001) report and indicate that the upper slope, including part of the abutting property upslope of the site, is the least stable.

In addition, my results suggest some potential for earthquake-induced landsliding. Such landsliding is possible using the lower-bound measured soil shear strengths in the Toland (2001, 2002) reports, even for conditions where ground water exceeds 25 feet deep in the upper slope.

SCOPE OF REVIEW

As part of the review, I evaluated aerial photographs of the site, conducted slope-stability analyses using PCSTABL5M and STED software, and met with Mr. George Toland on two occasions to discuss slope-stability issues. The results of my slope-stability analyses were based on topographic, geologic, and geotechnical data in the Toland (2001, 2002) reports, including the direct shear test results of IGES (2001) and ground motion data based on a 10 percent probability of exceedance in 50 years (Frankel and others, 1996; U.S. Geological Survey, 2001). A reconnaissance of the site was conducted on February 12, 2002.

SUMMARY OF CONCLUSIONS

The Toland (2001, 2002) reports conclude that the slope is stable and suitable for residential development; however, the validity of this conclusion cannot be assessed until the absence of previous landsliding at the site has been adequately documented. In addition, my slope-stability analyses indicate the factor of safety of the slope under static conditions is likely lower than described in the Toland (2001) report even in the absence of previous landsliding at the site.

The UGS does not concur with the conclusion in the Toland (2001) report that the slope will remain stable during an earthquake. My analysis indicates that failure in weak soils is possible if lower-bound shear strengths control slope stability. If Layton City requires that hillslope stability during an earthquake be demonstrated before approval of a site for use as a residential subdivision, then a more detailed slope-stability analysis based on actual subsurface conditions at the site is needed. Alternatively, the probability of earthquake-induced landsliding could be assessed based on the probable range in soil shear strengths and ground-water levels.

The UGS does not believe the Toland (2001, 2002) reports meet the preferred standard of care necessary for adequate landslide/slope-stability investigations in Layton. The UGS was able to come to some conclusions regarding the reports only after additional discussions with the consultants and performing independent slope-stability analyses of the slope. The UGS encourages Layton City to require that qualified engineering geologists team with geotechnical engineers when performing landslide studies, and that consultants lacking considerable experience with landslide/slope-stability investigations and conditions in Layton meet with UGS Geologic Hazards Program staff and refer to Hylland (1996) to determine the minimum scope of proposed site investigations.

RECOMMENDATION

The UGS recommends that a geologic investigation be conducted to adequately assess the potential for previous landsliding at the site and to validate the slope-stability conclusions in the Toland (2001, 2002) reports. This investigation should be conducted by a qualified engineering geologist with specific experience in landslide investigations. We strongly encourage the use of trenching techniques in this investigation. Detailed trench logs should describe and show the nature, geologic interpretation of age and origin, bedding attitude, and deformation (or lack thereof) of soil units in the lower slope. The UGS has example trench logs that can be examined by the consultant prior to initiating the work. The UGS suggests that it be notified in advance so that our staff can visit the site when the trenches are excavated. The UGS believes that the trenching will either:

- demonstrate the lack of previous landsliding at the site and validate the conclusions of the slope-stability analyses in the Toland (2001, 2002) reports, or

- provide evidence of previous landsliding at the site and the need for site mitigation to increase the slope stability as a prerequisite for development.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc., 2001, Computer stability analysis, Layton, Utah: Sandy, Utah, unpublished consultant's report, 2 p.

Intermountain Geoenvironmental Services, 2001, Direct shear strength testing results and data: Salt Lake City, Utah, unpublished consultant's report, unpaginated.

Frankel, Arthur, Mueller, Charles, Barnhard, Theodore, Perkins, David, Leyendecker, E.V., Dickman, Nancy, Hanson, Stanley, and Hopper, Margaret, 1996, National Seismic Hazard Maps, June 1996, Documentation: U.S. Geological Survey Open-File Report 96-532, 100 p.

U.S. Geological Survey, 2001, National Seismic Hazards Project: interactive seismic hazard maps: Online, http://eqint.cr.usgs.gov/eq/html/zipcode.shtml, accessed Jan. 30, 2002.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Jones, W.V., 2002, Geotechnical study and evaluation – proposed Hidden Hideaway Unit 2 PUD, Layton, Utah: unpublished consultant's report, 2 p.

Toland, G.C., 1986, Soil evaluation – proposed Hidden Hollow Unit No. 1 subdivision, Layton, Utah: Bountiful, Utah, unpublished consultant's report, 7 p.

----2000, Soil and groundwater investigation – proposed Hidden Hideaway Unit No. 1, Layton, Utah: Bountiful, Utah, unpublished consultant's report, 8 p.

----2001, Stability analyses – proposed Hidden Hollow Unit 2 PRUD, 2250 North 1450 East, Layton, Utah: Bountiful, Utah, unpublished consultant's report, 6 p.

----2002, Response to slope stability review – proposed Hidden Hideaway Unit No, 1, 2250 North 1450 East, Layton, Utah: Bountiful, Utah, unpublished consultant's report, 5 p.

Utah Geological Survey

Project: Review of "Geologic and geotechnical investigation, Pioche residential development west of Keetley, Wasatch County, Utah"			Requested by: Doug Smith, Wasatch County Planning
By: Barry J. Solomon	Date: 04-23-02	County: Wasatch	Date report received at UGS: 03-25-02
USGS Quadrangle: Park City East	Section/Township/Range: E1/2 section 23, W1/2 section 24, T. 2 S., R. 4 E., SLBM		Job number: 02-03 (R-03)

INTRODUCTION

I reviewed the geologic and geotechnical report for the proposed Pioche residential development by Applied Geotechnical Engineering Consultants, Inc. (AGEC, 2001). For the review, I looked at relevant geologic literature and examined 1:24,000-scale aerial photographs (1962), but I did not inspect the property. The purpose of my review is to assess whether AGEC (2001) adequately identifies and addresses geologic hazards that could affect the development.

CONCLUSIONS AND RECOMMENDATIONS

I conclude that the report is adequate for all hazards except landslides. Air-photo evidence indicates the proposed development may lie on previously unidentified landslide deposits. Because of this possibility and local steep slopes at the site, I believe further study of the landslide hazard is warranted. I recommend the following:

- Information should be provided to document the presence or absence of existing landslides and describe site conditions with emphasis on stability of existing landslides and steep slopes (greater than 25 percent), based on observation and measurement of geologic criteria such as slope inclination, rock type and condition, the nature of planar features within soil or rock, ground-water conditions, and thickness and description of soil and colluvium overlying rock.
- An adequate map of the entire site should be provided that shows site geology, the extent of site slopes greater than 25 percent, existing landslides, and proposed setbacks or other hazard-reduction methods on a base map showing detailed topography, lots, and site boundaries at a scale of 1 inch=200 feet or larger, preferably 1 inch=100 feet.
- To demonstrate slope stability and determine setbacks and buildable areas, geotechnical-engineering slope-stability analyses may be needed consistent with Utah Geological Survey guidelines for evaluating landslide hazards (Hylland, 1996) to determine the stability of existing landslides and on-site slopes exceeding 25 percent.
- If retaining walls are planned, specific engineered designs for the walls should be provided and reviewed by qualified engineers; the designs must include a site map and slope profile showing cuts, fills, and retaining walls; the retaining-wall design must consider static and earthquake ground-shaking conditions and incorporate pertinent

drainage recommendations.

- Evidence supporting cut-and-fill slope recommendations and setback distances from 3H:1V (33 percent) slopes should be provided and reviewed by a qualified geotechnical engineer.
- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in AGEC (2001) and any subsequent studies.
- The existence of the AGEC (2001) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.
- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

AGEC (2001) lists earthquake ground shaking, expansive soils, and underground mine subsidence as potential geologic hazards on the property. I believe AGEC (2001) adequately addresses these geologic hazards and concur with the report's recommendations. However, I believe landsliding is a potential geologic hazard that may impact the proposed development and is not adequately addressed by AGEC (2001).

AGEC (2001, p. 10) reports, "No evidence of landslides or other stability problems were identified during our field study for the proposed development," but does not discuss the scope of their study or give details of rock condition and attitudes in test pits. Bromfield and Crittenden (1971) map no landslide deposits on or near the site, but show the dip of flow layering or compaction foliation in the Keetley Volcanics in the site vicinity is to the east, indicating preferential failure surfaces that may be subparallel to the ground slope. One alternative interpretation of aerial photographs is that a landslide deposit may underlie the site as shown on figure 1. The deposits at the site exhibit hummocky topography on the aerial photographs, with a possible landslide head in the Triassic Thaynes Formation and toe in Oligocene Keetley Volcanics. Keetley Volcanics, or possibly a landslide deposit in Keetley Volcanics, likely underlies most of the site.

Landslides are relatively common in the Keetley Volcanics of western Wasatch County, where Hylland and Lowe (1997) note 50 landslides in the unit. Several rock types are found in the Keetley Volcanics, and some are more susceptible to failure than others. Susceptible rock includes volcanic breccia of the type that underlies the proposed development. Because of the chaotic appearance of both the breccia and landslide debris, identifying in-place bedrock and differentiating it from landslide debris is difficult. AGEC should describe the rock condition and attitudes in their test pits. Also, investigations of outcrops where Bromfield and Crittenden (1971) measured dips and strikes at the site and in adjacent areas will help to evaluate the presence of landslide deposits.

To recognize slopes susceptible to landsliding in western Wasatch County, Hylland and Lowe (1997) defined “critical slope inclinations” based on the strong correlation between geologic material and landslide-slope inclination. The critical slope inclination is the slope angle above which late Holocene landslides have typically occurred. The critical slope inclination for the Keetley Volcanics is 25 percent and for the Thaynes Formation is 35 percent. Although I estimate an average slope of 16 percent across the proposed site, several slope segments are steeper than 25 percent (using figure 3 of AGEC [2001]), with the steepest almost 40 percent in the northwest corner of the site. Other steep slopes are common along the drainage on the south edge of the site and along the eastern edge of the site, and some lots are almost entirely on slopes greater than 25 percent. Many landslides on steep slopes underlain by Keetley Volcanics and the Thaynes Formation in western Wasatch County are shallow, translational debris slides. Thus, landslide hazards on the proposed development may include shallow debris slides on steeper slopes. Because debris slides studied by Hylland and Lowe (1997) commonly result from failure of unconsolidated colluvium overlying bedrock, rather than the bedrock itself, the potential for debris slides increases on soil slopes exceeding the critical angle for underlying bedrock. AGEC (2001, p. 10) states that permanent unretained cut-and-fill slopes up to 15 feet high may be constructed at slopes of up to 2 horizontal to 1 vertical (50 percent) in soil and ½ horizontal to 1 vertical (200 percent) in rock, both exceeding the critical angle. Steeper and higher cut-and-fill slopes are considered on an individual basis (AGEC [2001], p. 1). AGEC (2001, p. 11) also provides recommendations for setback distances for buildings from slopes steeper than 3 horizontal to 1 vertical (33 percent), but does not indicate how these setbacks were determined or how they relate to site conditions.

SUMMARY OF CONCLUSIONS

In conclusion, I concur with the assessment of AGEC (2001) regarding the potential for earthquake ground shaking, expansive soils, and underground mine subsidence. However, the AGEC (2001) report lacks sufficient documentation to determine the potential for slope failure on the proposed Pioche residential development or the possibility of landslide deposits underlying the proposed development. The report also does not identify all steep slopes, and does not adequately justify recommended cut-and-fill slopes and setbacks from steep slopes (both natural and cut). Further studies addressing the landslide hazard must be performed and documented with an adequate site map showing site geology, steep slopes, landslides, setbacks, and other recommended hazard-reduction measures.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc., 2001, Geologic and geotechnical investigation, Pioche residential development west of Keetley, Wasatch County, Utah: Sandy, Utah, unpublished consultant’s report, 22 p.

Bromfield, C.S., and Crittenden, M.D., Jr., 1971, Geologic map of the Park City East quadrangle, Summit and Wasatch Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-852, scale 1:24,000.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Hylland, M.D., and Lowe, Mike, 1997, Regional landslide-hazard evaluation using landslide slopes, western Wasatch County, Utah: Environmental & Engineering Geoscience, v. 3, no. 1, p. 31-43.

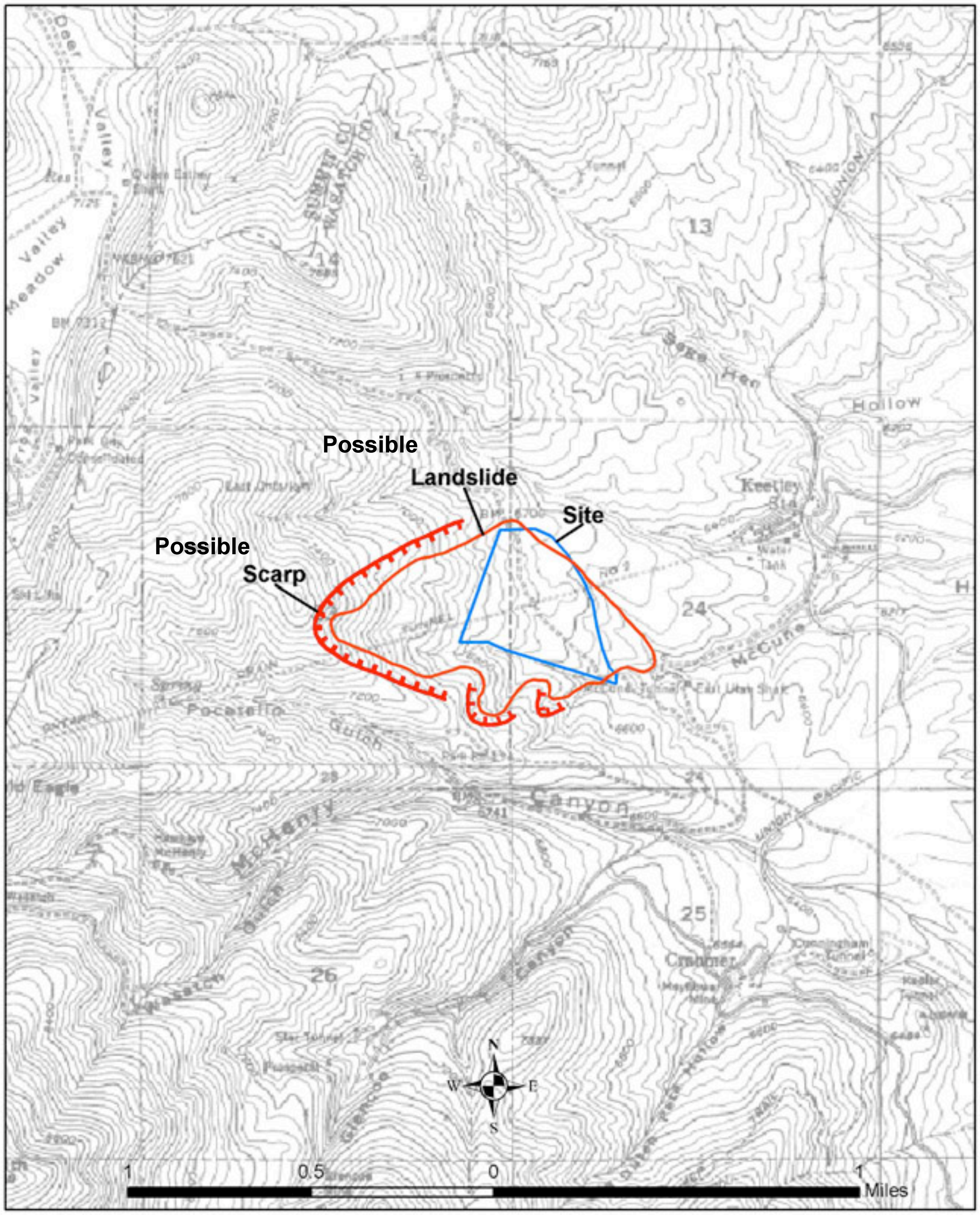


Figure 1. *Map of possible landslide deposits underlying the proposed Pioche residential development.*

Utah Geological Survey

<table>
<tr><td colspan="3">Project:
Review of “Deer Canyon Preserve, Jordanelle Basin, Wasatch County—soils report”</td><td>Requested by:
Doug Smith, Wasatch County Planning</td></tr>
<tr><td>By:
Barry J. Solomon</td><td>Date:
04-23-02</td><td>County:
Wasatch</td><td>Date report received at UGS:
03-27-02</td></tr>
<tr><td>USGS Quadrangle:
Park City East</td><td colspan="2">Section/Township/Range:
section 6, NE1/4 section 7, T. 2 S., R. 5 E., SLBM</td><td>Job number:
02-04 (R-04)</td></tr>
</table>

INTRODUCTION

I reviewed the geologic report for the proposed Deer Canyon Preserve subdivision by Wilding Engineering (2001), which evaluates phase I of the proposed development (Doug Smith, verbal communication, April 3). For the review, I looked at relevant geologic literature and examined 1:24,000-scale aerial photographs (1962), but I did not inspect the property. The purpose of my review is to assess whether Wilding Engineering (2001) adequately identifies and addresses geologic hazards that could affect the subdivision.

CONCLUSIONS AND RECOMMENDATIONS

I conclude that the Wilding Engineering (2001) report is adequate except for its assessment of expansive soil and landslide hazards on phase 1 of the proposed Deer Canyon Preserve subdivision. I recommend the following:

- Studies should be performed to determine whether expansive soil is present and, if found, appropriate foundation recommendations should be provided.
- Information should be provided to document the presence or absence of existing landslides and describe site conditions with emphasis on stability of existing landslides and steep slopes (greater than 25 percent), based on observation and measurement of geologic criteria such as slope inclination, rock type and condition, the nature of planar features within soil or rock, ground-water conditions, and thickness and description of soil and colluvium overlying rock.
- An adequate map of the site should be provided that shows site geology, the extent of site slopes greater than 25 percent, existing landslides (if present), and proposed setbacks or other hazard-reduction methods on a base map showing detailed topography, lots, and site boundaries at a scale of 1 inch=200 feet or larger, preferably 1 inch=100 feet.
- To demonstrate slope stability and determine setbacks and buildable areas, geotechnical engineering slope-stability analyses may be needed for slopes exceeding 25 percent and landslides (if present); the analyses should be consistent with Utah Geological Survey guidelines for evaluating landslide hazards (Hylland, 1996).
- If retaining walls are planned, specific engineered designs for the walls should be

provided and reviewed by qualified engineers; the designs must include a site map and slope profile showing cuts, fills, and retaining walls; the retaining-wall design must consider static and earthquake ground-shaking conditions and incorporate pertinent drainage recommendations.

- For permanent cuts with slopes steeper than 2H:1V (50 percent) that use 1H:1V rock walls rather than retaining walls as allowed by Wilding Engineering (2001, p. 3), cut-slope stability should be evaluated because rock-veneer walls are not retaining structures.
- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in Wilding Engineering (2001) and any subsequent studies.
- The existence of the Wilding Engineering (2001) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.
- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

Wilding Engineering (2001) lists surface fault rupture, liquefaction, flooding, and shallow ground water as potential geologic hazards on the property. The report adequately addresses these geologic hazards and I concur with the report's recommendations. The report does not specifically identify the potential for expansive clays, which commonly form as residual soil on the Oligocene Keetley Volcanics that underlie the site (Bromfield and Crittenden, 1971) (see, for example, the geologic report for the nearby site of the proposed Pioche residential development [AGEC, 2001]). Although the Deer Canyon Preserve report recommends site grading to divert water away from foundations, other measures may be needed if expansive soils are found. The report does not address the potential for earthquake ground shaking, but this hazard may be reduced by adherence to the requirements of the International Building Code (IBC) (International Code Council, 2000), which has replaced the Uniform Building Code referenced in the report.

Landsliding is another potential geologic hazard that may impact the proposed subdivision, but Wilding Engineering (2001) does not discuss landsliding. Landslides are relatively common in the Keetley Volcanics of western Wasatch County, where Hylland and Lowe (1997) note 50 landslides in the unit. Several rock types are found in the Keetley Volcanics, and some are more susceptible to failure than others. Susceptible rock includes volcanic breccia of the type that underlies most of the proposed subdivision. Slumps in breccia are found nearby in steep road cuts along Highway 40.

To recognize slopes susceptible to landsliding in western Wasatch County, Hylland and Lowe (1997) defined "critical slope inclinations" based on the strong correlation between geologic material and landslide slope inclination. The critical slope inclination is the slope angle above which late Holocene landslides have typically occurred. The critical slope inclination for the Keetley Volcanics is 25 percent. On their map of landslide hazards in the area, Hylland and

Lowe (1996) assigned a moderate landslide hazard to slopes with inclinations greater than the critical angle but showing no evidence of past landsliding. They map a moderate landslide hazard on slopes near Ross Creek in the eastern part of phase 1 of the proposed Deer Canyon Preserve subdivision. I measured slopes ranging from 25 to 30 percent in this area from the site plan included with Wilding Engineering (2001). In areas of moderate landslide hazard, Hylland and Lowe (1996) recommend at least a reconnaissance-level geologic-hazard evaluation and indicate that a quantitative slope-stability analysis may be necessary.

SUMMARY OF CONCLUSIONS

In conclusion, I concur with the assessment of Wilding Engineering (2001) regarding the potential for surface fault rupture, liquefaction, flooding, and shallow ground water. Wilding Engineering (2001) does not evaluate expansive clays as a hazard, but their presence nearby indicates that if present on-site, measures may be advisable beyond the recommended grading to direct water away from building foundations. Wilding Engineering (2001) does not address the potential for earthquake ground shaking, but this hazard may be reduced by adherence to the requirements of the IBC. Wilding Engineering (2001) does not address the potential for slope failure. Further studies addressing this hazard should be performed and documented with an adequate site map showing site geology, steep slopes, landslides (if present), setbacks, and other recommended hazard-reduction measures.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc., 2001, Geologic and geotechnical investigation, Pioche residential development west of Keetley, Wasatch County, Utah: Sandy, Utah, unpublished consultant's report, 22 p.

Bromfield, C.S., and Crittenden, M.D., Jr., 1971, Geologic map of the Park City East quadrangle, Summit and Wasatch Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-852, scale 1:24,000.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Hylland, M.D., and Lowe, Mike, 1996, Landslide hazard, western Wasatch County, Utah (plate 1A), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

---1997, Regional landslide-hazard evaluation using landslide slopes, western Wasatch County, Utah: Environmental & Engineering Geoscience, v. 3, no. 1, p. 31-43.

International Code Council, 2000, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

Wilding Engineering, 2001, Deer Canyon Preserve, Jordanelle Basin, Wasatch County—soils report: Draper, Utah, unpublished consultant's report, 6 p.

Utah Geological Survey

Project: Review of "Geotech report, Bonanza Mountain Resort, Wasatch County preliminary plan package"			Requested by: Doug Smith, Wasatch County Planning
By: Barry J. Solomon	Date: 05-02-02	County: Wasatch	Date report received at UGS: 04-18-02
USGS Quadrangle: Park City East	Section/Township/Range: Sections 25 and 36, T. 2 S., R. 3 E.; sections 29 through 33, T. 2 S., R. 4 E.; section 1, T. 3 S., R. 4 E.; section 6, T. 3 S., R. 4 E., SLBM		Job number: 02-05 (R-05)

INTRODUCTION

I reviewed the geologic and geotechnical report for the proposed Bonanza Mountain Resort by Applied Geotechnical Engineering Consultants, Inc. (AGEC, undated). My scope of work included reviewing relevant geologic literature and examining 1:24,000-scale aerial photographs (1962), but I did not inspect the property. The purpose of my review is to assess whether the AGEC report adequately identifies and addresses geologic hazards that could affect the development.

CONCLUSIONS AND RECOMMENDATIONS

I conclude that the report is suitable for a reconnaissance-level geologic-hazard investigation, but does not adequately address the site-specific potential for shallow ground water, moisture-sensitive soil, rock falls, or landslides. I recommend the following:

- Information should be provided to document the presence or absence of existing geologic hazards and describe site conditions based on observation and measurement of geologic criteria such as slope inclination, rock type and condition, the nature of planar features within soil or rock, ground-water conditions, and thickness and description of soil and colluvium overlying rock; a minimum slope inclination should be defined and justified to identify steep slopes needing more detailed study.
- An adequate map of the entire site should be provided showing site geology; the extent of shallow ground water, moisture-sensitive soil, existing rock-fall and landslide deposits, and steep slopes; and proposed setbacks or other hazard-reduction methods on a base map with detailed topography, lots (if known), and site boundaries at a scale of 1 inch=200 feet or larger, preferably 1 inch=100 feet.
- To demonstrate slope stability for existing landslides and steep slopes and to determine setbacks and buildable areas, geotechnical-engineering slope-stability analyses may be needed consistent with Utah Geological Survey guidelines for evaluating landslide hazards (Hylland, 1996).
- Seismic design must comply with the 2000 International Building Code (International Code Council, 2000), which has replaced the Uniform Building Code cited in the AGEC

report.

- Although AGEC provides general foundation and grading recommendations for cut-and-fill slopes and retaining walls, site-specific studies should be performed and reviewed by qualified geotechnical engineers prior to issuance of building permits.
- The existence of the AGEC report, this review, and subsequent reports and reviews should be disclosed to potential buyers.
- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

The AGEC report lists shallow ground water, moisture-sensitive soil, rock falls, earthquake ground shaking, landslides, and underground mine subsidence as potential geologic hazards on the property. I believe this is a complete list of potential geologic hazards, but I believe the AGEC report is a preliminary or reconnaissance-level study and does not adequately addresses the site-specific potential for shallow ground water, moisture-sensitive soil, rock falls, or landslides. Also, the report was apparently written prior to statewide adoption of the 2000 International Building Code (International Code Council, 2000), which supercedes the Uniform Building Code for use in seismic design.

Geologic-hazard studies are best performed early in the planning process. The level of detail necessary for the studies is related to the point in the planning process at which the studies are conducted. Early studies are generally a regional reconnaissance to determine broad areas that may be subject to hazards where subsequent site-specific study is needed. An example of this type of study is the engineering-geologic map folio that identifies geologically hazardous areas in western Wasatch County (Hylland and others, 1996). Once these areas are identified, more detailed studies are conducted to identify site-specific geologic hazards, which can then be used to determine buildable areas, appropriate setbacks, and hazard-reduction methods. These factors should be mapped on an appropriate base map (commonly at a scale of 1 inch=200 feet or larger) showing lot boundaries, if known. The AGEC report more closely resembles a reconnaissance study. AGEC has provided a description of geologic hazards and the broad areas in which they might be expected within the proposed resort, but repeatedly states that site-specific studies will be conducted in the future. These site-specific studies are needed prior to issuing building permits.

An example from the AGEC report illustrates the need for a greater level of detail in site-specific evaluations. AGEC states (p. 10) that the only evidence of slope instability observed on the site is in the northwest corner of the project area, caused by cut slopes associated with road construction. This is near a landslide mapped as a high landslide hazard by Hylland and others (1996), whose landslide-hazard map units underlying the proposed resort are shown on figure 3 of the AGEC report. The Hylland and others (1996) map units include areas of low, moderate, and high relative landslide hazard. However, AGEC recommends additional slope-stability investigation only in the area of the previously identified landslide, and states (p. 11) that "Major stability problems are not anticipated if site grading is carefully planned and steep slope areas are avoided." The AGEC report does not map areas with steep slopes and does not establish criteria for which slopes are considered steep and are therefore to be avoided.

To recognize slopes susceptible to landsliding in western Wasatch County, Hylland and Lowe (1997) defined "critical slope inclinations" based on the strong correlation between geologic material and landslide-slope inclination. The critical slope inclination is the slope angle above which late Holocene landslides have typically occurred. On their map of landslide hazards, Hylland and others (1996) assigned a moderate landslide hazard to slopes with inclinations greater than the critical angle but showing no evidence of past landsliding. In these areas, they recommend at least a reconnaissance-level geologic-hazard evaluation and indicate that a quantitative slope-stability analysis may be necessary. Many such slopes are present in the site area.

AGEC does not identify the steep slopes that it recommends be avoided. One conservative approach would be to avoid development of slopes greater than the critical slope inclination for the underlying geologic unit (that is, all areas with a moderate landslide hazard on Hylland and others, 1996). However, use of this approach without further investigation may be overly conservative. Also, Hylland and others (1996) mapped steep slopes on a topographic base map at a scale of 1:24,000, so the base-map scale limits the accuracy of hazard-unit boundaries. Furthermore, not all steep slopes need to be avoided. A slope-stability analysis may indicate an adequate factor of safety on some steep slopes. Such an analysis, though, requires an accurate geologic map to understand appropriate soil or rock properties and geologic conditions for evaluating slopes. The experience of the Utah Geological Survey has been that older geologic maps in western Wasatch County (such as Baker and others, 1966) commonly lack sufficient detail, particularly for Quaternary geologic units. A site-specific geologic-hazard investigation should therefore include accurate geologic mapping, based in part on aerial-photo interpretation to determine geologic structures and relationships often not evident on the ground.

Although my discussion concentrates on the landslide hazard, my comments apply to the study of other hazards as well. In particular, the AGEC report (p. 8-9) states: (1) "Proposed buildings will be located outside of areas of anticipated shallow ground water," but such areas are not mapped; (2) "Additional geotechnical investigation will be conducted at proposed building sites to determine if soil or bedrock may be moisture sensitive in areas not previously investigated," but such investigations should be conducted prior to proposing building sites; and (3) "Additional study of rockfall hazard will be conducted as locations of proposed buildings are established," but such locations should be established on the basis of hazard studies.

SUMMARY OF CONCLUSIONS

In conclusion, I believe the AGEC report is a reconnaissance study and lacks sufficient information to determine the site-specific potential for shallow ground water, moisture-sensitive soil, rock falls, or landslides on the proposed Bonanza Mountain resort. Further studies addressing these hazards should be performed and documented with an adequate site map showing site geology, geologic hazards, setbacks, and other recommended hazard-reduction measures. The report also does not identify all steep slopes or provide site-specific foundation and grading recommendations.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc., undated, Geotech report, Bonanza Mountain Resort, Wasatch County preliminary plan package: Sandy, Utah, unpublished consultant's report, 18 p.

Baker, A.A., Calkins, F.C., Crittenden, M.D., Jr., and Bromfield, C.S., 1966, Geologic map of the Brighton quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-534, scale 1:24,000.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Hylland, M.D., and Lowe, Mike, 1997, Regional landslide-hazard evaluation using landslide slopes, western Wasatch County, Utah: Environmental & Engineering Geoscience, v. 3, no. 1, p. 31-43.

Hylland, M.D., Lowe, Mike, and Bishop, C.E., 1996, Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

International Code Council, 2000, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

<table>
<tr><td colspan="3">Project:
Review of geotechnical and geologic hazards reports for the proposed Foothill Park residential subdivision, Provo, Utah.</td><td>Requested by:
Dave Graves, Provo City</td></tr>
<tr><td>By:
Francis X. Ashland</td><td>Date:
6-07-02</td><td>County:
Utah</td><td>Date report received at UGS:
4-8-02</td></tr>
<tr><td>USGS Quadrangle:
Provo (1047)</td><td colspan="2">Section/Township/Range:
Section 5, T.7 S., R.3 E., SLBM</td><td>Job number:
02-06 (R-06)</td></tr>
</table>

INTRODUCTION AND PURPOSE

I have completed my review of two geotechnical and geologic hazards reports (Earthtec Testing and Engineering, P.C., [Earthtec], 2001, 2002) for the proposed Foothill Park residential subdivision in Provo, Utah. The Earthtec (2001) report addresses earthquake ground shaking, surface fault rupture, liquefaction, problem (collapsible) soils, shallow ground water, landslides, rock falls, debris flows, and alluvial-fan flooding. The Earthtec (2002) report addresses potential surface-fault-rupture and debris-flow hazards partly in response to comments by the Utah Geological Survey in our letter to Provo City dated October 12, 2001. The purpose of my review is to determine whether geologic hazards have been adequately addressed to allow for safe site development.

CONCLUSIONS

The Earthtec (2001, 2002) reports identify numerous potential geologic hazards at the site. The most significant of these include surface fault rupture, rock falls, and debris flows. Other hazards at the site include collapsible soils, shallow ground water, liquefaction, and earthquake ground shaking. Earthtec (2001, 2002) recommends measures to reduce these geologic hazards. In general, the Utah Geological Survey (UGS) concurs with Earthtec's conclusions and geologic-hazard-reduction recommendations. Earthtec indicates that the proposed or current subdivision layout or design is at least in part incompatible with geologic-hazard-reduction recommendations and requires revision.

The UGS believes that adequate implementation of Earthtec's proposed geologic-hazard-reduction and other design recommendations is necessary for safe hillside development at the site. The multi-hazard nature of the site warrants oversight and field inspection by the developer's geotechnical/geologic consultant during all phases of site grading, foundation excavation and preparation, and construction of recommended site-drainage and geologic-hazard-reduction measures.

RECOMMENDATIONS

To ensure safe development at the site, the UGS suggests the following:

- The developer's geotechnical/geologic consultant should review the final plans for the proposed subdivision and verify their compatibility with Earthtec's proposed geologic-hazard-reduction and other design recommendations.

- Final subdivision plans and design documents should show the location and, as necessary, design details of proposed debris basins, rock-fall-hazard reduction structures, and building setbacks in the surface-fault-rupture zones identified by Earthtec (2002).

- Provo City should require the developer to retain its geotechnical/geologic consultant for field inspection for all site grading, foundation excavation and preparation work, and construction of site drainage and geologic-hazard-reduction measures including the proposed debris basins and rock-fall-hazard-reduction structures. The developer's geotechnical/geologic consultant should provide written verification to Provo City that site development and construction was performed according to their design recommendations.

- Major geologic-hazard-reduction measures, specifically to reduce rock-fall and debris-flow hazards, should be completed as an initial phase of the development before issuing building permits for individual lots.

- Earthquake ground shaking recommendations in the Earthtec (2001) report refer to seismic zone 3 of the Uniform Building Code (International Conference of Building Officials, 1997). Utah adopted the International Building Code (IBC) (International Code Conference, 2000) in January 2002 and all structures should be built according to seismic provisions in the IBC and applicable residential building code (International Residential Code) provisions.

SCOPE OF REVIEW

As part of the review, I evaluated aerial photographs, and geologic maps and reports of the site. No reconnaissance of the site was conducted as part of this review; however, UGS geologist Richard E. Giraud visited the site on July 26, 2001, as part of a debris-flow-hazard assessment following the Y-Mountain fire.

REFERENCES

Earthtec Testing and Engineering, P.C., 2001, Geotechnical study, Foothill Park, Provo, Utah: Orem, Utah, unpublished consultant's report, 50 p.

-----2002, Geologic hazards study, Foothill Park, Provo, Utah: Orem, Utah, unpublished consultant's report, 25 p.

International Code Conference, 2000, International Building Code: Falls Church, Virginia, 756 p.

International Conference of Building Officials, 1997, Uniform Building Code; Volume 2: Whittier, California, 492 p.

Utah Geological Survey

Project: Review of “Preliminary subsurface report, North Village 50-acre site”			Requested by: Doug Smith, Wasatch County Planning
By: Barry J. Solomon	Date: 07-23-02	County: Wasatch	Date report received at UGS: 06-29-02
USGS Quadrangle: Heber City	Section/Township/Range: section 18, T. 3 S.,R. 5 E., SLBM		Job number: 02-07 (R-07)

INTRODUCTION

I reviewed geologic portions of the preliminary subsurface report for the proposed North Village subdivision by Intermountain GeoEnvironmental Services, Inc. (IGES, 2002). For the review, I looked at relevant geologic literature, examined 1:20,000-scale (1962) and 1:40,000-scale (1987) aerial photographs, and inspected the property on July 22, 2002. The purpose of my review is to assess whether IGES (2002) adequately identifies and addresses geologic hazards that could affect the subdivision.

CONCLUSIONS AND RECOMMENDATIONS

I believe that further study is needed and recommend the following:

- Landslides and landslide potential are not addressed in the report; site conditions should be evaluated with emphasis on stability of existing landslides (if present) and steep slopes (greater than 25 percent), based on observation and measurement of geologic criteria such as slope inclination, rock type and condition, the nature of planar features within soil or rock, ground-water conditions, and thickness and description of soil and colluvium overlying rock.
- If necessary, conduct geotechnical-engineering slope-stability analyses as outlined in Hylland (1996) for landslides (if present) and slopes greater than 25 percent to demonstrate slope stability and determine setbacks and buildable areas.
- Consider the potential contribution of water leaking from the Timpanogos and Wasatch Canals when evaluating slope stability and the potential for shallow ground water.
- Take appropriate action to reduce hazards identified by IGES (2002) from canals flowing through the site; this may require a cooperative effort between the developer, Wasatch County, and canal owners to ensure that canals are adequate to prevent leakage or flooding.
- Evaluate the debris-flow, flood, and collapsible-soil hazards associated with the alluvial fan at the south end of the property.
- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in IGES (2002) and any subsequent studies.
- The existence of the IGES (2002) report, this review, and subsequent reports and reviews

should be disclosed to potential buyers.

§ To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

IGES (2002) lists shallow ground water, earthquake ground shaking, surface fault rupture, liquefaction, stream and canal flooding, and dam failure as potential geologic hazards on the property. The report adequately addresses these hazards, but does not identify landsliding and alluvial-fan flooding and debris flows as potential hazards. The report also lists collapsible soils as a potential geologic hazard, but I believe additional testing may be needed to assess this hazard. In addition, a course of action to deal with the hazards posed by the canals remains to be determined.

Bromfield and others (1970) map rocks underlying most of the site as the volcanic breccia of Coyote Canyon, an informal member of the Keetley Volcanics. IGES (2002) notes that this unit is typically shallow onsite and could not be excavated with a backhoe, implying stable slopes. However, the IGES report did not discuss landslides or slope stability. To recognize slopes susceptible to landsliding in western Wasatch County, Hylland and Lowe (1997) defined "critical slope inclinations" based on the strong correlation between geologic material, slope inclination, and landsliding. The critical slope inclination is the slope angle above which late Holocene landslides have typically occurred. The critical slope inclination for the Keetley Volcanics is 25 percent. On their map of landslide hazards in the area, Hylland and Bishop (1996) assigned a moderate landslide hazard to slopes with inclinations greater than the critical angle but showing no evidence of past landsliding. They map a moderate landslide hazard on slopes underlying most of the North Village site. I measured slopes ranging from 30 to 35 percent in this area from the 7-1/2 minute topographic map of the Heber City quadrangle. In areas of moderate landslide hazard, Hylland and Bishop (1996) recommend at least a reconnaissance-level geologic evaluation and indicate that a quantitative slope-stability analysis may be necessary.

Landslides are relatively common in the Keetley Volcanics of western Wasatch County, where Hylland and Lowe (1997) note 50 landslides in the unit. Several rock types are found in the Keetley Volcanics, and some are more susceptible to failure than others. Susceptible rock is commonly mapped as volcanic breccia of the type that underlies most of the North Village site. However, lithology of this map unit is highly variable, characterized by interbedded resistant beds and softer layers. Although the resistant beds may be more evident in excavations and outcrops and may suggest stable slopes, the softer layers increase the risk of slope failure. I observed evidence of soft interbeds (altered tuff in outcrop and float) during my site inspection.

Although slumps in the volcanic breccia map unit are found in Wasatch County in steep road cuts along Highway 40, neither Bromfield and others (1970) nor Hylland and Bishop (1996) map landslides on or near the site in their 1:24,000-scale mapping. However, I identified some features on aerial photographs that may be evidence of landsliding. These features include scarp-like steepening of slopes and irregular topography between the canals in the central part of the site, particularly near the concave slope above ITP-2. Test pits in the area encountered shallow, resistant bedrock, so geologic studies would need to evaluate whether these features are related to landslides or to erosional resistance. Future seismic-refraction and/or coring studies recommended by IGES (2002) to evaluate excavatability can also provide data to evaluate landslides and slope stability.

Hylland and Bishop (1996) map an alluvial fan underlying the southern end of the North Village site. The fan extends from the drainage that exits the range front in the southeast corner of the site. I believe alluvial-fan deposits are encountered in boreholes B-1, B-2, and B-3 and test pits ITP-3 and ITP-4, in which unconsolidated soil containing gravel and cobbles is found to total depths of as much as 26.5 feet in contrast with shallow bedrock in other onsite borings and test pits. Debris flows and flooding are hazards on the alluvial fan and the hazard potential should be evaluated prior to development. Collapsible soils are also a potential hazard on alluvial fans, particularly those derived from volcanic material such as the Keetley Volcanics. IGES (2002) conducted collapse/consolidation tests on one sample from boring B-2 and reported that the soil has a low collapse potential. Additional testing of alluvial-fan material is advisable during final geotechnical investigations to ensure that collapsible soil is not present.

Two canals flow through the site: Timpanogos Canal along the eastern edge of the site and Wasatch Canal along the western edge of the site. I concur with IGES (2002) that these canals may cause flooding that could impact the site. The IGES report notes that the Timpanogos Canal was recently lined with concrete. This reduces the potential for flooding from canal failure and also the potential for shallow ground water and possible slope failure from infiltration of Timpanogos canal water into the hillside. To address this hazard, the developer and Wasatch County may need to work with the canal owner to assess and reduce hazards and ensure the canals are adequate to prevent leakage or flooding.

SUMMARY OF CONCLUSIONS

In conclusion, I concur with the assessment of IGES (2002) regarding the potential for shallow ground water, earthquake ground shaking, surface fault rupture, liquefaction, stream flooding, and dam failure. However, additional work is needed to address the potential for landsliding, alluvial-fan flooding and debris flows, and collapsible soils, and to determine a course of action to reduce canal flooding and leakage potential. Additional studies addressing these hazards should be documented with a site map showing site geology, steep slopes, landslides (if present), alluvial fans, setbacks, other hazards and recommended hazard-reduction measures.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in IGES (2002). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in IGES (2002) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS make no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Bromfield, C.S., Baker, A.A., and Crittenden, M.D., Jr., 1970, Geologic map of the Heber quadrangle, Wasatch and Summit Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-864, scale 1:24,000.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Hylland, M.D., and Bishop, C.E., 1996, Flood hazards, earthquake hazards, and problem soils, western Wasatch County, Utah (plate 2A), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

Hylland, M.D., and Lowe, Mike, 1996, Landslide hazard, western Wasatch County, Utah (plate 1A), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

---1997, Regional landslide-hazard evaluation using landslide slopes, western Wasatch County, Utah: Environmental & Engineering Geoscience, v. 3, no. 1, p. 31-43.

Intermountain GeoEnvironmental Services, Inc., 2002, Preliminary subsurface report, North Village 50-acre site: Orem, Utah, unpublished consultant's report, 10 p.

Project: Review of "Engineering geology assessment, 30-acre parcel, Deer Creek Drive, Timber Lakes development, Wasatch County, Utah"			Requested by: Doug Smith, Wasatch County Planning
By: Barry J. Solomon	Date: 07-31-02	County: Wasatch	Date report received at UGS: 07-08-02
USGS Quadrangles: Center Creek and Heber Mountain	Section/Township/Range: E ½ section 15, T. 4 S.,R. 6 E., SLBM		Job number: 02-08 (R-08)

INTRODUCTION

I reviewed the engineering-geologic report for the 30-acre parcel along Deer Creek Drive in the Timber Lakes subdivision by AMEC Earth and Environmental, Inc. (AMEC, 2002). For the review, I looked at relevant geologic literature and examined 1:20,000-scale (1962) aerial photographs, but I did not inspect the property. The purpose of my review is to assess whether AMEC (2002) adequately identifies and addresses geologic hazards that could affect the subdivision.

CONCLUSIONS AND RECOMMENDATIONS

I believe that AMEC (2002) does not adequately identify the potential for landslides on the 30-acre parcel. The report states that there is no evidence of slope instability on or near the site and indicates that slopes with the greatest potential for instability lie along the steep northeastern edge of the site, and I concur. However, AMEC (2002) does not adequately document that the recommended 2H:1V setback line projected from the base of the steep slopes is sufficient to prevent damage. I therefore recommend:

- At least a preliminary geotechnical-engineering evaluation of the steep slope, consistent with the recommendations of Hylland (1996), to support the recommended setback and assess the potential impact of landslides on proposed construction and on downslope development.

I further recommend that:

- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in any subsequent studies.
- The existence of the AMEC (2002) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.
- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

AMEC (2002) identifies earthquake ground shaking as a potential geologic hazard on the 30-acre parcel near Deer Creek Drive. To address earthquake ground shaking, the report recommends following the seismic-design procedures of the International Building Code (International Code Council, 2000) for this site, and I concur.

AMEC (2002) also identifies slope stability as a potential geologic hazard. The report states that no evidence of slope instability was found on or near the site and the steepest onsite slopes, along the northeastern edge of the site, are stable under present conditions despite grades greater than 45 percent. However, to avoid future slope instability, AMEC (2002) recommends that footings of any structure be placed west of a 2H:1V setback line projected from the base of the steep slopes. This setback was established on the basis of an earlier study of the stability of slopes on Timber Lakes lot 1003 in a similar geologic setting nearby (AMEC, 2000).

Although the geologic settings of lot 1003 and the 30-acre parcel are similar, the northeast slope of the 30-acre parcel is much steeper and higher than steep slopes on lot 1003. The minimum gradient of the northeastern slope on the 30-acre parcel (about 45 percent) is comparable to the gradient of the analyzed slope on lot 1003 (about 50 percent). However, that slope gradient is almost uniform, whereas much of the northeastern slope of the 30-acre parcel exceeds 60 percent and reaches almost 80 percent. Also, the slope at lot 1003 is about 100 feet (30 m) high, whereas slopes at the 30-acre parcel range from about 70 to 190 feet (20-60 m) high. As such, possible slope failures and slip surfaces will have a different configuration and may require a different setback. Therefore, the slope-stability analysis for lot 1003 may not apply to the 30-acre parcel and it should be re-run for the steeper, higher slopes.

In addition, AMEC (2000) calculated factors of safety for the steep slope on lot 1003 as low as 1.37 under static conditions. The report therefore recommended that structures be placed 10 feet beyond a 2H:1V setback, which places footings beyond failure surfaces with static factors of safety less than 1.5 (the minimum criteria recommended in Hylland, 1996). AMEC (2002) recommends using the 2H:1V setback, without an additional buffer. If the 2H:1V setback, without a buffer, is inadequate to avoid potential failure surfaces on a 50 percent slope, it may also be inadequate for steeper, higher slopes in similar geologic settings.

SUMMARY OF CONCLUSIONS

In conclusion, I concur with the assessment of AMEC (2002) regarding the potential for earthquake ground shaking. However, AMEC (2002) does not adequately address the potential for landsliding. Further studies addressing slope stability should be performed and documented with an adequate site map showing steep slopes and recommended hazard-reduction measures.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in AMEC (2002). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in AMEC (2002) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS make no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

AMEC Earth and Environmental, Inc., 2000, Slope stability evaluation, lot 1003, Deer Run Drive, Timber Lakes subdivision, Wasatch County, Utah: Salt Lake City, Utah, unpublished consultant's report.

AMEC Earth and Environmental, Inc., 2002, Engineering geology assessment, 30-acre parcel, Deer Creek Drive, Timber Lakes development, Wasatch County, Utah: Salt Lake City, Utah, unpublished consultant's report, p. 6.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

International Code Council, 2000, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

Utah Geological Survey

Project: Review of "Preliminary geologic/geotechnical investigation, Little Pole Canyon property, east of Heber City, Utah"			
By: Barry J. Solomon, P.G.	Date: 11-21-02	County: Wasatch	
USGS Quadrangle: Francis (1167)	Section/Township/Range: Section 36, T. 3 S., R. 5 E. and N½ section 1, T. 4 S., R. 5 E., SLBM		
Requested by: Doug Smith, Wasatch County Planning	Date report received at UGS: 10-24-02		Job number: 02-10 (R-09)

INTRODUCTION

I reviewed the preliminary report of the geologic/geotechnical investigation for the Little Pole Canyon property by Intermountain GeoEnvironmental Services, Inc. (IGES, 2002). For the review, I looked at relevant geologic literature and examined 1:20,000-scale (1962) aerial photographs, but I did not inspect the property. The purpose of my review is to assess whether IGES (2002) adequately identifies and addresses geologic hazards that could affect the property.

CONCLUSIONS AND RECOMMENDATIONS

I believe that IGES (2002) adequately identifies most geologic hazards at a scale suitable for a preliminary investigation. The report states that IGES understands that development "is planned in areas where the slopes are less than 25 percent," and I believe this to be prudent. The IGES report: (1) does not discuss seismic design categories for earthquake-resistant design under the International Building Code (IBC) (International Code Council, 2000a) and International Residential Code (IRC) (International Code Council, 2000b), (2) states that closure of the apparent main access road into the property may be necessary during flash flooding of Little Pole Canyon, and (3) does not identify the potential for flooding and debris flows on small alluvial fans in Little Pole Canyon. For the final report, I therefore recommend:

- If development proceeds on steep slopes (greater than 25 percent) underlain by the Keetley Volcanics, conduct slope-stability analyses as outlined in Hylland (1996) to demonstrate slope stability and determine building setbacks and buildable areas.
- Determine site classes and seismic design categories in accordance with procedures of the IBC and IRC.
- As recommended by IGES (2002), consider and reduce the flood potential in the design of the Pole Canyon road; if this is the only access into the development, temporary road closure during an emergency may present an unacceptable risk.
- Evaluate the flood and debris-flow hazards associated with the alluvial fans in Little Pole Canyon.

I further recommend that:

- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in any subsequent studies.
- The existence of the IGES (2002) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.
- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

Landslides

IGES (2002) did not observe any landslides on the Little Pole Canyon property but notes the susceptibility of the Keetley Volcanics, underlying much of the property, to landsliding. Hylland and Lowe (1997) determined that late Holocene landslides in western Wasatch County typically occur in the Keetley Volcanics on slopes greater than 25 percent. IGES (2002) understands that development is planned only in areas with slopes less than 25 percent, and I believe this to be prudent. If development is proposed on steeper slopes, the developer's geotechnical consultant should conduct slope-stability analyses as outlined in Hylland (1996) to demonstrate slope stability and determine building setbacks and buildable areas.

Earthquake Ground Shaking

IGES (2002) identifies earthquake ground shaking as a potential geologic hazard on the Little Pole Canyon property. The report states that the property is likely underlain by rock of IBC site class B, and presents horizontal ground accelerations and amplification factors (site coefficients) appropriate for the location and site class. Although I agree that earthquake ground shaking is a potential geologic hazard, I do not believe the IGES (2002) discussion adequately characterizes site conditions relevant to the hazard or provides sufficient information to identify appropriate earthquake-resistant design requirements.

The IBC specifies earthquake-resistant design requirements for most structures and the IRC specifies these requirements for one- and two-family dwellings and townhouses. Design requirements depend on the seismic design category of a structure, which is based on spectral response accelerations and, for the IBC, seismic use group (a function of the nature of occupancy). To determine appropriate spectral response accelerations, you must first determine the site class of the upper 100 feet (30 meters) of soil and rock.

IGES (2002) believes that site class B (rock) underlies the property. This is apparently based on the location of the site on rock mapped as the Keetley Volcanics and Nugget Sandstone (Bryant, 1990). However, I believe that the Nugget Sandstone may belong to site class A. Furthermore, the IBC states (p. 352), "The rock categories, Site Classes A and B, shall not be used if there is more than 10 feet (3048 mm) of soil between the rock surface and the bottom of the spread footing or mat foundation." IGES encountered at least 11 feet of soil without reaching rock in 3 of their 8 test pits (TP-3, 5, and 7), so more than 10 feet of soil beneath spread footings or mat foundations is possible at these locations. If, in fact, site class B underlies part of the property, structures in these areas would be assigned to seismic design category C by both the IBC and IRC. However, seismic design categories B or D are possible if the site class is other than B. The final report should verify site classes and determine seismic design categories and associated earthquake-resistant design requirements.

Flooding and Debris Flows

IGES (2002) notes that Little Pole Canyon is subject to flash floods that may result in restricted access to the planned canyon road. The IGES report recommends that the flood potential along the road alignment be considered and the hazard reduced in the road design, and I concur. This is particularly important if the Little Pole Canyon Road will be the only access to the property. If access is restricted (or blocked) during flash floods, emergency-response personnel and equipment may be unable to provide needed services and residents may be unable to leave.

Alluvial-fan flooding and debris flows may also affect the planned road and proposed development. Hylland and Bishop (1996) map four small alluvial fans on the property lying at the mouths of drainages in Little Pole Canyon. Three of the alluvial fans are on the west side of the canyon and the fourth, which is the largest, is on the east side. Flood and debris-flow hazards should be evaluated on these alluvial fans and their potential effects considered in road design and building location.

SUMMARY OF CONCLUSIONS

In conclusion, I believe that planning development only on slopes less than 25 percent, as understood by IGES (2002), is reasonable and will reduce the potential for landsliding. If development is proposed on steeper slopes, I recommend slope-stability analyses. I agree with IGES (2002) that earthquake ground shaking is a potential geologic hazard, but further characterization of site class is needed to determine appropriate IBC and IRC seismic design categories. I agree with the IGES (2002) recommendation to consider the flood potential of Little Pole Canyon in the design of the canyon road, and further recommend consideration of alluvial-fan debris-flow and flood hazards in road design and building construction.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in IGES (2002). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in IGES (2002) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Bryant, Bruce, 1990, Geologic map of the Salt Lake City 30' x 60' quadrangle, north-central Utah, and Uinta County, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1944, scale 1:100,000.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Hylland, M.D., and Bishop, C.E., 1996, Flood hazards, earthquake hazards, and problem soils, western Wasatch County, Utah (plate 2B), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

Hylland, M.D., and Lowe, Mike, 1997, Regional landslide-hazard evaluation using landslide slopes, western Wasatch County, Utah: Environmental & Engineering Geoscience, v. 3, no. 1, p. 31-43.

Intermountain GeoEnvironmental Services, Inc., 2002, Preliminary geologic/geotechnical investigation, Little Pole Canyon property, east of Heber City, Utah: Orem, Utah, unpublished consultant's report, 13 p.

International Code Council, 2000a, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

--- 2000b, International Residential Code for One- and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 578 p.

Project: Review of “Geotechnical investigation, Crossings at Lake Creek development, east of Heber City, Utah”			
By: Barry J. Solomon, P.G.	Date: 01-10-03	County: Wasatch	
USGS Quadrangles: Center Creek (1126), Charleston (1127), Francis (1167), Heber City (1168)	Section/Township/Range: SW ¼ section 34, T. 3 S., R. 5 E. and section 3, T. 4 S., R. 5 E., SLBM		
Requested by: Doug Smith, Wasatch County Planning	Date report received at UGS: 12-12-02		Job number: 03-01 (R-10)

INTRODUCTION

I reviewed the report of the geotechnical investigation for the Crossings at Lake Creek development by Kleinfelder, Inc. (Kleinfelder, 2000). For the review, I studied relevant geologic literature and examined 1:20,000-scale (1962) aerial photographs, but I did not inspect the property. The purpose of my review is to assess whether Kleinfelder (2000) adequately identifies and addresses geologic hazards that could affect the property.

CONCLUSIONS AND RECOMMENDATIONS

I believe that the Kleinfelder (2000) report adequately identifies geologic hazards at the site. The report considers landsliding and liquefaction hazards and concludes that their potential is low, and I concur. The report prudently identifies earthquake ground shaking, stream flooding (based on the 100-year flood plain mapped by the Federal Emergency Management Agency [FEMA]), alluvial-fan flooding, and shallow ground water as local hazards and recommends their consideration during site planning. I agree with this recommendation, and add that debris flows should be included when considering alluvial-fan flooding. Because the Kleinfelder report was written before statewide adoption of the International Building Code (IBC) (International Code Council, 2000a) and International Residential Code (IRC) (International Code Council, 2000b), the report does not discuss seismic design categories required by these codes for earthquake-resistant design. I therefore recommend:

- The debris-flow hazard should be included when considering alluvial-fan flooding; alluvial-fan flooding hazards cover much of the northeastern part of the site in Coyote Hollow and to the southeast, and such consideration will likely require further geologic study.
- To address the hazard from earthquake ground shaking, the developer’s geotechnical consultant should verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design

requirements in accordance with procedures of the IBC and IRC.

I further recommend that:

- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in this and any subsequent studies.
- The existence of the Kleinfelder (2000) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.
- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

Flooding and Debris Flows

Kleinfelder (2000) notes that FEMA mapped part of the site as a 100-year flood plain (Lake Creek in the southern half of the site) and that Hylland and others (1996) mapped other parts as alluvial fans with associated flood hazards (Coyote Hollow and an area in the southwest part of the site). Kleinfelder (2000) recommends that these hazards be considered during site planning, and I agree. Although not specifically mentioned in the Kleinfelder (2000) report, the possible debris-flow hazard in Coyote Hollow should be included in the alluvial-fan-flooding evaluation. Hylland and others (1996) did not map alluvial fans southeast of Coyote Hollow, in the northeast part of the site, but I believe alluvial-fan deposits extend into this area and associated hazards should be evaluated there, as well.

Biek and others (2000) map valley-fill deposits on the site south of the Lake Creek flood plain, noting that these deposits likely contain Holocene sediment. I believe that aerial photographs show possible evidence of recent flooding in this area. The area is not included in the FEMA 100-year flood plain, but the developer may wish to consider possible flood hazards south of the Lake Creek flood plain, as well.

Earthquake Ground Shaking

Kleinfelder (2000) identifies earthquake ground shaking as a potential geologic hazard on the site and states that the site is located in Uniform Building Code (UBC) Seismic Zone 3. This was correct when the Kleinfelder report was written, but the UBC has since been replaced by statewide adoption of the IBC and IRC. The IBC specifies earthquake-resistant design requirements for most structures and the IRC specifies these requirements for one- and two-family dwellings and townhouses. Whereas design requirements specified by the UBC depended upon the Seismic Zone, design requirements specified by the IBC and IRC depend on the seismic design category of a structure, which is based on spectral response accelerations and, for the IBC, seismic use group (a function of the nature of occupancy). To determine appropriate spectral response accelerations, the site class of the upper 100 feet (30 meters) of soil and rock must first be verified. The final report for Crossings at Lake Creek should verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements.

SUMMARY OF CONCLUSIONS

I agree with the conclusion of Kleinfelder (2000) that the potential for landsliding and liquefaction on the site for Crossings at Lake Creek is low. Kleinfelder (2000) believes that earthquake ground shaking, stream flooding, alluvial-fan flooding, and shallow ground water are the principal geologic hazards at the site. I concur, but add that the potential for debris flows in Coyote Hollow, and the potential for debris flows and flooding southeast of Coyote Hollow, should be considered in site planning, as well. Although a flood hazard is not mapped by FEMA south of the Lake Creek flood plain, recent geologic mapping (Biek and others, 2000) and my aerial photo interpretation indicate that flooding may be possible in this area, and the developer may wish to consider its potential.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Kleinfelder (2000). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in Kleinfelder (2000) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Biek, R.F., Hylland, M.D., Welsh, J.E., and Lowe, Mike, 2000, Interim geologic map of the Center Creek quadrangle, Wasatch County, Utah: Utah Geological Survey Open-File Report 370, scale 1:24,000.

Hylland, M.D., Lowe, Mike, and Bishop, C.E., 1996, Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

International Code Council, 2000a, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

---2000b, International Residential Code for One- and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 578 p.

Kleinfelder, Inc., 2000, Geotechnical investigation, Crossings at Lake Creek development, east of Heber City, Utah: Salt Lake City, Utah, unpublished consultant’s report, 25 p.

Project: Review of "Surface fault rupture hazard investigation phase I, Norma Thomas Property, Provo, Utah."			
By: F.X. Ashland and Gary E. Christenson, P.G.	Date: January 31, 2003	County: Utah	
USGS Quadrangles: Provo (1047)	Section/Township/Range: Sec. 17 T. 7 S., R. 3 E.		
Requested by: David J. Graves, Provo City Engineering Department	Date report received at UGS: January 10, 2003		Job number: 03-02 (R-11)

INTRODUCTION

We reviewed the surface-fault-rupture-hazard investigation report for the Norma Thomas property by RB&G Engineering Inc. (2002) (RB&G). For the review, we studied relevant geologic literature and examined aerial photographs, but we did not inspect the property. The purpose of the review is to assess whether RB&G adequately addressed surface-fault-rupture and related hazards at the site.

CONCLUSIONS AND RECOMMENDATIONS

The RB&G (2002) report adequately identifies and defines the locations of active faults at the site. RB&G's recommended building setbacks are adequate and should prevent occupied buildings from being located on known active faults at the site if properly implemented. In addition, RB&G identifies minor prehistoric liquefaction features at the site, but concludes that liquefaction is not currently a hazard and documents the absence of ground water in the upper 20 feet at the site. We concur with this conclusion.

RB&G identifies earthquake ground shaking as a potential geologic hazard at the site, provides probabilistic (10 and 5 percent exceedance probability in 50 years) peak bedrock ground motions, and states that the site is located in Uniform Building Code (UBC) Seismic Zone 3. However, the UBC was replaced by statewide adoption of the International Building Code (IBC; International Code Council, 2000a) and International Residential Code (IRC; International Code Council, 2000b) in 2002. The IBC specifies earthquake-resistant design requirements for most structures and the IRC specifies requirements for one- and two-family dwellings and townhouses. Whereas UBC design requirements depended on the Seismic Zone, IBC and IRC design requirements depend on the seismic design category of a structure, which is based on spectral response accelerations (2 percent exceedance probability in 50 years), and for the IBC, seismic use group (a function of the nature of occupancy). To determine the appropriate spectral response accelerations, the site class of the upper 100 feet (30 m) of soil and rock must first be determined or estimated. Thus, we recommend that the developer's geotechnical consultant determine site class and, in conjunction with the developer, determine the seismic use group(s), seismic design category(ies), and associated earthquake-resistant design requirements in accordance with procedures of the IBC and IRC. We concur with RB&G's recommendations regarding additional structural reinforcement and utility connections.

Finally, we recommend that:

- the existence of the RB&G (2002) report, this review, and subsequent reports and reviews be disclosed to potential buyers, and

- the developer submit to Provo City written documentation from its geotechnical consultant that recommendations in the RB&G (2002) report, particularly the building setbacks, were followed.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the RB&G (2002) report. The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the RB&G (2002) report are correct and accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Provo City in reducing the risks from geologic hazards, but the UGS makes no warranty, expressed or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

International Code Council, 2000a, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

-----2000b, International Residential Code for One and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 578 p.

RB&G Engineering Inc., 2002, Surface fault rupture hazard investigation phase I, Norma Thomas Property, Provo, Utah: Provo, Utah, unpublished consultant's report, 9 p.

Project: Review of "Geotechnical/geological study, Kunzler subdivision, 6260 South 2125 East, Weber County, Utah"			
By: Greg N. McDonald, Gary E. Christenson	Date: February 24, 2003	County: Weber	
USGS Quadrangles: Ogden	Section/Township/Range: Sec. 23, T.5N., R.1W.		
Requested by: Jim Gentry, Weber County Planning	Date report received at UGS: February 10, 2003		Job number: 03-03 (R-12)

INTRODUCTION

We reviewed portions of a geotechnical/geological report for the proposed Kunzler subdivision in south Weber County by Earthtec Testing and Engineering, P.C., in conjunction with Western GeoLogic, LLC (Earthtec, 2003). For the review, we conducted a literature review and examined 1972 1:12,000-scale and 1985 1:24,000-scale aerial photos. The purpose of the review is to determine whether geologic hazards at the site are adequately addressed in the report.

CONCLUSIONS

Earthtec (2003) adequately assesses all geologic hazards except seismic design for earthquake ground shaking and slope stability. Earthtec's scope of work did not include a detailed liquefaction analysis. We therefore recommend:

- Earthtec reevaluate the IRC Seismic Design Category using the IBC Seismic Design 3.01 program.
- Earthtec further evaluate the landslide hazard at the site including, at a minimum, a preliminary geotechnical-engineering evaluation following the guidelines in Hylland (1996).
- Disclosure of the low to moderate liquefaction potential to homeowners. More detailed analysis of the liquefaction hazard as recommended by Earthtec is prudent, but generally not required for individual residential lots.

DISCUSSION

Earthtec (2003) evaluates seismic design criteria as part of the earthquake ground shaking hazard. Earthtec determined the site is within IRC Seismic Design Category E and IBC site class D, and thereby reclassified the site as IRC Seismic Design Category D2 purportedly in accordance with IRC section R301.2.2.1.2. However, we determined the site (latitude 41.1487 degrees, longitude –111.9245 degrees) to also be in IBC seismic design category E using IBC

Seismic Design 3.01 software. The discrepancy may be explained if Earthtec classified the site using spectral accelerations from the U.S. Geological Survey National Seismic Hazard Mapping Project website rather than the IBC Seismic Design 3.01 software. Differences exist between the two sources, and the IBC software represents the design level required under the IBC and IRC.

Further evaluation of the landslide hazard at the site is warranted due to the following:

- Earthtec indicates the amphitheater containing the site was formed by landsliding and we concur.

- The walls of the amphitheater appear to be at slopes at or near critical friction angles for Lake Bonneville silty sands.

- Earthtec observed signs of recent landsliding adjacent to (southwest of) the site. In addition, Yonkee and Lowe (2003) map several small, young landslides in the Highway-89 roadcut adjacent to the site.

- The bluff above the site has been mostly developed which could lead to elevated ground-water levels from landscape irrigation, surface drainage alteration, and/or ruptured or leaking utilities. Elevated ground-water levels could result in piping and/or landsliding at the Kunzler property.

Earthtec indicates the amphitheater slopes to be 24 to 28 percent, but these slope gradient appear incorrect. Using the site plan (figure 4; Earthtec, 2003), we calculated a slope of 44 percent (24 degrees) for the north (back) side of the alcove and slopes of 51 and 57 percent (27 and 30 degrees) for the west and east sides, respectively. These slopes are near average friction angles estimated from limited laboratory tests for peak shear strengths of Lake Bonneville silty sand (SM) along the Wasatch Front that indicate a mean friction angle of about 34 degrees and a low of about 26 degrees (UGS, unpublished database). However, the origin of the soils in the test pits is not identified, so we do not know if they represent in-place Lake Bonneville Weber River delta material, which presumably controls stability in slopes surrounding the site, or slope-derived colluvium, landslide debris, or alluvium. It is important to determine the nature of the Weber River delta material, particularly the presence and extent of clay layers, to assess slope stability, and determine what strengths and ground-water conditions are appropriate. This may require excavation of additional test pits on slopes.

Earthtec indicates shallow landsliding is the primary mechanism for slope retreat along the Weber River. However, west of the Kunzler property, several large, deep-seated landslides and landslides that mobilized into earth flows with extensive runout have been mapped and documented, including two historical landslides about 2 miles east of the Kunzler site in Lake Bonneville Weber River delta sediments. In 1981, several days of above-normal precipitation triggered a large, deep-seated, rotational landslide about 1,000 feet in length and width, along a section of the bluff where its base had been cut for a railroad track alignment (Gill, 1981). In 1983, about 1.5 miles east of the Kunzler property, saturated soil conditions, likely due to seepage from a pond, resulted in a landslide that mobilized into a rapid earth flow traveling several hundred feet (Lowe, 1985). Earthtec should consider geologic conditions in slopes at the site in comparison to those at these landslides and provide evidence that shallow landsliding is the primary mechanism for slope retreat at the Kunzler property and that the potential for large-scale, deeper sliding or earth flows affecting the site beyond the proposed 30-foot setback from the base of slopes is not present.

Development of the bluff above the property is also of concern because long-term landscape irrigation, surface drainage alterations, possible broken/leaking utilities, or ponded water could elevate ground-water levels and/or induce piping at the site. The slope-stability analysis should evaluate slope sensitivity to various potential ground-water conditions and levels. To assess likely ground-water conditions, more information is needed for soil types, particularly the presence of less permeable layers, found in the slopes surrounding the site.

Earthtec states the site is within a zone of low to moderate liquefaction potential but indicate their scope of work did not include a more detailed evaluation of the hazard. At a minimum, the low to moderate liquefaction potential should be disclosed to future homeowners. A more detailed evaluation of the liquefaction hazard, as recommended by Earthtec, is prudent, but not typically required for single lots.

SUMMARY

Earthtec (2003) adequately assesses geologic hazards with the exception of seismic design for earthquake ground shaking and slope stability. In addition, Earthtec's scope of work did not include a detailed liquefaction analysis. Earthtec should reevaluate the site's Seismic Design Category using IBC Seismic Design 3.01 program. In regard to the landslide hazard at the site, we recommend at least a preliminary geotechnical-engineering evaluation of slope stability be performed to estimate the present stability of slopes and model their sensitivity under various soil strength and ground-water conditions using final slope grades and cuts. Because this site is within a low to moderate zone of liquefaction potential, at a minimum, disclosure of the potential hazard to future homeowners should be given. More detailed analysis of the liquefaction hazard as recommended by Earthtec is prudent but generally not required.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Earthtec (2003). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in Earthtec (2003) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Weber County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Anderson, L.R., Keaton, J.R., and Bay, J.A., 1994, Liquefaction potential map for the northern Wasatch Front, Utah – complete technical report: Utah Geological Survey Contract Report 94-6, scale 1:48,000, 150 p.

Earthtec Testing and Engineering, P.C., 2003, Geotechnical/geological study, Kunzler subdivision, 6260 South 2125 East, Weber County, Utah: Ogden, unpublished consultant's report, 26 p.

Gill, H.E., 1981, Geologic investigation of a major slope failure in the Washington Terrace landslide complex near the mouth of Weber Canyon, Weber County, Utah: Utah Geological and Mineral Survey Report of Investigation 163, 18 p.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Lowe, Mike, 1985, Report of geological reconnaissance: Landslide southwest of Gibbons and Reed Co. north pond, west of Uintah, Weber County, *in* Black, B.D., and Christenson, G.E., compilers, Technical reports of the Wasatch Front County Geologists, June 1985 to June 1988: Utah Geological and Mineral Survey Report of Investigation 218, p. 76-79.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Map I-2199, 22 p. pamphlet, scale 1:50,000.

Yonkee, Adolph, and Lowe, Mike, 2003, Geologic map of the Ogden 7.5-minute quadrangle, Weber and Davis Counties, Utah: Utah Geological Map (in review).

Utah Geological Survey

Project: Review of "Mustang Property—lower property development, geologic and preliminary geotechnical investigation, Wasatch County, Utah"			
By: Barry J. Solomon, P.G.	Date: 02-21-03	County: Wasatch	
USGS Quadrangles: Park City East (1209)	Section/Township/Range: S ½ section 17, NE ¼ section 20, and NW ¼ section 21, T. 2 S., R. 5 E., SLBM		
Requested by: Doug Smith, Wasatch County Planning	Date report received at UGS: 02-10-03		Job number: 03-04 (R-13)

INTRODUCTION

I reviewed the report of the geologic and preliminary geotechnical investigation for the lower Mustang Property Development by Intermountain GeoEnvironmental Services, Inc. (IGES, 2002). For the review, I studied relevant geologic literature and examined 1:20,000-scale (1962) aerial photographs, but I did not inspect the site. The purpose of my review is to assess whether IGES (2002) adequately identifies and addresses geologic hazards that could affect the property.

CONCLUSIONS AND RECOMMENDATIONS

I believe the IGES report adequately identifies geologic hazards on the lower Mustang Property Development. Because of its preliminary nature, however, the report does not adequately address seismic design requirements of the International Building Code (IBC) (International Code Council, 2000a) and International Residential Code (IRC) (International Code Council, 2000b) for earthquake-resistant design. I therefore recommend:

- To address the hazard from earthquake ground shaking, the final geotechnical report should verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements in accordance with procedures of the IBC and IRC.

I also recommend the following:

- Slope-stability analyses should be conducted if additional development is proposed on steep slopes.
- A qualified geotechnical engineer should review recommendations pertaining to adverse soil conditions, foundation design, and site grading in this and any subsequent studies.
- The existence of the IGES (2002) report, this review, and subsequent reports and reviews

should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

I believe that IGES (2002) adequately identifies geologic hazards at the site. The IGES report notes springs observed during the field investigation, landslides mapped by Hylland and Lowe (1995) and observed by IGES, and areas subject to a stream-flood hazard mapped by Hylland and Bishop (1995). The site map in the IGES report (plate A-2) shows that proposed residential and high-use areas will prudently avoid these hazards. Comparison of the site map with the UGS map of landslide hazards in western Wasatch County (Hylland and Lowe, 1995) shows that proposed residential and high-use areas also avoid steep slopes (greater than 25 per cent) with moderate or high landslide hazards. IGES recommends that slope-stability analyses should be conducted if additional development is proposed on steep slopes, and I concur. The IGES report considers liquefaction hazards and concludes that their potential is low, and I agree.

IGES (2002) identifies earthquake ground shaking as a potential geologic hazard on the site. The IBC specifies earthquake-resistant design requirements for most structures and the IRC specifies these requirements for one- and two-family dwellings and townhouses. Design requirements depend on the seismic design category of a structure, which is based on spectral response accelerations and, for the IBC, seismic use group (a function of the nature of occupancy). To determine appropriate spectral response accelerations, the site class of the upper 100 feet (30 meters) of soil and rock must first be verified. The IGES report states that the property is likely underlain by IBC site class C (very dense soil and soft rock) and presents appropriate amplification factors (site coefficients). I agree that site class C is a reasonable estimate, although site class A (hard rock) or B (rock) may be locally present in areas underlain by the Nugget Sandstone and Keetley Volcanics (Bromfield and Crittenden, 1971). The final report for the Mustang property should verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements.

IGES (2002) provides laboratory analyses of soil samples collected from test pits to document adverse soil conditions. Consolidation/collapse tests indicate to IGES that some "site soils have a minor to moderately high potential to collapse under increased moisture and loading conditions (p. 5)." Swell tests indicate to IGES that clay on the site exhibits a relatively low potential to expand with increased moisture, but under lightly loaded conditions (as might occur with sidewalks, pavements, and concrete slab-on-grade) some damage may occur (p. 19). Although laboratory tests suggest a low potential for sulfate in soils to corrode concrete, a resistivity test indicates to IGES that "on-site soils are categorized as severely corrosive to metal if placed within the fine-grained clay soils (p. 24)." IGES (2002) recommends actions to minimize the effects of adverse soil conditions, and a qualified geotechnical engineer should review these recommendations.

SUMMARY OF CONCLUSIONS

I believe that IGES (2002) adequately identifies areas subject to landsliding, stream flooding, and springs at a scale suitable for a preliminary geotechnical investigation. The IGES site plan indicates that development will prudently avoid these hazards. If additional development is proposed on steeper slopes than indicated on the site plan, I recommend slope-stability analyses. I agree with the conclusion of IGES (2002) that the potential for liquefaction on the site is low. I also agree with IGES (2002) that earthquake ground shaking is a potential geologic hazard and recommend that the final geotechnical report for the Mustang Property verify the site class and determine seismic design categories and associated earthquake-resistant design requirements. A qualified geotechnical engineer should review IGES (2002) recommendations regarding actions to minimize the effects of adverse soil conditions identified in the IGES report.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in IGES (2002). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in IGES (2002) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Bromfield, C.S., and Crittenden, M.D., Jr., 1971, Geologic map of the Park City East quadrangle, Summit and Wasatch Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-852, scale 1:24,000.

Hylland, M.D., and Bishop, C.E., 1995, Flood hazards, earthquake hazards, and problem soils, western Wasatch County, Utah (plate 2A), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

Hylland, M.D., and Lowe, Mike, 1995, Landslide hazard, western Wasatch County, Utah (plate 1A), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

Intermountain GeoEnvironmental Services, Inc., 2002, Mustang Property—lower property development, geologic and preliminary geotechnical investigation, Wasatch County, Utah: Orem, Utah, unpublished consultant's report, 26 p.

International Code Council, 2000a, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

---2000b, International Residential Code for One- and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 578 p.

Utah Geological Survey

Project: Review of geotechnical and slope-stability-analysis reports for the proposed Chadwick Farms residential subdivision, Layton, Utah			
By: F.X. Ashland and Gary E. Christenson, P.G.	Date: March 12, 2003	County: Davis	
USGS Quadrangles: Kaysville (1320)	Section/Township/Range: Sec. 23 T. 4 N., R. 1 W.		
Requested by: Kem Weaver, Layton City Community Development Department	Dates reports received at UGS: October 4, 2002 and February 28, 2003		Job number: 03-05 (R-14)

INTRODUCTION

We reviewed geologic-hazards and slope-stability aspects of two reports (Applied Geotechnical Engineering Consultants, Inc. [AGEC], 2002; Earthtec Testing & Engineering, P.C. [Earthtec], 2003) for the proposed Chadwick Farms subdivision in Layton, Utah. The Earthtec (2003) report addresses a comment on the slope-stability analysis in the AGEC (2002) report raised in a letter by the Utah Geological Survey (UGS) dated October 11, 2002. For the review, we studied relevant geologic literature, examined aerial photographs, conducted slope-stability analysis using PC-STABL5M and STED computer software, and inspected the property and adjacent areas on October 8, 2002. In addition, UGS geologists have measured ground-water levels in AGEC well B-1 on three occasions subsequent to the last ground-water-level measurement by AGEC. The purpose of the review is to assess whether the reports adequately address geologic hazards, particularly the potential for landsliding at the site.

CONCLUSIONS AND RECOMMENDATIONS

The AGEC (2002) report adequately addresses most of the geologic hazards at the site including earthquake ground shaking, liquefaction, and surface fault rupture. AGEC identifies landsliding along the bluff on the north side of the property as a potential hazard and provides building and road setback and site drainage recommendations to reduce the risk from the hazard. In general, we agree with these recommendations and encourage Layton City to consider similar setbacks, based on site-specific data, in other places where development is proposed atop bluffs.

The Earthtec (2003) report assesses whether the AGEC setback recommendations are adequate if ground-water levels were to rise 10 feet higher than present levels. Data regarding long-term ground-water-level fluctuations at the site are not available, and our measurements at AGEC well B-1 are too few and over too short a time period to document likely fluctuations. We do not believe that a ground-water level 10 feet higher than at present represents the likely highest ground-water level because the UGS has documented seasonal fluctuations in ground-water levels at other sites in Layton that exceed 6 feet in a single year. However, the Earthtec (2003) analysis reduces the uncertainty regarding slope stability and supports the adequacy of the AGEC setback recommendations. We believe the proposed setbacks are an adequate, important step in reducing risks to acceptable levels. However, Layton City, the developer, and future homeowners must understand that the setbacks do not entirely eliminate the risk if higher ground-water levels and/or stronger earthquake ground motions occur.

The AGEC (2002) report gives the International Building Code (IBC; International Code Council, 2000a) site class and provides the correct mapped spectral response accelerations for the site. Based on the mapped spectral response accelerations, structures at the site fall into seismic design category E according to both the IBC and the International Residential Code (IRC; International Code Council, 2000b). The IRC indicates that residential structures in seismic design category E need to be designed in accordance with the IBC unless they are constructed in a manner that meets the exception in IRC section R301.2.2.1.2.

Finally, we recommend that:

- the existence of the two reports and this review be disclosed to potential buyers, and

- the developer submit to Layton City written documentation from its geotechnical consultant that recommendations in the AGEC (2002) report, particularly the building setbacks and drainage recommendations, were followed.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the AGEC (2002) and Earthtec (2003) reports. The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the AGEC (2002) and Earthtec (2003) reports are correct and accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Layton City in reducing the risks from geologic hazards, but the UGS makes no warranty, expressed or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc., 2002, Geotechnical investigation and slope stability analysis – the Highlands at Oak Hills subdivision, 2400 East Oak Hills Drive, Layton, Utah: Sandy, Utah, unpublished consultant’s report, 18 p.

Earthtec Testing & Engineering, P.C., 2003, untitled letter report for the proposed Chadwick Farms subdivision, Layton, Utah: Ogden, Utah, unpublished consultant’s report, 2 p.

International Code Council, 2000a, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

-----2000b, International Residential Code for One and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 578 p.

Utah Geological Survey

<table>
<tr><td colspan="3">Project:
Review of geologic-hazards reports for the proposed Bonneville Trail Estates subdivision and nearby water tank, North Logan, Utah</td><td rowspan="3"></td></tr>
<tr><td>By:
Barry J. Solomon, P.G.</td><td>Date:
04-08-03</td><td>County:
Cache</td></tr>
<tr><td>USGS Quadrangles:
Smithfield (1469)</td><td colspan="2">Section/Township/Range:
NE ¼ section 13, T. 12 N., R. 1 E. and NW ¼ section 18, T. 12 N., R. 2 E., SLBM</td></tr>
<tr><td>Requested by:
Jeff Jorgensen, City of North Logan</td><td colspan="2">Date report received at UGS:
03-23-03</td><td>Job number:
03-06 (R-15)</td></tr>
</table>

INTRODUCTION

I reviewed the report of the engineering-geologic and geologic-hazards investigation for the proposed Bonneville Trail Estates subdivision in North Logan by Western GeoLogic, LLC (Western GeoLogic, 2002). This subdivision is referred to as phase III of the Canyon Ridge Heights subdivision in earlier reports (BIO/WEST, Inc., 1997; Growth Resources, Inc., 1997). I also reviewed the report by Western GeoLogic that addressed the surface-fault-rupture hazard for a proposed water tank near the subdivision (Western GeoLogic, 2003). For the review, I studied relevant geologic literature but I did not inspect the sites. The purpose of my review is to assess whether Western GeoLogic (2002, 2003) adequately identifies and addresses geologic hazards that could affect the properties.

CONCLUSIONS AND RECOMMENDATIONS

I believe the Western GeoLogic (2002) report adequately identifies most geologic hazards at the proposed Bonneville Trail Estates subdivision. However, I believe that the potential for surface fault rupture and landsliding requires further study at both the proposed subdivision and adjacent water tank site. I therefore recommend:

- A site-specific study should be conducted to determine the surface-fault-rupture hazard at the proposed Bonneville Trail Estates subdivision and the water tank site.
- Because landslide deposits underlie the tank site and may pose a threat to downslope homes, I recommend performing a site-specific geologic evaluation to assess the stability of the deposits and, if necessary, a subsequent geotechnical-engineering slope-stability analysis.

I also recommend the following:

- The existence of the Western GeoLogic (2002) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to North Logan City written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

Western GeoLogic (2002) addresses the potential for several geologic hazards at the proposed Bonneville Trail Estates subdivision. I believe that Western GeoLogic (2002) adequately identifies the potential for most geologic hazards at the site, but recommend further study of the potential for surface fault rupture and landsliding at sites for both the proposed subdivision and water tank.

Surface Fault Rupture

Lowe and Galloway (1993) mapped two north-trending faults across the proposed subdivision and two additional faults that lie between the proposed subdivision and the water-tank site to the east. The faults are mapped as "concealed," indicating that they are buried and approximately located, at a scale of 1:24,000. These faults are part of the East Cache fault zone, a zone of normal faulting showing evidence of Quaternary surface fault rupture (younger than 1.6 million years old) (McCalpin, 1989). The East Cache fault zone bounds the east side of Cache Valley along the Bear River Range front and is divided into three segments, each independently capable of generating large earthquakes. The faults near the proposed subdivision are part of the northern segment, and the boundary between the northern and central segments lies near the southeastern corner of the site. In general, the northern segment has no evidence of surface fault rupture during the past 10,000 years, whereas the central segment has evidence of the most recent surface fault rupture along the fault zone, which occurred about 4,000 years ago (McCalpin, 1994). However, data suggest that the southern part of the northern segment is a transition zone between contrasting fault behavior to the north and south. McCalpin (1994) believes that movement on the southern part of the northern segment, which includes the faults crossing the proposed subdivision, is a continuation of movement on the central segment. Thus, faulting in the East Cache fault zone in the vicinity of the proposed Bonneville Trail Estates subdivision may be important to both the subdivision and water tank because of the hazard of surface fault rupture posed by faults with possible evidence of relatively recent movement.

Site-specific special studies are needed to determine the hazard posed by Quaternary faults. Because of the inexact location of faults mapped at a scale of 1:24,000, the Utah Geological Survey (UGS) recommends special studies within 250 feet of "well-defined" faults (generally shown as solid lines on geologic maps) on their upthrown side and 500 feet on the downthrown side. Typically, these special studies consist of detailed geologic mapping, documentation of fault-related features, and excavation of trenches across faults to determine the size and timing of earthquakes. For "buried or approximately located" faults, such as are indicated at this site, we recommend at least detailed geologic mapping and documentation of fault-related features within 1,000 feet of mapped fault traces, followed by trenching if evidence for faults is found. Growth Resources, Inc. (1997) conducted a geophysical investigation of faulting at the subdivision site, consisting of a gravity survey along three survey lines. This survey identified as many as 20 faults across the site, leading Growth Resources to recommend that development of the subdivision await results of further site-specific work to determine the surface-fault-rupture hazard. Western GeoLogic (2002, p. 7) agreed with this recommendation, and I concur. Once site-specific special studies determine the location and age of these faults, appropriate setbacks can be specified as needed. The UGS is currently developing guidelines for surface-fault-rupture-hazard studies (Batatian and others, in preparation) that are in review by the Association of Engineering Geologists, Utah Section. Although not final, the draft document can be consulted for additional guidance in performing these studies.

Western GeoLogic (2003) stated that the surface-fault-rupture hazard at the proposed water-tank site was low because faulting was not identified within 100 feet of the tank site, and as an additional precaution recommended inspecting the foundation excavation to determine if evidence of faulting is present. However, the tank site lies within 1,000 feet of a mapped buried or approximately located Quaternary fault and is thus within an area where the UGS recommends special fault studies. In addition, because spacing between faults found in the gravity survey by Growth Resources, Inc. (1997) is sometimes greater than 100 feet and the gravity survey did not extend through the tank site, a distance of 100 feet from the nearest mapped fault is insufficient to demonstrate the absence of faulting at the site. I therefore recommend that a site-specific special study be conducted at the proposed tank site to determine the surface-fault-rupture hazard. This study should be conducted prior to tank-foundation excavation. As recommended by Western GeoLogic (2003), inspecting the foundation excavation itself should be performed as an additional precaution. Determining the surface-fault-rupture hazard at the tank site is important because, although the site is not meant for human occupancy, a water tank poses a threat to human safety downslope should it fail and is a critical facility for water supply and fire fighting.

Landsliding

Lowe and Galloway (1993) mapped two bedrock landslide deposits along the Bear River Range front near North Logan. The older deposit consists of scattered erosional remnants of a major landslide north of Green Canyon. The extensive erosion suggested to Lowe and Galloway (1993) a pre-Quaternary (more than 1.6 million years) age for landsliding. One remnant underlies the proposed water tank site and part of the subdivision. The younger deposit, designated as “slide blocks,” consists of intact rock masses that have moved downslope a relatively short distance. These slide blocks also are found north of Green Canyon, and one underlies the base of the range front along the entire eastern edge of the proposed subdivision. The pre-Quaternary landslide beneath the water tank is part of this slide block.

Although Western GeoLogic (2002) cites Lowe and Galloway (1993) as suggesting a pre-Quaternary age for the slide blocks, the latter report does not specify an age for movement of the younger slide blocks other than to state that they formed later than the pre-Quaternary landslides (Lowe and Galloway, 1993, p. 12). I agree that the slide blocks are younger than the pre-Quaternary landslides but do not know how much younger. Lowe and Galloway (1993) map a slight bulge of the range front on the western, downslope edge of the slide block near the site, which may indicate relatively recent slope movement. Although the regional dip of rock along the Bear River Range front is eastward, into the slope, the dip of rock in the slide block is to the west, downslope. This downslope dip, combined with fractures and brecciation within the block, may contribute to slope instability. Because a slide block underlies the tank site and may pose a threat to downslope homes, I recommend that at least a site-specific geologic evaluation as outlined in Hylland (1996) be performed to assess the stability of the slide block and, if necessary, subsequent geotechnical-engineering slope-stability analysis.

SUMMARY OF CONCLUSIONS

I believe that Western GeoLogic (2002) adequately identifies the potential for most geologic hazards at a scale suitable for a reconnaissance geotechnical investigation. Western GeoLogic (2002) recommends additional study of the potential for surface fault rupture, and I concur. I believe that additional study of the potential for slope failure is needed to demonstrate the stability of the proposed subdivision and water tank site.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Western GeoLogic (2002, 2003). The Department of Natural Resources, UGS, provides no warranty that the data in Western GeoLogic (2002, 2003) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid North Logan City in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Batatian, D.D., Christenson, G.E., and Nelson, C.V., in preparation, Guidelines for evaluating surface-fault-rupture hazards for new buildings in Utah: Utah Geological Survey Miscellaneous Publication.

BIO/WEST, Inc., 1997, Canyon Ridge Heights subdivision phase III, North Logan City, Utah—a report on natural hazards and resource impacts: Logan, Utah, unpublished consultant's report, 15 p.

Growth Resources, Inc., 1997, Results of gravity surveys/geophysical investigation of faulting—Canyon Ridge, North Logan project area, Cache County, Utah: Salt Lake City, Utah, unpublished consultant's report, 5 p.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Lowe, Mike, and Galloway, C.L., 1993, Provisional geologic map of the Smithfield quadrangle, Cache County, Utah: Utah Geological Survey Map 143, scale 1:24,000.

McCalpin, James, 1989, Surficial geologic map of the East Cache fault zone, Cache County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2107, scale 1:50,000.

---1994, Neotectonic deformation along the East Cache fault zone, Cache County, Utah: Utah Geological Survey Special Study 83, 37 p.

Western GeoLogic, LLC, 2002, Engineering geology and geologic hazards analysis, proposed Bonneville Trail Estates subdivision phase I, North Logan, Utah: Salt Lake City, Utah, unpublished consultant's report, 12 p.

---2003, Surface fault-rupture hazard—proposed water tank, North Logan, Utah: Salt Lake City, Utah, unpublished consultant's report, 1 p.

<table>
<tr><td colspan="3">Project:
Review of "Geologic and geotechnical report--proposed North Village at Jordanelle Ridge development, Wasatch County, Utah"</td><td rowspan="3"></td></tr>
<tr><td>By:
Barry J. Solomon, P.G.</td><td>Date:
05-07-03</td><td>County:
Wasatch</td></tr>
<tr><td>USGS Quadrangles:
Heber City (1168)</td><td colspan="2">Section/Township/Range:
Sections 6, 7, 17, 18, 19, 20, 28, and 29, T. 3 S., R. 5 E., SLBM</td></tr>
<tr><td>Requested by:
Doug Smith,
Wasatch County Planning</td><td colspan="2">Date report received at UGS:
04-14-03</td><td>Job number:
03-07 (R-16)</td></tr>
</table>

INTRODUCTION

I reviewed the geologic and geotechnical report for the proposed North Village at Jordanelle Ridge development in Wasatch County by Applied Geotechnical Engineering Consultants, Inc. (AGEC, 2003). For the review, I studied relevant geologic literature and examined 1:20,000-scale (1962) and 1:40,000-scale (1987) aerial photographs, but I did not inspect the site. The purpose of my review was to assess whether AGEC (2003) adequately identified and addressed geologic hazards that could affect the proposed development.

CONCLUSIONS AND RECOMMENDATIONS

I believe the AGEC (2003) report adequately identifies geologic hazards at the proposed North Village at Jordanelle Ridge development. If development proceeds, I recommend:

- Because of the variability of the Keetley Volcanics, which may include softer layers than were modeled in the AGEC slope-stability analysis, the developer's geotechnical consultant should monitor cut slopes and significant excavations.
- If weaker, potentially unstable materials are encountered in cut slopes and significant excavations, or if development proceeds on steep slopes (greater than 25 percent) underlain by the Keetley Volcanics, additional slope-stability analyses should be conducted as outlined in Hylland (1996) to demonstrate slope stability and determine setbacks and buildable areas.
- To address the hazard from earthquake ground shaking, the developer's geotechnical consultant should verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements in accordance with procedures of the International Building Code (IBC) (International Code Council, 2000a) and International Residential Code (IRC) (International Code Council, 2000b).

I also recommend the following:

- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in this and any subsequent studies.
- The existence of the AGEC (2003) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.
- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that its recommendations were followed.
- Wasatch County should require that the report be stamped by the licensed professional geologist performing the geologic aspects of the study, as required under Utah state law effective January 1, 2003.

DISCUSSION

AGEC (2003) addresses the potential for several geologic hazards at the proposed North Village at Jordanelle Ridge development. These hazards include earthquake ground shaking, surface fault rupture, liquefaction, landslides, debris flows, rock fall, shallow ground water, and expansive soil. I believe that AGEC (2003) adequately identifies the potential for these geologic hazards.

AGEC (2003) did not observe any landslides on the property, but states that the Keetley Volcanics underlie the site. Hylland and Lowe (1997) note that landslides are relatively common in this geologic unit, with late Holocene landslides typically occurring on slopes greater than 25 percent. Hylland and Lowe (1996) map one onsite landslide in the Keetley Volcanics on a steep slope adjacent to the Provo River in the northwest part of the property. However, this landslide lies outside the approximate limits of development mapped by AGEC (2003, figures 1 and 2). Although not specifically stated in the AGEC (2003) report, development is apparently limited to slopes less than 25 percent, and AGEC (2003, p. 17) proposes a setback from steep slopes consistent with the IBC (International Code Council, 2000a, figure 1805.3.1). I believe the IBC setback and mapped development limits, which include a greater setback from some of the steeper slopes, are prudent. However, because of the variability of the Keetley Volcanics, which may include softer layers than were modeled in the AGEC slope-stability analysis, I recommend that cut slopes and significant excavations be monitored by the developer's geotechnical consultant. If weaker, potentially unstable materials are encountered in cut slopes and significant excavations, or if development proceeds on steep slopes (greater than 25 percent) underlain by the Keetley Volcanics, I recommend that additional slope-stability analyses be conducted as outlined in Hylland (1996) to demonstrate slope stability and determine setbacks and buildable areas.

The proposed North Village at Jordanelle Ridge development lies adjacent to the proposed St. Moritz at Heber development, for which I previously reviewed geologic-hazard reports (Intermountain GeoEnvironmental Services, Inc. [IGES], 2002a, 2002b, 2002c). The reports for St. Moritz, and my reviews (Solomon, 2002a, 2002b), indicated the potential for collapsible soils, alluvial-fan flooding, and debris flows on part of the St. Moritz property.

Because of the proximity of St. Moritz to North Village at Jordanelle Ridge, Doug Smith (Wasatch County Planning Dept.) expressed concern that the hazards at St. Moritz might extend onto the North Village property. However, review of the geologic-hazards maps (Hylland and Bishop, 1996) indicates that the potential for collapsible soils, alluvial-fan flooding, and debris flows at North Village at Jordanelle Ridge is low due to a lack of alluvial fans at the site. Therefore, these hazards are unlikely and special studies are not warranted.

SUMMARY OF CONCLUSIONS

I believe that AGEC (2003) adequately identifies the potential for geologic hazards. AGEC (2003) indicates that development will occur only on slopes less than 25 percent and proposes setbacks from steeper slopes. If weak material is encountered in excavations or if development is planned for steeper slopes, I recommend additional slope-stability analysis. The licensed professional geologist performing geologic aspects of the study should stamp the report, as required by Utah state law.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in AGEC (2003). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in AGEC (2003) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc., 2003, Geologic and geotechnical report—proposed North Village at Jordanelle Ridge development, Wasatch County, Utah: Sandy, Utah, unpublished consultant's report, 30 p.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Hylland, M.D., and Bishop, C.E., 1996, Flood hazards, earthquake hazards, and problem soils, western Wasatch County, Utah (plate 2A), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

Hylland, M.D., and Lowe, Mike, 1996, Landslide hazard, western Wasatch County, Utah (plate 1A), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

---1997, Regional landslide-hazard evaluation using landslide slopes, western Wasatch County, Utah: Environmental and Engineering Geoscience, v. 3, no. 1, p. 31-43.

Intermountain GeoEnvironmental Services, Inc., 2002a, Final geologic/geotechnical investigation—St. Moritz at Heber, Wasatch County, Utah: Orem, Utah, unpublished consultant's report, 30 p.

---2002b, Geologic/geotechnical investigation—St. Moritz at Heber 12-acre addition, Wasatch County, Utah: Orem, Utah, unpublished consultant's report, 25 p.

---2002c, Preliminary subsurface report—North Village 50-acre site, Wasatch County, Utah: Orem, Utah, unpublished consultant's report, 10 p.

International Code Council, 2000a, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

---2000b, International Residential Code for One- and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 578 p.

Solomon, B.J., 2002a, Review of "Preliminary subsurface report, North Village 50-acre site:" Utah Geological Survey Technical Report 02-07, 4 p.

---2002b, Review of "Final geologic/geotechnical investigation—St. Moritz at Heber, Wasatch County, Utah" and "Geologic/geotechnical investigation—St. Moritz at Heber 12-acre addition, Wasatch County, Utah," done in response to UGS Technical Report No. 02-07: unpublished letter report, Utah Geological Survey, 3 p.

Utah Geological Survey

Project: Review of "Surface fault rupture assessment and report for Aspen Summit Development 22 acre property, Provo, Utah"			
By: Richard E. Giraud, P.G.	Date: 05-14-03	County: Utah	
USGS Quadrangles: Provo (1047)	Section/Township/Range: SW ¼ section 8, T. 7 S., R. 3 E.		
Requested by: Dave Graves, Provo City Engineering	Date report received at UGS: 04-10-03		Job number: 03-08 (R-17)

INTRODUCTION

I reviewed the surface-fault-rupture-hazard report for the proposed residential Aspen Summit Development 22-acre property by Intermountain GeoEnvironmental Services, Inc. (IGES, 2003). For this review, I studied relevant geologic maps, hazard maps, and aerial photographs, and inspected the site on April 29, 2003. The purpose of my review is to assess whether IGES adequately identifies and addresses the surface-fault rupture and other geologic hazards at the site.

CONCLUSIONS AND RECOMMENDATIONS

IGES (2003) performed trench investigations at the site to assess the surface-fault-rupture hazard, and concludes that the hazard is low. Although this is likely correct, additional information is needed to properly document this conclusion. Regarding surface-fault rupture I recommend the following:

- A site vicinity map showing the mapped location of the Wasatch fault, faults on adjacent properties south of the site, and the surface-fault-rupture special-study zone relative to trench locations and proposed buildings (if known) should be provided so that the adequacy of trench coverage can be assessed.

- Scaled graphic trench logs showing interpreted stratigraphic and structural relationships to document the presence or absence of faulting and fault-related deformation should be provided, at least for those site areas within the special-study zone. The trench photographs in the report do not qualify as trench logs. If faulting or fault-related deformation is present, provide specific recommendations and restrictions pertaining to site development.

In addition to surface fault rupture, several other geologic hazards may exist at the site. I recommend that these be addressed prior to development as follows:

- Since IGES (2003) noted evidence of possible liquefaction-related deformation, I recommend the geotechnical consultant address the modern liquefaction potential at the site.

- I concur with the site class D earthquake site coefficients determined by IGES (2003), but to fully address the hazard from earthquake ground shaking the geotechnical consultant in conjunction with the developer should determine the seismic use groups, seismic design categories, and associated earthquake-resistant design requirements in accordance with procedures of the International Building Code (IBC) and/or International Residential Code (IRC) (International Code Council, 2000a, 2000b) as appropriate.

- Parts of the site are within the Utah County rock-fall, landslide, and debris-flow hazards overlay zones (Robison, 1990), and within stream-flooding (Federal Emergency Management Agency [FEMA], 1988) and alluvial-fan-flooding-hazard areas. These hazards should be evaluated and, if found to be present, specific recommendations and restrictions pertaining to site development should be provided.

I also recommend the following:

- Disclose the existence of the IGES (2003) report, this review, and subsequent reports and reviews to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Provo City written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

Surface-Fault-Rupture Hazard

IGES (2003) states that based on the Provo City geologic-hazard maps (International Engineering Company, Inc., 1984), the site is not within the surface-fault-rupture-hazard special-study zone. However, the current regulated special-study zone as defined in the "Sensitive Lands" section of the Provo Code (Provo City, 1999) is from the "Utah County Natural Hazards Overlay Zone" map series (Robison, 1990; cited as 1992 in Provo Code). Robison outlines a 500-foot-wide special-study zone west of the Wasatch fault. IGES (2003) states the eastern boundary of the site is 277 to 345 feet west of the fault. This places the eastern portion of the site (the easternmost 155 to 223 feet) within the special-study zone.

Because the report does not include a map showing the Wasatch fault, secondary faults mapped south of the site, special-study-zone boundaries, or building locations, I cannot evaluate the adequacy of trench coverage. IGES (2001) mapped secondary faults splaying westward from the main fault outside the special-study zone immediately south of the site at the Sunridge Hills 16-acre development.

Fault-trenching studies require trench logs to document the presence or absence of faulting and fault-related deformation. IGES (2003) states that the trenches were photographically logged and includes the photographs on a CD as plate 3 of their report. The portion of the site within the special-study zone is on the downthrown side of the fault, where tectonic deformation such as small cracks, tilted or displaced blocks, grabens, or antithetic faults may occur (Robison, 1993, figure 46). Scaled graphic trench logs are necessary to show interpreted stratigraphic and structural relationships to document the presence or absence of tectonic deformation; photographs can be used as a base for compiling such a detailed trench log (McCalpin, 1996), but photographs alone do not constitute trench logs. Therefore, I recommend the geotechnical consultant provide scaled graphic trench logs for at least that portion of the site in the special-study zone.

IGES (2003) also explored for faults trending westward from the main fault zone by trenching into areas outside of the special-study zone because a secondary fault zone was discovered south of the site (IGES, 2001). Since no faults were found, these trenches adequately demonstrate that similar fault splays from the main trace are not present at this site, although here again IGES (2003) includes only photographs of the trenches but no trench logs.

To ensure that adequate geologic information is submitted in future reports, I recommend developer's consultants follow the Utah Section of the Association of Engineering Geologists (1986, 1987) guidelines for preparing engineering-geologic reports and performing surface-fault-rupture investigations. Draft guidelines for evaluating surface-fault-rupture hazards are also available from the Utah Geological Survey. Also, the geologic information recorded on trench logs can be used to address other potential geologic hazards at the site.

IGES (2003) identified three locations where sedimentary layers are offset but not by faults. IGES states the layers were likely offset by soft sediment deformation or liquefaction. The site is mapped as an area of very low liquefaction potential by Anderson and others (1994), so IGES should determine whether this is correct in light of the evidence for possible liquefaction-related deformation.

Earthquake Ground Shaking

IGES states an opinion, based on their field investigations, that soils at the site are representative of a stiff soil profile best represented by IBC site class D. IGES did not supply borehole or geophysical evidence to support their opinion for characterizing the upper 100 feet, but based on the surficial geologic units, site class D appears reasonable. Also, site class D is the default parameter for both the IBC and IRC unless site class E or F soils are present, which appears unlikely unless a potential for liquefaction is found. IGES (2003) determined the site coefficients for site class D for both short and long period accelerations to be $F_z = 1.04$ and $F_v = 1.55$, respectively. Based on the mapped spectral response accelerations in the IBC Earthquake Spectral Response Acceleration Map CD (International Code Council, 2000a) and in the U.S. Geological Survey National Seismic Hazard Mapping Project website (http://geohazards.cr.usgs.gov/eq/), I agree with these site class D site coefficients. To fully address the earthquake ground-shaking hazard, the seismic use groups, seismic design categories, and associated earthquake-resistant design requirements must be determined in accordance with procedures of the IBC and/or IRC, as appropriate.

Rock-Fall, Landslide, Debris-Flow, and Flood Hazards

The scope of work for the IGES report included only surface-fault-rupture and earthquake ground-shaking hazards. However, Robison (1990) shows parts of the site are also within areas of potential rock-fall, landslide, and debris-flow hazard. Although it appears gravel mining subsequent to Robison's (1990) mapping may have modified slopes and reduced or eliminated the landslide and rock-fall hazards, I recommend the geotechnical consultant evaluate these hazards in light of present topography and proposed development to determine if they impact the site. The FEMA flood insurance rate map (FEMA, 1988) shows a special flood-hazard area along Slate Creek at the northern site boundary (IGES, 2003, plate 2). In addition to stream flooding, I believe a potential for alluvial-fan flooding may also exist since the site is on the Slate Canyon alluvial fan. I recommend the geotechnical consultant evaluate the stream and alluvial-fan-flooding hazards.

SUMMARY OF CONCLUSIONS

IGES (2003) used an older set of Provo City hazard maps to define the surface-fault-rupture special-study zone, so they did not recognize that part of the site is within the surface-fault-rupture special-study zone on the more recent Provo City hazard maps adopted in 1999. IGES (2003) does not include a map showing the complete site boundaries, the Wasatch fault, faults mapped south of the site in site-specific studies, and the special-study zone. Therefore, I cannot evaluate if the trench coverage is adequate. Detailed trench logs are required to document the presence or absence of faulting and fault-related deformation. I recommend the geotechnical consultant provide detailed, scaled, graphic trench logs, at least for trenches in that portion of the site in the special-study zone. In the future, I recommend logging all trenches to thoroughly document the faulting hazard or lack thereof. Because IGES (2003) noted evidence of possible liquefaction-related deformation, I recommend the geotechnical consultant address the liquefaction potential at the site. To fully address the earthquake ground-shaking hazard, the seismic use groups, seismic design categories, and associated earthquake-resistant design requirements must be determined in accordance with procedures in the IBC and/or IRC, as appropriate. Portions of the site are within mapped areas of potential rock-fall, landslide, debris-flow and flood hazards; these hazards should also be addressed to determine if they impact the site.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in IGES (2003). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in IGES (2003) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Provo City in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Anderson, L.R., Keaton, J.R., and Bischoff, J.E., 1994, Liquefaction potential map for Utah County: Utah Geological Survey Contract Report 94-8, 46 p., 16 plates, scale 1:48,000.

Association of Engineering Geologists, Utah Section, 1986, Guidelines for preparing engineering geologic reports in Utah: Utah Geological and Mineral Survey Miscellaneous Publication M, 2 p.

—1987, Guidelines for evaluating surface fault rupture hazards in Utah: Utah Geological and Mineral Survey Miscellaneous Publication N, 2 p.

Federal Emergency Management Agency, 1988, National Flood Insurance Program flood insurance rate map, City of Provo, Utah, Utah County: Federal Emergency Management Agency, Community-Panel Number 490159 0011C, scale 1:4,800.

Intermountain GeoEnvironmental Services, Inc., 2001, Surface fault rupture hazard study and report for Sunridge Hills 16 acre property, Provo, Utah: Orem, Utah, unpublished consultant’s report, 21 p.

—2003, Surface fault rupture hazard study and report for Aspen Summit Development, 22 acre property, Provo, Utah: Orem, Utah, unpublished consultant’s report, 17 p.

International Code Council, 2000a, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

—2000b, International Residential Code for One- and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 578 p.

International Engineering Company, Inc., 1984, Provo geological hazard study: San Francisco, California, unpublished consultant’s geological hazard maps for Provo City, 24 p. pamphlet, scale 1:1,200.

McCalpin, J.P., 1996, Paleoseismology: San Diego, California, Academic Press, 588 p.

Provo City, 1999, Provo City Code – Sensitive Lands: Provo, Utah, p. 386 – 391.

Robison, R.M., 1990, Utah County natural hazards overlay (NHO) zone: Unpublished Utah County Planning Department maps, scale 1:50,000 and 1:24,000.

—1993, Surface-fault rupture — a guide for land-use planning, Utah and Juab Counties, Utah, *in* Gori, P.L., editor, Applications of research from the U.S. Geological Survey program, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1519, p. 121-128.

Utah Geological Survey

Project: Review of "Rockfall assessment, Phase I, Boulder Top subdivision, Morgan, Utah"			
By: Greg N. McDonald, P.G.	Date: June 16, 2003	County: Morgan	
USGS Quadrangles: Morgan, Devils Slide	Section/Township/Range: Sec. 28, T.4N., R.3E.		
Requested by: Kent Wilkerson, Morgan County Planning	Date report received at UGS: June 3, 2003		Job number: 03-09 (R-18)

INTRODUCTION

I reviewed a rock-fall hazard assessment for a proposed 4- to 6-lot phase (Phase I) of the Boulder Top subdivision east of Morgan City by Earthtec Testing and Engineering, P.C. (Earthtec, 2003). For the review, I conducted a literature review, examined 1972 1:12,000-scale and 1985 1:24,000-scale aerial photos, and visited the site on June 6, 2003. The purpose of the review is to determine whether the rock-fall hazard at the site is adequately addressed in the report, and to note whether other possible geologic hazards should be evaluated at the site.

CONCLUSIONS AND RECOMMENDATIONS

Earthtec's (2003) assessment of the rock-fall hazard evaluates one precarious boulder upslope of the proposed Phase I lots. However, no site map is provided showing the location of this boulder with respect to the subdivision. Also, other outcrops above Phase I which may be potential rock-fall sources, and conditions in the rock-fall runout zone below, are not addressed. To adequately address the rock-fall hazard, I recommend Earthtec supply the following additional information:

- Provide a site map at an appropriate scale (preferably 1 inch = 100 feet) showing lots and site boundaries in relation to potential rock-fall sources.
- Provide input parameters and slope profiles used for the computer modeling.
- Evaluate the rock-fall hazard from other outcrops above the site, or provide evidence demonstrating that these outcrops are not rock-fall sources.
- If necessary, re-evaluate rock-fall hazard-reduction recommendations following these additional studies.

In addition, I recommend a comprehensive geologic-hazards evaluation be performed for the site, in particular addressing the debris-flow and alluvial-fan-flooding hazard.

DISCUSSION

Earthtec's rock-fall hazard assessment included evaluation of a large boulder described as precariously positioned "laterally upslope" above the Phase I lots. Earthtec (2003) concludes the boulder poses a low risk to the Phase I lots based on field observations and results of a 2-dimensional computer model analysis. Because an adequate map showing the lots in relation to the boulder is not provided, I cannot assess the adequacy of the analysis. Also, Earthtec (2003) did not include input data and profiles used in the analysis. Such documentation should be included to support modeling results.

Earthtec (2003) did not address other potential rock-fall sources directly above Phase I, including outcrops visible on aerial photos. A complete rock-fall assessment should evaluate the nature of all potential rock-fall sources above the site including evaluation of outcrops for the presence and orientation of discontinuities. If outcrops are determined not to be sources, corroborating evidence should be provided. Also, the slope and runout zone below outcrops should be evaluated for the nature, extent, and size distribution of possible rock-fall fragments to help determine the relative frequency and size of rock falls and typical runout distances. Such analysis is necessary to support the computer model which indicated a maximum 20-foot runout distance.

Earthtec rates the rock-fall hazard as low, but states that an earthen berm could be constructed at the base of the slope to serve as a hazard-reduction measure if a "higher level of safety is desired." Based on data presented in the report, I cannot assess whether an earthen berm or other engineered hazard-reduction measures are needed. At a minimum, the existence of the rock-fall-hazard report, this review, and subsequent reports and reviews should be disclosed to potential buyers to ensure they are informed of the hazard and are willing to accept the risks.

Earthtec's scope of work did not include a comprehensive geologic-hazard evaluation, which I recommend be performed. In particular, I recommend a debris-flow and alluvial-fan-flooding hazard analysis of Yence Hollow and adjacent drainages above the site. In 1958, debris flows emanated from Yence Hollow and several nearby drainages, including the small drainage above Phase I east of Yence Hollow (Butler and Marcell, 1972; Kaliser, 1972). In light of historical debris-flow activity at the site, responsible planning requires assessing the hazard prior to development.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Earthtec (2003). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in Earthtec (2003) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Morgan County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Butler, Elmer, and Marcell, R.E., 1972, Developing a state water plan, cloudburst floods in Utah, 1939-69: Utah Division of Water Resources and U.S. Geological Survey Cooperative-Investigations Report No. 11, 103 p.

Earthtec Testing and Engineering, P.C., 2003, Rockfall assessment, Phase I, Boulder Top subdivision, Morgan, Utah: Ogden, Utah, unpublished consultant's report, 4 p.

Kaliser, B.N., 1972, Geologic hazards in Morgan County with applications to planning: Utah Geological and Mineralogical Survey Bulletin 93, 56 p., 2 pl., scale 1:126,720.

<table>
<tr><td colspan="3">Project:
Review of “Deer Meadows soils report—Jordanelle Basin, Wasatch County”</td><td rowspan="3"></td></tr>
<tr><td>By:
Barry J. Solomon, P.G.</td><td>Date:
06-19-03</td><td>County:
Wasatch</td></tr>
<tr><td>USGS Quadrangles:
Park City East (1209)</td><td colspan="2">Section/Township/Range:
Section 1, T. 2 S., R. 4 E., and sections 6 and 7, T. 2 S., R. 5 E., SLBM</td></tr>
<tr><td>Requested by:
Doug Smith,
Wasatch County Planning</td><td colspan="2">Date report received at UGS:
06-04-03</td><td>Job number:
03-10 (R-19)</td></tr>
</table>

INTRODUCTION

I reviewed the soils report for the proposed Deer Meadows development in Wasatch County by Wilding Engineering (2003). For the review, I studied relevant geologic literature and examined 1:40,000-scale (1987) aerial photographs, but I did not inspect the site. The purpose of my review was to assess whether Wilding Engineering (2003) adequately identifies and addresses geologic hazards that could affect the proposed development.

CONCLUSIONS AND RECOMMENDATIONS

I believe the Wilding Engineering (2003) report adequately addresses geologic hazards at the proposed Deer Meadows development except for its assessment of landsliding and earthquake ground shaking. I recommend the following:

- Provide information to document site conditions with emphasis on the stability of steep slopes (greater than 25 percent), based on observation and measurement of geologic conditions such as slope inclination, rock type and condition, the nature of planar features within soil or rock, ground-water conditions, and thickness and description of soil and colluvium overlying rock.

- Alternatively, provide an adequate map of the site that shows site geology, the extent of site slopes greater than 25 percent, and proposed setbacks or other hazard-reduction methods on a base map showing detailed topography, lots, and site boundaries at a scale of 1 inch = 200 feet or larger, preferably 1 inch = 100 feet.

- If development proceeds, the developer’s geotechnical consultant should address the hazard from earthquake ground shaking by verifying site classes and, in conjunction with the developer, determining seismic use groups, seismic design categories, and associated earthquake-resistant design requirements in accordance with procedures of the International Building Code (IBC) (International Code Council, 2000a) and/or International Residential Code (IRC) (International Code Council, 2000b).

I further recommend that:

- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in this study and any subsequent studies.

- The existence of the Wilding Engineering (2003) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that its recommendations were followed.

- Wasatch County should require that the report be stamped by the licensed professional geologist performing or supervising the geologic aspects of the study, as required under Utah state law effective January 1, 2003.

DISCUSSION

Wilding Engineering (2003) lists surface fault rupture, liquefaction, expansive soils ("moisture-sensitive soils"), and shallow ground water as potential geologic hazards on the property. The report adequately addresses these geologic hazards and I concur with the report's recommendations. Wilding Engineering (2003) also discusses the potential for landslides and earthquake ground shaking. I believe additional information related to these hazards is needed, and my recommendations are discussed below.

Note that the Utah Professional Geologist Licensing Act, a Utah state law effective January 1, 2003, requires a report such as that by Wilding Engineering (2003) to bear the seal of the licensed professional geologist performing or supervising geologic aspects of the study. Although the licensing act provides for exemptions from licensure, these exemptions do not apply if the report is submitted to a local government.

Landslides

Wilding Engineering (2003) does not consider landsliding to be a hazard to the proposed project. This conclusion is apparently based on inspection of local slopes for landslides. However, Hylland and Lowe (1996) map a moderate landslide hazard on steeper on-site slopes. A moderate hazard indicates that, although no landslides were found, slopes exceed a "critical inclination" representing the angle above which late Holocene landslides have typically occurred in western Wasatch County. The critical inclination for the Keetley Volcanics, the rock underlying most of the site (Bromfield and Crittenden, 1971), is 25 percent (Hylland and Lowe, 1997). I measured slopes ranging from 25 to 30 percent on the Deer Meadows site from the 7-1/2 minute topographic quadrangle map. In areas of moderate landslide hazard, Hylland and Lowe (1996) recommend at least a reconnaissance-level geologic-hazard evaluation and indicate that a quantitative slope-stability analysis may be necessary, as outlined in Hylland (1996).

I believe that the reconnaissance-level evaluation conducted by Wilding Engineering (2003) adequately documents that no evidence of landslides exists at the site, but does not adequately address the potential for future landsliding on steep slopes that have not experienced past slope failure. AGRA Earth and Environmental, Inc. provided supporting evidence for the stability of the Keetley Volcanics on nearby similar slopes for the Deer Mountain subdivision southeast of Deer Meadows (AGRA, 2000; Solomon, 2000). The AGRA report may be used as evidence of slope stability at Deer Meadows if geologic conditions there (including rock type, moisture, and orientation with respect to slopes of potential failure surfaces such as joints or bedding planes) are shown to be similar to those used in the slope-stability analyses for Deer Mountain. Alternatively, if construction on steep slopes is avoided, no additional geologic or geotechnical evaluation of the landslide hazard will be needed. In this case, the developer's geotechnical consultant should provide an adequate map of the site that shows site geology, the extent of slopes greater than 25 percent, and proposed setbacks or other hazard-reduction methods on a base map showing detailed topography, lots, and site boundaries. This is the approach used by Wilding Engineering for the adjacent Deer Canyon Preserve subdivision to the east of Deer Meadows (Wilding Engineering, 2002; Solomon, 2002).

Earthquake Ground Shaking

Wilding Engineering (2003) identifies earthquake ground shaking as a potential geologic hazard on the site and states that the site is located in Uniform Building Code (UBC) Seismic Zone 3. However, the UBC (International Conference of Building Officials, 1997) no longer applies to evaluation of earthquake ground shaking in Utah. The UBC was replaced in 2002 by statewide adoption of the 2000 editions of the IBC and IRC. The IBC and IRC have since been updated with 2003 editions (International Code Council, 2002a, 2002b), although these have not yet been adopted by local governments in Utah. The IBC specifies earthquake-resistant design requirements for most structures and the IRC specifies these requirements for one- and two-family dwellings and townhouses. Whereas design requirements specified by the UBC depended upon the Seismic Zone, design requirements specified by the IBC and IRC depend on the seismic design category of a structure, which is based on spectral response accelerations and, for the IBC, seismic use group (a function of the nature of occupancy). To determine appropriate spectral response accelerations, the site class of the upper 100 feet (30 meters) of soil and rock must first be verified. The final report for Deer Meadows should verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements.

SUMMARY OF CONCLUSIONS

I believe that Wilding Engineering (2003) adequately identifies the potential for surface fault rupture, liquefaction, expansive soils, and shallow ground water. The report adequately documents that no evidence of landslides exists at the site, but does not adequately address the potential for future landsliding on steep slopes that have not experienced past slope failure. This hazard may be addressed either by documenting the stability of steep slopes, or avoiding them. The final report for Deer Meadows should verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements in accordance with the IBC and IRC. The licensed professional geologist performing or supervising geologic aspects of studies for Deer Meadows should stamp the resulting geologic report, as required by Utah state law.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Wilding Engineering (2003). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in Wilding Engineering (2003) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

AGRA Earth and Environmental, Inc., 2000, Letter report, slope stability analysis, proposed Deer Mountain Resort housing community, phase III, Township 2S, Range 5E, sections 5, 7, and 8, SLB&M, northeast of Jordanelle Reservoir, Wasatch County, Utah: Salt Lake City, Utah, unpublished consultant's report, 10 p.

Bromfield, C.S., and Crittenden, M.D., Jr., 1971, Geologic map of the Park City East quadrangle, Summit and Wasatch Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-852, scale 1:24,000.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Hylland, M.D., and Lowe, Mike, 1996, Landslide hazard, western Wasatch County, Utah (plate 1A), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

---1997, Regional landslide-hazard evaluation using landslide slopes, western Wasatch County, Utah: Environmental and Engineering Geoscience, v. 3, no. 1, p. 31-43.

International Code Council, 2000a, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

---2000b, International Residential Code for One- and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 578 p.

---2002a, International Building Code: Falls Church, Virginia, International Code Council, 656 p.

---2002b, International Residential Code for One- and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 604 p.

International Conference of Building Officials, 1997, Uniform Building Code: Whittier, California, International Conference of Building Officials, Volume 2, 492 p.

Solomon, B.J., 2000, Review of "Letter report, slope stability analysis, proposed Deer Mountain Resort housing community, phase III, Township 2S, Range 5E, sections 5, 7, and 8, SLB&M, northeast of Jordanelle Reservoir, Wasatch County, Utah" *in* McDonald, G.N., compiler, Technical reports for 2000-01 Geologic Hazards Program: Utah Geological Survey Report of Investigation 250, p. 41-43.

---2002, Review of "Deer Canyon Preserve, Jordanelle Basin, Wasatch County—soils report": unpublished Utah Geological Survey Technical Report 02-04, 4 p.

Wilding Engineering, 2002, Deer Canyon Preserve—Jordanelle Basin, Wasatch County, landslide and slope analysis report: Draper, Utah, unpublished consultant's report, 5 p.

---2003, Deer Meadows soils report—Jordanelle Basin, Wasatch County: Draper, Utah, unpublished consultant's report, 7 p.

Project: Review of "Geotechnical consultation, Radford Hills culinary water tank, Weber County, Utah"			
By: Gary E. Christenson Greg N. McDonald	Date: July 11, 2003	County: Weber	
USGS Quadrangles: Huntsville (1369)	Section/Township/Range: Sec. 3, T.6N., R.1.E.		
Requested by: Kevin Hamilton, Weber County Planning	Date report received at UGS: June 26, 2003		Job number: 03-11 (R-20)

INTRODUCTION

We reviewed geologic-hazards parts of the geotechnical report for a proposed culinary water tank in the Radford Hills development in Ogden Valley, Weber County, by Earthtec Testing and Engineering, P.C. (Earthtec, 2003). For the review, we conducted a literature review and examined 1:20,000-scale 1953 aerial photos. We visited the site in 2002 while conducting field work for the Utah Geological Survey (UGS) Ogden Valley geologic-hazards mapping project. The purpose of this review is to determine whether geologic hazards at the site are adequately addressed in the report.

CONCLUSIONS

Earthtec (2003) indicates that their report is a limited geotechnical evaluation, and geotechnical (soil-foundation) aspects of the report should be reviewed by a qualified geotechnical engineer. The report addresses geologic hazards, specifically seismic considerations, only in a general way. Additional investigations of possible fault and landslide hazards involving a licensed Professional Geologist experienced in such investigations are necessary, and we recommend that Earthtec:

- provide supporting documentation for their conclusion that the fault in the area does not pass through the site and is inactive, and

- evaluate possible landslide hazards at the site, taking into consideration the landsliding in similar geologic settings elsewhere in Ogden Valley.

Trenching of the footprint of the water tank and an expected fault setback distance on either side would provide the most conclusive subsurface data to resolve both of these issues. If subsurface investigations are not performed, we recommend the water-tank excavation be inspected for faults and landslide-related deformation and that the results of the inspection be submitted to Weber County for approval.

DISCUSSION

In the *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson and others, in press), the UGS recommends that critical facilities such as a culinary water tank (water tanks, when used for fire suppression, are included in 2000 International Building Code [IBC; International Code Council, 2000] category II or III critical structures) be set back from both Late Quaternary (movement in the past 130,000 years) and Holocene (movement in the past 10,000 years) faults. We recommend a risk assessment to determine whether to set back from Quaternary faults (movement in the past 1.6 million years).

Little is known regarding the activity and exact location of the Ogden Valley southwestern margin fault(s) mapped near the site along the west side of Ogden Valley (Sullivan and others, 1988; Black and others, 2003). Earthtec (2003) indicates the fault is several hundred feet west of the site based on "published maps," but the most detailed published geologic map for the area (Sorensen and Crittenden, 1979) shows the fault just east of the water-tank site. Sullivan and others (1988), Coogan and King (2001), and the draft geologic map of Ogden Valley presently being compiled by the UGS (G.N. McDonald, unpublished 1:24,000-scale UGS map) show the fault along the range front separating the Precambrian sedimentary rocks of the Wasatch Range from the more erodible Tertiary Norwood Tuff forming the foothills just east of the site. Our brief reconnaissance of exposures in cuts for the irrigation reservoir east of the water-tank site identified probable Precambrian rocks, indicating that the site is likely on the footwall of the fault and confirming Sorensen and Crittenden's (1979) mapping of the fault east rather than west of the site as indicated by Earthtec (2003).

Because this fault is potentially within 1000 feet of the site, detailed surface investigations to look for evidence of the fault at the site should be performed as recommended in Christenson and others (in press). If any evidence for faulting is found at or near the site, trenching of the footprint of the water tank and an expected setback distance on either side will be necessary to determine whether the fault passes through the site and, if so, the age of most recent faulting. Guidelines for conducting such studies are given in Christenson and others (in press). The age of most recent faulting must be determined because paleoseismic investigations have not been performed on the Ogden Valley southwestern margin fault(s), so the middle and late Quaternary age assigned in Black and others (2003) is only a best (non-conservative) age estimate based on limited existing data and is not sufficient for assigning an activity class to assess surface-faulting hazards. Therefore, if a fault is found at the site, a geologist must determine the activity class of the fault to assess the need for setbacks.

Earthtec (2003) determined the IBC site class is D, and we concur. Earthtec does not indicate the IBS seismic design category.

The geologic origin of site soils and nature of internal structure (massive, bedded, deformed) is not given. Presumably, the deposits are colluvium or alluvium, but they may be landslide deposits or may contain indications of deformation or downslope movement. Earthtec (2003) does not address natural slope stability in their investigation, but we believe an evaluation of possible landslide hazards is warranted because deposits are predominantly clay on a relatively steep slope (40 percent, as indicated by Earthtec). Also, colluvium derived from or overlying the Maple Canyon Formation and Formation of Perry Canyon, and the Norwood Tuff, all of which are mapped in the site area, are highly susceptible to landsliding. Many landslides are mapped in these units elsewhere in Ogden Valley, even on relatively gentle slopes (Crittenden, 1972; Sorensen and Crittenden, 1979; McDonald, unpublished UGS map). Earthtec should consider geologic conditions in slopes at the site in comparison to those at these other landslides in Ogden Valley, and determine whether a potential exists for slope failure, particularly if extensive slope modifications are planned and if soils become wet. We recommend additional subsurface investigations, which could be performed in the fault trench, to document the nature of internal structures and possible need for additional slope-stability evaluation.

Beginning in January 2003, geologic investigations such as those described above must be performed and final reports stamped by a licensed Professional Geologist along with the licensed Professional Engineer, as appropriate. The geologist should be an engineering geologist experienced in fault and landslide investigations.

SUMMARY

The Earthtec (2003) report is a limited geotechnical evaluation only and does not adequately address possible fault and landslide hazards at the site. A qualified geotechnical engineer should review geotechnical aspects of the report, and a licensed Professional Geologist should conduct additional surface investigations at the site for evidence of the Ogden Valley southwestern margin fault(s), and, if necessary, excavate a trench to determine whether the fault traverses the site. If a fault is found, the activity class of the fault must be determined to assess the risk posed and need for setbacks. Also, the geologist and engineer should assess possible landslide hazards at the site. If subsurface investigations are not performed, the water-tank excavation should be inspected for faults and landslide-related deformation and the results of the inspection submitted to Weber County for approval.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Earthtec (2003). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in Earthtec (2003) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Weber County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map

193DM.

Christenson, G.E., Batatian, L.D., and Nelson, C.V., in press, Guidelines for evaluating surface fault-rupture hazards in Utah: Utah Geological Survey Special Study.

Coogan, J.C., and King, J.K., 2001, Progress report, geologic map of the Ogden 30'X60' quadrangle, year 3 of 3: Utah Geological Survey Open-File Report 380, scale 1:100,000.

Crittenden, M.D. Jr., 1972, Geologic map of the Browns Hole quadrangle, Utah: U.S. Geological Survey Quadrangle Map GQ-968, scale 1:24,000.

Earthtec Testing and Engineering, P.C., 2003, Geotechnical consultation, Radford Hills culinary water tank, Eden, Utah: Ogden, unpublished consultant's letter report, 7 p.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

International Code Council, 2000, International Building Code-2000: Falls Church, Virginia, International Code Council, 756 p.

Sorensen, M.L., and Crittenden, M.D. Jr., 1979, Geologic map of the Huntsville 7.5-minute quadrangle, Weber and Cache Counties, Utah: U.S. Geological Survey Geological Quadrangle Map GQ-1503, scale 1:24,000.

Sullivan, J.T., Nelson, A.R., Laforge, R.C., Wood, C.K., and Hansen, R.A., 1988, Central Utah regional seismotectonic study for USBR dams in the Wasatch Mountains: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-5, 269 p., scale 1:250,000.

Project: Review of “Geotechnical investigation and report—North Village 17-acre site, Wasatch County, Utah”			
By: Barry J. Solomon, P.G.	Date: 07-30-03	County: Wasatch	
USGS Quadrangles: Heber City (1168)	Section/Township/Range: NE¼ Section 19, T. 3 S., R. 5 E., SLBM		
Requested by: Doug Smith, Wasatch County Planning	Date report received at UGS: 07-23-03		Job number: 03-12 (R-21)

INTRODUCTION

I reviewed geologic parts of the geotechnical report for the North Village 17-acre site in Wasatch County by Intermountain GeoEnvironmental Services, Inc. (IGES, 2002). For the review, I studied relevant geologic literature and examined 1:20,000-scale (1962) aerial photographs, but I did not inspect the site. The purpose of my review was to assess whether IGES (2002) adequately identifies and addresses geologic hazards that could affect the proposed development.

CONCLUSIONS AND RECOMMENDATIONS

I believe the IGES (2002) report adequately addresses geologic hazards at the proposed North Village site except for its assessment of earthquake ground shaking and alluvial-fan flooding or debris flows. I recommend the following:

- If development proceeds, the developer’s geotechnical consultant should address the hazard from earthquake ground shaking by verifying site classes and, in conjunction with the developer, determining seismic use groups, seismic design categories, and associated earthquake-resistant design requirements in accordance with procedures of the International Building Code (IBC) (International Code Council, 2000a) and/or International Residential Code (IRC) (International Code Council, 2000b).

- Flood and debris-flow hazards associated with the alluvial fan underlying the south end of the property should be evaluated.

I further recommend that:

- Appropriate action should be taken to reduce hazards identified by IGES (2002) from canals flowing adjacent to the site; this may require a cooperative effort among the developer, Wasatch County, and canal owners to ensure that canals are adequate to prevent leakage or flooding.

- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in this study and any subsequent studies.

- The existence of the IGES (2002) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that its recommendations were followed.

- Wasatch County should require that future reports with geologic content be stamped by the licensed professional geologist performing or supervising the geologic aspects of the study, as required under Utah state law effective January 1, 2003.

DISCUSSION

IGES (2002) lists surface fault rupture, liquefaction, stream flooding, canal flooding, problem soils, and shallow ground water as potential geologic hazards on the property. The report adequately addresses these geologic hazards and I concur with the report's recommendations. To further address the hazard from canal flooding, the developer and Wasatch County may need to work with the owners of the canals on the northeastern edge of the property to assess and reduce hazards and ensure the canals are adequate to prevent leakage or flooding. IGES (2002) also discusses the potential for earthquake ground shaking, but does not discuss the potential for alluvial-fan flooding or debris flows. I believe additional information related to these hazards is needed, and my recommendations are discussed below.

Note that the Utah Professional Geologist Licensing Act, a Utah state law effective January 1, 2003, requires a report such as that by IGES (2002) to bear the seal of the licensed professional geologist performing or supervising geologic aspects of the study. Although the licensing act provides for exemptions from licensure, these exemptions do not apply if the report is submitted to a local government. Because the IGES report is dated June 2002, the report does not need to bear the seal of a licensed professional geologist. However, all future reports with geologic content related to this property should be stamped by the licensed professional geologist performing or supervising the geologic aspects of the study.

Earthquake Ground Shaking

IGES (2002) identifies earthquake ground shaking as a potential geologic hazard on the site. The IBC specifies design requirements for most structures to resist the effects of earthquake ground shaking, and the IRC specifies these requirements for one- and two-family dwellings and townhouses. Earthquake-resistant design requirements specified by the IBC and IRC depend on the seismic design category of a structure, which is based on spectral response accelerations and, for the IBC, seismic use group (a function of the nature of occupancy). To determine appropriate spectral response accelerations, the site class of the upper 100 feet (30 meters) of soil and rock must first be determined. IGES (2002) states that the site is underlain by soils representative of a "very dense soil and soft rock" profile (IBC site class C). I recommend that the final report for the North Village 17-acre site verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements.

Alluvial-Fan Flooding and Debris Flows

Hylland and Bishop (1996) map an alluvial fan underlying the southern end of the 17-acre site. The fan extends from the drainage that exits the range front on the southeast side of the site. This drainage is incised into older fan deposits to the north (the "steep slope" noted on p. 8 of the IGES report), but after flowing across an elevated terrace of the Provo River (the "bench area") the drainage drops through the embankment along the Provo River floodplain (where the "terrain steepens sharply" along the edge of the "generally flat pasture"). A late Holocene alluvial fan formed at the mouth of the drainage where the stream gradient decreases and the channel loses its confinement. The uppermost soil encountered in boreholes (B-8 and B-9) and a test pit (ITP-2) on the fan are fine grained, suggesting that the most recent sedimentation events on the fan were primarily flooding rather than debris flows, but I recommend that the potential for both alluvial-fan flooding and debris flows be evaluated.

The canals along the northeast edge of the 17-acre site may affect alluvial-fan flooding hazards. The canals cross the drainage at the fan head, which may either impede flow through the drainage or contribute additional water to alluvial-fan floods and debris flows when they reach the canal, similar to flooding that occurred as debris flows crossed a canal in Spring Lake near Santaquin in 2002 (McDonald and Giraud, 2002). I recommend that the interaction between the canals and alluvial-fan hazards be evaluated.

SUMMARY OF CONCLUSIONS

I believe that IGES (2002) adequately identifies the potential for surface fault rupture, liquefaction, stream flooding, canal flooding, problem soils, and shallow ground water. To further address the hazard from canal flooding, the developer and Wasatch County may need to work with the owners of the canals on the northeastern edge of the property to assess and reduce hazards and ensure the canals are adequate to prevent leakage or flooding. In the final report for the 17-acre site, the consultant should verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements in accordance with the IBC and IRC. The potential for both alluvial-fan flooding and debris flows should be evaluated, as should the interaction between the canals and alluvial-fan flooding hazards.

The licensed professional geologist performing or supervising geologic aspects of future studies for the 17-acre site should stamp the resulting geologic report, as required by Utah state law.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in IGES (2002). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in IGES (2002) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Hylland, M.D., and Bishop, C.E., 1996, Flood hazards, earthquake hazards, and problem soils, western Wasatch County, Utah (plate 2A), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

Intermountain GeoEnvironmental Services, Inc. 2002, Geotechnical investigation and report—North Village 17-acre site, Wasatch County, Utah: Orem, Utah, unpublished consultant's report, 25 p.

International Code Council, 2000a, International Building Code: Falls Church, Virginia, International Code Council, 756 p.

---2000b, International Residential Code for One- and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 578 p.

McDonald, G.N., and Giraud, R.E., 2002, September 12, 2002 fire-related debris flows east of Santaquin and Spring Lake, Utah County, Utah: Utah Geological Survey Technical Report 02-09, 15 p.

Utah Geological Survey

Project: Review of "North Fork Special Services District, slope stability analysis"			
By: F.X. Ashland and Gary E. Christenson, P.G.	Date: November 17, 2003	County: Utah	
USGS Quadrangles: Aspen Grove (1128)	Section/Township/Range: Sec. 14, T. 5 S., R. 3 E.		
Requested by: Timothy Beavers, Utah Division of Water Quality	Dates reports received at UGS: October 16 and 22, 2003		Job number: 03-13 (R-22)

INTRODUCTION

We reviewed a slope-stability-analysis report (Forsgren Associates Inc., 2003b) for the proposed expansion of a treated wastewater disposal drainfield system at the Sundance ski resort in the North Fork Special Service District, Utah County, Utah. The report is in response to a concern raised by the Utah Division of Water Quality in a letter dated May 12, 2003, regarding the potential impact to hillslope stability from additional water associated with the proposed drainfield expansion. The report is supplemental to a slope-stability analysis performed in an earlier study (Forsgren Associates Inc., 2003a) and addresses the potential influence on hillslope stability of a combination of possible conditions, including a rise in ground-water levels beneath the expanded drainfield and the presence of landslide-prone Manning Canyon Shale beneath the site. Specifically, the report assesses the sensitivity of hillslope stability to the depth of the shale, assuming elevated ground-water levels beneath the expanded drainfield and using estimated soil and rock properties. For our review, we studied relevant geologic literature (Baker, 1964; Kaliser, 1992), examined aerial photographs, checked the slope-stability analysis using PC-STABL5M and STED computer software, and inspected the drainfield area on September 25, 2003. The purpose of the review is to assess whether the report adequately addresses the potential for landsliding at the site related to the proposed drainfield expansion.

CONCLUSIONS AND RECOMMENDATIONS

Although the Forsgren Associates Inc. (2003b) report adequately assesses the sensitivity of hillslope stability to the depth of a possible subsurface shale unit, the report's conclusion that no stability problems exist with the proposed expanded drainfield system is limited by uncertainties; these uncertainties must be understood when using the conclusion to make decisions. The slope-stability analysis in the Forsgren Associates Inc. (2003b) report is generally conservative because it assumes two worst-case conditions, specifically:

- elevated ground-water levels beneath the expanded drainfield resulting in saturation of the soil and rock underlying the drainfield trenches (a mounded ground-water condition), and

- the presence of Manning Canyon Shale or other landslide-prone unit beneath the surficial glacial deposits.

The analysis used reasonable estimates for soil and rock properties, including shear strength, for the glacial deposits and underlying shale. However, in our check of the slope-stability analysis, using different software, we considered possible variations in subsurface conditions, landslide dimensions, and soil properties, and found that lower factors of safety than indicated in the Forsgren Associates Inc. (2003b) report are possible for the hypothetical worst-case condition described above. In certain cases, the selection by Forsgren Associates Inc. of specific search-limits parameters in the slope-stability software (used in the analysis for section B) and a section line that was not perpendicular to contour lines (in the case of section A) resulted in higher factors of safety than indicated in our check of the slope-stability analysis. The Forsgren Associates Inc. (2003b) report did not assess the sensitivity of hillslope stability to variations in soil shear strength from the estimated values.

The slope-stability analysis in the Forsgren Associates Inc. (2003b) report is only preliminary because hypothetical conditions rather than actual conditions are evaluated. Thus, the calculated factors of safety are estimates and the results indicate only the relative stability rather than the actual stability of the hillslope.

We concur with the results in the Forsgren Associates Inc. (2003b) report that suggest the hillslope will likely remain stable (estimated static factors of safety greater than 1.5) even if ground-water levels rise beneath the drainfield to near the ground surface and Manning Canyon Shale underlies glacial deposits at the site, as long as the shale is deeper than about 40 feet. However, in our opinion, hillslope stability has not been adequately demonstrated if the shale is present at depths shallower than 40 feet, specifically for the northeast-facing slope modeled in section B of the Forsgren Associates Inc. (2003b) report. Based on our check of the slope-stability analysis for this slope, we believe the slope may be vulnerable to failure, particularly during an earthquake.

We understand that decisions regarding the feasibility of this project are subject to the conclusion that the hillslope will remain stable. We believe that the potential for future landsliding is likely low, but cannot be precluded if the worst-case conditions exist. To reduce the likelihood of future landsliding to an acceptable level, additional investigations and analysis may be required to assess the reality of the worst-case conditions assumed in Forsgren Associates' Inc. slope-stability analysis. Based on discussions with Utah Division of Water Quality engineers, assessment of the ultimate ground-water level beneath the expanded drainfield may not be practical given the current state of knowledge concerning the impact of this type of drainfield system on ground-water levels and available site-specific hydrogeologic information. Thus, to reduce the uncertainties regarding hillslope stability, determining the presence or absence of shallow (less than 40 feet deep) shale or similar landslide-prone rock at the site may be the best alternative. We recommend that any additional subsurface investigations be along the section B line in the Forsgren Associates Inc. (2003b) report. These subsurface investigations should:

- determine the depth of rock in the hillslope and, if rock exists at shallow depths (less than 40 feet), identify the presence/absence of Manning Canyon Shale or other slide-prone rock units,

- as necessary, determine the shear-strength properties of the glacial deposits (particularly if any weak zones are encountered) and underlying shale, and

- determine natural ground-water levels in the hillslope to help estimate the likely shallowest ground-water table with the expanded drainfield in place.

If shallow shale or landslide-prone rock is encountered, or if potential weak zones in the glacial deposits are identified, slope-stability analysis should be performed using the new data from the subsurface investigations.

If the expanded drainfield system is approved, we recommend monitoring of ground-water levels beneath and downslope of the drainfield to identify ground-water conditions that vary from those assumed in the slope-stability analysis, and that these variations be evaluated to determine if they adversely impact hillslope stability.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Forsgren Associates Inc. (2003b) report. The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the Forsgren Associates Inc. (2003b) report are correct and accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid the North Fork Special Service District and Utah Division of Water Quality in assessing the feasibility of the proposed drainfield expansion and reducing the risks from landsliding, but the UGS makes no warranty, expressed or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Baker, A.A., 1964, Geology of the Aspen Grove quadrangle, Utah: U.S. Geological Survey Map GQ-239, scale 1:24,000, 9 p. pamphlet.

Forsgren Associates Inc., 2003a, North Fork Special Services District – wastewater treatment upgrade facilities planning study, supplement to January 2003 FPS report: Salt Lake City, unpublished consultant's report, variously paginated.

-----2003b, North Fork Special Services District – slope stability analysis: Rexburg, Idaho, unpublished consultant's report, 3 p.

Kaliser, B.N., 1992, Hydrogeologic investigation for Sundance wastewater disposal system: Salt Lake City, unpublished consultant's report, 23 p.

Project: Review of "College Downs at the North Village—Off Site Storm Water Analysis"			
By: Barry J. Solomon, P.G.	Date: 12-18-03	County: Wasatch	
USGS Quadrangles: Heber City (1168)	Section/Township/Range: NE¼ Section 19, T. 3 S., R. 5 E., SLBM		
Requested by: Doug Smith, Wasatch County Planning	Date report received at UGS: 12-5-03		Job number: 03-14 (R-23)

INTRODUCTION

I reviewed geologic parts of the storm-water analysis for the College Downs site in Wasatch County by Epic Engineering, P.C. (Epic, 2003). This site was referred to as the North Village 17-acre site in a geotechnical report by Intermountain GeoEnvironmental Services, Inc. (IGES, 2002), which I reviewed earlier (Solomon, 2003). For these reviews, I studied relevant geologic literature and examined 1:20,000-scale (1962) aerial photographs, but I did not inspect the site. The purpose of my review of the storm-water analysis is to assess whether Epic (2003) adequately identifies and addresses geologic sources of potential flooding on the College Downs site. However, I did not review parts of the Epic (2003) report related to engineering calculations of impacts caused by potential runoff or the design of improvements needed to protect the site, which are beyond my area of expertise.

CONCLUSIONS AND RECOMMENDATIONS

The Epic (2003) report analyzes the impact of two worst-case design scenarios for flooding from drainage areas near the College Downs site and proposes a drainage system to protect the site from the scenario floods. The report maps alluvial-fan flood hazards affecting the site, but does not analyze their impact or determine whether the proposed drainage system adequately protects the site from alluvial-fan flooding. I recommend the following:

- The developer's geotechnical consultant should address the hazard from alluvial-fan flooding by delineating the drainage basins that serve as the source of the alluvial fans and determining the volume of flood water resulting from a design event in the drainage basins. This volume is in addition to flood waters analyzed in the Epic (2003) report.

- The alluvial-fan-flooding hazard assessment should include the contribution of canal water from the breaching of both canals that cross the drainage basins, similar to the worst-case scenarios analyzed in the Epic (2003) report.

- The hazard assessment should determine if the drainage system proposed by Epic (2003) would provide adequate protection from alluvial-fan flooding.

- If the drainage system proposed by Epic (2003) does not provide adequate protection from alluvial-fan flooding, an alternate system should be proposed that may require cooperation among the developer, Wasatch County, and owners of adjacent property.

I further recommend that:

- A qualified engineer should review calculations of impacts caused by potential runoff and the design of improvements needed to protect the site in this study and any subsequent studies.

- The existence of the Epic (2003) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's engineering consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that its recommendations were followed.

DISCUSSION

Epic (2003) analyzed flooding that may result from a storm that occurs on average once every 100 years at the College Downs site, lasting 24 hours. The report maps drainage basins tributary to the site and estimates flows and sediment loads that may cross the site from the basins during the analyzed storm event. To ensure that the worst-case event was analyzed, Epic (2003) assumed that two irrigation canals that cross the drainage basins would be breached during the storm, contributing canal water to downslope flow. Epic (2003) notes that the canals were not specifically designed to accommodate the analyzed event, and thus reasonable doubt exists as to their performance under those conditions. In a similar setting, canal water contributed to flooding that occurred as debris flows crossed a canal in Spring Lake near Santaquin in 2002 (McDonald and Giraud, 2002).

Epic (2003) analyzed two scenarios to determine the effects of flooding from upslope drainage basins adjacent to the north and east boundaries of the site. However, small parts of the site are underlain by alluvial fans from drainage basins that do not directly bound the site. Hylland and Bishop (1996) map alluvial fans underlying the northwest and south corners of the College Downs site, shown on figure 2 of the Epic (2003) report. I discussed the potential for alluvial-fan flooding at College Downs in my earlier review of the IGES (2002) geotechnical report for the site (Solomon, 2003). The relative contribution of alluvial-fan flooding to the overall hazard is unknown because Epic (2003) does not estimate its impact, but I believe clear-water floods originating from canyons upslope from the fans could extend beyond the fans themselves.

Epic (2003) proposes a system of riprap channels, berms, and local roads to convey flood waters from upslope drainage basins and canals to a natural depression on the west part of the site, which will act as a retention basin. However, this system does not extend off the College Downs site to the fan heads, and thus will not reduce the alluvial-fan flood hazard, and the ability of the depression to contain the additional contribution of alluvial-fan floodwater is unknown. I therefore recommend that the alluvial-fan flood hazard be assessed and its contribution to flood waters flowing into the depression be determined by delineating the drainage basins that serve as the source of the alluvial fans and estimating the volume of flood water resulting from a design event in the drainage basins. The hazard assessment should assume that irrigation canals crossing the drainage basins are breached during flooding, similar to the scenarios described in the Epic (2003) report. If the capacity of the depression to contain flood waters is inadequate, the developer and Wasatch County may need to work with the owners of adjacent property to reduce hazards.

SUMMARY OF CONCLUSIONS

Engineering calculations and the design of the storm-water drainage system in Epic (2003) are beyond my area of expertise and I therefore did not review them. However, alluvial fans that underlie parts of the College Downs site are a geologic source that may contribute to flooding during the storm event analyzed by Epic (2003) but are not considered in the calculations. I therefore recommend that the impact of alluvial-fan flooding be determined. Because recent alluvial-fan flooding in Santaquin was worsened by the contribution of canal water, and Epic (2003) assumed that two irrigation canals would be breached during the analyzed storm, the impact of alluvial-fan flooding should include the contribution of water from off-site breached canals as well. If the capacity of the on-site depression is inadequate to contain additional flood waters from the alluvial fans, the developer and Wasatch County may need to work with the owners of adjacent property to reduce hazards.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Epic (2003). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in Epic (2003) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Epic Engineering, P.C., 2003, College Downs at the North Village—off site storm water analysis: Heber City, Utah, unpublished consultant's report, 13 p.

Hylland, M.D., and Bishop, C.E., 1996, Flood hazards, earthquake hazards, and problem soils, western Wasatch County, Utah (plate 2A), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

Intermountain GeoEnvironmental Services, Inc. 2002, Geotechnical investigation and report—North Village 17-acre site, Wasatch County, Utah: Orem, Utah, unpublished consultant's report, 25 p.

McDonald, G.N., and Giraud, R.E., 2002, September 12, 2002 fire-related debris flows east of Santaquin and Spring Lake, Utah County, Utah: Utah Geological Survey Technical Report 02-09, 15 p.

Solomon, B.J., 2003, Review of "Geotechnical investigation and report—North Village 17-acre site, Wasatch County, Utah": Utah Geological Survey Technical Report 03-12, 4 p.

Utah Geological Survey

<table>
<tr><td colspan="3">Project:
Review of geotechnical/geological study, Red Fox Ridge (Wiederholt) subdivision, Layton, Utah</td><td rowspan="3"></td></tr>
<tr><td>By:
Richard E. Giraud, P.G.</td><td>Date:
01-08-04</td><td>County:
Davis</td></tr>
<tr><td>USGS Quadrangles:
Kaysville (1320)</td><td colspan="2">Section/Township/Range:
NW¼SE¼ and SW¼NE ¼ section 23, T. 4 N., R. 1 W.</td></tr>
<tr><td>Requested by:
Kem Weaver, Layton Community Development Department</td><td colspan="2">Date report received at UGS:
12-03-03</td><td>Job number:
04-01 (R-24)</td></tr>
</table>

INTRODUCTION

I reviewed the geologic parts of the geotechnical/geological study by Earthtec Testing and Engineering, PC (Earthtec, 2002) for the Red Fox Ridge subdivision (formerly known as the Wiederholt subdivision) located at approximately 2700 East Oak Hills Drive in Layton. The Earthtec (2002) report includes a geologic-hazards evaluation by Western GeoLogic, LLC and a geotechnical study by Earthtec. For this review, I studied relevant geologic literature and examined 1:24,000-scale (1985) aerial photographs, but I did not inspect the site. I also studied geologic reports and a review for the Chadwick Farms subdivision (formerly known as the Highlands at Oak Hills subdivision) that abuts part of the Red Fox Ridge subdivision (Applied Geotechnical Engineering Consultants, Inc. [AGEC], 2002; Ashland and Christenson, 2003; Earthtec, 2003). The purpose of my review is to assess whether geologic hazards are adequately addressed at the site. I did not review the geotechnical engineering aspects of the report.

CONCLUSIONS AND RECOMMENDATIONS

I believe Earthtec (2002) adequately addresses geologic hazards at the site except for landsliding and earthquake ground shaking.

- The boundaries of all landslides and setbacks from landslides and slopes prone to failure must be shown on the site plan to delineate buildable and nonbuildable areas. Earthtec (2002; figure 3) identifies a landslide in parcel 13, and another lies in parcel 12 as mapped by Lowe (1988).

- The recommended 120-foot setback from the crest of the slope is less than the 150-foot setback recommended by AGEC (2002) for the adjoining Chadwick Farms subdivision. Subsequent to preparing the Red Fox Ridge subdivision report, Earthtec (2003) analyzed the slope setbacks recommended by AGEC (2002) using a 10-foot rise in ground water at the adjoining Chadwick Farms and concurred with the 150-foot AGEC (2002) setback. I recommend the setback discrepancy between these abutting subdivisions be addressed.

- To address the hazard from earthquake ground shaking, Earthtec (2002) indicates, "According to the IRC, this site is classified as site class E." Based on figure 301.2(2) in the *International Residential Code* (IRC; International Code Council, 2003), the site falls into seismic design category E, not site class E. The IRC does not assign site classes. The IRC (section R301.2.2.1) provides alternatives to seismic design category E depending on site class and other considerations. I recommend the geotechnical consultant determine the site class at the Red Fox Ridge subdivision, and determine whether an alternative seismic design category is appropriate. The *International Building Code* (IBC; International Code Council, 2002) and IRC are scheduled for adoption by Layton City in January 2004 (Steve Hamblin, Layton City Building Official, verbal communication, December 16, 2003).

  I also recommend the following:

- A qualified geotechnical engineer should review geotechnical-engineering aspects of the report.

- The existence of the Earthtec (2002, 2003) and AGEC (2002) reports, the Chadwick Farms review (Ashland and Christenson, 2003), this review, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Layton City written documentation from the consultant indicating that their recommendations were followed.

The report is not signed or stamped by the engineer. Also as required by Utah state law, a licensed professional geologist must also sign and stamp the report.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Earthtec (2002, 2003) and AGEC (2002) reports. The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the Earthtec (2002, 2003) and AGEC (2002) reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Layton City in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc., 2002, Geotechnical investigation and slope stability analysis – the Highlands at Oak Hills subdivision, 2400 East Oak Hills Drive, Layton, Utah: Sandy, Utah, unpublished consultant's report, 18 p.

Ashland, F.X., and Christenson, G.E., 2003, Review of geotechnical and slope-stability analysis reports for the proposed Chadwick Farms residential subdivision, Layton, Utah: Unpublished Utah Geological Survey Technical Report 03-05, 3 p.

Earthtec Testing and Engineering, P.C., 2002, Geotechnical – geological study, Wiederholt subdivision, Layton, Utah: Ogden, Utah, unpublished consultant's report, 32 p.

—2003, untitled letter report for the proposed Chadwick Farms subdivision, Layton, Utah: Ogden, Utah, unpublished consultant's report, 2 p.

International Code Council, 2002, International Building Code - 2003: Falls Church, Virginia, International Code Council, 656 p.

—2003, International Residential Code for One- and Two-Family Dwellings - 2003: Falls Church, Virginia, International Code Council, 604 p.

Lowe, Mike, 1988, Natural hazards overlay zone - slope failure inventory, Kaysville quadrangle: Weber County Planning Department unpublished map, scale 1:24,000.

Utah Geological Survey

Project: Review of the geologic-hazard and slope-stability study, lot D-83, Sherwood Hills subdivision, Provo, Utah			
By: Richard E. Giraud, P.G.	Date: 02-17-04	County: Utah	
USGS Quadrangles: Orem (1088)	Section/Township/Range: SW¼SW¼ section 17, T. 6 S., R. 3 E.		
Requested by: Nick Jones, Provo City Engineering	Date report received at UGS: 01-08-04		Job number: 04-02 (R-25)

INTRODUCTION

I reviewed the geologic-hazard and slope-stability study by Earthtec Testing and Engineering, PC (Earthtec, 2003) for lot D-83 in the Sherwood Hills subdivision, Provo. Earthtec (2003) used previous investigations by URS/Dames and Moore (2001) on geologic hazards and by Terracon (2001, 2002) on slope stability for the Sherwood Hills subdivision. I studied relevant geologic maps, hazard maps, and 1:20,000-scale (1973) aerial photographs, but I did not inspect the site. The purpose of my review is to assess whether geologic hazards are adequately addressed at the site. My review comments address only the lot-specific slope-stability analysis of Earthtec (2003) and not the subdivision-wide landslide stability. I did not review the geotechnical-engineering aspects of the report.

CONCLUSIONS AND RECOMMENDATIONS

I believe Earthtec (2003) adequately addresses most geologic hazards at lot D-83, Sherwood Hills subdivision except for landslides and the fault setback. I therefore recommend the following:

- Earthtec (2003) accurately states that a subdivision-wide landslide, subject to "global" instability, may affect the lot. Based on this conclusion, Provo City should determine whether they will allow development on the lot, assuming local hazard issues can be addressed.

- Earthtec (2003) analyzed lot-specific slope stability and determined a marginal factor of safety for certain types of slides under earthquake ground-shaking conditions when strengths are reduced to account for possible saturated conditions. This marginal factor of safety should be considered prior to approving development.

- Because continued operation of the drains cannot be guaranteed, I recommend an analysis of shallow landsliding using the stabilizing effect of the retaining wall, but not the drains, to ensure the slope is stable or determine a 1.5 static factor-of-safety building setback if needed.

- Additional recommendations are needed for foundation drain discharge water to ensure that discharged water does not negatively impact the stability of the slope and retaining wall west of the lot.

- Earthtec (2003) should reconsider their 10-foot setback from the antithetic fault, that is less than the recommended minimum 15-foot setback in the new guidelines by Christenson and others (2003).

- Earthtec (2003) states that the landslide deposits are displaced by tectonic faults, but a landslide origin or possible landslide movement on tectonic faults cannot be precluded. Therefore, the hazard implications of possible landslide movement should be stated.

I also recommend the following:

- A qualified geotechnical engineer should review geotechnical-engineering aspects of the report.

- Inspect the foundation excavation for evidence of landslide and/or fault deformation.

- The existence of the Earthtec (2003) report, this review, and future reports should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Provo City written documentation from the consultant indicating that their recommendations were followed.

DISCUSSION

Earthtec (2003) does not analyze subdivision-wide landslide stability because it is addressed in the URS/Dames and Moore (2001) and Terracon (2001, 2002) reports. Earthtec (2003) concludes, "this instability may continue in the vicinity of the subject lot." Movement of the subdivision-wide landslide cannot be precluded and could possibly damage a house and infrastructure at this lot. Provo City is considering allowing development on parts of the subdivision-wide landslide that are not presently moving, so Provo City should determine if lot D-83 is developable if local hazards are addressed.

Earthtec (2003) modeled the lot-specific slope stability. Although I did not review the geotechnical-engineering aspects of the slope-stability analysis, the input strengths and ground parameters appear geologically reasonable. Earthtec used two strengths, a higher strength for natural moisture conditions and a lower strength for possible saturated conditions. They consider the slope stable under static conditions using both strengths. For earthquake ground-shaking conditions they determined the factor of safety is sufficient with the higher strength and marginal with the lower strength. The marginal factor of safety during an earthquake is a risk that should be considered before approving development.

Earthtec (2003) describes a small historical landslide in the cut slope at the west lot boundary and states that the landslide was regraded and a retaining wall and drains were installed. In their geologic interpretations, Earthtec (2003) states that the small landslide resulted from cutting the toe of the slope and that future slope cuts are unlikely. Another shallow failure occurred in this same slope in 1999 west of lot D-85 (two lots south). In their lot-specific slope-stability analysis, Earthtec (2003) does not model the shallow slope failure at the west edge of the lot and apparently believes that the retaining wall and drains provide adequate stability. I recommend an analysis of shallow landsliding using the stabilizing effect of the retaining wall, but not the drains, to ensure the slope is stable or determine a 1.5 static factor-of-safety setback if needed. The deep slip-surfaces in Earthtec's lot specific slope stability model do not assess the potential for shallow landslides.

Earthtec (2003) provides recommendations for a foundation drain and discusses the problems of discharging the water to sanitary and storm sewers. I believe additional recommendations are necessary to ensure that water is not discharged in a manner that will negatively impact stability of the slope and retaining wall west of the lot.

Earthtec (2003) identifies a fault crossing the southeast part of the lot and interprets the fault to be an antithetic fault (a minor fault that is oriented opposite to the main fault). Earthtec recommends a minimum 10-foot setback from the fault. However the recently published *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (Christenson and others, 2003) suggest a minimum 15-foot setback for the type of residential structure proposed at this site. Therefore, I recommend Earthtec reconsider their setback given the new guidelines and update the setback distance on the site plan (Earthtec, 2003; figure 3). I agree with Earthtec's (2003) recommended 50-foot setback on the downthrown (western) block of the main fault mapped on the east side of Chapel View Circle, which they state will be accommodated with normal building setback from the street.

Earthtec's (2003) interpretation that the landslide deposits are displaced by a tectonic fault is reasonable. However, in this geologic setting this fault could have a landslide rather than tectonic origin, or could be a tectonic fault on which landsliding has occurred. Because one cannot conclusively determine the fault origin in this setting, I recommend considering a possible landslide origin and addressing potential landslide implications.

SUMMARY OF CONCLUSIONS

I believe Earthtec (2003) adequately addresses the potential for surface fault rupture, liquefaction, rock falls, flooding, debris flows, and earthquake ground shaking. The marginal lot-specific earthquake factor of safety under saturated conditions and potential instability of the subdivision-wide landslide are significant risks that must be considered in approving development. I recommend an analysis of the shallow landslide at the west property boundary to determine whether a building setback is necessary. I also recommend Earthtec reconsider their fault setback given the 15-foot minimum setback recommended in Christenson and others (2003) and address potential hazards associated with a possible landslide origin for this fault.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Earthtec (2003) report. The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the Earthtec (2003) report are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Provo City in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Christenson, G.E., Batatian, L.D., and Nelson, C.V., 2003, Guidelines for evaluating surface-fault-rupture hazards in Utah: Utah Geological Survey Miscellaneous Publication 03-6, 14 p.

Earthtec Testing and Engineering, P.C., 2003, Geologic hazard and slope stability study, lot D-83, Sherwood Hills subdivision, Provo, Utah: Orem, Utah, unpublished consultant's report, 22 p.

Terracon, 2001, Report of phase II, initial geotechnical engineering evaluations, Sherwood Hills, subdivision-wide studies, Provo, Utah: Salt Lake City, Utah, unpublished consultant's report, 44 p.

—2002, Report of additional studies for phase II, initial geotechnical engineering evaluations, Sherwood Hills, subdivision-wide studies, Provo, Utah: Salt Lake City, Utah, unpublished consultant's report, 17 p.

URS/Dames & Moore, 2001, Phase I geologic evaluation and phase V geological hazards map update, Sherwood Hills subdivision-wide studies and update of Provo City geologic hazard maps: Salt Lake City, Utah, unpublished consultant's report, 33 p.

Utah Geological Survey

Project: Review of geotechnical reports, Basin View Estates, 5502 Snow Basin Road, Weber County, Utah			
By: Greg N. McDonald Mike Lowe	Date: April 8, 2004	County: Weber	
USGS Quadrangles: Snow Basin	Section/Township/Range: Section 22 and 23, T. 6 N., R. 1 E.		
Requested by: Curtis Christensen, Weber County Engineering	Date report received at UGS: March 19, 2004		Job number: 04-03 (R-26)

INTRODUCTION

We reviewed portions of the geotechnical/geological reports for the proposed Basin View Estates subdivision in Weber County by Terracon (2003a, 2003b) and Earthtec Testing and Engineering, P.C. (2004). For the review, we conducted a literature review, examined 1966 1:24,000-scale aerial photos, and visited the site on September 29, 2003 while Terracon was performing their field investigations. The purpose of the review is to determine whether slope stability and/or seepage associated with proposed community drainfields is adequately addressed in the reports. We did not review the reports with respect to geologic hazards for lot development at the subdivision, and recommend this be done if development approval proceeds.

CONCLUSIONS AND RECOMMENDATIONS

Earthtec's (2004) conclusion that effluent is unlikely to surface east of the community absorption system needs additional supporting information. Terracon's (2003b) analysis of slope stability was performed using average values and reasonable assumptions and methods, although more conservative values would have been prudent given the importance of the facility, consequences of failure, and the occurrence of landslides under similar conditions elsewhere in this geologic unit. Constructing community drainfields at the site warrants extreme caution given:

- Earthtec (2004) indicates the possibility for seepage exists, although Earthtec considers it unlikely.

- Terracon (2003a) observed and mapped natural seeps and slumps about 200 to 300 feet north-northwest of the proposed drainfields on an east-facing slope of similar aspect, slope, and geology as that directly east of the proposed drainfields.

- Terracon's analysis indicates slope stability is sensitive to the addition of water into the subsurface as will occur at the drainfield.

- Terracon's modeling indicates stability of the natural east-facing slope is also sensitive to bedding dip angles assuming a block-slide-type failure along a bedding plane. According to Terracon (2003b), beds dip toward the slope at variable angles up to 23 degrees; greater than the maximum dip angle Terracon considers stable (20 degrees).

- Local failures in road cuts indicate the potential for human-induced block slides in the Norwood Tuff.

We believe additional information and investigation and more prudent analyses are warranted to determine if community drainfields could induce seepage and/or slope instability. In addition, some of the assumptions and modeling input parameters used in Terracon's slope-stability analyses are not clear from the report text. We therefore recommend:

- Data should be provided to demonstrate that the soils at the drainfields are capable of accepting the total load of wastewater from the system and that the effluent flow will only be a "6 to 12 inch layer above the less weathered bedrock layer" (Earthtec, 2004), and that the monitoring period for seepage be extended beyond 3 years.

- The depth to shallow bedrock or impermeable zone should meet Utah and Weber-Morgan County regulations for drainfields.

- The potential for shallow slope failures in saturated colluvium should be evaluated using drainfield-induced ground-water conditions.

- Terracon should provide modeling input data and results in a comprehensive format, including profiles showing inferred slide planes and ground-water conditions.

- If reconfiguration and moving of the drainfields to the west is planned, reevaluation of slope stability should be done to demonstrate the extent to which slope stability is enhanced.

- The effects that block sliding, shallow soil slumping, and/or effluent seepage would have on existing and proposed development and infrastructure east of the proposed drainfields should be considered.

DISCUSSION

Earthtec (2004) should provide more information to determine if the possibility for effluent surfacing east of the community drainfields exists. The Norwood Tuff is known to have the potential for swelling when wetted and a soil sample from the site swelled when tested (Terracon, 2003a). Earthtec (2004) states that the effluent flow will be in a "6 to 12 inch layer above the less weathered bedrock layer," presumably referring to flow in the slope at the edge of this layer, without providing evidence or calculations. Also, it is not stated whether percolation rate tests accounted for possible reduced primary and secondary permeability induced by prolonged exposure to water from the drainfields to determine if the soils at the site are capable of accepting the total load of wastewater to the system. Terracon (2003a) observed and mapped seeps and slumps about 200 to 300 feet north-northwest of the proposed drainfields on an east-facing slope of similar aspect, slope, and geology as that directly east of the proposed drainfields. The presence of a natural seep on a slope of similar aspect and grade suggests substantial input of wastewater could induce seepage. Also, the recommended three-year monitoring period is probably insufficient. Monitoring should be continued for at least several years after the entire subdivision is built out and maximum effluent discharge in reached. Utah State Administrative Rules require at least four feet of soil between bedrock, or any other impervious formation, and the anticipated bottom of the drainfields. Although this applies only to the area directly beneath a drainfield, Earthtec's test-pit logs indicate these criteria are not met in the slope downgradient from the drainfields in the area where effluent is most likely to migrate.

Terracon's (2003b) analysis of slope stability was performed using average, although not always conservative or lower-bound values, and reasonable methods and assumptions. However, more prudent analyses are advisable because of the limitations to using laboratory soil-strength test results, and the fact that natural conditions and human-induced factors are highly variable and difficult to accurately characterize. Recently a block slide at a road cut on the west side of Trappers Loop Road occurred about 2.3 miles south of the proposed site (NE 1/4 section 3, T. 5 N., R. 1 E.). The landslide occurred on an east-southeast-facing cut slope of about 26 degrees and failed on a Norwood Tuff clay bed dipping out of the cut slope about 13 degrees. The source of ground water was just natural precipitation in this case. Landslides of widely varying sizes and ages are common in areas underlain by Norwood Tuff, deposits derived from Norwood Tuff, and in fills placed over such material.

Terracon's modeling indicates stability of the slope is sensitive to the addition of water into the subsurface and to bedding dip angles assuming a block-slide-type failure along a clayey bed in the Norwood Tuff. A community drainfield system serving nine residential homes is designed to introduce an estimated 3,600 gallons of effluent per day into the subsurface (Utah Division of Administrative Rules, 2003), or roughly the equivalent of an additional 70+ inches of precipitation per year, assuming 100% infiltration and a drainfield area of 27,950 ft^2. Terracon's slope-stability analysis indicates beds dipping about 20 degrees or less should be stable under an assumed ground-water level "beginning at the leach lines and sloping outward to the (arbitrary) failure plane." From the information provided, it is not clear if this is a reasonable analysis or not. We recommend modeling the slope's sensitivity to different ground-water levels, including estimating the highest expected levels. Presumably, a more conservative analysis would indicate possible sliding at shallower bedding dips. Using a bedding-plane sliding-block analysis, Terracon (2003b) concluded that slope stability would decrease at dips greater than 20 degrees. Because 20 degrees is approximately the surface slope, this conclusion seems inconsistent because beds having steeper dips would not daylight in the slope and therefore the slope should not be prone to this type of failure. Therefore, we assume this conclusion applies to local areas where the slope is steeper than 20 degrees.

Because of concerns over slope stability, Terracon recommends moving and reconfiguring the proposed drainfields to the west. Because Terracon (2003b) indicates the depth of the slide is not as critical a factor as bedding dip, we recommend demonstrating how much slope stability is enhanced by moving the drainfields to the west.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Terracon (2003a and 2003b) and Earthtec (2004). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Weber County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Earthtec Testing and Engineering, P.C., 2004, Engineering consultation, proposed Basin View Estates subdivision, 5502 Old Snow Basin Road, Huntsville, Utah: Ogden, unpublished consultant's report, 3 p.

Lowe, Mike and Sorensen, Darwin, 1999, Guidelines for preparing hydrogeologic and soil reports addressing suitability for alternative wastewater disposal systems in Weber County, Utah: Utah Geological Survey Circular 102, 10 p.

Terracon, 2003a, Geological engineering report, proposed Basin View Estates development, 5502 Snow Basin Road, Weber County, Utah: Draper, unpublished consultant's report, 9 p.

Terracon, 2003b, Geotechnical engineering report, Basin View Estates - Slope stability, 5502 Snow Basin Road, Weber County, Utah: Draper, unpublished consultant's report, 6 p.

Utah Division of Administrative Rules, 2003, Rules R317-4 and R317-5. Onsite wastewater systems. Accessed online March 22, 2004 <http://www.rules.utah.gov/pulicat/code/r317/r317-00[4,5].htm>

Utah Geological Survey

Project: Review of geotechnical study and surface fault rupture study, Bromsfield subdivision, Layton, Utah			
By: Richard E. Giraud, P.G.	Date: 04-15-04	County: Davis	
USGS Quadrangles: Kaysville (1320)	Section/Township/Range: NW¼ section 25, T. 4 N., R. 1 W.		
Requested by: Kem Weaver, Layton Community Development Department	Date report received at UGS: 03-17-04		Job number: 04-04 (R-27)

INTRODUCTION

I reviewed the geologic parts of the geotechnical study and surface-fault-rupture study by Y^2 Geotechnical, P.C. (Y^2 Geotechnical, 2004) for the Bromsfield subdivision at approximately 100 South Corral Drive in Layton. The Y^2 Geotechnical (2004) report is a geotechnical study that includes a surface-fault-rupture study by Western GeoLogic, LLC (Western GeoLogic, 2004). For this review, I studied relevant geologic literature and examined 1:24,000-scale (1985) aerial photographs, but I did not inspect the site. The purpose of my review is to assess whether geologic hazards are adequately addressed at the site. I did not review the geotechnical engineering aspects of the report.

CONCLUSIONS AND RECOMMENDATIONS

I believe Y^2 Geotechnical (2004) and Western GeoLogic (2004) adequately address geologic hazards at the site except for earthquake ground shaking, liquefaction, alluvial-fan flooding, and debris flows. I have the following comments:

- I agree with the Western GeoLogic (2004) fault setbacks and nonbuildable areas shown on figure 3.

- To address the hazard from earthquake ground shaking, Y^2 Geotechnical (2004) states, "based on section R301.2.2 of the IRC this site is [sic] may be classified as Site Class D_2." Based on figure 301.2(2) in the *International Residential Code* (IRC; International Code Council, 2003), the site falls into seismic design category D_2, not site class D_2. The IRC does not assign site classes.

- Y^2 Geotechnical (2004) notes that the site is classified as having a moderate liquefaction potential but does not assess the liquefaction hazard at the site. Because the site has a moderate liquefaction potential, I recommend the geotechnical consultant assess the liquefaction hazard and provide specific recommendations and restrictions pertaining to site development if necessary.

- Based on mapping by Lowe (1988) and Nelson and Personius (1993), the site lies on Holocene alluvial-fan deposits. Alluvial-fan debris-flood and debris-flow deposits were also identified in the fault trenches (Western GeoLogic, 2004). Therefore, I recommend evaluation of alluvial-fan flooding and debris-flow hazards.

I also recommend the following:

- A qualified geotechnical engineer should review the geotechnical-engineering aspects of the Y^2 Geotechnical (2004) report.

- The existence of the Y^2 Geotechnical (2004) and Western GeoLogic (2004) reports, this review, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, Layton City should require the developer to submit written documentation from the consultant indicating that their recommendations were followed.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Y^2 Geotechnical (2004) and Western GeoLogic (2004) reports. The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the Y^2 Geotechnical (2004) and Western GeoLogic (2004) reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Layton City in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

International Code Council, 2003, International Residential Code for One- and Two-Family Dwellings - 2003: Falls Church, Virginia, International Code Council, 604 p.

Lowe, M., 1988, Natural hazards overlay zone - debris-flow hazard map, Kaysville quadrangle: Davis County Planning Department unpublished map, scale 1:24,000.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2199, 22 p. pamphlet, scale 1:50,000.

Western GeoLogic, LLC, 2004, Surface fault rupture study, proposed Bromsfield residential development, Davis County, Utah: Salt Lake City, Utah, unpublished consultant's report, 16 p.

Y^2 Geotechnical, P.C., 2004, Geotechnical study and surface fault rupture study, Bromsfield subdivision, approximately 100 South Corral Drive, Layton, Utah: Layton, Utah, unpublished consultant's report, 12 p.

Utah Geological Survey

Project: Review of geotechnical and surface-fault-rupture reports for the Springs development, Fruit Heights, Utah			
By: Richard E. Giraud, P.G.	Date: 06-15-04	County: Davis	
USGS Quadrangles: Kaysville (1320)	Section/Township/Range: S½ section 1 and N½ section 12, T. 3 N., R. 1 W.		
Requested by: Jeff Oyler, Fruit Heights Planning	Date report received at UGS: 04-30-04		Job number: 04-05 (R-28)

INTRODUCTION

I reviewed the geologic parts of a geotechnical report and addendum report by Earthtec Testing and Engineering, P.C. (Earthtec, 2003, 2004) and a surface-fault-rupture report (phase II only) by Western GeoLogic, LLC (Western GeoLogic, 2004) for the Springs development at approximately 1000 South, east of Mountain Road in Fruit Heights. The Earthtec (2003) geotechnical report includes a geologic hazards evaluation by Western GeoLogic. For this review, I studied relevant geologic literature and examined 1:20,000-scale (1937) and 1:12,000-scale (1989) aerial photographs. I visited the site with Chris DuRoss of the Utah Geological Survey (UGS) on June 2, 2004. The purpose of my review is to assess whether geologic hazards are adequately addressed at the site. I did not review the geotechnical engineering aspects of the reports.

CONCLUSIONS AND RECOMMENDATIONS

I believe Earthtec (2003, 2004) and Western GeoLogic (2004) adequately address some geologic hazards at the site but additional investigations are necessary to fully address certain potential hazards. I have the following comments and recommendations:

- All geologic hazards investigations should be completed prior to development.

- A site-specific geologic map showing all faults, landslides and related features, alluvium, and debris-flow and alluvial-fan deposits is needed to provide a basis for delineating and evaluating hazards. Geologic interpretations of the origin of material encountered in test pits and drill holes is critical in evaluating hazards and should also be provided.

- The likelihood and relative importance of liquefaction-induced flow and lateral-spread landsliding vs. non-liquefaction-induced landsliding should be investigated to identify likely future landslide types.

- The locations of mapped landslides (deposits and source areas) and other landslide features should be incorporated into the computer models to realistically evaluate landslide stability.

- I agree with Earthtec's (2003) recommendation that drilling is necessary to characterize subsurface materials and ground-water levels in slopes at the site. This information is a prerequisite for the landslide- and liquefaction-hazard analyses.

- Adequate fault setbacks and nonbuildable areas are designated in the luxury home area, but additional trenching is needed in the unexplored areas where structures are planned. The surface-fault-rupture special-study area extends northward into the adult home area where the hazard remains to be evaluated.

- I recommend Earthtec define the site class and provide supporting information for reclassifying the seismic design category from E to D_2.

- Because an increase in ground-water levels can increase the liquefaction potential, I recommend including development-induced ground-water conditions in the liquefaction analysis and evaluating liquefaction potential throughout the site, including bench areas. I recommend review of the liquefaction evaluation by a geotechnical engineer.

- I recommend site-specific analysis of the flood and debris-flow hazards to determine if the proposed structures would be impacted.

- I recommend evaluating the shallow ground-water hazard where basements are planned.

- I agree with Earthtec's (2003) recommendation to remove the collapsible soils and replace them with structural fill where necessary.

- Show all setbacks and hazard areas on a subdivision map. The subdivision map should be reviewed to ensure adequate buildable space or the need for modifying subdivision layout.

I also recommend the following:

- A qualified geotechnical engineer should review geotechnical engineering aspects of the report.

- The existence of the Earthtec (2003, 2004) and Western GeoLogic (2004) reports, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultants are followed, the developer should submit to Fruit Heights written documentation from the consultants indicating that their recommendations were followed.

DISCUSSION

Earthtec (2004) states that not all areas are accessible for investigation until development begins and additional studies will be necessary, particularly for structures proposed near slope crests or on slopes at the site. Completing studies after development begins is not a prudent or cost-effective alternative because few options exist to redesign a subdivision if a problem is found during subsequent studies. Therefore, I recommend completing all geologic hazards investigations prior to development.

Landslide Hazard

Earthtec (2003, 2004) recognized that parts of the site are within the Davis County landslide special-study area (Lowe, 1988a). Earthtec (2004) states that inactive liquefaction-induced lateral-spread landslide deposits have been mapped within the site by Lowe (1988b, landslide SPd626). Liquefaction-induced landslide deposits and main scarps have also been mapped by Nelson and Personius (1993) and are shown on Earthtec (2003) figure 3. Earthtec (2003) completed a "reconnaissance for recent slope instability," but a reconnaissance investigation is inadequate at this stage, particularly when buildings are proposed on mapped landslides. A site-specific detailed landslide investigation is needed to assess the feasibility of placing structures on or near pre-existing landslides.

With regard to mapped landslides and deposits, the regional 1:50,000-scale Nelson and Personius (1993) geologic map (Earthtec, 2003; figure 3) is inadequate for evaluating the landslide hazard and slope stability at the site scale of 1:4,800 (Earthtec, 2003, figure 33; 2004, figure 2). In my review of aerial photographs I recognized younger landslide scarps along the slope crests that are not on the 1:50,000-scale regional map. During my field visit I recognized a small, shallow colluvial landslide northwest of the wetland and small landslides associated with near-vertical cuts for an inactive irrigation ditch. Establishing the location and failure mechanism (or type) of landslides and landslide features is critical to modeling slope stability, determining appropriate slope setbacks, and understanding how landsliding may impact the proposed development.

The existence of liquefaction-induced flow and lateral-spread landslides within the site (Nelson and Personius, 1993) indicates the need to evaluate the potential for future liquefaction-induced landslides. The site is adjacent to the liquefaction-induced Farmington Siding landslide complex, where Hylland and Lowe (1998) concluded, "Based on geologic conditions and the pattern of previous landsliding, the relative hazard associated with liquefaction-induced landsliding is higher in the northern part of the landslide complex and in the crown area adjacent to the north and northeast margins of the complex…." The Springs subdivision is 0.5 mile east of the landslide complex. The *International Building Code* (IBC; International Code Council, 2002) grading appendix J also requires a liquefaction study for sites having mapped maximum earthquake short-period accelerations greater than 0.5 *g*, which applies to the Springs development.

Given the potential landslide hazards documented by others, I recommend mapping the surficial geology and showing all landslides (deposits and source areas), landslide features, and other surficial geologic units on a site map (1:4,800-scale or larger) for site planning and slope-stability analysis. I also recommend evaluating landslides to determine their origin (non-liquefaction-induced landslides and/or liquefaction-induced flow or lateral-spread landslides, shallow colluvial debris slides and flows). Trenching landslide deposits has been effective at similar sites to determine landslide origin and to identify the presence of liquefaction features and other landslide features to provide appropriate input for landslide stability analysis. If liquefaction-induced landslides are present, I recommend identifying the unit that liquefied, and determining present and likely development-induced ground-water levels and the potential for liquefaction in slopes at the site. Where non-liquefaction-induced landslides are found, additional slope-stability analyses should be conducted using appropriate parameters. I also recommend considering the potential for shallow debris slides in colluvium with subsequent debris-flow runout.

Earthtec (2003) evaluated the static and seismic slope stability for non-liquefaction-induced rotational failures in previously unfailed hillslopes, but they did not map on-site landslides or use the site-specific information on main scarp and landslide location to constrain their analysis. Even though Earthtec (2003, 2004) logged test pits and drill holes in the landslide deposits mapped by Nelson and Personius (1993), they do not provide geologic descriptions of any landslide features or deposits, discuss the landslide or other geologic origin of the deposits, or determine slope-failure conditions (ground water, soil strength, earthquake ground shaking) for the landslides. Earthtec (2004) states that slope stability is sensitive to ground-water elevation and believe the ground-water elevations used in their analysis are accurate, but they did not measure ground-water depths. I agree with Earthtec's (2003) slope drilling recommendation to verify that the subsurface materials and ground-water levels are consistent with those used in their slope-stability analysis.

For slope stability sections 1, 2, 3, and 4, Earthtec (2003, figure 33) states, "To avoid impacting structures at the base of the slope in the adult community we recommend the structures not be placed closer than 25 feet from the toe of any slope steeper than 30 %, unless a retainage structure is designed." Earthtec should explain how they determined that a 25-foot setback is adequate. Because adult-community building pads are shown at or on the toe of the north-facing slope in figure 2 (Earthtec, 2004) and the overall slopes of sections 1, 2, 3, and 4 are greater than 35 %, setbacks from the slope toe and locations of retaining structures should be shown on the site plan. Earthtec (2003) also recommended a 20-foot setback from the slope crest for sections 2 and 3 to achieve a 1.5 factor of safety, and these setbacks should also be shown on the site map.

In their analysis of slope stability section 4, Earthtec (2003) determined the slope had unacceptable factors of safety. Earthtec (2003) states that for the lot above section 4 (figure 33), an adequate setback cannot be obtained and still have sufficient buildable area and recommends the lot be eliminated without mitigation. For the lots below section 4 Earthtec (2003) recommends not placing buildings closer than 25 feet from the toe of the slope unless a retaining structure is in place. However, in the event of a landslide, this recommendation is effective only if the landslide toe, runout zone, or other downslope effects extend less than 25 feet outward beyond the present slope toe. Because property and buildings at the base of the slope could be damaged by a landslide, I recommend Earthtec explain why they consider a setback of 25 feet adequate.

For the lots below section 5 in the adult home area, Earthtec (2003) again recommends placing buildings no closer than 25 feet from the toe of the slope where the slope is steeper than 35 % unless a buttress fill or retaining wall is installed. This slope is a fault scarp and surface-fault rupture hazard should also be considered if mitigation structures are planned.

To ensure the landslide hazard is thoroughly addressed I recommend the following:

- Map the surficial geology at the site map scale (1:4,800 or larger) and show all landslides (deposits and source areas), landslide features, and other surficial geologic units.

- Determine the origin of landslides (non-liquefaction-induced and/or liquefaction-induced flow or lateral-spread landslides) within the site, including possible shallow debris slides in colluvium, and incorporate the landslide type(s) into the hazard analysis.

- Drill slopes to verify that the subsurface materials and ground-water levels are consistent with those used in the analyses. I recommend all drill holes be adequately sampled to describe subsurface stratigraphy, soil strength, and potential liquefaction-prone layers. Piezometers should be installed to monitor ground-water levels and development-induced changes in ground-water levels should be considered. The UGS has preliminary data available for ground-water-level fluctuations in Davis County.

- Provide recommendations for cut and fill slopes and setbacks in accordance with IBC appendix J (International Code Council, 2002).

- Provide a subdivision map with legible contours so slope steepness can be measured to check setback recommendations.

- Show the locations of drill holes TH-1 and TH-5 on a site map along with other drill holes.

- Any setbacks, hazard areas, and slope-stabilization structures determined from the hazard evaluations must be shown on the site map to delineate buildable areas.

Surface-Fault-Rupture Hazard

Earthtec (2003) and Western GeoLogic (2004) discovered faults in trenches within the luxury home area and recommended setbacks away from active faults shown in Western GeoLogic (2004) figure 3, and I concur with their setbacks. All setbacks should be shown on a subdivision map with lot boundaries to show buildable and nonbuildable areas. Western GeoLogic (2004, figure 3) shows an unexplored area where utilities prevented trenching. However, lots are planned within this unexplored area (Earthtec, 2004, figure 2). The area is within the surface-fault-rupture special-study area (Lowe, 1988c) and contains two faults mapped by Nelson and Personius (1993) (Western Geologic, 2004, figure 3). Therefore, I recommend additional trenching in this unexplored area.

The surface-fault-rupture-hazard area (Lowe, 1988c) extends northward from the luxury home area into the adult home area but the surface-fault-rupture hazard was not evaluated. Building pads are shown in this area and a slope-stabilizing structure may also be necessary at the base of the main fault scarp (Earthtec, 2003), therefore I recommend evaluating the surface-faulting hazard in the adult home area where structures are planned.

Earthquake Ground Shaking and Liquefaction Hazards

To address the hazard from earthquake ground shaking, Earthtec (2003) states, "The IRC designates this area as site class E." Based on figure 301.2(2) in the *International Residential Code* (IRC; International Code Council, 2003), the site falls into seismic design category E, not site class E. The IRC does not assign site classes. Earthtec (2003) also states, "…in accordance with IRC Section R301.2.2.1.2 the site can be reclassified as site class D_2" (actually seismic design category D_2, see above). Earthtec (2003) does not state if the site is reclassified to seismic design category D_2 based on additional construction restrictions outlined in the IRC or by a more detailed evaluation of seismic design category in accordance with the IBC (International Code Council, 2002). Because seismic design category D_2 is less restrictive than E, I recommend Earthtec provide supporting information for reclassifying the site as D_2.

Earthtec (2004) evaluated the liquefaction potential for structures planned in the valley bottom only and recommended liquefaction risk-reduction measures in some areas, but did not state if they accounted for development-induced (landscape irrigation) ground-water conditions as they did in their slope-stability analysis (Earthtec, 2003). Because an increase in ground-water levels can increase the liquefaction potential, I recommend including development-induced ground-water conditions in the analysis. Also, as stated in the landslide hazard section, the likelihood and relative importance of liquefaction-induced flow and lateral-spread landsliding vs. non-liquefaction-induced landsliding in slopes at the site should be investigated. Anderson and others (1994) show a high liquefaction potential in the valley and a moderate liquefaction potential in the bench areas. I recommend review of the liquefaction hazard analysis by a geotechnical engineer.

Flood and Debris-Flow Hazards

Earthtec (2003) states that part of the site is on a small alluvial fan, but they do not show the alluvial fan on the site map or determine if planned structures would be impacted by floods or debris flows. In their debris-flow hazard analysis, Earthtec (2003) cites sediment volumes estimated by Evenstad and Rasely (1995). Evenstad and Rasely (1995) state that their model only evaluates slope contributions in a runoff event and does not evaluate debris-flow hazard. To evaluate the debris-flow potential, Evenstad and Rasely (1995) recommend an evaluation of the amount of channel sediment that could be incorporated into a debris flow. Determining the volume of channel sediment available for sediment bulking is critical because the study of historical debris flows indicates 80 to 90 % of the debris-flow volume is eroded from the channel (Croft, 1967; Keaton and Lowe, 1998).

I recommend a site-specific flood and debris-flow hazard analysis to show the extent of alluvial-fan and debris-flow deposits, travel paths, and depositional areas. Because flood and debris-flow deposits are likely present in the valley bottom, the hazard should be evaluated in part based on the coarse-grained deposits in test pits 6, 7, and 8. In the eastern part of the site, I recognized small debris-flow lobes in both the north and south drainages.

Earthtec (2004) states that the area sustained record rainfall amounts on April 8 and 9, with over an inch of rain each day, and that no debris flows were observed. The National Oceanic and Atmospheric Administration (2003) lists the precipitation frequency estimate for 1 inch of rainfall in 24 hours as having a return period of less than two years, which would not be considered record rainfall. My investigation of the April 6, 2004, fire-related debris flows on Compton Bench in Farmington (1 mile south of this site) indicated relatively small amounts of intense thunderstorm rainfall triggered those debris flows from relatively small drainages (15 to 80 acres). The Farmington Pond gauge (0.25 mile southwest of the debris-flow area) recorded 0.16 inch in 17 minutes (Kim Wallace, Davis County, written communication, April 15, 2004) and a portable rain gauge above the Rudd Canyon debris basin (0.75 mile south of the debris-flow area) recorded 0.4 inches in 15 minutes (Paul Flood, U.S. Forest Service, written communication, April 23, 2004). Similar rainfall amounts and intensities on a burn area generated debris flows east of Santaquin (McDonald and Giraud, 2002). Because small amounts of intense thunderstorm rainfall can trigger debris flows in burn areas, I recommend conditions be evaluated at the Springs area. The April 6, 2004, Farmington debris flows were from smaller drainage basins than those above the Springs development and they damaged three properties in Farmington and plugged the storm sewer with sediment in several places.

Shallow Ground Water and Problem Soil Hazards

Earthtec (2003) encountered ground water in test pit 6 at a depth of 10 feet in the fall of 2003. During my field visit I measured a ground water depth of 5 feet. Because shallow basements are planned and landscape irrigation can raise ground-water levels, I recommend addressing the shallow ground-water hazard and providing risk-reduction recommendations.

Earthtec (2003) found that soils in the bench areas above a 6-foot depth have a moderate to high risk of soil collapse. I agree with their recommendation to remove the collapsible soil and replace it with structural fill where shallow footings are planned in the bench areas.

SUMMARY OF CONCLUSIONS

A site-specific surficial geologic map is needed to show all faults, alluvium, debris-flow and alluvial-fan deposits, and landslides. A site-specific subdivision map should show fault and slope setbacks and debris-flow/flood hazard areas. The subdivision map should be reviewed to ensure adequate buildable space or the need to modify subdivision layout.

Earthtec (2003, 2004) analyzed slope stability assuming rotational failures in previously unfailed material, but did not map or evaluate the stability of existing landslides or address other landslide types such as liquefaction-induced landslides or shallow debris slides in colluvium. Therefore, I believe additional landslide-hazard analysis is necessary to ensure safe development. In the luxury home area, the reports adequately identify faults and recommend appropriate setbacks from faults, but unexplored areas are also shown. The surface-fault-rupture hazard in the adult home area was also not evaluated. Therefore, the surface-fault-rupture hazard must be evaluated in the luxury home unexplored area and the adult home area where structures are planned. A site-specific flood and debris-flow hazard analysis is needed to identify hazard areas and recommend hazard-reduction measures, if required. The shallow ground-water hazard should be addressed where basements are planned. Development-induced ground-water conditions should be included in the shallow ground-water, liquefaction, and landslide analyses. The appropriate IBC site class and IRC seismic design category need to be stated and supporting information must be provided for the proposed seismic design category reclassification from E to D_2.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Earthtec (2003, 2004) and Western Geologic (2004) reports. The Department of Natural Resources, UGS, provides no warranty that the data in the Earthtec (2003, 2004) and Western Geologic (2004) reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Fruit Heights in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Anderson, L.R., Keaton, J.R., Aubrey, K., and Ellis, S., 1994, Liquefaction potential map for Davis County, Utah: Utah Geological Survey Contract Report 94-7, 50 p., scale 1:48,000.

Croft, A.R., 1967, Rainstorm debris floods, a problem in public welfare: University of Arizona, Agricultural Experiment Station Report 248, 35 p.

Earthtec Testing and Engineering, P.C., 2003, Geotechnical study, the Springs development, Fruit Heights, Utah: Ogden, Utah, unpublished consultant's report, 35 p.

—2004, Addendum geotechical study, the Springs development, Fruit Heights, Utah: Ogden, Utah, unpublished consultant's report, 7 p.

Evenstad, N.C., and Rasely, R.C., 1995, G.I.S. applications in the northern Wasatch Front pre-fire hazard risk assessment, Davis and Weber Counties, Utah, *in* Lund, W.R., editor, Environmental and engineering geology of the Wasatch Front region: Utah Geological Association Publication 24, p. 169-184.

Hylland, M.D., and Lowe, M., 1998, Characteristics, timing, and hazard potential of liquefaction-induced landsliding in the Farmington Siding landslide complex, Davis County, Utah: Utah Geological Survey Special Study 95, 35 p.

International Code Council, 2002, International Building Code - 2003: Falls Church, Virginia, International Code Council, 656 p.

—2003, International Residential Code for One- and Two-Family Dwellings - 2003: Falls Church, Virginia, International Code Council, 604 p.

Keaton, J.R., and Lowe, Mike, 1998, Evaluating debris-flow hazards in Davis County, Utah - engineering versus geological approaches, *in* Welby, C.W., and Gowan, M.E., editors, A paradox of power - voices of warning and reason in the geosciences: Geological Society of America Reviews in Engineering Geology, Volume XII, p. 97-121.

Lowe, M., 1988a, Natural hazards overlay zone – slope failure inventory, Kaysville quadrangle: Davis County Planning Department unpublished map, scale 1:24,000.

—1988b, Natural hazards overlay zone – landslide hazard map, Kaysville quadrangle: Davis County Planning Department unpublished map, scale 1:24,000.

—1988c, Natural hazards overlay zone – surface fault rupture hazard map, Kaysville quadrangle: Davis County Planning Department unpublished map, scale 1:24,000.

McDonald, G.N., and Giraud, R.E., 2002, September 12, 2002, fire-related debris flows east of Santaquin and Spring Lake, Utah County, Utah: unpublished Utah Geological Survey Technical Report 02-09, 15 p.

National Oceanic and Atmospheric Administration, 2003, Precipitation frequency atlas of the United States: Online, <http://hdsc.nws.noaa.gov/hdsc/pfds/sa/ut_pfds.html>, accessed May 13, 2004.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2199, 22 p. pamphlet, scale 1:50,000.

Western GeoLogic, LLC, 2004, Surface fault rupture study, the Springs residential development phase II, Fruit Heights, Davis County, Utah: Salt Lake City, Utah, unpublished consultant's report, 14 p.

Utah Geological Survey

Project: Review of geological hazards and slope stability report for the proposed Heritage Hills development, Alpine, Utah			
By: Richard E. Giraud, P.G.	Date: 07-20-04	County: Utah	
USGS Quadrangles: Lehi (1130)	Section/Township/Range: NE¼SE¼ section 13, T. 4 S., R. 1 E. and NW¼SW¼ section 18, T. 4 S., R. 1 E.		
Requested by: Alpine City	Date report received at UGS: 06-15-04		Job number: 04-06 (R-29)

INTRODUCTION

I reviewed the geological hazards and slope stability report for the proposed Heritage Hills development by Terracon (2004) at approximately 1000 North 200 East in Alpine. For this review, I studied relevant geologic literature and maps, but I did not inspect the site. The purpose of my review is to assess whether Terracon (2004) adequately identified and addressed geologic hazards at the site.

CONCLUSIONS AND RECOMMENDATIONS

I believe Terracon (2004) adequately addressed most geologic hazards at the site but additional investigation is necessary to fully address all hazards. I have the following comments and recommendations:

- Drainage-specific sediment and water volumes are needed for the design of proposed debris basins.

- For areas below small drainages and steep hillslopes not protected by debris basins, the localized flood hazard should be evaluated.

- I recommend evaluating the 100-year-flood and shallow-ground-water hazards along the stream channel and existing ditch in the southeast part of the site.

- Terracon should provide supporting evidence for assigning soil site class E.

- I recommend evaluating the stability of slopes steeper than 3:1 (horizontal to vertical) and if development-induced ground water will impact slope stability.

- Setbacks from slopes, debris-basin locations, and other risk-reduction structures or hazard areas should be shown on the subdivision map.

I also recommend the following:

- The existence of the Terracon (2004) report, and subsequent reports and reviews should be disclosed to potential buyers.
- The developer should submit to Alpine City written documentation from the geotechnical consultant indicating that their recommendations were followed.

DISCUSSION

Terracon (2004) addresses flooding and debris flows, earthquake ground shaking, liquefaction, and slope instability at the proposed Heritage Hills development. In general I agree with their hazard assessment and their recommendations to reduce geologic hazards at the site but I believe that additional investigation is necessary to further address specific hazards.

Flooding and Debris Flows

To protect from flooding and debris flows in small drainages north of the site, Terracon (2004) recommends constructing debris basins above lots 17 and 22 and not constructing basements on lots 17, 18, 21, 22, and 23. Terracon (2004) provides a basin design volume range of 800 to 1,000 cubic yards and states "further exploration may be considered to provide additional information to better assess debris flow volume estimates for design purposes." This volume range appears reasonable for small drainages with moderate channel gradients and short channel lengths, but I recommend Terracon provide specific design volumes for each debris basin based on the erodible sediment stored in the channels. If the debris basins are also intended to retain flood water, the volume of potential flood water and a flood-water receiving area must be considered in basin design as recommended by Terracon (2004). I recommend showing the location of the debris basins on the site plan. Because other lots are planned below small drainages on hillslopes not protected by the debris basins, I recommend evaluating the potential for localized flooding from these drainages and slopes and providing risk-reduction measures.

Terracon (2004) states that the Federal Emergency Management Agency (FEMA) flood insurance rate map (FEMA, 1983) does not cover the entire site, but based on projections from mapped areas, the site appears to be in zone C, an area of minimal flooding. Some of the site is likely within zone C as suggested by Terracon but for flood insurance purposes the flood hazard cannot be projected outside of mapped boundaries. For site areas within mapped zone C, FEMA (1989) states that buildings in this zone could be flooded by severe, concentrated rainfall coupled with inadequate local drainage systems. Flood insurance is available in participating communities but is not a requirement by regulation in this zone. FEMA does not impose any building restrictions in zone C.

On the site plan, Terracon (2004) shows a wash and existing ditch in the southeast part of the development. The wash is a stream channel of a small drainage basin on the southwest side of the Lone Peak and Big Hollow drainage north of the site. Biek (2004) mapped stream alluvium along this drainage channel east of the site and stream alluvium (not mappable at 1:24,000 scale) also likely exists along the channel within the site. The drainage channel crosses three lots before entering the detention pond/park shown on the site plan. Because building lots are planned along this stream channel, I recommend evaluating the 100-year flood hazard and providing risk-reduction measures if necessary. If the existing ditch will remain as part of the development, I also recommend evaluating the flooding potential of the ditch.

Shallow Ground Water

Terracon (2004) did not encounter shallow ground water in test pits or the drill hole and did not further evaluate the shallow-ground-water hazard, although I believe shallow ground water may occur seasonally near the existing ditch and stream channel in the southeast part of the site. Because houses may have basements and water in the ditch or stream channel can raise ground-water levels, I recommend addressing the shallow-ground-water hazard and providing risk-reduction recommendations if necessary.

Earthquake Ground Shaking and Liquefaction

To address the hazard from earthquake ground shaking, Terracon (2004) states that site class E best represents the shallow subsurface soil profile. Terracon (2004) states soils are "interbedded layers of clay and silt, clayey sand and silty sand with gravel and cobbles" with standard penetration test blow counts per foot from 21 to refusal. Based on the *International Building Code* (IBC; International Code Council, 2002, table 1615.1.1) soils with this blow count range have properties of soil site class C or D rather than E. Therefore, I recommend Terracon provide supporting evidence for assigning soil site class E. Terracon (2004) states that the soils at the site are generally not susceptible to liquefaction and I agree.

Slope Stability

Terracon (2004) modeled the slope stability of a 50-foot high 3:1 (horizontal to vertical) (33%) slope and determined acceptable factors of safety. However based on the site plan, steeper slopes are present within the development and Terracon (2004) recommends road cuts up to 2.5:1 (40%) but no steeper. To ensure the stability of all slopes within the development, I recommend Terracon evaluate the stability of these steeper slopes. Also development is planned above slopes where development-induced ground water from landscape irrigation may influence slope stability. Therefore I recommend evaluating potential impacts of development-induced ground water on slope stability. The IBC (International Code Council, 2002) outlines drainage and terracing provisions for cut and fill slopes greater than 3:1 (33%). Because road cuts could be as steep as 2.5:1 (40%), I recommend at a minimum following the IBC drainage and terracing provisions for cut and fill slopes steeper than 3:1 (33%). I also recommend that Terracon include supporting information for slope-stability analysis in future reports.

Terracon (2004) recommends structures be set back a minimum horizontal distance equal to 1/3 the slope height from the natural unmodified slope crest. This setback recommendation complies with the foundation clearance from the top of a slope outlined in IBC figure 1805.3.1 (International Code Council, 2002) to ensure adequate lateral support. I also recommend following the IBC foundation clearance from the toe of the slopes steeper than 3:1 (33%). Based on the road and lot locations on the site plan, the road cuts and setbacks from road cuts may change the buildable area of lots 6 and 11. All setbacks should be shown on the site plan to show the buildable area of each lot.

SUMMARY OF CONCLUSIONS

Drainage-specific sediment and water volumes are needed to appropriately size the proposed debris basins. The flooding and shallow-ground-water hazards along the ditch and drainage channel in the southeast part of the site should be evaluated. To protect from earthquake ground shaking and ensure appropriate seismic design, data supporting designation of site class E should be provided. To ensure the stability of all slopes within the development, the stability of slopes steeper than 3:1 should be evaluated. An analysis of the potential impacts of development-induced ground water on slope stability is also necessary. A subdivision map should show the location of slope setbacks, debris basins, and other risk-reduction measures.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Terracon (2004) report. The Department of Natural Resources, UGS, provides no warranty that the data in the Terracon (2004) report are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Alpine City in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Biek, R.F., 2004, Interim geologic map of the Lehi quadrangle, Salt Lake and Utah Counties, Utah: Utah Geological Survey Open-File Report 416, 24 p. pamphlet, scale 1:24,000.

Federal Emergency Management Agency, 1983, Flood insurance rate maps for City of Alpine, Utah County, Utah: FIRM community panel number 490228-0005 A, scale 1:4,800.

—1989, Answers to questions about the national flood insurance program: Washington, D.C., 48 p.

International Code Council, 2002, International Building Code - 2003: Falls Church, Virginia, International Code Council, 656 p.

Terracon, 2004, Geological engineering report, proposed Heritage Hills Development, geologic hazards and slope stability exploration, Alpine, Utah: Alpine, Utah, unpublished consultant's report, 10 p., 4 appendices.

Utah Geological Survey

Project: Review of geologic-hazards report for the proposed Three Falls Ranch subdivision, Alpine, Utah			
By: Christopher B. DuRoss Gary E. Christenson	Date: October 14, 2004	County: Utah	
USGS 7.5' Quadrangles: Draper (1171) Lehi (1130)	Section/Township/Range: Section 12, T. 4 S., R. 1 E., Section 7, T. 4 S., R. 2 E., Salt Lake Base Line and Meridian.		
Requested by: Alpine City	Date report received at UGS: 09-16-04		Job number: 04-07 (R-30)

INTRODUCTION

At the request of Ted Stillman, City Administrator for Alpine City, Utah, we reviewed a geologic-hazards report for the proposed 800-acre Three Falls Ranch residential subdivision (Western GeoLogic, LLC [Western GeoLogic], 2004). The proposed subdivision is at the head of Fort Canyon near the junction of the Traverse Mountains and Wasatch Range, in section 12, T. 4 S., R. 1 E. and W1/2 section 7, T. 4 S., R. 2 E., Salt Lake Base Line and Meridian. The purpose of this review is to assess if geologic hazards potentially impacting the subdivision have been adequately identified and addressed. The scope of work for this review included examination of aerial photography and review of existing geologic reports and maps. DuRoss visited the site on April 23, 2004, with Robert Biek, Michael Hylland, and Greg McDonald (Utah Geological Survey), and Bill Black (Western GeoLogic).

CONCLUSIONS AND RECOMMENDATIONS

Western GeoLogic (2004) identified and addressed the earthquake hazards at the proposed subdivision site. We agree with most of the conclusions and recommendations made in the Western GeoLogic (2004) report regarding earthquake hazards as well as the need for additional studies to address potential stream-flooding, debris-flow, shallow-ground-water, collapsible-soil, landslide, rock-fall, and snow-avalanche hazards at the individual lots. Additional geologic and geotechnical investigations should address the geologic hazards potentially impacting the areas of high-hazard lots on figure 4 of Western GeoLogic (2004).

To more fully understand and reduce the potential geologic hazards at the site we recommend the following:

- Additional geologic and geotechnical engineering investigation(s) should address and provide recommendations to reduce, as necessary, potential landslide, debris-flow, flooding, shallow-ground-water, collapsible-soil, and liquefaction hazards.

- Appropriate geologic parameters and civil engineering design should be provided to account for shallow-ground-water, surface-water runoff, debris-flow, flood, and rock-fall hazards.

- The width of the zone of deformation and setbacks for the antithetic fault in trench 4 should be increased to the south to include the zone of faults/shears, and projected to the east and west.

- Additional trenches should be excavated and logged to more accurately locate the main fault strands and to provide evidence for/against surface faulting on the graben floor, and/or setback zones should be widened to account for widely spaced trenches. Alternatively, building footprints could be trenched prior to permitting.

- A licensed geologist(s) should also examine building foundation excavations on designated high-hazard lots located within the Fort Canyon graben for potentially active unmapped faults to ensure a lack of surface faults.

- All lots located within the subdivision should be designated as having a potential tectonic-subsidence hazard, and hazard-reduction measures should be provided, as necessary.

- A qualified snow-avalanche specialist(s) should address potential avalanche hazards at high-hazard lots.

- The Western GeoLogic (2004) report and this review should be made available to potential buyers of lots.

GEOLOGIC HAZARDS

Western GeoLogic (2004) identified and addressed earthquake hazards at the site, including the potential for ground shaking, surface fault rupture, liquefaction, and tectonic subsidence. Western GeoLogic (2004) identified and recommended additional investigations of potential stream-flooding, debris-flow, shallow-ground-water, collapsible-soil, landslide, rock-fall, and snow-avalanche hazards at the site. We agree that additional detailed geologic and geotechnical engineering evaluations are required to address these non-earthquake-related hazards.

Earthquake Hazards

Western GeoLogic (2004) considers that earthquake ground shaking may potentially impact each lot in the subdivision, and recommends design and construction of homes in accordance with appropriate building codes, and we concur.

The surface-fault-rupture hazard at the site is associated with a rupture on the graben-forming Fort Canyon fault (Bruhn and others, 1987; Machette, 1992), part of the northernmost Provo segment of the Wasatch fault (Black and others, 2003). Western GeoLogic (2004) mapped the locations of the main and antithetic faults by reviewing geologic maps (Machette, 1992; Biek, 2003) and aerial photographs, and performing fault-trench excavations. Their radiocarbon dating of bulk soil exposed by trenching indicates that the Fort Canyon fault ruptured shortly after 2700-2900 cal yr B.P., and is therefore considered a Holocene fault.

Western GeoLogic (2004) excavated seven trenches across the inferred main and antithetic traces of the Fort Canyon fault. Five of the trenches located the fault strands; two of the trenches were not long enough to expose the main fault. Setback distances were calculated following Christenson and others (2003). We agree that lots having high surface-fault-rupture hazards include those crossed by faults and setback zones for the main and antithetic fault traces. However, Western GeoLogic (2004) did not trench the entire width of the graben between the main and antithetic faults, and did not identify lots in the graben as potential high-hazard lots. Because unmapped faults having no surficial expression may exist on lots in the graben, we recommend these lots also be considered potential high-hazard lots until proven otherwise. Also, the setback distance calculated for trench 4 does not incorporate the numerous faults/shears south of the main antithetic fault. Western GeoLogic (2004) suspects a landslide origin for the deformation, but cited no conclusive evidence and provided no recommendations for risk reduction. Thus, the faults/shears could be related to surface fault rupture, so the setback zone should be widened to include the shear zone unless a landslide origin can be confirmed. The increased setback should apply to the areas of unknown fault geometry east and west of trench 4. Also, we do not recommend projecting setbacks between such widely spaced trenches along a fault that has such an indistinct surface expression. We recommend additional trenches to better define fault locations and/or wider setbacks, or lot-specific studies such as trenching of building footprints, in the fault and graben zones.

Western GeoLogic (2004) reports low liquefaction and lateral-spread ground-failure hazards for most of the site. However, shallow ground water was encountered in trenches along the north-central part of the site and Western GeoLogic (2004) assigned a high liquefaction hazard for the north-central lots based on the existence of susceptible glacial deposits. We concur with Western GeoLogic (2004) that the liquefaction potential should be evaluated and addressed in a separate geotechnical engineering evaluation prior to construction.

We agree with Western GeoLogic (2004) that the area between the two major graben-bounding faults is most susceptible to tectonic subsidence, but also consider all lots south of the main trace of the Fort Canyon fault as being susceptible to some amount of subsidence in the event of a surface-faulting earthquake on the fault. However, Western GeoLogic (2004) mapped only those lots immediately adjacent to the fault traces as high-hazard lots, and provided no recommendations regarding hazard reduction.

Other Geologic Hazards

Other geologic hazards identified at the site include debris flows, stream flooding, shallow ground water, collapsible soil, landslides, rock fall, and snow avalanches. Holocene stream and alluvial-fan deposits mapped within the site (Biek, 2003) indicate areas of potentially high debris-flow, flooding, shallow-ground-water, and collapsible-soil hazards. To address flooding and debris-flow hazards, Western GeoLogic (2004) estimated single-event sediment volumes for individual drainages using various bulking rates, and recommends using a 5 cubic yards/linear foot rate. Western GeoLogic (2004) also estimated maximum sediment volumes for six geologic units based on various flow thicknesses and coverage percentages, and recommends preferred values of 3 feet and 30%, respectively. However, the units include multiple alluvial fans and/or non-debris-flow deposits (e.g., stream alluvium and colluvium). We recommend that the sediment volume estimates be used with the appropriate hydrologic parameters to evaluate flooding and debris-flow hazards for each individual drainage and alluvial fan, and to develop civil-engineering design of risk-reduction measures for the subdivision.

Significant landslide deposits on Tertiary alluvial-fan deposits (Biek, 2003), and a possible landslide-related shear zone in trench 4 indicate an important slope-failure hazard. Western GeoLogic (2004) identified and briefly addressed the landslide hazard; however, detailed geologic and geotechnical analyses are necessary to quantify and reduce the hazard, as necessary.

We agree that civil engineering design, based on appropriate geologic parameters, should address both the shallow-ground-water and rock-fall hazards. We also support the need for further geologic and geotechnical engineering evaluations to investigate and/or reduce potential landslide, shallow-ground-water, snow-avalanche, collapsible-soil, and liquefaction hazards prior to construction.

SUMMARY

We reviewed the Western GeoLogic (2004) report on the potential geologic hazards at the proposed Three Falls Ranch subdivision to assess whether the geologic hazards have been adequately identified and addressed. Potential hazards impacting the subdivision include earthquake-related hazards, debris-flows and flooding, landslides, shallow ground water, collapsible soil, rock fall, and snow avalanches.

Of the potential earthquake-related hazards, Western GeoLogic did not adequately address the potential for surface fault rupture and tectonic subsidence, and thus we recommend the following:

- The width of the setback zones for the antithetic fault in trench 4 should be increased to include the zone of faults/shears, and projected to the east and west.

- Additional trenches along the main and antithetic fault traces and across the graben floor should be excavated and logged, and/or wider setback zones should account for widely spaced trenches, or building footprints should be trenched prior to permitting.

- A licensed geologist(s) should examine building foundation excavations on high-hazard lots within the Fort Canyon graben for potentially active unmapped faults.

- All lots located within the subdivision should be designated as having a potential tectonic-subsidence hazard, and hazard-reduction measures should be provided, as necessary.

Western GeoLogic (2004) identified and recommended additional studies for other geologic hazards affecting the subdivision. We agree and recommend the following additional investigations to fully address the geologic hazards in areas of high-hazard lots:

- Multi-lot investigations should address and recommend risk-reduction measures, as necessary, for areas having high landslide, debris-flow, flooding, shallow-ground-water, collapsible-soil, and liquefaction hazards.

- Additional investigations should provide appropriate geologic parameters and civil engineering design to account for shallow-ground-water, surface-water-runoff, debris-flow, flood, and rock-fall hazards.

- A qualified snow-avalanche specialist(s) should address potential avalanche hazards at high-hazard lots.

REFERENCES

Biek, R.F., 2003, Interim geologic map of the Lehi and Jordan Narrows quadrangles, Salt Lake and Utah Counties, Utah: Utah Geological Survey Open-File Report 415/416, scale 1:24,000, 24 p.

Black, B.D., Hecker, S. Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:500,000, compact disc.

Bruhn, R.L., Gibler, P.R., and Parry, W.T., 1987, Rupture characteristics of normal faults–an example from the Wasatch fault zone, Utah, *in* Coward, M.P., Dewey, J.F., and Hancock, P.L., editors, Continental extensional tectonics: Geological Society Special Publication No. 28, p. 337–353.

Christenson, G.E., Batatian, L.D., and Nelson, C.V., 2003, Guidelines for evaluating surface-fault-rupture hazards in Utah: Utah Geological Survey Miscellaneous Publication 03-6, 16 p.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–2095, scale 1:50,000.

Western GeoLogic, LLC, 2004, Report, geologic hazards evaluation, Three Falls Ranch proposed subdivision, Alpine City, Utah: Salt Lake City, Utah, unpublished consultant's report, 25 p.

Project: Review of "Engineering geology/geotechnical study, Quail Ridge Estates, Skyline Drive and Quail Ridge Drive, Ogden, Utah"			
By: Greg N. McDonald	Date: November 26, 2004	County: Weber	
USGS Quadrangles: Ogden	Section/Township/Range: Section 10, T. 5 N., R. 1 W.		
Requested by: Rick Grover, Ogden City Planning	Date report received at UGS: October 27, 2004		Job number: 04-08 (R-31)

INTRODUCTION

I reviewed parts of engineering geology/geotechnical reports for the above-referenced site by Earthtec Testing and Engineering, P.C. (Earthtec) (2004) that include a surface-fault-rupture-hazard study by Western GeoLogic (2003) and an engineering geology/geotechnical report by Sergent, Hauskins, & Beckwith (SHB) (1992). I also reviewed earlier reports/memoranda by Dames & Moore (1987a, 1987b) and EarthStore (1987, 1988) and associated review comments by the former Weber County geologist (Lowe, 1987a, 1987b, 1988a) and Ogden City Planning (Montgomery, 1987). In addition, I conducted a literature review and examined 1985 1:24,000-scale aerial photos. The purpose of the review is to determine whether geologic hazards have been adequately addressed at the site. I did not review the reports with respect to engineering aspects, and recommend a qualified geotechnical engineer review such report sections.

CONCLUSIONS AND RECOMMENDATIONS

After reviewing the above-referenced reports for the Quail Ridge Estates subdivision, my conclusions and recommendations regarding geologic hazards at the site are presented below.

- Earlier conclusions and recommendations by the former Weber County geologist to assess, reduce, and disclose rock-fall hazards at lots east of Spring Drive should be followed.

- Earthtec's recommendation for lot-specific slope-stability investigations for development along the western part of the site should be followed, although the location of the study-area boundary should be re-assessed pending results of the study of the landslide in the area. Also, the final zone depicted for lot-specific study by Earthtec should be shown on a to-scale map (map in report is not to scale).

- Slope-stability characterization of the steeper slope at the northeast part of the site is needed if development is planned there.

- If construction will occur in the area west of Western GeoLogic's westernmost trench and along the southern edge of the property, additional trenching is needed to characterize the surface-fault-rupture hazard there.

- A more comprehensive analysis of alluvial-fan-flooding and debris-flow hazards at the site is needed given mapped Holocene alluvial fans and debris-flow deposits identified in trenches by Western GeoLogic (2003).

DISCUSSION

After reviewing the above-referenced reports for the Quail Ridge Estates subdivision, I believe geologic hazards associated with rock falls, slope instability, surface fault rupture, and debris flows warrant further evaluation.

Rock Fall

Regarding rock-fall hazards at the site, Earthtec refers to the 1992 study by SHB, which in turn refers to several earlier studies and discussions by Dames & Moore/EarthStore performed in 1987 and 1988. Mike Lowe, the Weber County geologist at that time, reviewed the Dames & Moore and EarthStore reports and agreed with the consultant's conclusions that:

> "1) Some of the boulders, especially in the eastern portion of the site, have been deposited by rock-fall activity; 2) very few of the boulders appear to show any signs of fairly recent rock-fall deposition (within the last 50 – 100 years); 3) the dense growth of scrub oak and other deciduous trees on the east side of the extension of Spring Drive appear to have been very effective in restricting rock-fall material from passing over the lower portions of the site; and 4) although residential lots, especially on the east side of the extension of Spring Drive, will not be totally free of rock-fall hazard, risk levels will be extremely low." (Lowe, 1987b)

Additionally, the Weber County geologist recommended development-siting guidelines that include:

> "1) Placement of structures outside of areas of potential rockfall "chutes"; 2) advantageous usage of site-specific topography; 3) maintenance of as much heavy vegetation as possible, particularly trees, east of proposed structures; and 4) site-specific grading plans, which may include benches, small retaining walls, reverse slopes, low-visibility low-height fences, etc., to reduce the possibility of rockfall damage to homes." (Lowe, 1988a)

EarthStore also recommended each lot owner submit site-specific plans showing how the rock-fall hazard will be mitigated and that the potential rock-fall hazard be disclosed to future homeowners. The Weber County geologist (Lowe, 1988a) recommended that these guidelines be applied to "at least those lots on the east side of the proposed extension of Spring Drive," and I concur.

A later report by SHB (1992), which was not reviewed by the Weber County geologist or UGS, acknowledges conclusions and recommendations from the prior studies and reviews and adds:

> "… in our opinion, it can be concluded that even during a major earthquake, rockfall or rock slides have not been a significant factor at the site."

And regarding rock-fall-hazard mitigation:

> "…homes on the east and far eastern side of the site should be constructed in close proximity to the east side of the extension of Spring Drive," and "mitigation measures such as construction of large berms upgradient from the homes, construction of rockfall fences, etc., should not be initiated. It is our opinion that they would be ineffective and would possibly do more environmental harm than good."

I agree with the conclusion that rock falls are likely a low-frequency event at the site, but reiterate that evidence indicates the eastern part of the site has experienced rock falls and a hazard exists that can be reduced to an acceptable level through appropriate building siting and landscaping on lots east of Spring Drive.

Slope Stability

Both Earthtec (2004) and SHB (1992) identify a landslide in the western part of the property, but neither adequately characterizes the landslide or addresses its stability. If this feature is a landslide, it has implications regarding the slope-stability analysis by Earthtec (2004). I recommend the landslide be mapped and characterized with appropriate subsurface investigations, and the results be used to re-evaluate the area requiring additional study shown on figure 2 of the Earthtec report. At present, the main scarp of the landslide is east and outside of the area of recommended additional study, indicating the area may not extend far enough to the east. Also, the final area recommended for additional study should be shown on a to-scale site-specific map (map in report not to scale) to facilitate site planning and comparison to slope-stability modeling results.

The northeast part of the site consists of a steeper, colluvium-covered slope above the Lake Bonneville shoreline bench. The hillside has been mapped as a possible older landslide mass (Yonkee and Lowe, 2004) and colluvium derived from Precambrian-age Farmington Canyon Complex (Nelson and Personius, 1993). Mapping suggests that soil on the slope likely contains clayey soils that may be prone to slope instability and/or high shrink/swell potential. SHB (1992) indicates slopes of up to 32 degrees (62%) are present in this part of the site but does not have any information on soil depth and type. I believe further evaluation of the northeast part of the development is warranted given the steepness of the slopes, mapped landslides, and likely need for extensive grading to establish building pads on these lots.

Surface Fault Rupture

Western GeoLogic's surface-fault-rupture study characterizes the hazard at the site except for west of the westernmost trench and along the southern edge of the property. Additional trenching will be needed to the west if any homes are to be placed west of the existing trenches. It should be noted that this steep area is also within the zone delineated by Earthtec recommended for more detailed slope-stability analysis. Also, at least the southern part of lots along the southern edge of the property are within Weber County's surface-fault-rupture-hazard special-study area (Lowe, 1988b). If houses are planned on parts of the lots within the special-study area, a north-south-oriented trench south of the existing trench alignment is advisable.

Debris Flow

SHB (1992) recommendeds a thorough evaluation of "the potential of flash floods/debris flows" at the site and I concur. Earthtec performed only a reconnaissance-level debris-flow-hazard evaluation and indicates no evidence of recent deposition was observed. However, a more detailed debris-flow-hazard evaluation is warranted given that Holocene-age alluvial fans are mapped on the site (Nelson and Personius, 1993; Yonkee and Lowe, 2004), and Western GeoLogic's eastern and central trench logs show that nine distinct, thick debris-flow units overlie Lake Bonneville near-shore sediments. Also, the nearly horizontal, apparently erosionally truncated nature of the debris-flow deposits in the trench is enigmatic; typically bedding parallels the ground surface in post-Bonneville alluvial fans. A more comprehensive debris-flow-hazard evaluation should include appropriate site-scale mapping of alluvial-fan deposits, debris-flow volume and frequency estimates, and appropriate risk-reduction measures, if necessary.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Earthtec (2004). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Ogden City in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Dames & Moore, 1987a, Supplemental report, rock fall considerations, proposed Spring Valley subdivision, east of Beus Reservoir, Ogden, Utah, for C.R. England & Sons: Salt Lake City, unpublished consultant's report, 8 p.

--- 1987b, Interim report, geotechnical and geoseismic study, proposed Oakview Estates and Spring Valley subdivision plats, east and east-southeast of Beus Reservoir, Ogden, Utah, for C.R. England & Sons: Salt Lake City, unpublished consultant's report, 6 p.

EarthStore, 1987, Discussions, site of proposed residential structure, two northerly-most lots, Spring Valley subdivision, Ogden, Utah, for C.R. England & Sons: Salt Lake City, unpublished consultant's letter report, 3 p.

--- 1988, Discussions, geotechnical studies, proposed residential structures, proposed Spring Valley subdivision, Ogden, Utah, for C.R. England & Sons: Salt Lake City, unpublished consultant's letter report, 5 p.

Earthtec Testing and Engineering, P.C., 2004, Engineering geology/geotechnical study, Quail Ridge Estates, Skyline Drive and Quail Ridge Drive, Ogden, Utah: Ogden, unpublished consultant's report, 18 p.

Lowe, M., 1987a, Summary of meeting at site of proposed Spring Valley subdivision: Weber County Planning Commission memorandum, 1 p.

--- 1987b, Review of supplemental report, rock fall conditions, proposed Spring Valley subdivision: Weber County Planning Commission memorandum, 2 p.

--- 1988a, Review of EarthStore (1988) report concerning the proposed Spring Valley subdivision: Weber County Planning Commission memorandum, 2 p.

--- 1988b, Potential surface fault rupture sensitive area overlay zone – Ogden quadrangle: Davis and Weber Counties Planning Department unpublished maps, scale 1:24,000.

Montgomery, G., 1987, Re: Reports on proposed residential structures on Spring Valley subdivision, Ogden, Utah: Ogden City Community Development memorandum, 2 p.

Nelson, A.R., and Personius, S.P., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Map I-2199, 22 p., 1 plate scale 1:50,000.

Sergent, Hauskins, & Beckwith, 1992, Report, engineering geology/geotechnical study, proposed Quail Ridge subdivision, located approximately three-eights of a mile southeast of Beus Reservoir, Ogden, Utah: Salt Lake City, unpublished consultant's report, 27 p.

Western GeoLogic, L.L.C., 2003, Surface fault rupture hazard analysis report, proposed Quail Ridge Estates subdivision, Ogden, Utah: Salt Lake City, unpublished consultant's report, 12 p.

Yonkee, W.A., and Lowe, M., 2004, Geologic map of the Ogden 7-1/2 minute quadrangle: Utah Geological Survey Map M-200, 42 p., 1 plate scale 1:24,000.

Utah Geological Survey

Project: Review of geotechnical and geologic-hazards-reconnaissance reports for the Hill/Athay (Silver Leaf Estates) subdivision, South Weber, Utah			
By: Richard E. Giraud, P.G.	Date: 12-10-04	County: Davis	
USGS Quadrangles: Kaysville (1320)	Section/Township/Range: NE1/4 section 2, T. 4 N., R. 1 W.		
Requested by: Boyd Davis, South Weber City Engineering	Date report received at UGS: 11-18-04		Job number: 04-09 (R-32)

INTRODUCTION

I reviewed the geologic parts of a geotechnical report by Earthtec Testing and Engineering, P.C. (Earthtec, 2004) and a geologic-hazards-reconnaissance report by Western GeoLogic, LLC (Western GeoLogic, 2004) for the Hill/Athay (Silver Leaf Estates) subdivision at approximately 2550 East 8300 South in South Weber. Reeve and Associates Inc. (2004) show the lot layout on a subdivision plat. The Earthtec (2004) geotechnical report includes the geologic-hazards report by Western GeoLogic. For this review, I studied relevant geologic literature and examined 1:20,000-scale (1937) and 1:24,000-scale (1985) aerial photographs. The purpose of my review is to assess whether geologic hazards are adequately addressed at the site. I did not review the geotechnical engineering aspects of the reports.

CONCLUSIONS AND RECOMMENDATIONS

I believe Earthtec (2004) and Western GeoLogic (2004) adequately address some geologic hazards at the site but additional investigations are necessary to fully address certain potential hazards. I have the following comments and recommendations:

- A site-specific geologic map showing landslides and related features at a scale appropriate for subdivision planning (approximately 1:1,000) is needed to provide a basis for delineating and evaluating landslide hazards. The map should not be merely an enlargement of previous geologic mapping at scales of 1:24,000 or smaller. Geologic interpretations of the origin and nature of material encountered in test pits should also be provided for evaluating landslide hazards.

- Consideration of landslide type (flow vs. rotational slide; shallow vs. deep), as well as the possibility of earthquake-induced landsliding, should be incorporated into the slope-stability analysis. The Earthtec analysis considers only deep-seated rotational failures in dry material; geologic conditions at the site indicate flow-type landslides have also occurred in the past.

- Drilling in the slope bordering the site to the south is necessary to characterize subsurface stratigraphy, soil strength, and ground-water levels in the landslide source area to adequately assess slope stability and the likelihood of future landslides.

- I agree with Earthtec's (2004) conclusion that liquefaction may impact the site and drilling is necessary to obtain information for liquefaction analysis. I recommend review of the liquefaction evaluation by a geotechnical engineer. The results of the liquefaction analysis should be considered in the site-specific detailed landslide investigation.

- Because a rise in ground-water levels can increase the landslide and liquefaction potential, I recommend considering climatic and development-induced ground-water conditions in the landslide and liquefaction analyses.

- To address earthquake ground shaking, the geotechnical consultant must determine the appropriate IRC seismic design category for the site.

- I agree with Western Geologic's (2004) grading recommendation to reduce flood and debris-flow hazards. Lot-specific grading recommendations should be shown on a subdivision grading plan along with a designated surface-water runoff and sediment receiving area.

- All setbacks and hazard areas should be shown on a subdivision map.

- Because the lot numbering and lot and street layouts have changed on the most recent subdivision plat (Reeve and Associates Inc., 2004), Earthtec and Western GeoLogic must update their lot-specific recommendations.

I also recommend the following:

- A qualified geotechnical engineer should review geotechnical engineering aspects of the report.

- The existence of the Earthtec (2004) and Western GeoLogic (2004) reports, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultants are followed, the developer should submit to South Weber written documentation from the consultants indicating that their recommendations were followed.

DISCUSSION

Earthtec (2004) and Western GeoLogic (2004) list landsliding, earthquake ground shaking, liquefaction, flooding, and debris flows as potential hazards at the subdivision. The report adequately addresses flooding and debris-flow hazards. I believe additional investigations are needed to fully address the other potential geologic hazards at the site.

Landslide Hazard

Western GeoLogic (2004) states that the subdivision lies on mapped landslide deposits (Nelson and Personius, 1993). The Davis County Planning Department slope failure inventory map (Lowe, 1988a, landslide LS335) and nearby mapping at the North Davis County Landfill also show landslide deposits underlying most of the site (Lowe, 1988b). Western GeoLogic (2004) excavated trenches into landslide deposits at the site and suggested a possible earthquake-induced flow-landslide origin for the deposits. Western GeoLogic (2004) states that because slopes south of the site have experienced instability, the risk from landslides is moderate to high and the stability of the slopes should be evaluated in a geotechnical-engineering evaluation.

Earthtec (2004) evaluated the static and seismic slope stability of the southern slope and determined that the slope was marginally stable in a drained dry condition (no ground water in the slope). Earthtec (2004) states that slope stabilization is likely cost prohibitive and recommends that structures be placed 20 feet from slope gradients 30% or greater to prevent slope failures from impacting proposed houses. The justification for the 20-foot setback is not clear, but appears to consider only rotational-type failure in dry soils with no downslope effects or transition to soil flow. Earthtec (2004) does not evaluate the potential for flow-type landsliding as recommended by Western GeoLogic (2004). Prehistoric landslides of this type likely transported material as far as the north edge of the property (much farther downslope than the 20-foot building setback recommended by Earthtec). Even though Earthtec (2004) logged test pits in the landslide deposits in the flatter northern part of the site, they do not provide geologic descriptions of any landslide features or deposits, or discuss the origin of the deposits. Also, they did not determine slope-failure conditions in the steeper source area (ground water, soil strength, stratigraphy, earthquake ground shaking) for the landslides. Therefore, I believe the moderate to high risk of landsliding described by Western GeoLogic (2004) has not been adequately addressed.

A site-specific detailed landslide investigation is needed to assess the safety of placing houses on or near pre-existing landslides and marginally stable slopes. The site is within the Davis County Planning Department landslide special-study area (Lowe, 1988c) where detailed landslide studies are recommended (Robison and Lowe, 1993). Pashley and Wiggins (1972) recognized both rotational and flow landslides in the South Weber and Washington Terrace landslide complexes bordering the Weber River northwest of this site. A large rotational slump and earthflow occurred in 1981 northwest of the site (Gill, 1981) in the bluff north of the Weber River. Shallow landsliding northwest and west of this site in 1998 occurred along the Davis-Weber canal (Black, 1999) and above the Cedar Bench subdivision (Solomon, 1999) in South Weber. Flow-type landslides similar to those that likely formed the scallops in the slope south of the site were common elsewhere in the area in 1983 and 1986 (Lowe, 1988d,e; Lowe and others, 1992). All of the above landslides involved failure of Lake Bonneville Weber River delta sediments and demonstrate the susceptibility of these slopes to landsliding.

Given the landslides mapped at the site and recent landsliding in the vicinity, I recommend mapping the surficial geology of the site and showing all landslides (deposits and source areas), landslide features, and other surficial geologic units on a large-scale site map for site planning and slope-stability investigation. I recommend a detailed geotechnical-engineering slope-stability investigation, as outlined in Hylland (1996), of the slope along the south part of the site to determine the stratigraphy, ground-water depth, and soil-strength parameters to assess types and likelihood of future landslides. Drilling and sampling are necessary to characterize subsurface stratigraphy and soil strengths. Piezometers should be installed to monitor ground-water levels. Estimated climatic and development induced rises in ground-water levels should be used in the analysis. The Utah Geological Survey (UGS) has preliminary data available for ground-water-level fluctuations in landslides in Davis County. To gain an understanding of subsurface stratigraphy and ground-water levels outside of the subdivision, I recommend reviewing water-well records (Utah Division of Water Rights, 2004). Consideration of landslide type (flow vs. rotational slide; shallow vs. deep), as well as the possibility of earthquake-induced landsliding, should be incorporated into the slope-stability analysis.

Liquefaction and Earthquake Ground Shaking Hazards

Earthtec (2004) states that the site is in an area classified as having a low potential for liquefaction (Anderson and others, 1982). However, Earthtec (2004) also states that sand lenses at the site may be susceptible to liquefaction and settlement during a strong seismic event and that drilling would be necessary to evaluate liquefaction. I recommend evaluating the liquefaction hazard using existing soil conditions and estimated climatic and development-induced rises in ground-water levels. The *International Building Code* (IBC; International Code Council, 2002) grading appendix J also requires a liquefaction study for sites having mapped maximum earthquake short-period accelerations greater than 0.5 *g*, which applies to this subdivision. I recommend review of the liquefaction hazard analysis by a geotechnical engineer.

To address the hazard from earthquake ground shaking, Earthtec (2003) states, "The IRC designates this area as site class E." Based on figure 301.2(2) in the *International Residential Code* (IRC; International Code Council, 2003), the site may be in seismic design category E, but probably not site class E. The IRC does not assign site classes. To protect from earthquake ground shaking, the appropriate IRC seismic design category must be determined.

Flood and Debris-Flow Hazards

Western GeoLogic (2004) states that part of the site is on a small alluvial fan, and that to reduce the risk from flooding and debris flows from a small drainage south of the site, lots 45, 46, and 47 should be graded to deflect potential flood water and debris flows away from building pads. I concur and recommend showing lot-specific grading recommendations and a receiving area for surface-water runoff and sediment on a subdivision grading plan.

SUMMARY OF CONCLUSIONS

Earthtec (2004) determined marginal stability for the slope they analyzed and recommended a setback to protect houses. However, Earthtec does not include the mapped landslides or consider landslide type (flow vs. rotational slide, shallow vs. deep) in their analysis of slope stability. Therefore, I believe additional landslide-hazard investigation is necessary to ensure safe development, including a site-specific surficial geologic map to show all landslides (deposits and source areas) and landslide features. A detailed geotechnical-engineering slope-stability investigation is needed to evaluate the stability of landslides and slopes along the south edge of the property. The locations and features of mapped landslides, geologic information from test pits, and subsurface stratigraphy, soil strengths, and ground-water levels should be incorporated into the slope-stability analysis to realistically evaluate landslide stability. Climatic and development-induced changes in ground-water levels should also be considered.

Earthtec (2004) was unable to complete a liquefaction hazard evaluation and recommends further subsurface investigation to evaluate this hazard. To protect from earthquake ground shaking, the appropriate IRC seismic design category must be determined.

Adequate recommendations are provided for flood and debris-flow hazards but lot-specific grading recommendations and a surface-water runoff and sediment receiving area should be provided on a subdivision grading plan.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Earthtec (2004) and Western Geologic (2004) reports. The Department of Natural Resources, UGS, provides no warranty that the data in the Earthtec (2004) and Western Geologic (2004) reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid South Weber in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Anderson, L.R., Keaton, J.R., Aubrey, Kevin, and Ellis, S.J., 1982, Liquefaction potential map for Davis County, Utah: Logan, Utah State University Department of Civil and Environmental Engineering and Dames and Moore unpublished Final Technical Report prepared for the U.S. Geological Survey, National Earthquake Hazards Reduction Program Award No. 14-08-0001-19127, 50 p.; published as Utah Geological Survey Contract Report 94-7, 1994.

Black, B.D., 1999, Reconnaissance of a landslide along the Davis-Weber canal near 1250 East South Weber Drive, South Weber, Davis County, Utah, *in* McDonald, G.N., compiler, Technical reports for 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 36-41.

Earthtec Testing and Engineering, P.C., 2004, Geotechnical study, Hill/Athay property, 2550 East 8300 South, South Weber, Utah: Ogden, Utah, unpublished consultant's report, 14 p.

Gill, H.E., 1981, Geologic investigation of a major slope failure in the Washington Terrace landslide complex near the mouth of Weber Canyon, Weber County, Utah: Utah Geological and Mineral Survey Report of Investigation 163, 18 p.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

International Code Council, 2002, International Building Code - 2003: Falls Church, Virginia, International Code Council, 656 p.

—2003, International Residential Code for One- and Two-Family Dwellings - 2003: Falls Church, Virginia, International Code Council, 604 p.

Lowe, M., 1988a, Natural hazards overlay zone – slope failure inventory, Kaysville quadrangle: Davis County Planning Department unpublished map, scale 1:24,000.

—1988b, Geology and geologic hazards, North Davis Refuse District disposal site area, Davis County, Utah, *in* Black, B.D., and Christenson, G.E., compilers, Technical reports of the Wasatch Front county geologists, June 1985 to June 1988: Utah Geological and Mineral Survey Report of Investigation 218, p. 35-67.

—1988c, Natural hazards overlay zone – landslide hazard map, Kaysville quadrangle: Davis County Planning Department unpublished map, scale 1:24,000.

—1988d, Report of geologic reconnaissance – landslide southwest of Gibbons and Reed Co. north pond, west of Uintah, Weber County, *in* Black, B.D., and Christenson, G.E., compilers, Technical reports of the Wasatch Front county geologists, June 1985 to June 1988: Utah Geological and Mineral Survey Report of Investigation 218, p. 76-79.

—1988e, Gentile Street landslide, *in* Black, B.D., and Christenson, G.E., compilers, Technical reports of the Wasatch Front county geologists, June 1985 to June 1988: Utah Geological and Mineral Survey Report of Investigation 218, p. 6.

Lowe, M., Black, B.D., Harty, K.M., Keaton, J.R., Mulvey, W.E., Pashley, E.F., Jr., and Williams, S.R., 1992, Geologic hazards of the Ogden area, Utah, *in* Wilson, J.R. editor, Field guide to geologic excursions in Utah and adjacent areas of Nevada, Idaho, and Wyoming, prepared for the Geological Society of America, Rocky Mountain Section Meeting in Ogden, Utah: Utah Geological Survey Miscellaneous Publication 92-3, p. 231-285.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2199, 22 p. pamphlet, scale 1:50,000.

Pashley, E.F., Jr., and Wiggins, R.A., 1972, Landslides of the northern Wasatch Front, *in* Hilpert, L.S., editor, Environmental geology of the Wasatch Front, 1971: Utah Geological Association Publication 1, p. K1-K16.

Reeve and Associates Inc., 2004, Slope analysis, Silver Leaf Estates subdivision, South Weber, Utah: Ogden, Utah, unpublished consultant's map, scale 1:960.

Robison, R.M., and Lowe, M., 1993, Landslide hazards; a guide for land-use planning, Davis County, Utah, *in* Gori, P.L., editor, Applications of research from the U.S. Geological Survey program, Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1519, p. 129-137.

Solomon, B.J., 1999, Reconnaissance of a landslide near the Cedar Bench subdivision, South Weber, Davis County, Utah, *in* McDonald, G.N., compiler, Technical reports for 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 42-49.

Utah Division of Water Rights, 2004, Water well logs: Online, <http://www.waterrights.utah.gov/wellinfo/ugs.htm>, accessed November 26, 2004.

Western GeoLogic, LLC, 2004, Geologic hazards reconnaissance, proposed Hill-Athey subdivision, South Weber, Davis County, Utah: Salt Lake City, Utah, unpublished consultant's report, 14 p.

Utah Geological Survey

Project: Review of "Geotechnical and geological study, Valley Vistas, Provo, Utah"			
By: F.X. Ashland, P.G.	Date: March 17, 2005	County: Utah	
USGS Quadrangles: Provo (1047)	Section/Township/Range: Sec. 5, T. 7 S., R. 3 E.		
Requested by: David Graves, Provo City Engineering Department	Date report received at UGS: February 2, 2005		Job number: 05-01 (R-33)

INTRODUCTION

The Utah Geological Survey (UGS) reviewed geological aspects of a geotechnical and geological report (Earthtec Testing & Engineering, P.C. [Earthtec], 2005) for the proposed Valley Vistas senior living center in eastern Provo. Proposed buildings are assumed to be IBC residential building occupancy R class. The report assessed various potential geologic hazards at the site including surface faulting, rock falls, alluvial-fan flooding and debris flows, liquefaction, and earthquake ground shaking and deformation. For the review, I studied relevant geologic literature (Machette, 1992) and examined aerial photographs (early 1970s, scale 1:16,000), but conducted no field inspection of the site. The purpose of the review is to assess whether the report adequately addresses potential geologic hazards at the site.

CONCLUSIONS AND RECOMMENDATIONS

- Liquefaction and earthquake ground shaking (IBC site class) are adequately addressed.

- The UGS recommends rock-fall and debris-flow mitigation measures, as needed, to reduce risks to an acceptable level for the proposed use.

- Additional fault investigations along the northern and western edges of the property, and/or appropriately conservative setbacks based on assumed fault locations, are needed.

- Earthtec's foundation concerns and cautionary statements regarding construction on deep, loose fill at the site are important to consider; foundation recommendations should be reviewed by a qualified geotechnical engineer.

DISCUSSION

Earthtec (2005) adequately assesses the liquefaction and earthquake ground-shaking (IBC site class) potential at the site, but additional geological investigation is required to evaluate surface faulting. In addition, Earthtec's assessment of the rock-fall potential was limited because they did not consider that fill at the site and development directly to the south on the Utah State Hospital grounds prevents the inventory of rock-fall clasts in the area and assessment of the run-out area. Based on the proposed use of the site as a senior living center, the UGS recommends that both rock-fall and debris-flow hazard mitigation structures be incorporated into the design of the facility to reduce the risk from these hazards to the lowest acceptable level. We do not recommend that risks just be accepted as indicated by Earthtec.

With regard to surface faulting, Earthtec's (2005) assessment of the fault zone on the east edge of the site and the proposed building setback zone appear adequate. However, Earthtec's trenching solely on the southern part of the site does not preclude fault traces that may extend onto the property from the north. In addition, a topographic break in slope along the west edge of the site is approximately continuous with mapped faults to the north, near a possible fault by URS/Dames & Moore (2001), and needs to be investigated for surface faulting. Earthtec's (2005) assessment of URS/Dames & Moore (2001) fault mapping did not take into account the scale of their mapping (1:19,000) and possible location errors associated with it. Surface faulting studies on the property directly to the north of this site (Earthtec, 2002) suggest that another mapped fault trace may also cross onto the site. The UGS recommends:

- trenching near the northern edge of the site to evaluate the potential for additional faults,

- extension of trench 2 (if fill depth shallows) and any new northern trench(es) to the western edge of the property to assess the nature of the break in slope,

- alternate subsurface explorations such as shallow geophysics, as necessary, to study the possible fault origin of the western break in slope, including possibly on offsite locations, or

- other subsurface investigations, determined by the consultant, to address this issue.

In the event that additional subsurface investigations are not feasible or inconclusive, an alternative is to assume that the western break in slope is a fault and estimate appropriate building setbacks for site design purposes. In the absence of further surface-faulting investigations as recommended by the UGS, at a minimum foundation excavations should be inspected for possible faults and documented in a report by a qualified professional geologist. However, the developer and Provo City should recognize and accept that unexpected faults within building footprints may require last-minute changes to site design and could preclude the construction of individual structures at desired locations. In general, the UGS does not recommend this option.

Earthtec (2005) concludes that westward tilting of Lake Bonneville sediments in their trenches is due to tectonic deformation and speculates that structural damage could occur in a future surface-faulting earthquake. Earthtec's geologic interpretation is reasonable and these tilted beds suggest possible additional faults to the west of the trenches. The UGS cautions Provo City to closely evaluate the statements in the Earthtec (2005) report regarding the likely condition (usability) of buildings on the site following a surface-faulting earthquake, particularly considering the proposed use as a senior living center.

Finally, Earthtec (2005) identified deep, locally loose fill on the site and recommended various foundation options that should be reviewed by a qualified geotechnical engineer. Earthtec's (2005) pavement design recommendation is accompanied by a cautionary statement that it does not preclude differential settlement caused by the deeper fill. Provo City should carefully review Earthtec's comments regarding the potential impact of the fill on pavement performance and also consider its implication to long-term performance and appearance of landscaping and sidewalk areas.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Earthtec (2005) report. The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the Earthtec (2005) report are correct and accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Provo City in assessing and reducing the risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Earthtec Testing & Engineering, P.C., 2002, Geologic hazard study, Foothill Park, Provo, Utah: Orem, Utah, unpublished consultant's report, 25 p.

------2005, Geotechnical and geological study, Valley Vistas, Provo, Utah: Orem, Utah, unpublished consultant's report, 26 p.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, 26 p. pamphlet, scale 1:50,000.

URS/Dames & Moore, 2001, Phase I geologic evaluation and Phase V geological hazards map update, Sherwood Hills subdivision-wide studies and update of Provo City geologic hazard maps: Salt Lake City, Utah, unpublished consultant's report, 33 p.

Utah Geological Survey

Project: Review of geotechnical and geologic-hazards evaluation for the Nalder subdivision, Layton, Utah			
By: Richard E. Giraud, P.G.	Date: 04-26-05	County: Davis	
USGS Quadrangles: Kaysville (1320)	Section/Township/Range: SW1/4 section 10, T. 4 N., R. 1 W., SLBLM		
Requested by: Kem Weaver, Community Development Department	Date report received at UGS: 02-02-05		Job number: 05-04 (R-34)

INTRODUCTION

I reviewed the geologic parts of a geotechnical report by Earthtec Testing and Engineering, P.C. (Earthtec, 2004) and a geologic-hazards-evaluation report by Western GeoLogic, LLC (Western GeoLogic, 2004) for the Nalder subdivision at 2200 North Church Street in Layton. The Earthtec (2004) geotechnical report includes the geologic-hazards report by Western GeoLogic as an appendix. For this review, I studied relevant geologic literature and geologic reports for sites in the area, and examined 1:20,000-scale (1937), 1:10,000-scale (1958), and 1:24,000-scale (1985) aerial photographs. The purpose of my review is to assess whether geologic hazards are adequately addressed at the site. I did not review the geotechnical engineering aspects of the reports.

CONCLUSIONS AND RECOMMENDATIONS

I believe Earthtec (2004) and Western GeoLogic (2004) adequately address geologic hazards at the site except for landsliding, flooding, and earthquake ground shaking. I have the following comments and recommendations:

- Earthtec (2004) and Western GeoLogic (2004) do not identify or consider implications of landslides along the east boundary of the site. The scarp trenched by Western GeoLogic is likely the main scarp of a landslide identified by AGEC (2003) directly downslope.

- A site-specific geologic map showing landslides and related features on and east of the site at a scale appropriate for subdivision planning (approximately 1:1,000) is needed to provide a basis for delineating and evaluating landslide hazards.

- An analysis of landslide stability that considers soil strengths, ground-water conditions, and slope-stability results measured east of the site is needed to estimate setbacks from landslides and outline buildable and nonbuildable areas along the east edge of the property.

- Western GeoLogic (2004) should clarify the location of the east property boundary to determine if a 100-year flood zone is present in the southeast corner of the subdivision. If the subdivision is within or near North Fork Kays Creek, the potential for shallow ground water and creek-bank landslides and erosion should be addressed.

- To address earthquake ground shaking, the appropriate site class and seismic design category for the site should be determined.

- All setbacks and hazard areas should be shown on a subdivision map at a scale appropriate for subdivision planning.

I also recommend the following:

- A qualified geotechnical engineer should review geotechnical engineering aspects of the Earthtec (2004) report.

- The existence of the Earthtec (2004) and Western GeoLogic (2004) reports, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultants are followed, the developer should submit to Layton City written documentation from the consultants indicating that their recommendations were followed.

DISCUSSION

Earthtec (2004) and Western GeoLogic (2004) list landsliding, flooding, earthquake ground shaking, shallow ground water, and problem soils as potential hazards at the subdivision. The report adequately addresses shallow ground water outside of the North Fork Kays Creek area and problem soils. I believe additional investigations are needed to fully address the other potential geologic hazards at the site.

Landslide Hazard

Both Western GeoLogic (2004) and Earthtec (2004) evaluated the landslide hazard at the site but did not identify landslides along the east property boundary and immediately east of the site. Western GeoLogic (2004) recognized two possible landslide features within the site. They excavated trench 1 across a small swale possibly representing a small earth flow and trench 2 across an east-facing scarp and logged undeformed fine-grained Lake Bonneville sediments in both trenches. Western GeoLogic (2004) stated that slopes at the site appear stable and undeformed but recommended a geotechnical engineering evaluation of slope stability because of historical and prehistoric landslides in nearby slopes. Earthtec (2004) completed a slope-stability analysis for the northern end of the site and determined adequate factors of safety for subdivision development. Neither Western GeoLogic (2004) or Earthtec (2004) reference landslide and slope-stability investigations immediately east of the site that identify landslides in different phases of the Hidden Hollow development, or address the implications of other historical landslides in the area such as the nearby 1998 Sunset Drive landslide (Giraud, 1998).

At Hidden Hollow Unit 2 PRUD, Applied Geotechnical Engineering Consultants, Inc. (AGEC, 2003) excavated and logged trenches in landslide deposits downslope of Western GeoLogic's trench 2. AGEC (2003) determined marginal factors of safety for the upper slopes of the Hidden Hollow Unit 2 PRUD site. The upper slopes of the Hidden Hollow Unit 2 PRUD site adjoin the southeast-facing slopes of the Nalder site. Earthtec Engineering (1998) and Kaliser (1998) identified a landslide complex and landslides having historical movement east of the site. The landslide complex and landslides having historical movement east of the site are not considered in Earthtec's (2004) slope stability analysis. Therefore, I do not believe Western GeoLogic (2004) and Earthtec (2004) have adequately evaluated the landslide hazard at the site.

I recommend additional evaluation of the landslide hazard considering information obtained from landslide investigations at the Hidden Hollow sites by AGEC (2003), Earthtec Engineering (1998), and Kaliser (1998) and the Utah Geological Survey (UGS) reviews of those studies by Ashland (1999, 2002). The landslide-hazard analysis should consider landslides along the east boundary of the site that have the potential to impact the Nalder subdivision. I recommend mapping the landslides of the Hidden Hollow and Nalder sites and showing all landslides (deposits and source areas), landslide features, and other surficial geologic units on a large-scale site map for site planning and slope-stability investigation. The east-facing scarp trenched by Western GeoLogic (2004) is likely the main scarp of landslide deposits directly downslope (AGEC, 2003) that deflect North Fork Kays Creek to the south. Accurately mapping the landslides and extending slope-stability analysis offsite to the east are critical to constraining stability modeling of landslides, estimating a safe setback distance from the landslides, and outlining buildable and nonbuildable areas for the Nalder subdivision. The 2001 Heather Drive landslide (Giraud, 2002; AGEC, 2002) was a reactivation of an existing landslide in which the main scarp retrogressed up to 50 feet upslope from the old main scarp. AGEC (2002) determined that the 1.3 factor-of-safety boundary was up to 150 feet from the new main scarp. A 1.5 factor-of-safety boundary would be a greater distance from the new main scarp. A similar situation may exist here where instability related to offsite landslides may extend onto the site. The landslide stability analysis should consider soil strengths, ground-water levels, and slope-stability results measured off site as well as landslide back-calculated strengths. Estimated climatic and development-induced rises in ground-water levels should also be used in the analysis. The UGS has preliminary data available for ground-water-level fluctuations in the nearby Sunset Drive and Heather Drive landslides.

Stream Flooding

Western GeoLogic (2004) states that the site is not in a flood-hazard area. However, Western GeoLogic (2004, figures 1 and 3) shows two different locations for the east property boundary. Both Western GeoLogic (2004) figure 3 and Earthtec (2004) figure 1 show the southeast corner of the site as including North Fork Kays Creek. Western GeoLogic should clarify the correct location of the east property boundary. If the southeast corner of the site is within a 100-year flood zone, the flood zone should be shown on an appropriately scaled subdivision map. Likewise, the potential for shallow ground water, creek-bank landsliding, and erosion should also be addressed if the southeast corner of the site is near North Fork Kays Creek.

Earthquake Ground Shaking Hazards

To address the hazard from earthquake ground shaking, Earthtec (2004) states "The IRC designates this area as site class E." The IRC does not designate site classes; it assumes a default site class D. If a site is designated site class E, design under the *International Building Code* (IBC; International Code Council, 2002) is required. Based on figure 301.2(2) in the *International Residential Code* (IRC; International Code Council, 2003), the site may be in seismic design category E, rather than site class E. To protect from earthquake ground shaking, the appropriate site class, seismic design category and design code (IBC or IRC) must be determined.

SUMMARY OF CONCLUSIONS

Earthtec (2004) and Western GeoLogic (2004) do not address existing landslides along the eastern boundary of the site or incorporate these landslides in their hazard analysis. Additional landslide investigation should include a site-specific surficial geologic map to show all landslides (deposits and source areas) and landslide features. A landslide stability analysis that considers offsite soil and back-calculated strengths, ground-water levels, and slope-stability results east of the site is necessary to determine safe setbacks away from landslides. Western GeoLogic should clarify the correct east property boundary location and determine if flooding, shallow ground water, or creek-bank landslides and erosion could impact the site. The appropriate site class, seismic design category, and design code must be determined to address the earthquake ground shaking hazard.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Earthtec (2004) and Western GeoLogic (2004) reports. The Department of Natural Resources, UGS, provides no warranty that the data in the Earthtec (2004) and Western GeoLogic (2004) reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Layton City in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc., 2002, Geotechnical investigation, slope stability analysis, Heather Drive landslide, 1350 through 1500 East Heather Drive, Layton, Utah: Sandy, Utah, unpublished consultant's report, 14 p.

—2003, Slope stability evaluation, Hidden Hollow Unit 2 PRUD, approximately 1425 East 2250 North, Layton, Utah: Sandy, Utah, unpublished consultant's report, 13 p.

Ashland, F.X., 1999, Review of geologic-hazard and geotechnical reports for the Hidden Hollow no. 3 subdivision, Layton, Utah, *in* McDonald, G.N., compiler, Technical reports for 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 168-175.

—2002, Review of slope-stability-analyses reports for the proposed Hidden Hideaway Unit No. 1 residential subdivision, Layton, Utah: Utah Geological Survey Technical Report 02-02, 5 p.

Earthtec Engineering, P.C., 1998, Geotechnical study, Hidden Hollow #3 subdivision, 2355 North 1400 East, Layton, Utah: Ogden, Utah, unpublished consultant's report, 16 p.

Earthtec Testing and Engineering, P.C., 2004, Geotechnical study, Nalder subdivision, Layton, Utah: Ogden, Utah, unpublished consultant's report, 14 p.

Giraud, R.E., 1998, Reconnaissance of a landslide on East Sunset Drive, Layton, Davis County, Utah, *in* McDonald, G.N., compiler, Technical reports of 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 28-35.

—2002, Movement history and preliminary hazard assessment of the Heather Drive landslide, Layton, Davis County, Utah: Utah Geological Survey Report of Investigation 251, 22 p.

International Code Council, 2002, International Building Code - 2003: Falls Church, Virginia, International Code Council, 656 p.

—2003, International Residential Code for One- and Two-Family Dwellings - 2003: Falls Church, Virginia, International Code Council, 604 p.

Kaliser, B.N., 1998, Engineering geologic investigation of slope – location at approximately 2355 North 1400 East, Layton, Utah: Salt Lake City, Utah, unpublished consultant's report, 14 p.

Western GeoLogic, LLC, 2004, Geologic hazards evaluation, Nalder Estates subdivision, Layton City, Davis County, Utah: Salt Lake City, Utah, unpublished consultant's report, 14 p.

Project: Review of "Geotechnical study, Riverdale housing development, 5633 South 1200 West, Riverdale, Utah"			
By: Greg N. McDonald Francis X. Ashland	Date: May 5, 2005	County: Weber	
USGS Quadrangles: Roy	Section/Township/Range: Section 13, T. 5 N., R. 2 W.		
Requested by: Randy Daily, Riverdale City	Date report received at UGS: April 18, 2005		Job number: 05-05 (R-35)

INTRODUCTION

At the request of Randy Daily, Community Development Director for Riverdale City, we reviewed parts of the "Geotechnical study, Riverdale housing development, 5633 South 1200 West, Riverdale, Utah" by Earthtec Testing and Engineering, P.C. (Earthtec, 2004) that includes a geologic-hazards evaluation by Western GeoLogic (2004). For the review, we conducted a literature review and examined 1985 1:24,000-scale aerial photos. In addition, Francis Ashland and Chris DuRoss, Utah Geological Survey, visited the site on April 13, 2005. The purpose of our review is to determine whether geologic hazards have been adequately addressed at the site. We did not review the reports with respect to engineering aspects; Applied Geotechnical Engineering Consultants, Inc. (AGEC, 2005) has reviewed such report sections. Also, Riverdale City should consider hazards posed by the Davis-Weber Canal above any subdivision proposed near the base of the slope below the canal.

CONCLUSIONS AND RECOMMENDATIONS

After reviewing the Earthtec (2004) report for the proposed Riverdale housing development, our conclusions and recommendations regarding geologic hazards at the site are presented below.

- A site plan showing layout, lot configurations, and homes in relation to existing lots and the proposed special-study zone should be provided.

- A more comprehensive evaluation of landslide hazards at the site is warranted given the presence of landslides at the site and history of landsliding along the bluff (Lowe, 1988).

- Earthtec states their slope-stability analyses indicate that the steeper slopes are stable when "dry" but only marginally stable if "wet." However, Earthtec (2004) gives no documentation of the ground-water conditions used in their slope-stability modeling or supporting evidence for current and possible future ground-water conditions that take into account the locations (elevations) of the two observed springs.

- Earthtec's delineation of a special study zone for the steeper portion of the property does not take into consideration potential landslide runout that could affect property at the base of the steeper slopes beyond the special-study zone.

- The existence of the Earthtec (2004) and Western GeoLogic (2004) reports, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultants are followed, the developer should submit to Riverdale written documentation from the consultants indicating that their recommendations were followed.

DISCUSSION

We believe geologic hazards associated with slope stability have not been adequately addressed for the Riverdale housing development and warrant further evaluation.

Western GeoLogic states that no evidence exists for past landsliding at the site. However, the slope on which the proposed development is located has experienced numerous historical landslides documented by Lowe (1988), including two to three on the site and several more within a few hundred feet of the site. The inventoried slides are primarily slump/earth-flow types that occurred during the spring of 1983 (M. Lowe, Utah Geological Survey, verbal communication, 2005). Ashland and DuRoss observed evidence for the landslides at the site as well as more recent shallow soil-slip landslides. Larger, deep-seated, rotational-type landslides have also been mapped along the bluff including in Riverdale (Lowe, 1988; Yonkee and Lowe, 2004). In addition, a rapid earth-flow-type landslide occurred in South Weber on February 20 of this year about 2.5 miles southeast of, and along the same bluff as, the proposed Riverdale development. The South Weber landslide deposit measured about 80 feet wide by 480 feet long and flowed about 400 feet laterally, destroying several large trees, partially demolishing a barn, and running out 150 feet from the base of the slope across South Weber Drive onto flat farmland (Giraud, 2005).

Earthtec's slope-stability analyses lack supporting evidence and documentation for input parameters used in obtaining their results. In particular, ground-water conditions are not discussed except for identifying two springs on the site and indicating that the steeper portion of the site is marginally stable or unstable when wet. Earthtec needs to specify the wet versus dry conditions used in their analyses, and take into account current conditions, the two observed springs, and seasonal fluctuations in ground-water levels.

Earthtec acknowledges that the western, steeper portion of the site is "marginally stable" and recommends it be delineated as a special-study zone. Earthtec's delineation of a special-study zone for the steeper portion of the property does not consider potential landslide runout that could affect flatter parts of the site outside of the zone, as happened in South Weber this February (Giraud, 2005).

We believe a more comprehensive evaluation of slope stability and landslide-related hazards at the site is warranted given the presence and history of landslides along the bluff, geologic conditions and soil types observed, and the lack of supporting documentation for the slope-stability analyses. The study should also consider and address the implications of the results of other slope-stability analyses completed elsewhere along the bluff, such as the Terracon (2005) study for the Davis-Weber Canal Company.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Earthtec (2004). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the report are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Riverdale City in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc, 2005, Stability analysis review, Riverdale housing project, approximately 1200 West 5500 South, Riverdale, Utah: Sandy, unpublished consultant's letter report, 4 p.

Earthtec Testing and Engineering, P.C., 2004, Geotechnical study, Riverdale housing development, 5633 South 1200 West, Riverdale, Utah: Ogden, unpublished consultant's report, 16 p.

Giraud, R.E., 2005, Reconnaissance of the 425 East South Weber Drive landslide, South Weber, Utah: Unpublished Utah Geological Survey Technical Report 05-03, 10 p.

Lowe, M., 1988, Slope-failure inventory map – Roy quadrangle: Unpublished Weber County Planning Commission map, scale 1:24,000.

Sack, D., 2003, Interim geologic map of the Roy quadrangle, Weber and Davis Counties, Utah: Utah Geological Survey Open-File Report 409, scale 1:24,000, 50 p.

Terracon, 2005, Slope stability evaluation, Davis and Weber Canal at station 310, South Weber, Utah: Draper, Utah, unpublished consultant's report, 17 p., 4 appendices.

Western GeoLogic, L.L.C., 2004, Geologic hazards evaluation, Hill project, Riverdale City, Weber County, Utah: Salt Lake City, unpublished consultant's report, 14 p.

Yonkee, W.A., and Lowe, M., 2004, Geologic map of the Ogden 7-1/2 minute quadrangle: Utah Geological Survey Map M-200, 42 p. pamphlet, 1 plate, scale 1:24,000.

Utah Geological Survey

<table>
<tr><td colspan="3">Project:
Review of "Geologic and geotechnical investigation, proposed residential development southwest of Wallsburg, Wasatch County, Utah"</td><td rowspan="3"></td></tr>
<tr><td>By:
Barry J. Solomon, P.G.</td><td>Date:
07-11-05</td><td>County:
Wasatch</td></tr>
<tr><td>USGS Quadrangles:
Wallsburg Ridge (1086)</td><td colspan="2">Section/Township/Range:
Sections 19, 20, 29, 30, and 31, T. 5 S., R. 5 E., SLBM</td></tr>
<tr><td>Requested by:
Doug Smith,
Wasatch County Planning</td><td colspan="2">Date report received at UGS:
06-21-05</td><td>Job number:
05-09 (R-36)</td></tr>
</table>

INTRODUCTION

I reviewed geologic parts of the geologic and geotechnical report for the proposed residential development southwest of Wallsburg, Wasatch County, by Applied Geotechnical Engineering Consultants, P.C. (AGEC, 2004a). For the review I studied relevant geologic literature, looked at the report of a preliminary geologic-hazard investigation conducted by AGEC for the site of the proposed development and an adjacent area (AGEC, 2004b) (provided to me by Doug Hawkes of AGEC), and examined 1:20,000-scale (1962) and 1:40,000-scale (1987) aerial photographs, but I did not inspect the site. The purpose of my review is to assess whether AGEC (2004a) adequately identifies and addresses geologic hazards that could affect the proposed development.

CONCLUSIONS AND RECOMMENDATIONS

I believe the AGEC (2004a) report adequately addresses most geologic hazards at the proposed development site. Additional information will be needed to assess earthquake ground shaking. Hazards associated with alluvial-fan flooding, debris flows, and flooding from streams and shallow ground water on small parts of lots 1 and 9 should also be addressed. I recommend the following:

- If development proceeds, the developer's geotechnical consultant should address the hazard from earthquake ground shaking by verifying site classes and, in conjunction with the developer, determining seismic use groups, seismic design categories, and associated earthquake-resistant design requirements in accordance with procedures of the International Building Code (IBC) (International Code Council, 2002) and/or International Residential Code (IRC) (International Code Council, 2003), whichever applies.

- Flood and debris-flow hazards associated with the alluvial fans and streams in the northeast corner of the property should be evaluated as recommended in AGEC (2004b). If development is to be avoided in hazardous areas, the developer's geotechnical consultant should map the hazards and define buildable and non-buildable areas. If development proceeds in hazardous areas, additional information is needed. Giraud (2005) provides guidelines for the geologic evaluation of debris-flow hazards on alluvial fans in Utah.

I further recommend that:

- The AGEC (2004a) recommendation to use expansive clay underlying part of the site only for landscaped areas and not for fill below proposed buildings, slabs, and pavement appears prudent, but a qualified geotechnical engineer should review this and other recommendations pertaining to foundation design and site grading in this study and any subsequent studies.

- The existence of the AGEC reports (AGEC, 2004a, 2004b), this review, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating that its recommendations were followed.

- Wasatch County should require that all reports containing geologic content be stamped by the licensed professional geologist performing or supervising the geologic aspects of the study, as required under Utah state law effective January 1, 2003.

DISCUSSION

Earthquake Ground Shaking

AGEC (2004a) identifies earthquake ground shaking as a potential geologic hazard on the site. The IBC specifies design requirements for most structures to resist the effects of earthquake ground shaking, and the IRC specifies these requirements for one- and two-family dwellings and townhouses. Earthquake-resistant design requirements specified by the IBC and IRC depend on the seismic design category of a structure, which is based on spectral response accelerations and, for the IBC, seismic use group (a function of the nature of occupancy). To determine appropriate spectral response accelerations, the site class of the upper 100 feet (30 meters) of soil and rock must first be determined. I recommend that the final report for the proposed site verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements.

Flooding and Debris Flows

Hylland and Bishop (1996) mapped alluvial-fan-flood and debris-flow hazards in the northeast part of the site that are discussed in AGEC (2004b) but not addressed by AGEC (2004a). The potential hazards affect small areas in the northern parts of lots 1 and 9 and are associated with Holocene alluvial fans along the southwest edge of Round Valley next to Little

Hobble Creek, downslope from older alluvial fans with a lower hazard potential at the base of Wallsburg Ridge. Subsurface exploration is useful in obtaining geologic information regarding alluvial-fan-flood and debris-flow hazards, but none of the nine test pits excavated by AGEC were in the area underlain by the younger alluvial fans. Because of the relatively small areas affected by these hazards, they may be avoided by constructing elsewhere on the lots. I recommend that the potential for both alluvial-fan flooding and debris flows in the northeast part of the site be evaluated. The evaluation may be as simple as mapping the hazards at a suitable scale and defining buildable areas that avoid the hazards. If development is planned in hazardous areas, additional subsurface exploration and hazard-reduction measures may be required. Giraud (2005) provides guidelines for the geologic evaluation of debris-flow hazards on alluvial fans in Utah.

Hylland and Bishop (1996) also mapped potential flood hazards on lots 1 and 9 from streams and shallow ground water along Little Hobble Creek near its intersection with Penrod Creek. Although AGEC (2004a, p. 4) encountered no subsurface water in test pits, none of them were excavated in areas identified as potentially hazardous by Hylland and Bishop (1996). I recommend evaluation of these hazards as well.

Although flooding and debris-flow hazards may affect only a small portion of the proposed site, their impact to individual structures and occupants could be significant in hazardous areas. An evaluation of these hazards should map the hazards and define buildable and non-buildable areas or, if appropriate, design risk-reduction measures, describe the effect of such measures on adjacent properties, estimate the need for long-term maintenance, and define the residual risk to development after risk-reduction measures are in place.

Expansive Soils

AGEC (2004a) encountered expansive (fat) clays in one test pit on the proposed site. Laboratory tests indicate that the fat clay will significantly expand when wetted (AGEC, 2004a, p. 4). AGEC (2004a, p. 10) states, "The clay is not suitable as fill below proposed buildings, slabs, and pavement but may be used in landscaped areas." I concur with the statement, but a qualified geotechnical engineer should review this and other recommendations pertaining to foundation design and site grading in this study and any subsequent studies.

Licensed Professional Geologist

The Utah Professional Geologist Licensing Act, a Utah state law effective January 1, 2003, requires that the licensed professional geologist performing or supervising geologic aspects of studies stamp reports containing geologic content. The licensing act provides for exemptions from licensure, but these exemptions do not apply if the report is submitted to a local government. Although a licensed professional geologist signed the AGEC (2004a) report, he stamped the report with a licensed professional engineer stamp and not with a similar geologist stamp. Wasatch County should require a licensed professional geologist stamp on reports containing geologic content to assure compliance with state law and to provide evidence to the local government, client, and other interested parties that minimum requirements necessary to practice geology in Utah have been met.

SUMMARY OF CONCLUSIONS

I believe that AGEC (2004a) adequately identifies the potential for most geologic hazards at the proposed site. To address earthquake ground shaking, the consultant should verify site classes for the final site report and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements in accordance with the IBC and/or IRC, whichever applies. The potential for debris flows and flooding should be evaluated in the northeast part of the site. If construction will avoid the hazards, the developer's geotechnical consultant should provide a map at a suitable scale to Wasatch County that delineates hazardous areas and defines buildable and non-buildable areas.

The licensed professional geologist performing or supervising geologic aspects of future studies for the proposed site should stamp the resulting geologic report, as required by Utah state law.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in AGEC (2004a). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in AGEC (2004a) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Applied Geotechnical Engineering Consultants, P.C., 2004a, Geologic and geotechnical investigation, proposed residential development southwest of Wallsburg, Wasatch County, Utah: Sandy, Utah, unpublished consultant's report, 19 p.

---2004b, Preliminary geologic hazard investigation, proposed Little Hobble Creek Ranch development southwest of Wallsburg, Wasatch County, Utah: Sandy, Utah, unpublished consultant's report, 10 p.

Giraud, R.E., 2005, Guidelines for the geologic evaluation of debris-flow hazards on alluvial fans in Utah: Utah Geological Survey Miscellaneous Publication 05-6, 16 p.

Hylland, M.D., and Bishop, C.E., 1996, Flood hazards, earthquake hazards, and problem soils, western Wasatch County, Utah (plate 2C), *in* Hylland, M.D., Lowe, Mike, and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

International Code Council, 2002, 2003 International Building Code: Falls Church, Virginia, International Code Council, 656 p.

---2003, 2003 International Residential Code for One- and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 604 p.

Project: Review of “Geotechnical study, Blue Spruce subdivision, Ogden, Utah”			
By: Greg N. McDonald, P.G.	Date: July 19, 2005	County: Weber	
USGS Quadrangles: Ogden	Section/Township/Range: Section 13, T. 5 N., R. 2 W.		
Requested by: Jim Gentry, Weber County	Date report received at UGS: June 20, 2005		Job number: 05-11 (R-37)

INTRODUCTION

At the request of Jim Gentry, Ogden City Planning Department, I reviewed parts of the “Geotechnical study, Blue Spruce subdivision, Ogden, Utah” by Earthtec Testing and Engineering, P.C. (Earthtec, 2005) that includes a geologic-hazards evaluation by Western GeoLogic (2004). For the review, I conducted a literature review and examined 1985 1:24,000-scale aerial photos, and visited the site on July 18, 2005. The purpose of my review is to determine whether geologic hazards have been adequately addressed at the site. I did not review the reports with respect to engineering aspects.

CONCLUSIONS AND RECOMMENDATIONS

I believe the Earthtec (2004) report for the proposed Blue Spruce development adequately addresses most geologic hazards at the site. My conclusions and recommendations regarding possible additional geologic hazards investigations needed at the site are presented below.

- If construction will occur in the southern corner of the property (lot 7) west of Western GeoLogic’s trench, additional trenching is needed to characterize the surface-fault-rupture hazard there.

- Appropriate setbacks should be determined from the tops of road cuts along Karen Drive (lots 5 and 7) and along the steep stream cut in lot 1 to allow for raveling and erosion, if construction is planned close to these cuts.

- Western GeoLogic recommends evaluation of possible stream flooding on the southern drainage at lot 1. Several other small drainages and associated alluvium cross the property (lots 3, 4, 6, and 7), in addition to the southern drainage. Earthtec should determine if these represent a hazard that should be considered in site drainage design or building placement.

I also recommend the following:

- A qualified geotechnical engineer should review geotechnical engineering aspects of the report.

- The existence of the Earthtec (2005) and Western GeoLogic (2004) reports, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultants are followed, the developer should submit to Weber County written documentation from the consultants indicating that their recommendations were followed.

DISCUSSION

Western GeoLogic (2004) concludes the surface-faulting hazard at the site is low based on their trenching data, published mapping, and aerial photographic interpretation. Western GeoLogic (2004) states the main fault trace is about 250 feet west of the site. My review of aerial photos and recent orthophotos indicates the fault is likely at the base of the prominent escarpment just southwest of the property. The fault likely crosses Karen Drive and may traverse the Blue Spruce property at its southern corner. In addition, previous work at the adjacent property to the southeast by AGRA (1995a, 1995b, 1996), reviewed by Hylland (1995a, 1995b), identified the fault approximately 120 feet southeast of the southern corner of the Blue Spruce property. Western GeoLogic's trench adequately characterizes the surface-fault-rupture hazard for most of the site. However, if construction is to occur in the zone southwest of a projection from the southern end of the trench parallel to the mapped fault trace, additional trenching will be needed to characterize the southwestern half of lot 7.

Western GeoLogic indicates the northwestern part of the site is bounded by steep road cuts along Karen Drive. In addition, the stream cut along the southeastern margin of the site forms a steep escarpment. Therefore, appropriate setbacks should be determined for lots along Karen Drive and/or the southern stream cut (lots 1, 5 and 7) to allow for raveling and erosion, if construction is planned close to these cuts.

Western GeoLogic recommends evaluation of possible stream flooding on the southern drainage at lot 1. Although not shown accurately on the site geologic map, several other small drainages and associated alluvium cross the property (lots 3, 4, 6, and 7), in addition to the southern drainage. Earthtec should determine if these represent a hazard that should be considered in site drainage design or building placement.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Earthtec (2005). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the report are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Ogden City in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

AGRA Earth & Environmental, 1995a, Report – geologic hazards and groundwater imposed limitations evaluation, proposed Moses Mountain subdivision, 2527 East Bonneville Terrace Drive, and 5548 South Karen Drive, Weber County, Utah: Unpublished consultant's report, 7 p.

AGRA Earth & Environmental, 1995b, Report – Addendum, geologic hazards and groundwater imposed limitations evaluation, proposed Moses Mountain subdivision, 2527 East Bonneville Terrace Drive, and 5548 South Karen Drive, Weber County, Utah: Unpublished consultant's report, 5 p.

AGRA Earth & Environmental, 1996, Supplemental inspection report letter, earthwork and foundation observations, lot no. 2 Moses Mountain subdivision, Weber County, Utah: Unpublished consultant's report, 3 p.

Earthtec Testing and Engineering, P.C., 2005, Geotechnical study, Blue Spruce subdivision, Ogden, Utah: Ogden, unpublished consultant's report, 11 p.

Hylland, M.D., 1995a, Review of "Report, geologic hazards and groundwater imposed limitations evaluation, proposed Moses Mountain subdivision, 2527 East Bonneville Terrace Drive, and 5548 South Karen Drive, Weber County, Utah; AGRA Earth & Environmental, Inc. addendum report dated February 27, 1995: Unpublished Utah Geological Survey Technical Report 95-04, 5 p.

Hylland, M.D., 1995b, Response to proposed Moses Mountain subdivision; AGRA Earth & Environmental, Inc. addendum report dated February 27, 1995: Unpublished Utah Geological Survey letter report dated March 9, 1995, 2 p.

Lowe, M., 1988, Debris-flow hazard special study zone map – Ogden quadrangle: Unpublished Weber County Planning Commission map, scale 1:24,000.

Lowe, M., 1988, Potential surface-fault rupture sensitive area overlay zone map – Ogden quadrangle: Unpublished Weber County Planning Commission map, scale 1:24,000.

Western GeoLogic, L.L.C., 2004, Geologic hazards evaluation, Blue Spruce development, Weber County, Utah: Salt Lake City, unpublished consultant's report, 16 p.

Yonkee, W.A., and Lowe, M., 2004, Geologic map of the Ogden 7-1/2 minute quadrangle: Utah Geological Survey Map M-200, 42 p. pamphlet, 1 plate, scale 1:24,000.

Utah Geological Survey

Project: Review of “Geotechnical and geological study, the Ranger Station, Provo, Utah”			
By: Christopher B. DuRoss, Gary E. Christenson, P.G.	Date: 08-15-05	County: Utah	
USGS 7.5’ Quadrangle: Orem (1088)	Section/Township/Range: Section 29, T. 6 S., R. 3 E., Salt Lake Base Line and Meridian.		
Requested by: David Graves, Provo City	Date report received at UGS: 07-05-05		Job number: 05-13 (R-38)

INTRODUCTION

At the request of David Graves, Assistant City Engineer for Provo City, Utah, we reviewed the geological parts of a geologic and geotechnical report for a proposed residential subdivision north of 2300 North at approximately 1400 East in Provo, Utah (Earthtec Testing & Engineering [Earthtec], 2005). The proposed subdivision site is about 0.3 miles west of the mouth of Rock Canyon, south of Rock Creek, and southeast of the Rock Canyon debris basin. The purpose of this review is to assess if geologic hazards potentially impacting the subdivision have been adequately identified and addressed. The scope of work for this review included examination of 1:16,000-scale low-sun-angle aerial photography and review of relevant geologic literature and maps, but did not include a site visit.

CONCLUSIONS AND RECOMMENDATIONS

Earthtec (2005) adequately addressed most geologic hazards potentially affecting the proposed subdivision, including earthquake ground-shaking, tectonic-deformation, landslide, rock-fall, and flooding hazards. However, we recommend additional study east of the main fault and increased fault-setback distances to fully address the surface-fault-rupture hazards, and additional information is necessary to adequately assess potential debris-flow hazards at the site. We recommend the following:

- The surface-fault-rupture special-study area should extend 250 feet on the upthrown (east) side of the mapped main-fault trace. If development is planned for the eastern part of the site, east of the main fault, the geotechnical consultant should address the potential surface-fault-rupture hazard with field investigations and by extending the trench an appropriate distance to the east.

- Depending on the number of residences in the subdivision, the minimum setback distance on the upthrown and downthrown sides of faults F1 and F2 should be either 15 feet (fewer than 10 residences) or 20 feet (more than 10 residences), following the surface-fault-rupture-hazard evaluation guidelines in Christenson and others (2003).

- The minimum setback distance on the downthrown (west) side of the main fault should be 65 or 70 feet to include the graben and an additional 15 or 20 feet on the upthrown side of the westernmost graben-bounding antithetic fault (mapped by Lund and Black, 1998), depending on the number of residences. This increased setback distance should be projected north along the western main-fault strand.

- A geotechnical consultant, in conjunction with Provo City, should determine if a debris-flow hazard exists related to avulsion of the main Rock Creek channel up to 0.5 miles east of the site, because the development is upstream of the Rock Canyon debris basin. If necessary, the consultant should evaluate the debris-flow hazard and provide geologic parameters for risk reduction.

- The potential for hydrocompaction in alluvial-fan deposits at the site should be addressed.

We further recommend that:

- A licensed geotechnical engineer should review engineering aspects of the report.

- The existence of the Earthtec (2005) report, this review, and any future geotechnical and/or geologic-hazard reports should be disclosed to potential buyers.

- The developer submit to Provo City written documentation from the geotechnical consultant indicating that its recommendations were followed.

DISCUSSION

Surface-Fault-Rupture Hazards

The surface-fault-rupture hazard at the site is associated with a rupture on the central part of the Provo segment of the Wasatch fault zone (Machette, 1992; Lund and Black, 1998; Black and others, 2003). Earthtec (2005) states that surface faulting has occurred at the site in the past and that the potential for future surface faulting is high, and we concur. We agree with Earthtec (2005) that no-build areas should incorporate the mapped surface-fault traces (following Christenson and others, 2003) and that future property owners/residents should be made aware of the possibility of surface faulting along new, unmapped, or concealed faults. In addition, the Earthtec (2005) report, this review, and any future geotechnical and/or geologic-hazard reports should be disclosed to potential property owners.

Earthtec (2005) investigated the surface-fault-rupture hazard in trenches extending approximately 810 feet on the downthrown (west) side of the main trace of the Wasatch fault and 15 feet on the upthrown (east) side. In the Utah Geological Survey (UGS) guidelines for the evaluation of surface-fault-rupture hazards in Utah, Christenson and others (2003) recommend that special-study areas extend 250 feet on the upthrown side of the mapped main-fault trace, in contrast to the 100 feet recommended by URS/Dames & Moore (2001) and cited by Earthtec (2005) in this study. We recommend that Provo City use the special-study-area guidelines of Christenson and others (2003). Therefore, if residential development is planned within 250 feet east of the main-fault trace, we recommend that the geotechnical consultant address the potential surface-fault-rupture hazard with field investigations and by extending the trench an appropriate distance to the east to determine if footwall faults are likely to exist. Earthtec (2005) adequately investigated the surface-fault-rupture hazard on the downthrown (west) side of the main fault by using existing fault-trench data (Lund and Black, 1998) and excavating three additional trenches between the western end of the Lund and Black (1998) excavation and the western boundary of the study area.

Earthtec (2005) calculated setback distances from the main and antithetic faults located by Lund and Black (1998) and from two subsidiary faults (F1 and F2, figure 9; Earthtec, 2005) identified in their trenches. Earthtec (2005) reported setback distances ranging from 8 to 50 feet (table 2; Earthtec, 2005), which they calculated using the formulas given in the guidelines of Christenson and others (2003). However, these guidelines also prescribe minimum setback distances of 15 feet (if fewer than 10 residences) and 20 feet (if more than 10 residences) that should be used if the calculated setbacks are less than these distances. We recommend that the minimum setback distance on the downthrown side of the main fault be 65 or 70 feet rather than 50 feet (table 2; Earthtec, 2005). The setback distance of 65 or 70 feet accommodates the 50-foot-wide graben (mapped by Lund and Black, 1998) and includes an additional 15 or 20 feet (depending on the number of residences) on the upthrown (west) side of the antithetic fault bounding the west end of the graben. We recommend that this minimum setback distance on the downthrown side of the main fault be projected north, where the faults have not been trenched, and where fault mapping indicates that the main fault strand bifurcates north into two parallel, down-to-the-west strands (Lund and Black, 1998). This setback distance should be taken from the western main-fault strand north of the bifurcation (figure 9; Earthtec, 2005).

Debris-Flow Hazards

The proposed subdivision is located on undivided latest Pleistocene to Holocene alluvial-fan deposits (Machette, 1992; Lund and Black, 1998) in a proximal position relative to the mouth of Rock Canyon and upstream of the Rock Canyon debris basin. The paleoseismic trench of Lund and Black (1998), a natural exposure of the Wasatch fault at the northern site boundary (mapped by Lund and Black, 1998), and the exploration trenches of Earthtec (2005) exposed evidence for debris-flow deposits younger than the most recent surface faulting, which occurred shortly after about 650 cal yr B.P. (Lund and Black, 1998). Radiocarbon ages on detrital charcoal from within post-event debris flows in the natural exposure range from 540 to 630 cal yr B.P. (Lund and Black, 1998). Although Earthtec (2005) stated that the Rock Creek stream bed is "more than 10 feet lower in elevation than the site" and may have been "re-routed and deepened to accommodate future flood and debris flow events," they conclude that debris flows from Rock Canyon "have the potential to adversely affect development on the lot," and we agree. Greg Beckstrom (Provo City, Assistant Public Works Director, verbal communication, 2005) indicated that he believes the Rock Creek stream channel adjacent to the site is adequate for floodwater containment (up to 100-200 cubic feet per second), although he said a debris-flow analysis has not been performed for the more confined channel east of the site, where channel blockage and avulsion is conceivable. Giraud (2005) emphasized that debris flows have unpredictable behavior and may avulse to new parts of the fan with blockage of the main channel.

Debris flows in a proximal-fan setting have the highest velocities, greatest flow depths, and are most destructive relative to other parts of the fan (Giraud, 2005); if Rock Creek channel avulsion is possible, debris flows could pose a significant hazard to the proposed subdivision. We recommend further study to evaluate the potential debris-flow hazard related to Rock Creek channel blockage and avulsion up to 0.5 miles east of the subdivision site. Provo City should be consulted in this investigation because it administers the debris basin and channel, and the likely area of avulsion and hazard reduction, if needed, is off site. If a debris-flow hazard exists at the site, qualified professionals should provide geologic parameters (e.g., flow frequency, extent, and depth) and engineering designs necessary for risk reduction. Giraud (2005) provides guidelines for the geologic evaluation of debris-flow hazards on alluvial fans in Utah, and Hungr and others (1984) and VanDine (1996) discuss the role of channel shape and gradient in the conveyance of debris flows.

Hydrocompaction and Soil Conditions

Hydrocompaction may occur when near-surface deposits containing significant void space (e.g., alluvial-fan or wind-blown deposits) are thoroughly wetted for the first time since deposition, resulting in localized surface subsidence and sometimes causing ground cracks. At the site, Lund and Black (1998) and Earthtec (2005) mapped matrix-supported debris flows, which were deposited after 540-630 years (Lund and Black, 1998) and may be susceptible to hydrocompaction. Earthtec (2005) did not address the potential for hydrocompaction of alluvial-fan deposits, which we recommend be evaluated.

Earthtec (2005) outlined recommendations for fill-material consistency, placement, and compaction, and foundation design. A qualified geotechnical engineer should review these and other recommendations pertaining to fill requirements and foundation design in this study and any subsequent studies.

SUMMARY OF CONCLUSIONS

Earthtec (2005) adequately evaluated most geologic hazards potentially affecting the proposed subdivision. Regarding the surface-fault-rupture hazard from an earthquake on the Provo segment of the Wasatch fault, Earthtec (2005) adequately evaluated the hazard on the downthrown side of the main fault, but we recommend additional field investigations and trenches if development on the upthrown side of the fault is planned. For the subsidiary faults west of the main fault (F1 and F2, figure 9; Earthtec, 2005), we recommend using minimum setback distances of 15 or 20 feet (depending on the number of residences) if the calculated distances are less than these distances, as prescribed in the UGS guidelines. For the downthrown (west) side of the main fault, we recommend a minimum setback of 65 or 70 feet to include the graben and incorporate a 15- or 20-foot setback from the westernmost graben-bounding antithetic fault. This minimum setback distance for the downthrown side of the main fault should be projected to the north, where the width of the main-fault deformation zone has not been determined by trenching.

Additional information is necessary to address the potential for damaging debris flows at the site. Radiocarbon dating by Lund and Black (1998) indicates that debris-flow deposition has occurred at the site in the past 540-630 years. Although Provo City indicates the current Rock Creek channel adjacent to the site is designed to convey floodwater, debris-flow deposition due to channel avulsion east of the site is conceivable (Greg Beckstrom, Provo City, verbal communication, 2005). We recommend that qualified professionals evaluate the potential debris-flow hazard and, if necessary, recommend geologic parameters for the design of risk-reduction measures.

A geotechnical consultant should evaluate the hydrocompaction hazard, and Earthtec's (2005) recommendations for fill-material consistency and use, and foundation design should be reviewed by a qualified geotechnical engineer.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Earthtec (2005) and guidelines of Christenson and others (2003). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in Earthtec (2005) are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Provo City in reducing risks from geologic hazards, but the Utah Geological Survey makes no warranty, expressed or implied, and shall not be liable for any direct, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Black, B.D., Hecker, S., Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:500,000, compact disc.

Christenson, G.E., Batatian, L.D., and Nelson, C. V, 2003, Guidelines for evaluating surface-fault-rupture hazards in Utah: Utah Geological Survey Miscellaneous Publication 03-6, 16 p.

Earthtec Testing & Engineering, P.C., 2005, Geotechnical and geological study, the Ranger Station, Provo, Utah: Orem, Utah, unpublished consultant's report, 22 p.

Giraud, R.E., 2005, Guidelines for the geologic evaluation of debris-flow hazards on alluvial fans in Utah: Utah Geological Survey Miscellaneous Publication 05-6, 16 p.

Hungr, O., Morgan, G.C., and Kellerhals, R., 1984, Quantitative analysis of debris torrent hazards for design of remedial measures: Canadian Geotechnical Journal, v. 21, p. 663-677.

Lund, W.R., and Black, B.D., 1998, Paleoseismology of Utah, volume 8-Paleoseismic investigation at Rock Canyon, Provo segment, Wasatch fault zone, Utah County, Utah: Utah Geological Survey Special Study 93, 21 p.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–2095, scale 1:50,000.

URS/Dames & Moore, 2001, Phase I – Geologic evaluation, Phase V – Geologic hazards map update, Sherwood Hills subdivision-wide studies and update of Provo City geologic hazards maps: unpublished consultant’s report, Project No. 14151-003-162, variously paginated.

VanDine, D.F., 1996, Debris flow control structures for forest engineering: British Columbia Ministry of Forests Research Program, Working Paper 22, 68 p.

Utah Geological Survey

Project: Review of "Geological hazards assessment—Victory Ranch (phase 1), Wasatch County, Utah"			
By: Barry J. Solomon, P.G.	Date: 09-27-05	County: Wasatch	
USGS Quadrangles: Francis (1167)	Section/Township/Range: Section 36, T. 2 S., R. 5 E., sections 31 and 32, T. 2 S., R. 6 E., and sections 5 and 6, T. 3 S., R. 6 E., SLBM		
Requested by: Doug Smith, Wasatch County Planning	Date report received at UGS: 09-01-05		Job number: 05-15 (R-39)

INTRODUCTION

I reviewed the geological hazards assessment for the proposed Victory Ranch (phase 1) development in Wasatch County by Earthtec Testing and Engineering, P.C. (Earthtec, 2005a). For the review, I studied supporting documents (Earthtec, 2005b, 2005c) and relevant geologic literature and examined 1:20,000-scale (1962) and 1:40,000-scale (1987) aerial photographs, but I did not inspect the site. The purpose of my review was to assess whether Earthtec (2005a) adequately identified and addressed geologic hazards that could affect the proposed development.

CONCLUSIONS AND RECOMMENDATIONS

I believe the Earthtec (2005a) report adequately identifies most geologic hazards at the proposed Victory Ranch (phase 1) development, and Earthtec's recommendations for addressing the hazards are reasonable. My principal concern is with the timing of landslide studies:

- To address landslide hazards, Earthtec recommends that site-specific slope-stability studies be conducted for lots with slopes greater than 25 percent at the time of building permit application, after building locations are known. I recommend that the studies are best conducted before building locations and even lot boundaries are known, to serve as a basis for defining lots and ensuring that a safe buildable area exists on all lots.

I also recommend the following:

- Radon-resistant construction techniques discussed in Appendix F of the International Residential Code (IRC) (International Code Council, 2003) should be incorporated to address the relatively high potential for elevated levels of indoor radon. However, approval of building permits should not depend upon fulfilling this recommendation.

- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in geotechnical studies cited in this review and any subsequent studies.

- The existence of the Earthtec (2005a, 2005b, 2005c) reports, this review, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating compliance with the recommendations.

DISCUSSION

Earthtec (2005a) addresses the potential for several geologic hazards at the proposed Victory Ranch (phase 1) development. These hazards include surface fault rupture, landslides, rock fall, alluvial-fan flooding, debris flows, flooding from the Provo River, tectonic deformation, and indoor radon. Earthtec (2005b) addresses the potential for earthquake ground shaking and shallow ground water, and Earthtec (2005c) addresses the potential for collapsible soils. With the exception of earthquake ground shaking and indoor radon, Earthtec believes that the potential for these hazards is low on all or most of the site. Their relative hazard assessment is generally reasonable, although I have concerns regarding the landslide hazard.

Landslides

Earthtec (2005a) recommends that site-specific slope-stability studies be conducted on lots with slopes greater than 25 percent. This is a prudent recommendation, but I disagree with some aspects of Earthtec's discussion of the landslide hazard.

Earthtec (2005a) states that their landslide hazard map (figure 4) was based on the Wasatch County Geologic Hazards Overlay Zone Map for landslides. The Earthtec map shows two small zones of "high" relative landslide hazard, which Earthtec believes were mapped primarily on the basis of slope gradient. However, the "high" hazard is based on both slope gradient and the presence of landslides originally mapped by Hylland and Lowe (1996), which serves as the source of mapping for the Wasatch County map. The easternmost area of "high" hazard on the Earthtec map is shown as fill by Hylland and Lowe (1996), who do not evaluate its landslide hazard. However, Hylland and Lowe (1996) map another landslide on the Victory Ranch site, not shown on figure 4 but mapped on figure 6 of Earthtec (2005c) with citations for Harty (1991, 1992).

Earthtec (2005a) states that the nearest landslide to the site, besides the on-site landslides, is about 2.5 miles to the west. However, Hylland and Lowe (1996) map several closer landslides on slopes bordering the Provo River flood plain and Jordanelle Reservoir. I therefore disagree with Earthtec's characterization of most of the site, including areas shown with a "moderate" landslide hazard on the Wasatch County landslide map, as having a "relatively low landslide risk." I believe the landslide hazard on steep north-facing slopes along the Provo River is significant, and steep slopes elsewhere on the site may pose a similar risk.

Earthtec (2005a) prudently recommends conducting slope-stability studies on steep slopes. However, Earthtec (2005a) recommends that slope-stability studies be conducted at the time of building permit application, when proposed building locations are known. I recommend that the studies should be conducted before building locations are known, and actually should serve as the basis of both lot layout and building locations by defining appropriate setbacks from steep slopes and using the setbacks to map buildable and nonbuildable areas.

Earthtec (2005a) cites section R403.1.7 of the IRC as the basis for a maximum setback from descending steep slopes. Section R403.1.7.2 (Footing setback from descending slope surfaces) refers to IRC figure R403.1.7.1, which illustrates IRC-recommended foundation clearances from slopes. That figure shows that the building-footing setback from the face of any slope greater than 33.3 percent "need not exceed 40 ft. max." Earthtec believes that a setback of 40 feet from any slope greater than 25 percent therefore conservatively provides an adequate factor of safety for the Victory Ranch site. However, section R403.1.7.2 defines the purpose of the setback from descending slopes as "sufficient to provide vertical and lateral support for the footing without detrimental settlement." The reason for this is to prevent foundation soils from settling more than anticipated if soils are forced laterally toward a free face (the steep slope), where they will encounter less resistance. Section R403.1.7.2 does not state or imply that the setback is to minimize the potential for slope failure (landsliding). This is in contrast to section R403.1.7.1 (Building clearances from ascending slopes), which defines the purpose of a setback from the base of a steep slope as providing "protection from slope drainage, erosion, and shallow failures." Neither of the IRC setbacks (from ascending or descending slopes) is meant to address the potential for deeper seated landsliding.

Radon

Earthtec (2005a) notes that the site is located in an area mapped with a high radon-hazard potential by Black (1993), and indicates the availability of radon-resistant construction techniques. Appendix F of the IRC contains requirements for new construction in jurisdictions where radon-resistant construction is required. Although Wasatch County does not require radon-resistant new construction, geologic factors contributing to elevated indoor-radon levels (particularly the presence of the Keetley Volcanics) are found on the Victory Ranch site and I recommend implementing techniques discussed in IRC Appendix F. Approval of building permits should not depend upon fulfilling this recommendation, but incorporating radon-resistant techniques in new construction is commonly less expensive than applying post-construction methods.

Other Geologic Hazards

Earthtec (2005a) makes several recommendations addressing other geologic hazards, and I believe all are prudent. These recommendations include: (1) loose rocks over one foot in diameter should be removed from site slopes above lots A5 to A9, A15, and A16 to reduce the rock-fall hazard; (2) no building lots are currently planned on alluvial fans, and to reduce the alluvial-fan-flooding and debris-flow hazard, debris should be removed from drainage channels, channels should be modified to divert water and debris from all building lots, and critical structures and utilities should not be located at drainage mouths; and (3) no building lots are currently planned in the Provo River flood plain and a qualified hydrologist should conduct a flood-hazard study prior to flood-plain development.

Earthtec addresses additional geologic hazards in the geotechnical reports for Victory Ranch, and gives reasonable conclusions and recommendations. To address earthquake ground shaking, Earthtec (2005b) determined that homes should be constructed in accordance with Seismic Design Category C of the IRC. Earthtec (2005b) proposed engineering techniques to reduce the hazard from shallow ground water. Although no significant visual evidence of collapsible soils was observed, Earthtec (2005c) recommends inspection of sub-grade conditions to assess the need for engineering techniques to reduce the hazard, if found. I recommend that a qualified geotechnical engineer should review proposed engineering techniques.

SUMMARY OF CONCLUSIONS

I believe that Earthtec (2005c) and supporting documents (Earthtec 2005a, 2005b) adequately identify the potential for most geologic hazards on the Victory Ranch (phase 1) site. The potential hazards addressed include surface fault rupture, rock fall, alluvial-fan flooding, debris flows, flooding from the Provo River, tectonic deformation, indoor radon, earthquake ground shaking, shallow ground water, and collapsible soils. Earthtec's recommendations to reduce these geologic hazards are reasonable, and I recommend incorporation of radon-resistant construction techniques to address the potential for elevated indoor-radon levels. I believe the landslide hazard is greater than described by Earthtec on steep slopes. Their recommendation to conduct slope-stability studies on such slopes is prudent, but I recommend that the studies should be conducted before lots are laid out and building locations are known, and should serve as the basis of lot and building locations, rather than conducting the studies after proposed building locations are known, as Earthtec recommends.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Earthtec (2005a, 2005b, 2005c). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the Earthtec reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, express or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Black, B.D., 1993, The radon-hazard-potential map of Utah: Utah Geological Survey Map 149, scale 1:1,000,000.

Earthtec Testing and Engineering, P.C., 2005a, Geological hazards assessment—Victory Ranch (phase 1), Wasatch County, Utah: Orem, Utah, unpublished consultant's report, 15 p.

-----2005b, Geotechnical study, Victory Ranch Club, Wasatch County, Utah: Orem, Utah, unpublished consultant's report, 17 p.

-----2005c, Geotechnical study, Victory Ranch (phases 1B, 1C, 1D), Wasatch County, Utah: Orem, Utah, unpublished consultant's report, 17 p.

Harty, K.M., 1991, Landslide map of Utah: Utah Geological Survey Map 133, scale 1:500,000.

-----1992, Landslide map of the Salt Lake City 30' x 60' quadrangle: Utah Geological Survey Open-File Report 236, scale 1:100,000.

Hylland, M.D., and Lowe, M., 1996, Landslide hazard, western Wasatch County, Utah (plate 1B), *in* Hylland, M.D., Lowe, M., and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

International Code Council, 2003, 2003 International Residential Code for One- and Two-Family Dwellings: Falls Church, Virginia, International Code Council, 604 p.

Utah Geological Survey

Project: Review of "Fault rupture investigation, 750 North Harrison Boulevard, Ogden, Utah"			
By: Greg N. McDonald, P.G.	Date: January 23, 2006	County: Weber	
USGS Quadrangles: North Ogden	Section/Township/Range: Section 9, T. 6 N., R. 1 W.		
Requested by: John Mayer, Ogden City Planning	Date report received at UGS: December 23, 2005		Job number: 06-02 (R-40)

INTRODUCTION

At the request of John Mayer, Ogden City Planning Department, I reviewed the fault-investigation report for the Scenic View Estates development by Bingham Engineering (Bingham, 2005). For the review, I conducted a literature review, examined 1970s 1:12,000-scale aerial photos, and briefly visited the site on January 6, 2006. The purpose of my review is to determine whether the surface-fault-rupture hazard has been adequately addressed. In addition, I make comments and recommendations regarding other potential geologic hazards at the site that were not part of Bingham's scope of work but were addressed in a cursory manner.

CONCLUSIONS AND RECOMMENDATIONS

After reviewing the Bingham (2005) report for the Scenic View Estates subdivision, I have the following conclusions and recommendations.

- Additional trenching is needed to evaluate the surface-fault-rupture hazard at the proposed building sites.
- I recommend a more comprehensive debris-flow/alluvial-fan-flooding hazard evaluation be performed for the site.
- Slope-stability is a concern along the western portion of the site for the access road and if construction is planned near the slope crest.
- The possible presence of collapsible soils at the site should be evaluated.

DISCUSSION

Surface-Fault-Rupture Hazard

Our review of the fault investigation is based on Utah Geological Survey (UGS) surface-fault-rupture hazard guidelines (Christenson and others, 2003) and may differ in approach to specific requirements in Ogden City's ordinances and sensitive area overlay zones. Bingham's characterization of the surface-fault-rupture hazard included excavating two trenches in the eastern part of the site in an Ogden City sensitive area overlay zone near the two proposed building pads. The faults shown in Bingham's figure 2 are apparently taken from 1:50,000-scale mapping by Nelson and Personius (1993). It is not clear that fault traces have been more accurately located based on site-specific field mapping and/or photo lineament interpretation as should be done in a site-specific study. In any case, the east fault, as depicted, is less than 20 feet from the southeast corner of the footprint of the southern pad, and trenches do not extend sufficiently far west to cover western parts of the footprints.

Bingham (2005) states "the nearest known rupture zone associated with the Weber segment of the Wasatch fault is about 350 feet east of the proposed site," although the two faults shown on Bingham's figures 2 and 3 are associated with the Weber segment of the Wasatch fault. The eastern fault is a discontinuous antithetic fault and was investigated by Bingham as described above. The western fault forms the steep escarpment east of Harrison Boulevard, is visible on the pre-Harrison Boulevard aerial photos, appears to be several meters high, and is thus a major splay of the Wasatch fault. Harrison Boulevard was built along the base of the scarp and there has been some modification (cutting) of the scarp associated with construction of the road, but the escarpment and fault trend along the west side of the property.

Although the building pads are outside Ogden City's sensitive areas, the entire site is within areas recommended for surface-fault-rupture-hazard special studies as defined by Christenson and others (2003). The building pads are both within 100 feet of the eastern fault and 150 feet of the western fault. In Earthfax's (1994) study for the Eagles subdivision to the south, faults were found throughout the zone between the two main fault traces. Therefore, I recommend trench TP-1 be extended to the west beyond the western edge of the building pads to determine if faults trend through the building pads, using the methods outlined by Christenson and others (2003, figure 2).

Debris-Flow Hazard

Bingham's scope of work did not include a debris-flow/alluvial-fan-flooding hazard assessment but they provide the general conclusion, based on their field observations and literature review, that the debris-flow hazard is low. Bingham indicates alluvial-fan deposition has not occurred in the recent past at the site, based on the presence of a 1 to 2-foot-thick layer of topsoil and the absence of organic-rich layers. However, their evaluation is subjective and infers a soil age based on the thickness of an organic A horizon without additional, more diagnostic supportive soil-age indicators.

Bingham cites a debris-flow-hazard analysis done in 1996 by Great Basin Earth Science for the Eagles subdivision, south of the Scenic View property, which concluded the potential for flooding and debris flows was low. However, the Great Basin study states "flow from Jumpoff Canyon is to the north of the (Eagles) subdivision," which is where the Scenic View development is located. Also, Nelson and Personius (1993) mapped an upper Holocene debris-flow deposit (cd1) along the southern edge of the site, and upper Holocene alluvial-fan deposits (af1) underlying the site. The soils in Bingham's trenches and test pit are likely alluvial-fan and debris-flow deposits, all of which indicate a potential hazard at the site.

In addition, as evident from aerial photos and UGS field visits (Ashland, 1997), the active Jumpoff Canyon drainage channel below the main scarp of the Wasatch fault east of the Scenic View property is incised very little. Thus, a debris flow could potentially avulse and flow onto the site.

A more comprehensive debris-flow-hazard evaluation is needed and should include appropriate site-scale mapping of alluvial-fan deposits, debris-flow volume and frequency estimates, and appropriate risk-reduction measures, if necessary. Giraud (2005) provides guidelines for evaluating debris-flow hazards with information specific to Utah. Depending on the extent of the hazard, appropriate mitigation may involve engineered structures closer to the source east of the site.

Following the UGS review (Ashland, 1997) of the Eagles subdivision debris-flow report (Great Basin Earth Science, Inc., 1996) in 1997, UGS personnel met with Curtis Christensen, Weber County Engineer, and discussed debris-flow hazards and possible mitigation in the area (Christenson, UGS, verbal communication, January 23, 2006). We indicated that because such mitigation generally benefits other development on an alluvial fan, it may not be the sole responsibility of an individual subdivider. Also, sometimes mitigation in one part of an alluvial fan at one site increases the hazard elsewhere, making a whole-fan approach preferable. In similar situations along the Wasatch Front, debris basins and other mitigation measures are considered a government public-works or shared public-private responsibility, rather than solely a private developer's responsibility, because the hazard area encompasses more than one subdivision and reliable long-term maintenance is required. Ogden City may wish to consider if a government public-works or shared public-private responsibility is appropriate at Jumpoff Canyon.

Other Hazards

Bingham's scope of work did not include a landslide study but they indicate a landslide hazard may be associated with the steep slope on the western boundary of the site under saturated conditions. Therefore, slope stability may be a concern locally along the western edge of the site where oversteepening due to road cutting of the already steep fault-scarp slope could cause small, local failures. I concur with Bingham's recommendation that stability of the western slope be considered in the design of the driveway and placement of the buildings.

Holocene-age debris-flow and alluvial-fan deposits, such as those that underlie the site, can be collapsible. Collapsible soils experience hydrocompaction, or settlement under loading conditions, when they become saturated as can occur from landscape irrigation associated with residential development. Therefore, the possible presence of collapsible soils should be evaluated in the geotechnical soil-foundation investigation for the subdivision.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Bingham (2005). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the report are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Ogden City in reducing risks from geologic hazards, but the UGS makes no warranty, expressed or implied regarding its suitability for a particular use. The UGS shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Ashland, F.X., 1997, Review of "Debris flow and flood hazard investigation – proposed Eagles subdivision, Weber County, Utah": Utah Geological Survey Technical Report 97-03, 4 p.

Bingham Engineering, 2005, Fault rupture investigation, 750 North Harrison Boulevard, Ogden, Utah: Salt Lake City, Utah, unpublished consultant's report, 7 p.

Christenson, G.E., Batatian, L.D., and Nelson, C.V., 2003, Guidelines for evaluating surface-fault-rupture hazards in Utah: Utah Geological Survey Miscellaneous Publication 03-6, 13 p.

EarthFax Engineering, Inc., 1994, Investigation of surface fault rupture hazard at the proposed Eagles subdivision, Ogden, Utah: Salt Lake City, Utah, unpublished consultant's report, 17 p.

Giraud, R.E., 2005, Guidelines for the geologic evaluation of debris-flow hazards on alluvial fans in Utah: Utah Geological Survey Miscellaneous Publication 05-6, 16 p.

Great Basin Earth Science, Inc., 1996, Debris flow and flood hazard investigation – proposed Eagles subdivision, Weber County, Utah: Salt Lake City, Utah, unpublished consultant's report, 9 p.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Investigations I-2199, 22 p., 1 pl., scale 1:50,000.

Project: Review of geologic hazard reports, proposed Shadow Mountain Phase II development, Ogden, Utah			
By: Greg N. McDonald	Date: April 14, 2006	County: Weber	
USGS Quadrangles: Ogden	Section/Township/Range: Sec. 14, T.5N., R.1W.		
Requested by: John Mayer, Ogden City Planning	Date report received at UGS: March 24, 2006		Job number: 06-06 (R-41)

INTRODUCTION

At the request of John Mayer, Ogden City Planning, I reviewed two geologic-hazard-related reports for the proposed Shadow Mountain Phase II development. I reviewed "Flood-hazard analysis, unnamed drainage between Dry Canyon and Burch Creek, proposed Shadow Mountain subdivision" dated January 6, 1994, by SHB AGRA, Inc. (SHB AGRA) and "Surface-fault-rupture hazard study, proposed Shadow Mountain Estates – Phase II subdivision, approximately 5525 South Skyline Drive, Ogden, Utah" dated February 10, 2006, by AMEC Earth and Environmental, Inc. (AMEC). For the review, I conducted a literature search and examined 1:12,000-scale (1952) and 1:24,000-scale (1985) aerial photos. In addition, I visited the site on March 30, 2006. The purpose of my review is to determine whether geologic hazards associated with flooding and surface faulting have been adequately addressed at the site.

CONCLUSIONS AND RECOMMENDATIONS

After reviewing the above-referenced reports for Shadow Mountain Phase II, I have the following conclusions and recommendations.

- As SHB AGRA (1994) indicates, the flood hazard associated with the drainage basin it assessed does not directly affect the Phase II part of the development. However, a flooding/debris-flow hazard associated with a smaller drainage basin to the northwest, which now contains a water-retention basin above Phase II, may potentially affect the site, as well as existing development east of the basin. The role of the basin in reducing the flood hazard at Phase II should be evaluated.

- AMEC's surface-faulting investigation discovered faults on the site. AMEC's fault setback determinations are reasonable except for the down-dropped sides of the larger displacement faults. I recommend those setbacks be determined using the "downthrown block" equation in Christenson and others (2003), which takes into account structure-footing depths and fault dips.

- The site is clearly within the zone of deformation of the Wasatch fault, and inferred traces and correlations of faults between trenches are uncertain. Therefore, I recommend footprints of proposed houses that are not crossed by AMEC's trenches be trenched or excavations inspected and documented prior to building to ensure all faults are identified and avoided.

- I recommend reinforced foundations be considered for construction to reduce impacts of possible new faulting.

I also recommend the following:

- The existence of the SHB AGRA (1994) and AMEC (2006) reports, and subsequent reports and reviews, should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultants are followed, the developer should submit to Ogden City written documentation from the consultants indicating that their recommendations were followed.

DISCUSSION

Flood-Hazard Analysis

The flood-hazard analysis by SHB AGRA (1994) was done for the entire Shadow Mountain development, presumably in response to UGS review comments (Lowe, 1993) on a geoseismic/geotechnical study (SHB AGRA, 1993) for Phase I. Phase II represents roughly the northwest tenth of the entire Shadow Mountain development. SHB AGRA (1994) evaluates the flood hazard associated with an unnamed drainage basin northeast of the subdivision between the Dry Canyon and Burch Creek drainages. SHB AGRA (1994) concludes the primary channel for this unnamed drainage is south of the development, and therefore the flood hazard at the site is relatively low and restricted to a "secondary" swale in the southern part of Phase I but does not affect Phase II.

However, a smaller drainage basin exists northwest of the unnamed drainage above Phase II that may present a debris-flow/flooding hazard at Phase II. Yonkee and Lowe (2004) map younger alluvial-fan deposits below the mouth of this drainage, which include the northern part of Phase II. AMEC's (2006) trench logs for trench 3 confirm post-Lake Bonneville debris-flow and alluvial-fan deposits at the site. This smaller drainage may also present a debris-flow/flooding hazard to existing development, as there are at least two newly built houses at the mouth of the drainage and a water-retention basin below the houses on the Bonneville-shoreline bench above Phase II. This basin could intercept flows from the drainage, but an evaluation of basin usage, storage, and overflow/spillway capacity will be needed to determine its potential effectiveness in reducing debris-flow and flood hazards at Phase II. This evaluation should also consider the effects of new construction/site grading above Phase II.

Surface-Fault-Rupture Hazard Study

AMEC (2006) evaluates the surface-fault-rupture hazard for Shadow Mountain Phase II. An earlier report (SHB AGRA, 1993) evaluated the surface-faulting hazard for Shadow Mountain Phase I. In addition, as AMEC (2006) indicates, AGRA (1997) evaluated the surface-faulting hazard for the Hamptons development adjacent to and northwest of the Shadow Mountain development, and Black (1997) reviewed their report. AMEC (2006) characterizes the surface-faulting hazard for Phase II by excavating and logging three trenches across the site. AMEC identifies several faults on the property with offsets ranging from a few inches up to 4.7 feet. AMEC calculates fault setbacks using statewide guidelines by Christenson and others (2003). AMEC calculates setbacks using an "upthrown block" equation (Christenson and others, 2003) and the largest observed fault displacement, yielding a setback less than a recommended minimum 15-foot setback for subdivisions with less than 10 single-family residential dwellings. AMEC's approach is reasonable except for the down-dropped (hanging-wall) sides of larger displacement faults. I recommend those setbacks be determined using the downthrown block equation in Christenson and others (2003), which takes into account structure-footing depths and fault dips.

AMEC (2006) figure 3 depicts fault locations with proposed setback zones. Some of their "inferred" fault projections do not appear to match the noted fault orientations on the trench logs, and AMEC does not provide documentation for all of the inferred fault locations and associated setback zones delineated from them. Faulting is complex at the site, and uncertainty exists in inferred traces and correlations of faults between trenches. Therefore, building footprints at sites that are not crossed by AMEC's trenches should still be trenched or excavations inspected and documented prior to building. Also, reinforced foundations should be considered because they yield additional protection from possible new faulting not addressed by setbacks.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the AMEC and SHB AGRA reports. The Department of Natural Resources, Utah Geological Survey (UGS) provides no warranty that the data in the reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Ogden City in reducing risks from geologic hazards, but the UGS makes no warranty, expressed or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

AGRA Earth & Environmental, Inc., 1997, Fault rupture hazard and geotechnical study, the Hamptons planned urban development, SW ¼ S. 14, T5N, R1W SLBM, Ogden, Utah: Salt Lake City, Utah, unpublished consultant's report, 19 p.

AMEC Earth & Environmental, Inc., 2006, Surface-fault-rupture-hazard study, proposed Shadow Mountain Estates – Phase II subdivision, approximately 5525 South Skyline Drive, Ogden, Utah: Salt Lake City, Utah, unpublished consultant's report, 9 p.

Black, B.D., 1998, Review of "Fault rupture hazard and geotechnical study, the Hamptons planned urban development, SW ¼ S. 14, T5N, R1W SLBM, Ogden, Utah," *in* McDonald, G.N., 1999, Technical reports for 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 203-206.

Christenson, G.E., Batatian, L.D., and Nelson, C.V., 2003, Guidelines for evaluating surface-fault-rupture hazards in Utah: Utah Geological Survey Miscellaneous Publication 03-6, 13 p.

Lowe, M., 1993, Review of "Report, geoseismic/geotechnical study, Shadow Mountain subdivision, Phase I, Ogden, Utah," *in* Mayes, B.H., and Wakefield, S.I., 1994, Technical reports for 1992 – 1993, Applied Geology Program: Utah Geological Survey Report of Investigation 224, p. 156-157.

SHB AGRA, Inc., 1993, Report, geoseismic/geotechnical study, Shadow Mountain subdivision, Phase I, Ogden, Utah: Salt Lake City, Utah, unpublished consultant's report, 15 p.

--- 1994, Flood-hazard analysis, unnamed drainage between Dry Canyon and Burch Creek, proposed Shadow Mountain subdivision: Salt Lake City, Utah, unpublished consultant's report, 5 p.

Yonkee, Adolph, and Lowe, Mike, 2004, Geologic map of the Ogden 7.5-minute quadrangle, Weber and Davis Counties, Utah: Utah Geological Survey Map 200, 42 p. pamphlet, scale 1:24,000.

Utah Geological Survey

Project: Review of geotechnical and geologic-hazards evaluation for 1740 East Ponderosa, Layton, Utah			
By: Richard E. Giraud, P.G.	Date: 05-10-06	County: Davis	
USGS Quadrangles: Kaysville (1320)	Section/Township/Range: SE1/4 section 22, T. 4 N., R. 1 W., SLBLM		
Requested by: Kem Weaver, Community Development Department	Date report received at UGS: 03-15-06		Job number: 06-07 (R-42)

INTRODUCTION

I reviewed the geologic parts of a geotechnical report by Earthtec Testing and Engineering, P.C. (Earthtec, 2005) and a geologic-hazards-evaluation report by Western GeoLogic, LLC (Western GeoLogic, 2005) for a lot at 1740 East Ponderosa, Layton. The Earthtec (2005) geotechnical report includes the Western GeoLogic geologic-hazards report as an appendix. For this review, I studied relevant geologic literature and geologic reports and examined geology and geotechnical landslide investigations for the property to the south. I also reviewed 1:20,000-scale (1937), 1:10,000-scale (1958), and 1:24,000-scale (1985) stereo aerial photographs; U.S. Geological Survey 1997 and 2003 aerial photos at various scales (TerraServer USA, 2006); and National Agriculture Imagery Program aerial photos at various scales (Utah Automated Geographic Reference Center, 2006). The purpose of my review is to assess whether geologic hazards are adequately addressed at the site. I did not review the geotechnical engineering aspects of the Earthtec report.

CONCLUSIONS AND RECOMMENDATIONS

I believe Earthtec (2005) and Western GeoLogic (2005) adequately address geologic hazards at the site except for landsliding. I have the following comments and recommendations:

- The southern half of the lot lies on a landslide that extends downslope to the North Fork of Holmes Creek. Both prehistoric and historical landslides have occurred on the lot (Earthtec, 1999b, 2000a) and suggest marginal stability of the southern half of the lot.

- Earthtec (2005) analyzed the stability of a shallow landslide in the upper slope and determined that a factor of safety of 1.5 is achieved with a 65-foot setback to the south from Ponderosa Street. Earthtec recommends a house foundation system at least 25 feet deep in the landslide crown, designed as a retaining wall to isolate the house from the landslide. The deep foundation system would not stabilize the landslide; therefore, future landslide movement on this and adjacent lots may occur but may not damage the house if the deep foundation system is successful.

- Earthtec (2005) provides recommendations for a foundation drain but does not include a design to designate where the drained water will be discharged. I recommend a drainage plan be developed showing the drain-water discharge location(s) to ensure that water is not discharged onto the landslide where it may promote movement.

- Earthtec (2005) does not show the position of the landslide main scarp on the lot. A site-specific geologic map is needed showing the landslide and related landslide features, particularly the main scarp, relative to the proposed foundation. Also, the depth of landsliding in the area of the proposed house should be shown on a cross section along with the main scarp, Ponderosa Street, and proposed deep foundation system. Earthtec also needs to provide evidence indicating the 25-foot-deep foundation is adequate to prevent damage to the structure if the landslide reactivates.

- The Earthtec (2005) landslide analysis mainly considered shallow landsliding in the upper slope and not deeper landsliding in the lower slope that extends to the North Fork of Holmes Creek. I recommend additional landslide analysis considering estimated climatic and development-induced rises in ground-water levels. Also where the analysis uses back-calculated strengths, I recommend using the existing deeper landsliding in the lower slope to determine likely factors of safety for various setback distances from the main scarp. Such an analysis also addresses the potential for landslides to enlarge upslope as occurred in the 2001 Heather Drive landslide.

I also recommend the following:

- A qualified geotechnical engineer should review geotechnical engineering aspects of the Earthtec (2005) report, including the foundation depth and design.

- The existence of the Earthtec (2005) and Western GeoLogic (2005) reports, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultants are followed, the developer should submit to Layton City written documentation from the consultants indicating that their recommendations were followed.

DISCUSSION

Earthtec (2005) and Western GeoLogic (2005) list landsliding, earthquake ground shaking, shallow ground water, and problem soils as potential geologic hazards at the site. The report adequately addresses these geologic hazards except for landsliding, which needs additional investigation and analysis.

Western GeoLogic (2005) mapped a possible landslide on the site. Western GeoLogic also excavated a trench across a potential landslide scarp but found no evidence of landsliding. Western GeoLogic concluded that the possible mapped landslide may be a surficial anomaly related to grading and fill material. However, a landslide main scarp crossing the lot is shown in figure 1 and Western GeoLogic's trench did not cross the landslide main scarp. Earthtec (2005) apparently misinterprets Western GeoLogic's conclusion because they state Western GeoLogic identified a landslide on the site. However, Earthtec has previous knowledge of existing landslides at the site from their investigations for the proposed Friez condominium complex immediately to the south (Earthtec, 1999a, 1999b, 2000a, 2000b, 2000c, 2000d). Based on discussions with the Utah Geological Survey regarding the proposed Friez condominium complex and discussions with the previous landowner (Earthtec, 2000b), Earthtec is also aware that a landslide at the site reactivated in the early to mid-1970s (figure 1) and impacted the lot at 1740 East Ponderosa. The early to mid-1970s landslide (figure 1) broke the foundation of a house being constructed at the time (Goode, 1975). Recent geologic mapping by Solomon (2005) shows the landslide main scarp crossing the lot.

Earthtec (2005) analyzed shallow landsliding and states that, based on their analysis, a factor of safety greater than 1.5 is achieved using a setback of 65 feet south of Ponderosa Street. Earthtec (2005) recommends a foundation at least 25 feet deep and a foundation system that will act as a 25-foot-high retaining wall to prevent damage if the landslide moves and removes lateral foundation support. It appears that Earthtec's recommendation intends to place the house in the landslide crown adjacent to the landslide main scarp and isolate the house from future landslide movement using a deep foundation system. Earthtec does not state their evidence supporting that a 25-foot-deep foundation system is adequate to protect from future landslide movement, and should provide that evidence. The deep foundation system may isolate the house from the landslide but would not stabilize the landslide. Therefore, future landslide movement may impact this lot, adjacent lots, and the hillslope below. Earthtec (2005) also recommends a foundation drain that drains water to a storm sewer or other free gravity outlet. In addition to Earthtec's drain recommendation, a drainage plan is needed that shows drain discharge location(s) to ensure the water is not discharged onto the landslide, which would promote movement.

In their landslide analysis, Earthtec modeled mainly shallow landsliding in the upper slope (Earthtec, 2005, figures 7, 8, 9) but did not model the 1970s failure and deeper landsliding in the lower slope that extends to the North Fork of Holmes Creek. Previous trenching in the lower slope (Earthtec, 1999b) shows that the toe of the landslide extends to the North Fork of Holmes Creek, and previous drilling (Earthtec, 2000a) shows deeper landsliding in the lower slope. Therefore, I do not believe Earthtec has adequately evaluated the landslide hazard and potential impacts to the lot.

Earthtec (2005) does not show the location of the landslide main scarp on a site map or cross section so I cannot evaluate if their recommended setback prevents the house from resting on the landslide. Fill on the lot (Earthtec, 2005; Western GeoLogic, 2005) placed after the early to mid-1970s landslide (figure 1) likely obscures the main scarp. The main-scarp location is critical for constraining landslide stability models and ensuring the house is not built on the landslide. For the Friez condominium complex landslide investigation, Earthtec (2000c) describes the early to mid-1970s landslide boundaries based on discussions with the previous property owner and shows an approximate area of historical landsliding on figure 1 of their report. Based on the area of historical landsliding, approximately the southern 50% of the 1740

East Ponderosa lot is on the landslide and a 65-foot setback from Ponderosa Street is not adequate to keep the entire house off of the landslide. I have included a 1975 photograph (figure 1) of the main scarp resulting from the 1970s movement of an existing landslide that is evident on 1937 and 1958 aerial photographs. Since the main-scarp location on the lot is not known, aerial photographs and trenching should be used to locate the main scarp so it can be shown on a site map and cross section to show the proposed building, property boundaries, and setbacks or other mitigation measures to identify a safe building location. The main-scarp location and analysis of deeper landsliding are critical to constraining landslide stability models, estimating setbacks, and outlining buildable and nonbuildable areas. The landslide stability analysis should consider soil strengths for a deeper landslide in the lower slope and consider climatic and development-induced changes in ground-water levels. Ashland and others (2005) show ground-water-level fluctuations in the nearby Sunset Drive and Heather Drive landslides.

The landslide at 1740 East Ponderosa is similar to the 2001 Heather Drive landslide (Giraud, 2002; Applied Geotechnical Engineering Consultants, [AGEC], 2002) that was a reactivated existing landslide. Both landslides extend down to the creeks and have similar slope angles and ground-water conditions. The 2001 Heather Drive landslide main scarp is up to 65 feet upslope into the landslide crown from the preexisting main scarp. For the Heather Drive landslide, AGEC (2002) determined that the 1.3 factor-of-safety boundary was up to 150 feet from the 2001 main scarp, a 1.5 factor-of-safety boundary would be even a greater distance from the 2001 main scarp. Similar factor-of-safety boundaries may also exist at 1740 East Ponderosa when deeper landsliding is considered in the stability analysis.

SUMMARY

Western Geologic (2005) found no evidence of landsliding even though their trench was excavated within a known historical landslide, but their trench did not cross the landslide main scarp. Approximately the southern 50% of the lot lies on a landslide that extends downslope to the North Fork of Holmes Creek. Prehistoric and historical landslide movements have displaced the southern part of the lot downslope to the south. Earthtec (2005) analyzed the stability of shallow landsliding in the upper slope and recommends building in the landslide crown, presumably adjacent to the landslide main scarp that crosses the lot. Earthtec (2005) recommends a deep foundation system for the house to isolate it from future landslide movement. However, the location of the main scarp on the lot is unknown and is likely obscured by fill, so the Earthtec (2005) 65-foot setback from Ponderosa Street may not prevent the house from being built at least partially on the landslide and therefore subject to damage should the landslide reactivate. Landslide investigations at the proposed Friez condominium complex indicate deeper landsliding that extends to the North Fork of Holmes Creek. The landslide-hazard analysis should consider this deeper landsliding in the lower slope and use back-calculated strengths for the deeper landsliding and climatic and development-induced changes in ground-water levels to model stability. The landslide is similar to the 2001 Heather Drive landslide that enlarged upslope. The potential for landslide enlargement upslope must also be evaluated at this site. Study of the Heather Drive landslide showed the 1.3 factor-of-safety boundary was a large distance upslope of the main scarp. A similar factor-of-safety boundary may exist at the 1740 East Ponderosa lot.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Earthtec (2005) and Western GeoLogic (2005) reports. The Department of Natural Resources, UGS, provides no warranty that the data in the Earthtec (2005) and Western GeoLogic (2005) reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Layton City in reducing risks from geologic hazards, but the UGS makes no warranty, expressed or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Applied Geotechnical Engineering Consultants, Inc., 2002, Geotechnical investigation, slope stability analysis, Heather Drive landslide, 1350 through 1500 East Heather Drive, Layton, Utah: Sandy, Utah, unpublished draft consultant's report, 14 p.

Ashland, F.X., Giraud, R.E., and McDonald, G.N., 2005, Ground-water-level fluctuations in Wasatch Front landslides and adjacent slopes, northern Utah: Utah Geological Survey Open-File Report 448, 22 p.

Earthtec Testing and Engineering, P.C., 1999a, Geotechnical study, PRUD condominium complex, 1700 East Ponderosa, Layton, Utah: Ogden, Utah, unpublished consultant's report, 11 p.

—1999b, Addendum to geotechnical investigation, PRUD condominium complex, 1700 East Ponderosa, Layton, Utah: Ogden, Utah, unpublished consultant's report, 3 p.

—2000a, Addendum to geotechnical investigation, PRUD condominium complex, 1700 East Ponderosa, Layton, Utah: Ogden, Utah, unpublished consultant's report, 2 p.

—2000b, Stability of landslide, PRUD condominium complex, 1700 East Ponderosa, Layton, Utah: Ogden, Utah, unpublished consultant's report, 2 p.

—2000c, Revised geotechnical study, PRUD condominium complex, 1700 East Ponderosa, Layton, Utah: Ogden, Utah, unpublished consultant's report, 19 p.

—2000d, Revised slope stability analysis, PRUD condominium complex, 1700 East Ponderosa, Layton, Utah: Ogden, Utah, unpublished consultant's report, 3 p., 4 map sheets.

—2005, Geotechnical study, 1740 East Ponderosa, Layton, Utah: Ogden, Utah, unpublished consultant's report, 14 p.

Giraud, R.E., 2002, Movement history and preliminary hazard assessment of the Heather Drive landslide, Layton, Davis County, Utah: Utah Geological Survey Report of Investigation 251, 22 p.

Goode, H.D., 1975, Environmental geology of the middle Wasatch Front, Utah: Field trip guidebook for a field trip of the annual meeting of the Geological Society of America, October 19, 1975, 22 p.

Solomon, B.J., 2005, Interim surficial geologic map of part of the Kaysville quadrangle, Davis County, Utah: Utah Geological Survey, Final Technical Report to the U.S. Geological Survey National Cooperative Geologic Mapping Program, contract number 04HQAG0040, scale 1:24,000.

TerraServer USA, 2006, U.S. Geological Survey 1997 and 2003 aerial photographs: Online, <http://terraserver.microsoft.com/image.aspx?T=4&S=11&Z=12&X=1054&Y=11365&W=1&qs=%7clayton%7cut>, accessed March 21, 2006.

Utah Automated Geographic Reference Center, 2006, National agriculture imagery program aerial photos: Online, <http://agrc.utah.gov/agrc_sgid/naip.html>, accessed March 20, 2006.

Western GeoLogic, LLC, 2005, Geologic hazards evaluation, single lot at 1740 East Ponderosa Street, Layton City, Davis County, Utah: Salt Lake City, Utah, unpublished consultant's report, 14 p.

Project: Review of "Geotechnical study, Pineview at Radford Hills, Huntsville, Utah"			
By: Greg N. McDonald	Date: June 1, 2006	County: Weber	
USGS Quadrangles: Huntsville	Section/Township/Range: Sec. 3 and 10, T.6N., R.1E.		
Requested by: Scott Mendoza, Weber County Planning	Date report received at UGS: April 17, 2006		Job number: 06-08 (R-43)

INTRODUCTION

At the request of Scott Mendoza, Weber County Planning, I reviewed "Geotechnical study, Pineview at Radford Hills, Huntsville, Utah" dated March 23, 2006, by Earthtec Testing & Engineering, P.C. (Earthtec), which includes "Geologic hazards evaluation, Pineview Estates at Radford Hills, Weber County, Utah" dated January 30, 2006, by Western GeoLogic, LLC (Western GeoLogic). For the review, I conducted a literature search, examined 1:12,000-scale (1952) aerial photos, and visited the site on May 4, 2006. The purpose of my review is to determine whether geologic hazards have been adequately addressed at the site.

CONCLUSIONS AND RECOMMENDATIONS

Earthtec and Western GeoLogic have adequately identified potential hazards at the Pineview Estates at Radford Hills development and give recommendations that should be followed during site development. In addition, I have the following conclusions and recommendations.

- Western GeoLogic/Earthtec found no evidence of Holocene faulting at the site and determined the design site-specific ground acceleration using International Residential Code criteria.
- Earthtec recommends lots along the western part of the site not be developed or graded unless slope stabilities are improved through engineering. Should slope-stabilization designs be considered, I recommend a qualified engineer review them.
- Western GeoLogic identifies areas of the site that are subject to debris-flow/flooding hazards and recommends risk-reduction measures be considered in site grading design.
- Seasonal shallow ground water may be a problem, especially in the western part of the site, and I recommend site grading design and individual house foundation design consider the effects of seasonal surface-water runoff and shallow ground water.

- Earthtec's preliminary assessment is that the liquefaction potential is low but further work would be needed for a more comprehensive evaluation. A detailed, site-specific analysis would be prudent.

- The existence of the Western GeoLogic (2006) and Earthtec (2006) reports, and subsequent reports and reviews, should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultants are followed, the developer should submit to Weber County written documentation from the consultants indicating that their recommendations were followed.

DISCUSSION

Surface Faulting and Earthquake Ground Shaking

Western GeoLogic's (2006) surface-fault-rupture-hazard investigation includes site reconnaissance and a nearly 200-foot-long fault trench in the southwestern part of the site. Western GeoLogic (2006) found no evidence of Holocene faulting at the site and concluded the surface-faulting hazard is low. Both Western GeoLogic (2006) and Earthtec (2006) recognize an earthquake ground-shaking hazard associated with the Wasatch fault zone and Earthtec determined a site-specific ground acceleration using International Residential Code criteria that should be used in residential construction.

Slope Stability/Landslides

Western GeoLogic (2006) indicates a high landslide hazard for lot 6 and both Western GeoLogic and Earthtec identify the western part of the site as potentially susceptible to landslides. Slope stability along the western part of the site is of particular concern as the landslide in lot 6 described by Western GeoLogic is historical and was likely caused by a roadcut. The landslide was active prior to 2001 and reactivated this spring, enlarging both laterally and upslope.

As part of their landslide hazard assessment, Earthtec performed slope-stability analyses for lots 1-7 along the western part of the site. Earthtec's slope-stability analyses yielded results below recommended factors of safety for both static and pseudo-static conditions. Earthtec therefore recommends lots 1-7 not be developed or graded unless slope stabilities are improved through engineering. Earthtec also indicates, based on its experience, slope stabilization of residential lots is generally not economically feasible. Should, however, slope stabilization designs be considered, I recommend a qualified engineer review them.

Debris flow

Western GeoLogic (2006) identifies a debris-flow hazard in the northwestern and southwestern parts of the site, recommends debris flow/flooding risk-reduction measures be considered in site grading design, and suggests deflection berms as one possible risk-reduction measure. Any debris-flow hazard reduction designs should use the 5-foot deposit thickness determined by Western GeoLogic to determine flow depth, and should consider the effects hazard-reduction structures may have on adjacent properties. In addition, I recommend all engineered hazard-reduction designs be reviewed by a qualified engineer.

Shallow Ground Water

Western GeoLogic indicates no springs or shallow ground water were observed during their field investigation. Western GeoLogic/Earthtec's field work was done during the winter when ground-water levels are typically at their seasonal low and, as Western GeoLogic indicates, ground-water levels can fluctuate based on seasonal and climatic conditions. On May 4, 2006, I observed seeps, flowing water, and small ponds along the western portion of the property, mostly in the area of, and associated with, the historical landslide. Therefore, seasonal shallow ground water may be a problem locally, especially in the western part of the site. I recommend site grading and individual foundation designs for the western part of the site consider the effects of seasonal surface-water runoff and shallow ground water.

Liquefaction

Earthtec (2006) and Western GeoLogic (2006) conclude liquefaction potential at the site is low based on observations of surficial deposits and soil types in the test pits. Earthtec's scope of work did not include a detailed, site-specific liquefaction-hazard evaluation. Earthtec indicates additional work, including at least one 40-foot-deep boring, is needed to comprehensively evaluate the liquefaction hazard. Based on Earthec/Western GeoLogic's preliminary evaluation of the liquefaction hazard and the likely presence of shallow ground water, a more detailed investigation of liquefaction potential would be prudent but should not be required.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Earthtec (2006) and Western GeoLogic (2006). The Department of Natural Resources, Utah Geological Survey (UGS) provides no warranty that the data in the reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Weber County in reducing risks from geologic hazards, but the UGS makes no warranty, expressed or implied regarding the suitability of this review for a particular use. The UGS shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Earthtec Testing & Engineering, P.C., 2006, Geotechnical study, Pineview at Radford Hills, Huntsville, Utah: Ogden, Utah, unpublished consultant's report, 15 p.

Western GeoLogic, LLC, 2006, Geologic hazards evaluation, Pineview Estates at Radford Hills, Weber County, Utah: Salt Lake City, Utah, unpublished consultant's report, 13 p.

Utah Geological Survey

Project: Review of "Slope stability study, proposed Area C, Wasatch County, Utah"			
By: Barry J. Solomon, P.G.	Date: 06-23-06	County: Wasatch	
USGS Quadrangles: Francis (1167)	Section/Township/Range: S1/2 section 35, T. 2 S., R. 5 E., and sections 2, 3, 10, and 11, T. 3 S., R. 5 E., SLBM		
Requested by: Al Mickelsen, Wasatch County Planning	Date report received at UGS: 05-11-06		Job number: 06-09 (R-44)

INTRODUCTION

I reviewed geologic portions of the slope-stability report by Dames & Moore, dated January 28, 1998, for the proposed Area C development (Dames & Moore, 1998). I previously reviewed the engineering geology and geotechnical report for the Area C development by Dames & Moore, dated July 28, 1997 (Dames & Moore, 1997), in Utah Geological Survey Technical Report 97-19, dated August 13, 1997 (Solomon, 1998), and the slope-stability report responds to my review comments. URS Corp. prepared a subsequent update to Dames & Moore (1997) to address geologic hazards for a 200-acre parcel added to the original proposed development, which has been renamed as The Aspens at Jordanelle (URS, 2003).

For the review, I studied relevant geologic literature and examined 1:20,000-scale (1962) and 1:40,000-scale (1987) aerial photographs, but I did not inspect the site. The purpose of my review was to assess whether Dames & Moore (1998) and URS (2003) adequately identified and addressed geologic hazards that could affect the proposed development.

CONCLUSIONS AND RECOMMENDATIONS

I do not believe that Dames & Moore (1998) and URS (2003) provide adequate documentation that slopes less than 25 degrees will be stable when developed. To address such potential slope instability, Dames & Moore (1998) recommends "areas proposed for structures be specifically investigated for. . .conditions which could lead to slope instability." Because a landslide exists on an on-site slope less than 25 degrees, I further recommend:

- Dames & Moore (or URS) clarify the types of data and slope-stability analyses recommended in areas proposed for structures. Of particular concern are areas with slopes between 14 degrees (25 percent) and 25 degrees (47 percent) that are underlain by relatively thick colluvium and/or weathered welded tuffs in the Keetley Volcanics as shown on the site geologic map;

- Additional geologic inspection on and near the site to see if any prominent weak layers or adverse joint/fracture patterns are evident in the Keetley Volcanics to determine the appropriate failure type(s) to use in slope-stability analyses;

- Dames & Moore's recommended additional slope-stability analyses in areas proposed for structures should use appropriate models for likely failure types and locations and configurations of potential failure surfaces;

- Review of the slope-stability analyses by a geotechnical engineer experienced in rock-slope stability.

I also recommend the following:

- A qualified geotechnical engineer should review recommendations pertaining to foundation design and site grading in geotechnical studies cited in this review and any subsequent studies.

- The existence of the Dames & Moore (1997, 1998) and URS (2003) reports, this review, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating compliance with the recommendations.

DISCUSSION

Dames & Moore (1998) includes slope-stability analyses for slopes of 30 and 35 degrees. They calculated minimum static factors of safety less than 1.5 for both slopes, and concluded from the analyses and their observations of site conditions that "natural slopes steeper than about 25 degrees present a relatively high risk of landslide or slope instability." They infer that slopes flatter than 25 degrees (47 percent) are relatively safe, and recommend "development within the steeper areas of the site (slopes equal to or greater than 25 degrees), should be avoided unless measures are taken to reduce the potential instability." However, they also document a landslide in the southern part of the site with slopes in the area ranging from 7 to 18 degrees (12 to 33 percent), suggesting that local landsliding is possible on slopes flatter than 25 degrees.

Dames & Moore's (1998) recommended avoidance of development on slopes steeper than 25 degrees, unless measures are taken to reduce the potential instability, is reasonable. However, I do not believe that Dames & Moore (1998) provides adequate documentation that slopes less than 25 degrees will be stable when developed, and the basis of their slope-stability study is an apparent misinterpretation of my original recommendation. In my review (Solomon, 1998) of the engineering geology and geotechnical report for the Area C development (Dames & Moore, 1997), I recommended slope-stability evaluation for slopes steeper than 25 **percent**, which was the basis for mapping areas of moderate relative hazard in the Keetley Volcanics by

Hylland and Lowe (1996), almost half the gradient of analyzed slopes of 25 **degrees** (47 percent) in the Dames & Moore report.

Dames & Moore (1998) documents the presence of "surface creep" in the northwest part of the site, "hummocky topography" in the southern part of the site, and a landslide on the added parcel in the southern part of the site (mapped by Hylland and Lowe, 1996). All of these features occur on slopes less than 25 degrees. Because static factors of safety are inferred by Dames & Moore to be greater than 1.5 on these more gentle slopes, indicating stability, they suggested that the instability evident on these slopes was due, in part, to locally steeper dips of the bedrock-colluvium interface (the surface on which sliding is presumed to have occurred). However, Dames & Moore (1998) did not observe this condition in any of its test pits excavated onsite, although they recommended additional test pits be excavated in areas proposed for structures to evaluate soil, rock, and moisture conditions.

There are other factors that may contribute to potential slope instability that Dames & Moore (1998) does not address. These factors include:

(1) The position of the failure surface—Dames and Moore modeled slope stability assuming that the failure surface was at the interface between colluvium and weathered bedrock; although this may be true, the failure may also have occurred on a planar surface such as a thin, weak ash or tuff layer within the bedrock (Keetley Volcanics); this would be consistent with the observation that bedding exposed in test pits generally parallels the slope;
(2) The nature of the failure type—although the slab failure in colluvium over bedrock assumed by Dames and Moore is possible, another likely mechanism is a wedge failure at the intersection of two planar surfaces in bedrock. Dames and Moore has already documented bedding as one such planar surface, and the Keetley is commonly cut by one or more joint sets which are often not visible in weathered rock exposed in shallow test pits;
(3) The cohesion of weathered bedrock—Dames and Moore used a cohesion of 3000 psf, but slope-stability analyses for other Wasatch County projects in similar material used a lower value for cohesion; Earthtec (2005), for example, used a value of 1000 psf. The UGS is not aware of any strength-test results for Keetley Volcanics;

Whatever the cause of the observed slope failures on and near the site, they and other landslides in western Wasatch County underlain by the Keetley Volcanics commonly occur on slopes with inclinations considerably less than the 25 degrees (47 percent) that Dames & Moore (1998) considered the lower bound of high-risk slopes on the project site. Hylland and Lowe (1997) calculated that such landslides occur on slopes in Keetley Volcanics averaging about 40 percent (21 degrees), with a minimum slope of 14 percent (8 degrees) for late Holocene landslides. This minimum slope is close to the minimum slope observed by Dames & Moore of 7 degrees (12 percent) in the area of the landslide in the southern part of the site. Hylland and Lowe (1997) identify a critical slope angle for the Keetley Volcanics of 25 percent, which was used to identify moderate landslide hazard areas on Hylland and Lowe (1996).

To ensure the stability of natural slopes, Dames & Moore (1998) recommends "that areas proposed for structures be specifically investigated for the presence of bedrock, soil and moisture conditions which could lead to slope instability. . . .site specific investigations could be efficiently investigated by excavating test pits with a backhoe." This recommendation, although conceptually prudent, is vague. The Dames & Moore recommendation does not specify what "conditions" could "lead to slope instability," what data should be gathered from the test pits to determine such "conditions," and what analyses would be needed for the collected data.

In addition to the Dames & Moore recommendations, additional slope-stability analyses should address the three factors listed above. Of particular concern are areas with slopes between 14 degrees (25 percent) and 25 degrees (47 percent) underlain by relatively thick colluvium and/or weathered welded tuffs in the Keetley Volcanics (as shown on the site geologic map in Dames & Moore, 1997). Obtaining a more accurate estimate of the peak strength of onsite materials may be possible by back-calculation using a reconstructed estimate of the pre-failure slope of the onsite landslide and the results of additional geologic inspection on and near the site to see if any prominent weak layers or joint/fracture patterns are evident. The results of additional slope-stability analyses in areas proposed for structures can then be used to determine buildable areas and setbacks from the top and base of steep slopes, and these areas and setbacks should be plotted on a suitable base map.

The assumptions and geologic interpretations used in these recommended slope-stability analyses should apply both to natural and cut slopes. Dames & Moore (1998) found that 2V:1H (200 percent) cut slopes about 20 feet high were stable, but if bedrock strengths are determined to be less than assumed, and additional prominent weak bedrock layers or adverse joint/fracture patterns are identified, then these cut slopes may not be stable. For cut slopes greater than 5 feet high, either standard International Building Code recommendations or other specific engineering-design recommendations, possibly modified based on site inspections with design modifications during excavation, will be required.

SUMMARY OF CONCLUSIONS

I do not believe that Dames & Moore (1998) provides adequate documentation that some slopes will be stable in the proposed The Aspens at Jordanelle development (proposed Area C). Dames & Moore recommends investigation of conditions leading to slope instability in "areas proposed for structures." Of particular concern are slopes between 14 degrees (25 percent) and 25 degrees (47 percent) that are underlain by relatively thick colluvium and/or weathered welded tuffs in the Keetley Volcanics. Additional slope-stability analyses should use the results of additional geologic inspection on and near the site to see if any prominent weak layers or joint/fracture patterns are evident. Strengths may be estimated by back-calculation using a reconstructed estimate of the pre-failure slope of the onsite landslide. The results of the analyses should then be used to determine buildable areas and setbacks from the top and base of steep slopes, and these areas and setbacks should be plotted on a suitable base map.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in Dames & Moore (1998) and URS (2003). The Department of Natural Resources, Utah Geological Survey (UGS), provides no warranty that the data in the Dames & Moore and URS reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, expressed or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Dames & Moore, 1997, Engineering geology reconnaissance and geotechnical study, proposed Area C, Wasatch County, Utah: Salt Lake City, Utah, unpublished consultant’s report, 17 p.

-----1998, Slope stability study, proposed Area C, Wasatch County, Utah: Salt Lake City, Utah, unpublished consultant’s report, 12 p.

Earthtec Testing & Engineering, 2005, Slope stability evaluation, Victory Ranch Pods B, C, D, Wasatch County, Utah: Orem, Utah, unpublished consultant’s report, 4 p.

Hylland, M.D., and Lowe, M., 1996, Landslide hazard, western Wasatch County, Utah (plate 1B), *in* Hylland, M.D., Lowe, M., and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

-----1997, Regional landslide-hazard evaluation using landslide slopes, western Wasatch County, Utah: Environmental & Engineering Geoscience, v. 3, p. 31-43.

Solomon, B.J., 1998, Review of “Engineering geology reconnaissance and geotechnical study, proposed Area C, Wasatch County, Utah,” *in* Mayes, B.H., compiler, Technical reports for 1997 Applied Geology Program: Utah Geological Survey Report of Investigation 236, p. 111-115.

URS Corp., 2003, 2003 update letter report, Engineering geology reconnaissance and geotechnical study, The Aspens at Jordanelle, Wasatch County, Utah: Salt Lake City, Utah, unpublished consultant’s report, 9 p.

Utah Geological Survey

Project: Review of geotechnical and geologic-hazards evaluation for 1681 East Hillsboro Drive, Layton, Utah			
By: Richard E. Giraud, P.G.	Date: 08-11-06	County: Davis	
USGS Quadrangles: Kaysville (1320)	Section/Township/Range: SW1/4NE1/4 section 15, T. 4 N., R. 1 W., SLBLM		
Requested by: Kem Weaver, Community Development Department	Date report received at UGS: 05-12-06		Job number: 06-11 (R-45)

INTRODUCTION

I reviewed the geologic parts of a geotechnical report by Y^2 Geotechnical, P.C. (Y^2 Geotechnical, 2005) and a geologic-hazards evaluation by Western GeoLogic, LLC (Western GeoLogic, 2005) for a lot at 1681 East Hillsboro Drive, Layton. I also reviewed a letter by Y^2 Geotechnical (2006) providing recommendations to stabilize a cut slope. For this review, I studied relevant geologic literature, including geologic and geotechnical landslide investigations in the area. I also reviewed 1:20,000-scale (1937), 1:10,000-scale (1958), and 1:24,000-scale (1985) stereo aerial photographs; U.S. Geological Survey 1997 and 2003 orthophotos at various scales (TerraServer USA, 2006); and National Agriculture Imagery Program orthophotos at various scales (Utah Automated Geographic Reference Center, 2006). The purpose of my review is to assess whether geologic hazards are adequately addressed at the site. I did not review the geotechnical engineering aspects of the Y^2 Geotechnical (2005) report.

CONCLUSIONS AND RECOMMENDATIONS

I believe Y^2 Geotechnical (2005) and Western GeoLogic (2005) adequately address geologic hazards at the site except for landsliding and earthquake ground shaking. I have the following comments and recommendations:

- A large historical landslide that extends from the slope crest downslope to South Fork Kays Creek was not identified; this landslide encompasses the majority of the lot and indicates marginal stability of the entire slope.

- A site-specific geologic map and cross section are needed to show the large landslide and related landslide features, particularly the main scarp and rupture surface, relative to Hillsboro Drive, South Fork Kays Creek, and the proposed house foundation.

- A stability analysis of the large landslide is needed; this analysis should consider estimated climatic and development-induced rises in ground-water levels, and setback distances from the main scarp or other risk-reduction measures to achieve adequate factors of safety.

- Y^2 Geotechnical's (2005) recommendations for a foundation drain should show the drain-water discharge location(s) to ensure that water is not discharged onto the lower part of the large landslide where it may promote movement.

- To address the earthquake ground-shaking hazard, the appropriate seismic design category should be determined.

I also recommend the following:

- A qualified geotechnical engineer should review geotechnical engineering aspects of the Y^2 Geotechnical (2005) report.

- The existence of the Y^2 Geotechnical (2005) and Western GeoLogic (2005) reports, and subsequent reports and reviews, should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultants are followed, the developer should submit to Layton City written documentation from the consultants indicating that their recommendations were followed.

DISCUSSION

Y^2 Geotechnical (2005) and Western GeoLogic (2005) address landsliding, earthquake ground shaking, shallow ground-water, and liquefaction hazards. Additional investigations are needed to adequately address the landslide and ground-shaking hazards.

Landslide Hazard

Western GeoLogic (2005) identified a small translational landslide that moved in the late 1980s in the north-facing slope on the north part of the lot (figure 4 of Western GeoLogic, 2005). Western GeoLogic (2005) trenched the landslide and identified a landslide scarp presumed to be the main scarp. Western GeoLogic (2005) found landslide deposits 7.5 feet thick, indicating a shallow landslide. Y^2 Geotechnical used the main-scarp location and the shallow landslide depth to locate the house and design a foundation to isolate the house from future landslide movement.

I visited the site on November 16, 2005, with Scott Carter (Layton City Community Development Director) after part of the site had been excavated for a building pad which resulted in a steep cut slope. Y^2 Geotechnical also visited the site, determined the unsupported cut slope was at risk of failure, and provided backfilling recommendations to reduce the risk of slope failure (Y^2 Geotechnical, 2006). During my site visit, I observed steeply inclined bedding (38° NE dip) in Lake Bonneville sediments in this cut slope just below the sidewalk on Hillsboro Drive (figure 1). The inclined bedding is likely related to landslide deformation and indicates the landslide identified by Western GeoLogic (2005) extends farther south than shown on figure 4 in their report. Part of the lot also lies in a small amphitheater. The amphitheater and the deformed Lake Bonneville sediments suggest that the proposed house location (figure 2 of Y^2 Geotechnical, 2005) may lie entirely within a landslide.

In addition to the small landslide identified by Western GeoLogic (2005), a large landslide is also present on the site. This landslide was mapped by Lowe (1988; LS 448) and extends from the small amphitheater on the lot to South Fork Kays Creek. This landslide was previously identified during an investigation for the lot to the east (1693 East Hillsboro Drive, previously 1701 East Hillsboro Drive) by American Geological Services, Inc. (AGS). Movement of this landslide in 1998 deformed the lower part of the slope above South Fork Kays Creek (figure 2). Utah Geological Survey Global Positioning System surveying indicates the lower slope moved approximately 6 centimeters (2.4 inches) northward toward South Fork Kays Creek in the spring of 2006. The large landslide may be a rotational landslide similar to the 2001 Heather Drive landslide (Giraud, 2002; Applied Geotechnical Engineering Consultants, Inc. [AGEC], 2002; Nordquist, 2002) and the Sunset Drive landslide (Giraud, 1998; 1998 and 2006 movement), on which the small translational landslide described by Western GeoLogic (2005) and modeled by Y^2 Geotechnical occurs. Since the Y^2 Geotechnical design is based on the small landslide identified by Western GeoLogic (2005) and not the large landslide, the Y^2 Geotechnical design does not protect the proposed house from future landslide damage. Because the large landslide is not recognized and considered in the landslide stability analysis and landslide mitigation, I do not believe the landslide hazard has been adequately addressed.

Accurately locating the main scarp of the large landslide is critical to ensure that either the house is not built on the landslide or that mitigation measures are properly designed. Therefore, I recommend using aerial photographs and subsurface investigation to locate the main scarp so it can be shown on a site-specific geologic map and cross section relative to the proposed building, property boundaries, and setbacks or other mitigation measures. The main scarp of the large landslide is evident on 1937, 1958, and 1985 aerial photographs. The other landslide boundaries must also be identified since they are critical to constraining landslide stability models, estimating setbacks, and outlining buildable and nonbuildable areas. Subsurface investigation may also be necessary to determine the depth of the large landslide and the type of movement (rotational versus translational). The AGS (1999) investigation at 1693 East Hillsboro Drive (the lot immediately east) includes mapped landslide features that may be helpful in assessing the landslide hazard at 1681 East Hillsboro Drive.

Because the large landslide has recently moved, it has a probable factor-of-safety near 1.0. As such, an estimate of soil strength can be back-calculated. Soil-strength data are also available from other landslide investigations at the nearby 2001 Heather Drive landslide (AGEC, 2002) and the Sunset Drive landslide (Terracon Consultants, Inc., 1998). Climatic and development-induced changes in ground-water levels occur in the Layton area and should be used in analyzing landslide stability. Ashland and others (2005, 2006) show ground-water-level fluctuations in the nearby Sunset Drive and Heather Drive landslides. Landslide investigations at 1693 East Hillsboro Drive (Earthtec Testing and Engineering, P.C., 1999a, 1999b) may be helpful in assessing and analyzing the landslide stability at 1681 East Hillsboro Drive.

Y^2 Geotechnical (2005) recommends a foundation drain that discharges at least 50 feet downslope of the house. In addition to the Y^2 Geotechnical drain recommendation, a drainage plan is needed that shows the drain discharge location(s) to ensure the water is not discharged onto the lower part of the large landslide and promote movement.

The large landslide at 1681 East Hillsboro is similar to the 2001 Heather Drive landslide (Giraud, 2002; AGEC, 2002; Nordquist, 2002) that was a reactivated pre-existing landslide. Both landslides extend downslope to South Fork Kays Creek and have similar slope angles and ground-water conditions. The 2001 Heather Drive landslide main scarp is as much as 65 feet upslope into the landslide crown from the pre-existing main scarp. For the Heather Drive landslide, AGEC (2002) determined that the 1.3 factor-of-safety boundary was as much as 150 feet upslope from the 2001 main scarp; a 1.5 factor-of-safety boundary would be an even greater distance upslope from the 2001 main scarp. Similar factor-of-safety setback boundaries may also exist at 1681 East Hillsboro Drive when the large landslide is considered in the stability analysis.

Earthquake Ground-Shaking Hazard

To address the hazard from earthquake ground shaking, Y^2 Geotechnical states that because of the landslide potential of the site, it is classified as soil site class F where a site-specific geotechnical investigation and dynamic site-response analysis is required by the *International Building Code* (IBC; International Code Council, 2006). Y^2 Geotechnical measured the soil shear-wave velocity and calculates an acceleration response spectrum but does not determine the seismic design category as outlined in the IBC (2006). I recommend Y^2 Geotechnical, in conjunction with the developer, determine the appropriate seismic design category.

SUMMARY

Western GeoLogic (2005) identified a small translational landslide that moved in the late 1980s, but did not identify a large landslide that extends from the slope crest to South Fork Kays Creek. Most of the lot may lie within the head of the large landslide. Landslide movement in 1998 and 2006 deformed the lower part of the large landslide. Additional work is needed to characterize the large landslide, accurately determine landslide boundaries, determine the type of landslide movement, evaluate landslide stability, and design appropriate risk-reduction measures. The landslide is similar to the 2001 Heather Drive landslide that enlarged as much as 65 feet upslope. The potential for landslide enlargement upslope must also be evaluated at this site. Study of the Heather Drive landslide showed the 1.3 factor-of-safety boundary was a large distance upslope of the main scarp. A similar factor-of-safety boundary may exist at the 1681 East Hillsboro Drive landslide. The appropriate seismic design category needs to be determined to address the earthquake ground-shaking hazard.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in the Y^2 Geotechnical (2005) and Western GeoLogic (2005) reports. The Department of Natural Resources, Utah Geological Survey, provides no warranty that the data in the Y^2 Geotechnical (2005) and Western GeoLogic (2005) reports are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Layton City in reducing risks from geologic hazards, but the Utah Geological Survey makes no warranty, expressed or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

American Geological Services, Inc., 1999, Landslide mapping, 1701 Hillsboro Drive, Layton, Utah: Provo, Utah, unpublished consultant's report, 4 p.

Applied Geotechnical Engineering Consultants, Inc., 2002, Geotechnical investigation, slope stability analysis, Heather Drive landslide, 1350 through 1500 East Heather Drive, Layton, Utah: Sandy, Utah, unpublished draft consultant's report, 14 p.

Ashland, F.X., Giraud, R.E., and McDonald, G.N., 2005, Ground-water-level fluctuations in Wasatch Front landslides and adjacent slopes, northern Utah: Utah Geological Survey Open-File Report 448, 22 p.

—2006, Slope-stability implications of ground-water-level fluctuations in Wasatch Front landslides and adjacent slopes, northern Utah, *in* Proceedings of the 40th Symposium on Engineering Geology and Geotechnical Engineering: Logan, Utah State University, May 24-26, 2006, compact disk.

Earthtec Testing and Engineering, P.C., 1999a, Geotechnical consultation, lot 37 Hillsboro subdivision, 1703 East Hillsboro Drive, Layton, Utah: Ogden, Utah, unpublished consultant's report, 3 p.

—1999b, Addendum to geotechnical consultation, lot 37 Hillsboro subdivision, 1703 East Hillsboro Drive, Layton, Utah: Ogden, Utah, unpublished consultant's report, 2 p.

Giraud, R.E., 1998, Reconnaissance of a landslide on East Sunset Drive, Layton, Davis County, Utah, *in* McDonald, G.N., compiler, Technical reports of 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 28-35.

—2002, Movement history and preliminary hazard assessment of the Heather Drive landslide, Layton, Davis County, Utah: Utah Geological Survey Report of Investigation 251, 22 p.

International Code Council, 2006, International Building Code - 2006: Falls Church, Virginia, International Code Council, 664 p.

Lowe, M., 1988, Natural hazards overlay zone - slope-failure inventory map, Ogden quadrangle: Weber County Planning Department unpublished map, scale 1:24,000.

Nordquist, J.E., 2002, Heather Dive landslide, *in* Elfass, S. Norris, G. and Watters, R,. editors, Proceedings of the 38th Symposium on Engineering Geology and Geotechnical Engineering: University of Nevada, Reno, March 19-21, 2003, p. 109-118.

Terracon Consultants, Inc., 1998, Geotechnical report, Sunset Drive landslide, Layton, Utah: Salt Lake City, unpublished consultant's report for City of Layton, 11 p.

TerraServer USA, 2006, U.S. Geological Survey 1997 and 2003 aerial photographs: Online, <http://terraserver.microsoft.com/image.aspx?T=4&S=11&Z=12&X=1054&Y=11365&W=1&qs=%7clayton%7cut>, accessed June 15, 2006.

Utah Automated Geographic Reference Center, 2006, National Agriculture Imagery Program aerial photos: Online, <http://agrc.utah.gov/agrc_sgid/naip.html>, accessed June 15, 2006.

Western GeoLogic, LLC, 2005, Geologic hazards evaluation, Hass Property, 1681 East Hillsboro Drive, Layton, Utah: Salt Lake City, Utah, unpublished consultant's report, 14 p.

Y^2 Geotechnical, P.C., 2005, Geotechnical study, Hass property, 1681 East Hillsboro Drive, Layton, Utah: Layton, Utah, unpublished consultant's report, 18 p., 2 appendices.

—2006, Slope protection, 1681 East Hillsboro Drive, Layton, Utah: Layton, Utah, unpublished Y^2 Geotechnical letter, 1 p.

Figure 1. View of cut slope at 1681 East Hillsboro Drive showing tilted Lake Bonneville sediments. The bedding strikes N. 65° W. and dips 38° NE. Photograph taken on November 11, 2005.

Figure 2. View west of fence displaced by landslide movement in lower slope north and downslope of 1681 East Hillsboro Drive. Photograph taken on April 10, 2006.

Utah Geological Survey

<table>
<tr><td colspan="3">Project:
Review of "Preliminary geotechnical and geological investigation, 350 acre Cummings property, Wasatch County, Utah"</td><td rowspan="3"></td></tr>
<tr><td>By:
Barry J. Solomon, P.G.</td><td>Date:
02-20-07</td><td>County:
Wasatch</td></tr>
<tr><td>USGS Quadrangles:
Francis (1167)</td><td colspan="2">Section/Township/Range:
Section 3, T. 3 S., R. 5 E., SLBLM</td></tr>
<tr><td>Requested by:
Darren James,
Wasatch County Planning</td><td colspan="2">Date report received at UGS:
01-22-07</td><td>Job number:
07-01 (R-46)</td></tr>
</table>

INTRODUCTION

I reviewed the geologic portions of the preliminary geotechnical and geological investigation report by Intermountain GeoEnvironmental Services, Inc. (IGES), dated January 3, 2007, for the proposed 350-acre subdivision on the Cummings property. For the review, I studied relevant geologic literature and examined 1:20,000-scale (1962) aerial photographs, but I did not inspect the site. The purpose of my review was to assess whether IGES (2007) adequately identified and addressed geologic hazards that could affect the proposed development.

CONCLUSIONS AND RECOMMENDATIONS

Although IGES indicates its report is preliminary, I do not believe that IGES (2007) adequately characterizes the landslide hazard, the potential for expansive soils, and the potential for strong earthquake ground shaking on the Cummings property for purposes of defining the scope of additional studies. IGES found no evidence of landsliding during their field investigation, and does not specifically recommend further study of landslide hazards. However, I have identified several features on aerial photos that may be related to landslides on north-facing slopes, and several landslides are mapped in similar geologic material in the site vicinity (Hylland and Lowe, 1996). IGES (2007) notes that steeper slopes on the property are mapped as having a moderate landslide potential (Hylland and Lowe, 1996), but does not adequately document geologic conditions to properly evaluate the potential as recommended on the landslide hazard map of western Wasatch County. One of those conditions is the presence of expansive soil (identified by IGES as "fat clay" on test-pit logs), material that may contribute to the landslide hazard as well as pose problems as foundation soils. To address these hazards, I recommend the following:

- IGES should provide information to document site conditions with emphasis on the stability of steep slopes (greater than 25 percent), based on observation and measurement of geologic conditions such as slope inclination, soil and rock type and condition, the nature of planar features within soil or rock, ground-water conditions, and thickness and description of soil and colluvium overlying rock.

- Documentation should include a map showing locations of test pits and a site geologic map showing the results of field investigations and aerial-photo mapping. If IGES disagrees with my interpretation of the features that I identified on aerial photos as possibly related to landsliding, they should provide an alternate explanation of the features with supporting evidence.

- If documentation recommended above does not provide adequate geologic evidence that slopes are stable and no landsliding has occurred, IGES should provide a map of the site that shows site geology, the extent of site slopes greater than 25 percent, and proposed setbacks or other hazard-reduction methods on a base map showing detailed topography, lots, and site boundaries at a scale of 1 inch = 200 feet or larger, preferably 1 inch = 100 feet. To evaluate stability and determine setbacks, a quantitative slope-stability analysis may be necessary. Sheet 6 of the Jordanelle Basin Master Plan by Dominion Engineering Associates, L.C. (Dominion, 2006) identifies slopes greater than 25 percent on the Cummings property, and several lots and building sites are on or near such slopes.

- The site geologic map should show the likely extent of expansive soils, and foundation excavations should be inspected to determine the presence of expansive soils. The developer's geotechnical-engineering consultant should recommend measures to reduce hazards posed by such soils by incorporating appropriate features into foundation design and site grading, and a qualified geotechnical engineer acting on behalf of Wasatch County should review the recommendations and any subsequent engineering studies.

- If development proceeds, the developer's geotechnical consultant should address the hazard from earthquake ground shaking by verifying site classes and, in conjunction with the developer, determining seismic use groups, seismic design categories, and associated earthquake-resistant design requirements in accordance with procedures of the International Building Code (IBC) (International Code Council, 2006a) and/or International Residential Code (IRC) (International Code Council, 2006b).

I also recommend the following:

- The existence of the IGES (2007) report, this review, and subsequent reports and reviews should be disclosed to potential buyers.

- To ensure that final recommendations from the developer's geotechnical consultant are followed, the developer should submit to Wasatch County written documentation from the consultant indicating compliance with the recommendations.

DISCUSSION

IGES (2007) correctly states that Hylland and Lowe (1996) did not map any landslides on the Cummings property, and IGES found no evidence of landslides during their field investigation. However, I have identified several features on aerial photos that may be related to landsliding on north-facing slopes (1962 aerial photos CVY-2BB-231 and 232). These features include arcuate alcoves, deposits downslope from the alcoves that overlie and obscure bedding and joints in underlying rock, and dense vegetation on downslope deposits within and below alcoves. The features may be, respectively, landslide scarps, landslide deposits that may have moved at least in part by flow failure downslope as much as 0.3 miles, and areas of springs or shallow ground water in fractured and permeable landslide deposits near main scarps. All of the alcoves are at or near the contact between units of the Keetley Volcanics mapped by Bryant (1990) as lahar, flow breccia, and tuff, and an overlying resistant cap of flow rock and breccia. Hylland and Lowe (1996) mapped several landslides in similar rock to the north of the Cummings property, on the shore of Jordanelle Reservoir. Although undercutting of slopes by the Provo River may have contributed to their movement, they are further evidence of a possible hazard on the subject property.

Landslides are relatively common in the Keetley Volcanics of western Wasatch County. A statistical analysis of these landslides allowed calculation of a critical slope inclination above which late Holocene landsliding has occurred, and this inclination is the primary basis for defining the relative landslide hazard (Hylland and Lowe, 1996, 1997). The critical slope inclination for the Keetley Volcanics is 25 percent, and slopes greater than this value are assigned a moderate landslide hazard even where no existing landslides have been identified. This takes into account the potential for future landsliding in landslide-susceptible material, and the potential may be increased by site grading and landscape irrigation, in addition to natural factors. Because the Jordanelle Basin Master Plan (Dominion, 2006) shows several lots and building sites on the Cummings property that are on or near slopes greater than 25 percent, the Utah Geological Survey (UGS) recommends at least a geologic evaluation of relevant factors to determine the landslide hazard. If geologic factors are found that may contribute to the hazard, a slope-stability analysis may be needed to determine buildable areas and setbacks. Guidelines for conducting the evaluations and analyses are given in Hylland (1996) and Blake and others (2002).

One of the factors that contributes to the landslide hazard in the Keetley Volcanics is the presence of expansive clay that forms as a product of weathering. The clay significantly reduces the shear strength of geologic materials, increasing the potential for slope failure. Several IGES test-pit logs show a substantial thickness of expansive (“fat”) clay, with TP-5 encountering 10 feet of expansive clay to the bottom of the pit, with additional similar material possible below. Because a map showing test-pit locations was not provided, I do not know if these clays underlie slopes. Additionally, expansive soil poses a hazard to building foundations, with the potential for irreparable foundation damage. This should be taken into account during site design and grading.

Earthquake ground shaking is also a potential geologic hazard at the site. The IBC (International Code Council, 2006a) specifies earthquake-resistant design requirements for most structures and the IRC (International Code Council, 2006b) specifies these requirements for one- and two-family dwellings. Design requirements specified by the IBC and IRC depend on the seismic design category of a structure, which is based on spectral response accelerations and, for the IBC, seismic use group (a function of the nature of occupancy). To determine appropriate spectral response accelerations, the site class of the upper 100 feet of soil and rock must first be verified. The final report for the Cummings property should verify site classes and, in conjunction with the developer, determine seismic use groups, seismic design categories, and associated earthquake-resistant design requirements.

SUMMARY OF CONCLUSIONS

I do not believe that the preliminary IGES (2007) report provides adequate documentation that slopes will be stable in the proposed Cummings property development to preclude a need for further study, or adequately documents the potential for expansive soils and strong earthquake ground shaking. IGES found no evidence of landsliding on the property but, at a minimum, a more complete geologic evaluation is needed, and a quantitative slope-stability evaluation may be necessary if indicated by the results of the geologic study. Of particular concern are north-facing slopes greater than 25 percent underlain by relatively thick colluvium and/or weathered tuff in the Keetley Volcanics. If additional slope-stability analyses are necessary, they should use the results of additional geologic inspection on and near the site to see if any prominent weak layers or joint/fracture patterns are evident. The results of the analyses should then be used to determine buildable areas and setbacks from the top and base of steep slopes, and these areas and setbacks should be plotted on a suitable base map, along with areas of potential expansive soils. Seismic-design parameters should also be provided.

LIMITATIONS

Conclusions and recommendations in this review are based on data presented in IGES (2007). The Department of Natural Resources, UGS, provides no warranty that the data in the IGES report are correct or accurate, and has not done an independent site evaluation. Recommendations in this review are provided to aid Wasatch County in reducing risks from geologic hazards, but the UGS makes no warranty, expressed or implied, and shall not be liable for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this review.

REFERENCES

Blake, T.F., Hollingsworth, R.A., and Stewart, J.P., editors, 2002, Recommended procedures for implementation of DMG Special Publication 117—Guidelines for analyzing and mitigating landslide hazards in California: Southern California Earthquake Center, 110 p.

Bryant, Bruce, 1990, Geologic map of the Salt Lake City 30' by 60' quadrangle, north-central Utah, and Uinta County, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1944, scale 1:100,000.

Dominion Engineering Associates, L.C., 2006, Cummings 350 acres, Jordanelle Basin master plan: Murray, Utah, unpublished consultant's report, 8 p.

Hylland, M.D., editor, 1996, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

Hylland, M.D., and Lowe, M., 1996, Landslide hazard, western Wasatch County, Utah (plate 1B), *in* Hylland, M.D., Lowe, M., and Bishop, C.E., Engineering geologic map folio, western Wasatch County, Utah: Utah Geological Survey Open-File Report 319, scale 1:24,000.

-----1997, Regional landslide-hazard evaluation using landslide slopes, western Wasatch County, Utah: Environmental & Engineering Geoscience, v. 3, p. 31-43.

Intermountain GeoEnvironmental Services, Inc., 2007, Preliminary geotechnical and geologic investigation, 350 acre Cummings property, Wasatch County, Utah: Bluffdale, Utah, unpublished consultant's report, 3 p.

International Code Council, Inc., 2006a, International Building Code: Country Club Hills, Illinois, International Code Council, Inc., 664 p.

-----2006b, International Residential Code for One- and Two-Family Dwellings: Country Club Hills, Illinois, International Code Council, Inc., 670 p.