MOVEMENT HISTORY AND PRELIMINARY HAZARD ASSESSMENT OF THE HEATHER DRIVE LANDSLIDE, LAYTON, DAVIS COUNTY, UTAH

by

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Utah Geological Survey

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ABSTRACT

Movement of the Heather Drive landslide in late-August 2001 forced homeowners to evacuate their houses and suffer significant economic loss. Preliminary loss estimates indicate that landslide-related losses exceed $1 million. The landside is a reactivation of a prehistoric landslide in lacustrine silt and clay of the Lake Bonneville Weber River delta on a north-facing slope above South Fork Kays Creek. Landslide movement impacted six houses; three were moved off the landslide and three were demolished due to landslide-related damage. The landslide movement history indicates a gradual reactivation followed by relatively rapid movement and an abrupt stop. The majority of landslide movement occurred between August 20 and 29, 2001.

The landslide surface is relatively undeformed indicating movement of a relatively intact mass. Landslide movement resulted in a main scarp ranging up to 9.5 feet high, and a minimum of 7.1 feet of northward displacement of the lower landslide and 4.1 feet of toe displacement into the creek restricting the flow in South Fork Kays Creek. The exact cause(s) of landslide movement in 2001 is unknown, but observations indicate that movement likely started in 1997 or 1998 when other nearby landslides reactivated. No documented changes in slope configuration or ground-water conditions preceded accelerated movement in 2001. The landslide apparently moved intermittently or at an extremely slow to very slow rate since at least 1998, perhaps until the slip surface developed and shear strengths along the slip surface were reduced sufficiently to allow accelerated movement in late-August 2001. Future movement could enlarge the landslide, placing additional houses, Heather Drive and underlying utilities, and South Fork Kays Creek at risk. The Utah Geological Survey recommends continued landslide monitoring and a geotechnical-engineering slope-stability investigation to determine the conditions under which future movement may occur and the risk posed to nearby houses, Heather Drive and underlying utilities, and flow in the creek.

INTRODUCTION AND PURPOSE

A landslide in Layton north of Heather Drive (figures 1 and 2) damaged houses, lots, and utilities during July and August 2001, forcing residents to evacuate homes and suffer significant economic losses. Six houses either straddled the landslide main scarp or were on the landslide head (figure 2). Of the six houses, three were moved off the landslide and three were demolished due to landslide-related damage. The landslide also restricted flow in South Fork Kays Creek, forcing Davis County to clear the channel to maintain flow. This report summarizes landslide movement, discusses future hazard potential, and provides recommendations for homeowners, Layton City, Davis County, and others to consider in managing landslide risk. Future landslide movement could impact additional houses and property, damage Heather Drive and underground utilities, and further restrict the flow of South Fork Kays Creek. The Utah Geological Survey (UGS) documented landslide features, monitored landslide movement, assessed the landslide hazard, and, in its role in emergency response, provided advice and recommendations to Layton City and homeowners.

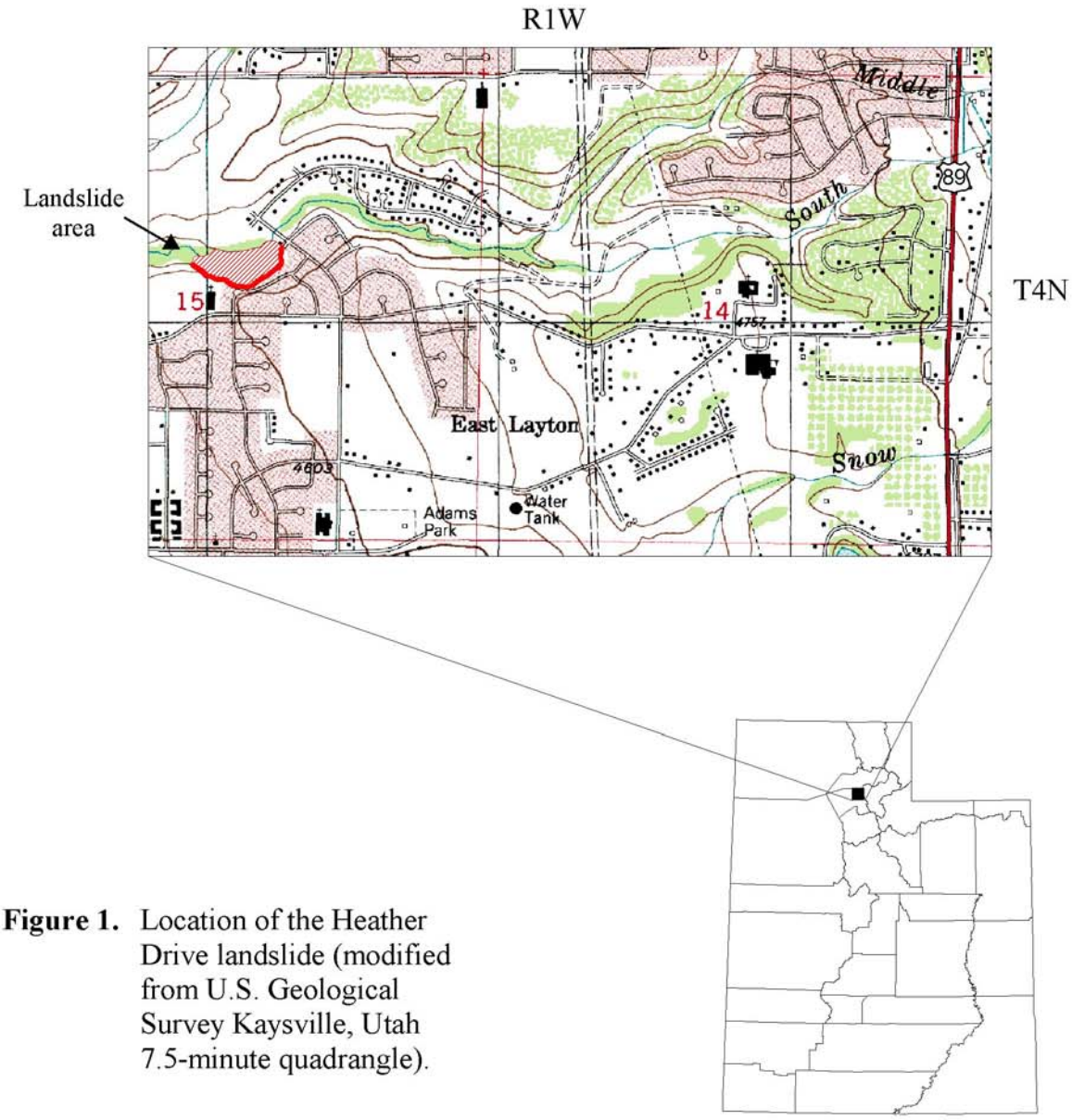


Figure 1. Location of the Heather Drive landslide (modified from U.S. Geological Survey Kaysville, Utah 7.5-minute quadrangle).

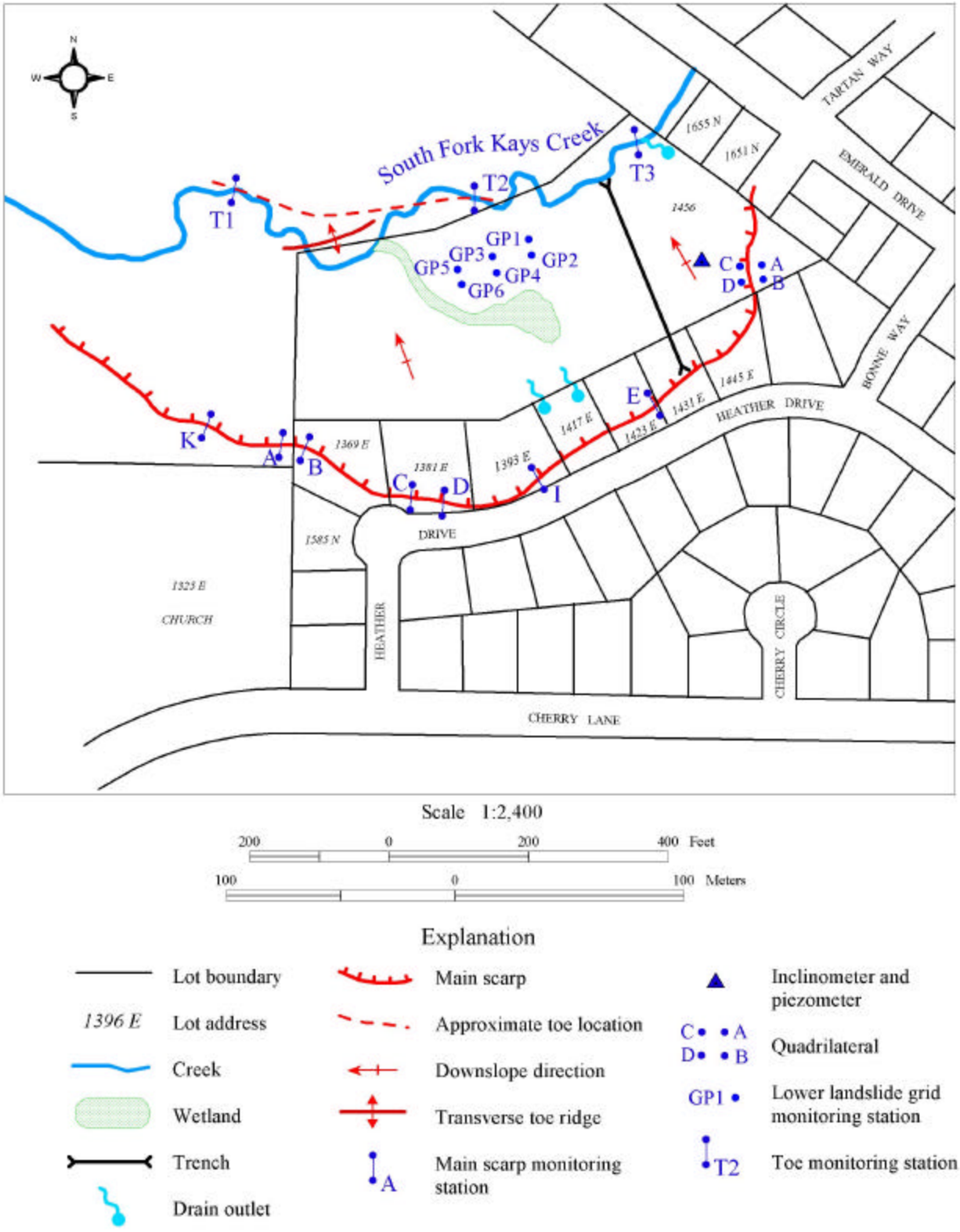


Figure 2. Heather Drive landslide area showing landslide features, monitoring locations, residential lots, and streets (modified from Layton City plat).

CONCLUSIONS AND RECOMMENDATIONS

Based on this geologic investigation and preliminary hazard assessment of the Heather Drive landslide, the UGS concludes the following:

- The landslide is a rotational failure with a volume of approximately 400,000 cubic yards involving partial reactivation of a prehistoric landslide. Landslide movement formed a main scarp 1,350 feet long, and heaved the creek bed upward at the toe, restricting flow in South Fork Kays Creek. Minor internal deformation of the landslide suggests movement of a relatively intact mass a short distance downslope.

- The landslide moved extremely slow to very slow until mid-August 2001, then accelerated rapidly until August 31 when movement stopped. Most landslide movement occurred between August 20 and 29, 2001. Vertical displacement on the main scarp ranged up to 9.5 feet. Northward movement of the lower landslide exceeded 7.1 feet. Horizontal displacement of the landslide toe (landslide movement into the creek) exceeded 4.1 feet.

- Landslide movement started prior to 2001; a specific starting date is unknown, but building damage and movement patterns indicate movement likely started in 1997 or 1998.

- The cause(s) of landslide movement is uncertain. No documented changes in slope or ground-water conditions preceded landslide movement; however, ground-water conditions are poorly understood. Erosion of the landslide toe by South Fork Kays Creek may have some long-term influence on landslide stability, but no extensive erosion is known to have immediately preceded movement in 2001.

- The overall movement pattern suggests landslide movement may have started in 1997 or 1998 following several years of above-normal precipitation that likely increased ground-water levels. The landslide then moved intermittently and/or at an extremely slow to slow rate until a through-going slip surface was finally established and the shear strengths along the slip surface were sufficiently reduced to allow the accelerated movement that took place in late-August 2001.

- Based on landslide movement patterns, South Fork Kays Creek is adjacent to and on the landslide toe. Landslide reactivation could cause further obstruction of creek flow.

- Landslide movement damaged six houses. Three of these houses were moved off the landslide and three were demolished due to landslide-related damage. Two houses straddled the main scarp and four were on the landslide head. Underground natural gas and electric utilities were relocated to the south side of Heather Drive.

- Preliminary loss estimates indicate the homeowner equity loss, mortgage company loss, and costs to Layton City exceed $1 million.

- Heather Drive and underlying utilities and some structures are potentially at risk from future landslide movement, and in some cases from main-scarp erosion or failure. The structures most at risk are houses at 1585 N. and 1445 E. Heather Drive, and 1651 and 1655 N. Emerald Drive.

To further understand the risk and manage possible future movement, the UGS recommends the following:

- Monitor existing and document new landslide features to determine if the landslide reactivates, particularly in the spring of 2002.

- Monitor for building distress and ground deformation related to possible landslide movement at 1325 E. Cherry Lane, 1585 N. and 1445 E. Heather Drive, and 1651 and 1655 N. Emerald Drive.

- Avoid slope modifications that would add weight at the landslide head or remove support at the toe.

- If removal of large amounts of material from South Fork Kays Creek becomes necessary to maintain flow, avoid removing it to locations off the landslide toe.

- Complete a detailed geotechnical-engineering slope-stability investigation of the landslide, as outlined in Hylland (1996), to determine: (1) the sensitivity of the landslide to various possible causes of movement, (2) the potential for landslide enlargement and conditions causing reactivation, (3) the risk posed by landslide movement and main scarp instability to Heather Drive and underlying utilities, houses at 1585 N. and 1445 E. Heather Drive, houses at 1651 and 1655 N. Emerald Drive, and flow in South Fork Kays Creek, and (4) the implications of this landslide in understanding overall hillslope stability in Layton City.

- In the vicinity of the landslide, implement measures to: (1) minimize landscape irrigation, (2) drain runoff from roof downspouts and driveways to the street and the storm-water system, where possible, (3) improve drainage to keep water from infiltrating into the landslide, and (4) ensure that underground culinary water, irrigation water, stormwater and sanitary sewer lines are not leaking.

POTENTIAL FOR FUTURE LANDSLIDE MOVEMENT

Recent movement of the Heather Drive landslide was in part a reactivation of a pre-existing landslide. Geologic evidence indicates this landslide had multiple periods of prehistoric movement. I believe the Heather Drive landslide has potential to reactivate because recent

movement has restored a continuous landslide slip surface, and increased permeability will allow greater water infiltration into the landslide. The Heather Drive landslide also has similar physical and geologic settings to other nearby landslides that reactivated in the spring of 1983 and/or 1998. Little is known about the subsurface conditions and the factors controlling landslide movement because the Heather Drive landslide has not been studied in detail. Therefore, large uncertainties exist regarding the conditions under which future landslide movement is likely. I believe the most immediate concern for landslide reactivation is during the spring of 2002 because other nearby landslides such as at South Fork Kays Creek (1543 N., 1050 E. [Giraud, 1999a]) and Hillsboro Drive (1703 E. Hillsboro Drive [Scott Carter, Layton City, verbal communication, March 26, 1999]) reactivated in springtime when ground-water levels generally rise. Future landslide movement could enlarge the landslide, placing the houses at 1585 N. and 1445 E. Heather Drive, houses at 1651 and 1655 N. Emerald Drive, and Heather Drive and the underlying utilities at risk. Future movement could also further restrict the flow in South Fork Kays Creek.

STUDY RESULTS

Landslide Description and Geology

The Heather Drive landslide lies on a north-facing slope above South Fork Kays Creek (figure 1). The landslide is covered with grass, shrubs, and trees, and a small wetland is present on the lower part of the slide (figure 2). The maximum landslide length is 450 feet extending from the creek to the north edge of Heather Drive. The maximum width from the east and west tips of the main scarp is 1,030 feet. The depth of the landslide surface of rupture (slip surface) at 1456 Tartan Way is approximately 45 feet (Jim Nordquist, Applied Geotechnical Engineering Consultants [AGEC], verbal communication, August 27, 2001). This depth was determined from an inclinometer (figure 2) installed by AGEC for the landowner. The slip-surface depth and associated landslide features indicate a rotational landslide. Using the above landslide dimensions and the volume estimation procedure for rotational landslides outlined by Cruden and Varnes (1996), the landslide volume is approximately 400,000 cubic yards. The prefailure slope gradient was measured by the UGS on June 27, 2001; the overall gradient ranged from 20 percent in the eastern portion of the landslide to 28 percent in the western portion (table 1).

Table 1. Prefailure slope gradients.

Location	Slope (percent)	Slope (degrees)	Gradient (horizontal:vertical)	Local Relief (feet)	Length (feet)
Creek to 1417 E.	20	11.3	5H:1V	78	390
Creek to 1369 E.	28	15.6	3.6H:1V	75	264

The most prominent landslide features are the main scarp and graben at the head and a transverse toe ridge and ground cracks at the toe in and adjacent to South Fork Kays Creek. The main scarp is 1,350 feet long (figure 2) and up to 9.5 feet high. Figure 3 shows the character of the main scarp. Most of the main scarp follows a pre-existing arcuate slope crest suggesting the movement in 2001 was a reactivation of a prehistoric landslide. However, the western end of the scarp (a 400-foot length west of 1369 E. Heather Drive and north of the church at 1325 E. Cherry Lane) does not follow the pre-existing arcuate slope crest, suggesting the 2001 landslide enlarged beyond the limits of the prehistoric landslide. The east and west ends of the main scarp turn downslope and terminate midslope. Ground cracks and lateral shearing that would define right and left flanks did not develop, likely due to the limited amount of downslope movement. Displacement along the main scarp and associated ground deformation in the head of the landslide damaged houses and lots from 1369 to 1445 E. Heather Drive and 1456 Tartan Way (figure 2). The lot at 1456 Tartan Way is quite large and includes the area between the creek and the lots north of Heather Drive (figure 2). Small grabens formed in the landslide head north of the church and from 1381 through 1393 E. Heather Drive (figure 3c).

Landslide toe features in and adjacent to the creek consist of several ground cracks in the south creek bank at landslide monitoring point T1 (figure 2), transverse ground cracks along the south creek bank at T2, and vertical heave of the creek bed west of T2. The approximate location of the landslide toe, based on deformation patterns, is shown in figure 2. The vertical heave of the creek bed is part of a small east-west transverse ridge (figure 4a) with parallel axial ground cracks (figure 4b) approximately 70 feet long west of T2. Clean well-sorted channel sands along the transverse ridge axis also display ground cracks (figure 4c). Based on the relative positions of vertically heaved channel gravel deposits and the creek water level (figure 4d), the creek bed was uplifted 1.5 feet. Several ground cracks are present in the western portion of the main body of the landslide, but relatively few ground cracks are present elsewhere, suggesting movement mainly as an intact mass.

South Fork Kays Creek flows west through a broad open valley (figures 1 and 2) and has incised into lacustrine sediments that were deposited in Lake Bonneville as part of the Weber River delta. Nelson and Personius (1993) map lacustrine clay, silt, and minor fine sand deposits of latest Pleistocene age in the valley slopes east of the Heather Drive landslide. Soft lacustrine silt and clay with minor thin beds and laminations of fine- to medium-grained sand were exposed in a trench excavated from the creek to 1431 E. Heather Drive by the homeowner at 1456 Tartan Way (figure 2). The trench was an attempt to isolate and stabilize the house at 1456 Tartan Way on the east side of the landslide but was unsuccessful. Silt and clay deposits were also encountered in the inclinometer borehole at 1456 Tartan Way (Jim Nordquist, AGEC, verbal communication, August 27, 2001). Stream alluvium in the creek is 1 to 2 feet thick. Soil test pits by Dames and Moore (1977) indicated fill along the slope crest up to 7 feet thick overlying silt and clay.

Kaliser (1975) mapped the north-facing slope north of Heather Drive as a landslide area and Lowe (1988) mapped it as prehistoric landslide deposits (LS 445 and LS 446). The slope crest from 1369 to 1445 E. Heather Drive is arcuate (figure 1), suggesting the crown of a

(a) (b)

(c) (d)

Figure 3. Main scarp of the Heather Drive landslide. (a) Main scarp north of the church (1325 E. Cherry Lane) on September 5, 2001; the scarp is 9 feet high, view looking east. (b) Main scarp at 1369 E. on August 29, 2001; the scarp is 9.5 feet high, view looking southeast. (c) Main scarp (at left) at 1381 E. on August 27, 2001; graben in foreground, view looking west. The house was moved off the landslide on August 28, 2001. (d) Main scarp at 1456 Tartan Way on September 5, 2001; quadrilateral stakes in center of photograph, view looking southwest.

Figure 4. Landslide toe deformation features in and adjacent to South Fork Kays Creek. (a) Bulge of transverse ridge, view looking west on September 5, 2001. A large ground crack is formed along the ridge axis. (b) Parallel ground cracks developed along transverse ridge axis, view looking east on September 5, 2001. (c) Ground cracks developed in sand bar adjacent to the creek on August 29, 2001, rock hammer for scale. (d) Vertical heave of the creek bed and incision into underlying silt and clay on September 12, 2001. The channel-bed gravel above the rock hammer handle is 1.5 feet above the current creek bed.

prehistoric landslide. UGS measurements of bedding attitudes in Lake Bonneville sediments (N. 65° E., 36° SE.; N. 45° W., 12° SW.; N. 55° E., 50° SE.) in the south creek bank indicate southward back-rotation by previous landsliding. Prehistoric landslide deposits composed of Lake Bonneville sediments and southward back-rotated stream alluvium exposed in the south creek bank indicate multiple periods of prehistoric movement and that the August 2001 movement is a reactivation of a pre-existing landslide. Undeformed horizontally bedded Lake Bonneville silt and clay deposits are exposed in the main scarp (figure 3a, 3b, and 3c) and in a vertical north creek bank exposure near monitoring station T2. The location of South Fork Kays Creek along the north edge of the valley bottom is probably due to northward displacement by prehistoric landslide movement. Three small landslides in the south creek bank were present prior to landslide movement in 2001 and were formed by local undercutting of creek banks. These small creek bank landslides did not reactivate during the August 2001 landslide movement.

In a preliminary plan for the Heather Hills No. 3 subdivision, Great Basin Engineering and Surveying Inc. (1975) showed an area of possible slope instability attributed by reference to the State Geologist. The possible slope-instability area was a rectilinear area on the northernmost portion of lots 10 through 17 (1369-1445 E. Heather Drive) and is different than the curvilinear areas shown by Kaliser (1975) and Lowe (1988 [LS 445]). The large difference in map scales prohibits direct comparison of the landslide area boundaries shown by Kaliser (1975) and Lowe (1988 [LS 445]) with those of Great Basin Engineering and Surveying Inc. (1975). In a landslide and soils study for the Heather Hills No. 3 subdivision, Dames and Moore (1977) showed an approximately located landslide area on the lower slope north of Heather Drive and noted surface indications of past slope movement adjacent to South Fork Kays Creek. Dames and Moore (1977) did not show an upper landslide boundary on lots 12 through 17 (1369–1423 E. Heather Drive) but stated, “our field reconnaissance and shallow test pits provided no indication of past or active slope instability.” Dames and Moore (1977) also stated that the slope north of Heather Drive was stable under site conditions at the time of their investigation, but if conditions changed the stability of the slope may be reduced.

Ground-Water Conditions

The landslide ground-water conditions are poorly documented but land drains provide some information on shallow ground water. Two ground-water drains are present along the west and east lot boundaries of 1417 E. Heather Drive. The western drain only drips, but the eastern drain discharges perennial flow of approximately 1.5 gallons per minute (Chad Schreeve, homeowner, verbal communication, August 8, 2001) near the northern property boundary (figure 2) where the water is piped downslope to a stock watering trough. The water overflows the trough and drains into a wetland that extends to South Fork Kays Creek (figure 2). Test-pit logs (Dames and Moore, 1977) indicate no shallow ground water in the upper 10.5 feet along the slope crest or on the lower slope on January 25, 1977. However, Dames and Moore (1977) stated that shallow drains had been installed along Heather Drive, and the drains at 1417 E. Heather Drive suggest the presence of relatively shallow ground water at the time of construction as well as in 2001. One of the street drains was encountered under the north edge of Heather Drive when a road was cut to remove the house at 1381 E. Heather Drive. The drain pipe was camera logged and was intercepting water only locally near 1381 E. (Scott Carter, Layton City,

verbal communication, October 9, 2001). A building inspection for 1381 E. Heather Drive (March 1979) indicated shallow ground water in the sanitary sewer line trench (Scott Carter, verbal communication, June 26, 2001). Subsequent repair of the sewer line in April 2001 indicated shallow ground water at 11 feet (Fred Meese, homeowner, verbal communication, June 14, 2001). Based on this information, shallow ground water is present in the landslide head and crown (in the vicinity of 1381 and 1417 E. Heather Drive) but no large change in ground-water levels is apparent over time. Another land drain is present west of 1655 N. Emerald Drive and north of 1456 Tartan Way (figure 2) and discharges a trickle flow directly into the creek.

AGEC installed a piezometer with the inclinometer at 1456 Tartan Way (figure 2) in the lower and eastern part of the landslide. The UGS collected water-level data from this piezometer from August 31 to October 3, 2001 (figure 5). During this time period the ground-water level dropped 0.8 foot. This ground-water level approximately 6 feet below the ground surface indicates confined ground water at depth because the trench, excavated to depths of 20 feet immediately west of the piezometer, was open for several days and did not encounter shallow unconfined ground water. Thus ground water is shallow and unconfined in the landslide head and crown, but is deeper and confined within or below the eastern portion of the landslide at 1456 Tartan Way.

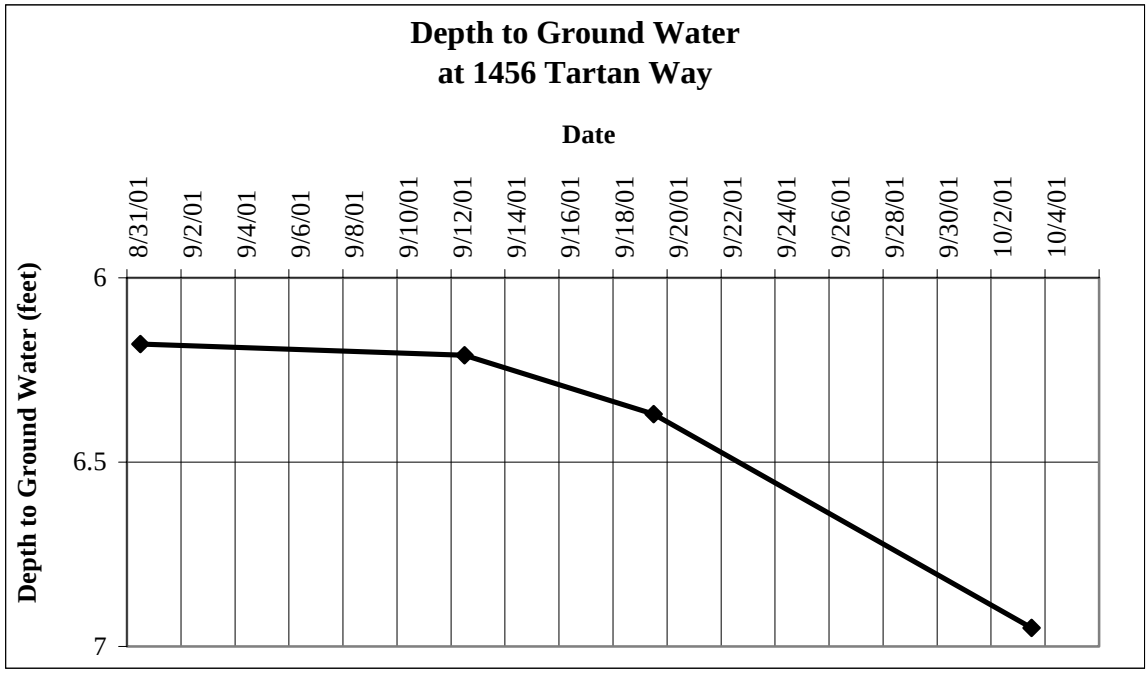


Figure 5. Plot of depth to ground water at 1456 Tartan Way.

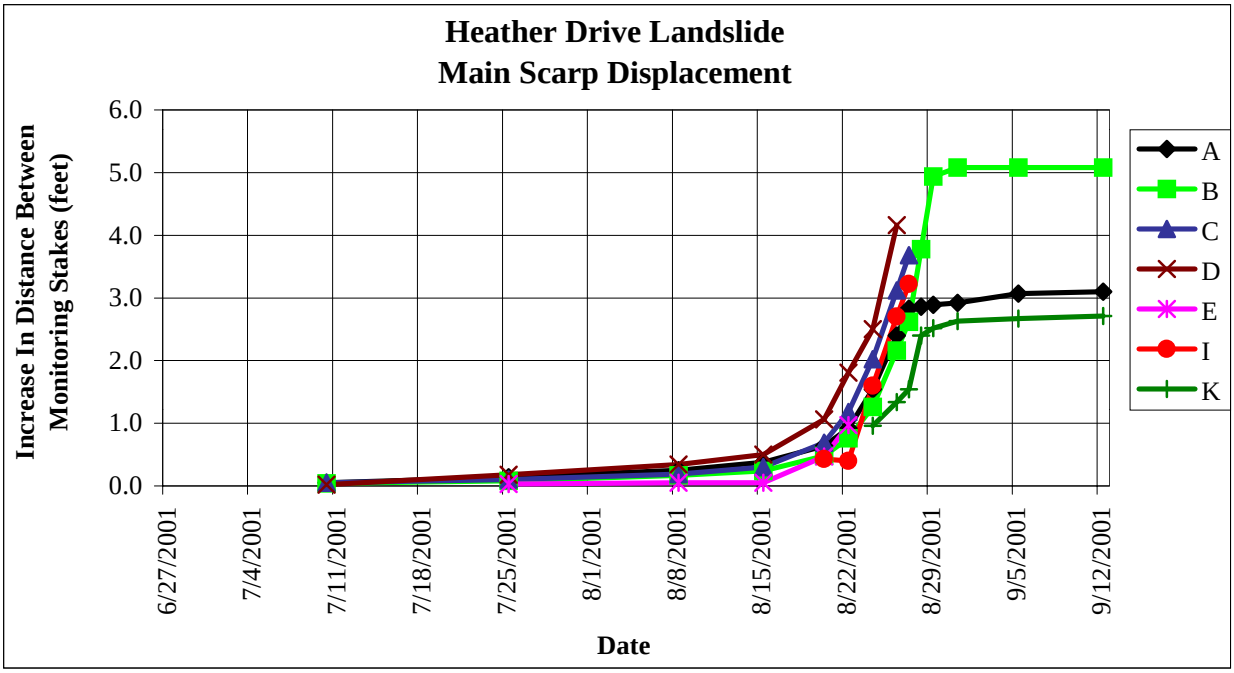
Chronology of Landslide Movement

The chronology of landslide movement documented through homeowner interviews and movement monitoring indicates a long gradual period of extremely slow to very slow movement (classification of Cruden and Varnes, 1996), or perhaps intermittent movement, followed by relatively rapid movement and an abrupt stop. The homeowner at 1369 E. Heather Drive stated

that building distress was recognized in 1998 and that previous owners noted building distress prior to 1998. The house foundation at 1369 E. was repaired during December 2000 and January 2001 and had shown continual cracking since January 2001. The homeowner at 1381 E. replaced his concrete driveway in July 2000 due to damage attributable to landsliding, and noted continual displacement in the new driveway since that time. The owner of the garden lot at 1431 E. stated that a small ground crack had formed by June 2000. This information suggests a gradual onset of landslide movement. Based on these building distress observations, at least localized landslide movement apparently triggered on or before 1998, but early movement was intermittent or at an extremely slow rate and not recognized by most homeowners until 2001. The apparent initial landslide movement at Heather Drive in 1997 or 1998 coincides with movement at other nearby landslides, including South Fork Kays Creek (1543 N. 1050 E. [Giraud, 1999a]), Hillsboro Drive (1703 E. Hillsboro Drive [Scott Carter, Layton City, verbal communication, March 26, 1999]), and Sunset Drive (1851 E. Sunset Drive [Giraud, 1999b]). Landslide movement in 1998 also occurred along the Davis-Weber canal (Black, 1999) and near the Cedar Bench subdivision (Solomon, 1999) in South Weber.

The UGS first visited the landslide on June 14, 2001, and observed a few small ground cracks and minor building distress at six properties on the north side of Heather Drive (1369 E. to 1431 E., figure 2). During a subsequent visit on June 27, 2001, the increase in ground crack widths, additional ground cracks, and the increase in building distress confirmed active landsliding, and landslide-monitoring stations (figure 2) were established. These ground cracks became the main scarp as landslide movement progressed, and additional monitoring stations were established. As the main-scarp height increased, the scarp height interfered with measurements between some stakes so additional landslide-monitoring stations were established. Several main-scarp monitoring stations were abandoned when the stakes were removed during moving and/or demolition of houses. Some station records are discontinuous because stakes were removed and subsequently reset. The locations of main-scarp monitoring stations A–K are shown on figure 2.

Figure 6a shows the increases in distance measured across main-scarp monitoring stations from June 27 to October 3, 2001. Because the main-scarp height continually increased and interfered with movement measurements (see Scope and Methods section), figure 6a qualitatively shows the history and timing of landslide movement rather than cumulative main scarp displacement. The landslide moved very slowly in June, July, and early August (figure 6a), but on August 15 the rate of landslide movement increased until nearly all movement stopped on August 31. Most movement on the main scarp occurred between August 20 and 29. The most dramatic movement occurred between 6:00 p.m. on August 27 and 8:00 a.m. on August 28 when a vertical displacement of 2 to 2.5 feet occurred on the main scarp (Scott Carter, Layton City, verbal communication, August 28, 2001). As a result, a road constructed on the afternoon of August 27 to move the house at 1381 E. Heather Drive off the landslide was displaced. On August 25 and 26, prior to this pulse of movement, the vertical displacement rate of the driveway slab at 1381 E. was approximately 1 foot per day. The relatively rapid rate of movement between August 20 and 29 hampered efforts to move houses and severely distressed the houses at 1393 E. and 1417 E. Heather Drive. Main-scarp displacements were largest in the



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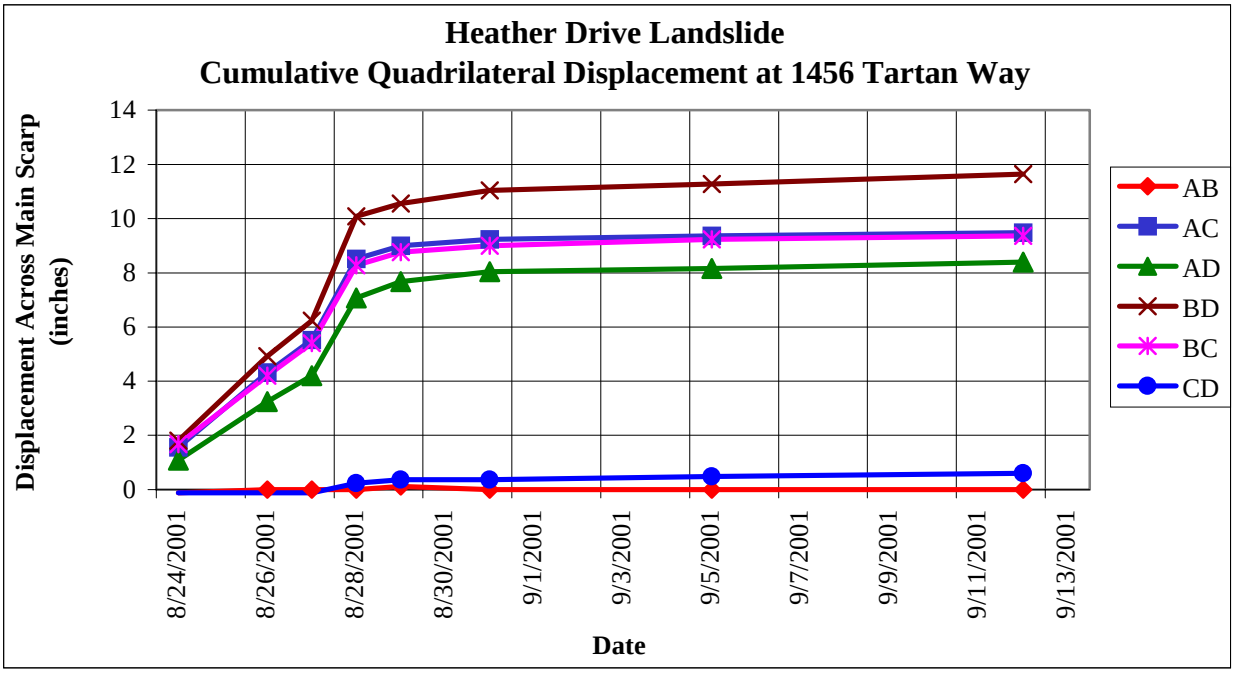
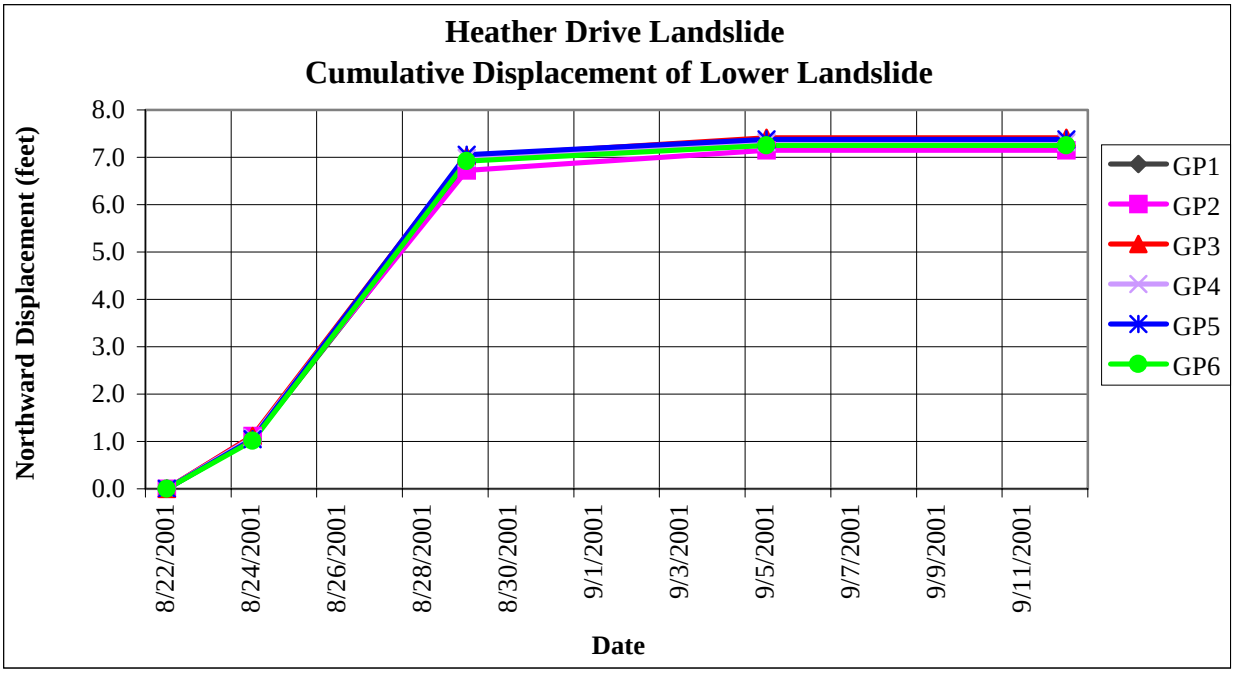


6 (b)

Figure 6. Plots showing landslide displacement. The landslide monitoring stations are shown on figure 2. (a) Measured increases in distance across the main scarp between June 27 and September 12, 2001. (b) Displacement plot of quadrilateral points showing the amount of extension across the main scarp at 1456 Tartan Way between August 22 and September 12, 2001.



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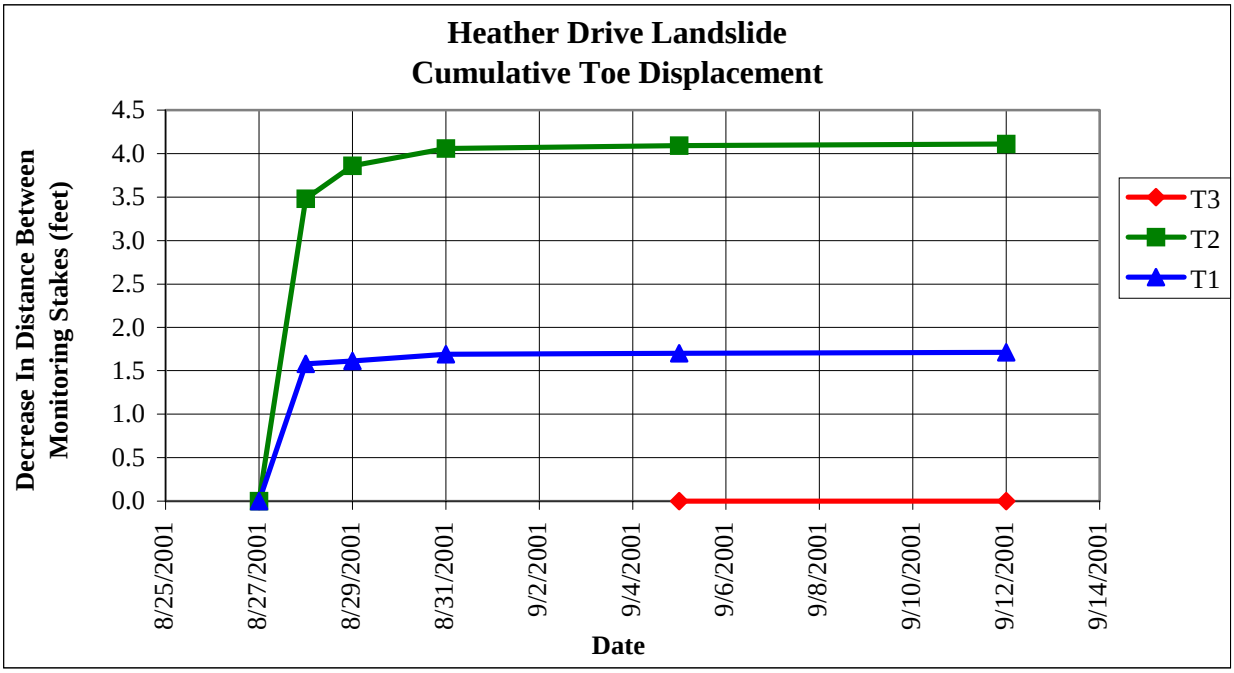

6 (d)

Figure 6 cont. (c) Displacement plot showing movement of the lower landslide northward between August 22 and September 12, 2001.
(d) Displacement plot showing movement of the landslide toe northward between August 27 and September 12, 2001.

middle of the landslide (figures 3a, 3b, 3c, and 9d) and decreased toward the east (figure 3d) and west.

As main-scarp development progressed downslope of 1445 E. Heather Drive onto 1456 Tartan Way in mid-August, a quadrilateral (Baum and others, 1988 [figures 2, 3d]) was installed across the scarp to measure possible right-lateral shearing along a suspected landslide flank. Figure 6b shows cumulative measured extension across the quadrilateral stakes from August 24 to October 3, 2001. The quadrilateral diagonals AD and BC have nearly equal displacements indicating little right-lateral shear along the scarp. These diagonal displacements and displacements perpendicular to the scarp (AC and BD) indicate landslide movement in a northwest direction. The quadrilateral data also show that nearly all landslide movement stopped by August 31.

As the main-scarp height increased, movement was suspected on the lower portion of the landslide even though ground cracks were not present. On August 22, 2001, the UGS established a grid of six survey stakes on the lower landslide (figure 2). Resurvey of the grid on August 24 confirmed movement in the lower slope. Figure 6c shows a cumulative 7.1 –7.5 feet of northward displacement of the six grid points relative to a surveying base station north of South Fork Kays Creek between August 22 and September 5. Most of the movement recorded on the lower landslide occurred between August 22 and 29. Nearly equal northward movement of all points within the 100-foot grid width suggests this portion of the landslide moved northward as an intact mass.

As ground cracks developed in the south bank of the creek, monitoring stations (T1, T2, and T3) were established across the creek to measure the amount of toe displacement and rate of landslide movement into the creek. Figure 6d shows the cumulative toe displacement measured across the creek from August 27 to October 31, 2001. Nearly 4.1 feet of northward movement was recorded at station T2. Station T1 showed 1.7 feet of toe displacement. Station T3 showed no toe displacement but was established after August 31 when nearly all landslide toe movement had stopped.

Restriction of Creek Flow

Landslide toe movement along South Fork Kays Creek restricted flow and pooled water upstream to Emerald Drive. The UGS traversed the creek on August 24, 2001, to search for ground cracks and other landslide deformation features. On August 24, 0.5-inch-wide ground cracks parallel to the south creek bank were developing at monitoring station T2 and the creek was free-flowing at an approximate flow rate of one cubic foot per second. By August 27 the creek bed was heaved vertically west of T2 and was pooling water upstream to depths of 1 to 2 feet. On August 27, ground-crack widths had increased to 6 inches at T2 (figure 7). By August 28 the pooled water had increased to depths of 3 to 4 feet and south creek banks had moved northward and were toppling into the creek at T2 (figure 8), further restricting flow. At T2, 3.5 feet of northward landslide movement into the creek was documented between August 27 and 28 (figure 6d). This northward movement coincides with the 2 to 2.5 feet of vertical displacement on the main scarp at 1381 E. Heather Drive discussed above. Given the channel conditions and the landslide toe movement rate, on August 29 Davis County Public Works cleaned a small channel reach west of T2 to ensure a free-flowing channel. Davis County removed only enough

Figure 7. Ground crack in the south bank of South Fork Kays Creek on August 27, 2001. Crack width is 6 inches.

Figure 8. Toppling of the south bank into South Fork Kays Creek on August 27, 2001. Landslide movement is from right to left, view looking upstream to the east, rock hammer for scale.

material to ensure unobstructed creek flow; the material was placed on the south bank because removal of material from the landslide toe area could promote further landslide movement.

Possible Causes of Landsliding

The Heather Drive landslide is unusual in that the majority of landslide movement occurred in late summer in a year with below-normal precipitation preceded by several years of below-normal precipitation. Other nearby landslides that were active in 1997 and 1998 had the majority of their movement during the spring of 1998 following several years of above-normal precipitation (Ashland, 2001). None of the typical factors that directly cause landslide movement, such as recent loading of the head or removal of material at the toe, was apparent. The slope crest was likely regraded during house construction and fill was identified in test pits north of Heather Drive (Dames and Moore, 1977), but the placement of fill is not a recent change coinciding with landslide reactivation. Most of the houses impacted by the landslide were 15 to 20 years old. South Fork Kays Creek erodes the landslide toe and may have some long-term influence on landslide stability, but no recent erosion coinciding with landslide movement could be documented. Also, no significant earthquakes coinciding with the onset and acceleration of landslide movement occurred in the area (University of Utah Seismograph Stations, 2001), and no earthquakes large enough to trigger landslide movement (Keefer, 1984) were recorded during the reported movement period (1998-2001).

Ground-water conditions are poorly understood, but may play a role in landslide movement. Based on sewer trench and drain observations, no apparent significant rise occurred in the shallow unconfined ground-water level in the 1381 to 1417 E. Heather Drive vicinity since the time of original construction, but changes in the potentiometric surface of the deeper confined ground water are possible. Inspections of culinary and irrigation water lines showed no leaks that may have contributed to a rise in ground-water level (verbal communications with Scott Carter, Layton City, and Scott Green, Kays Creek Irrigation). Seasonal landscape irrigation occurs throughout the subdivision and has been shown to cause late-summer increases in ground-water levels elsewhere in Layton (unpublished UGS data), but such effects are not documented at Heather Drive.

A possible cause of initial movement may be high ground-water levels associated with the above-normal precipitation period that triggered movement at other nearby landslides in the spring of 1997 and 1998 (Ashland, 2001). Homeowner reports indicate minor landslide movement in 1998 and perhaps earlier. The overall movement pattern suggests landslide movement may have triggered in 1997 or 1998 and was probably intermittent at first; the landslide then moved at extremely slow to very slow rates until mid–August 2001. Accelerated movement in 2001 may have resulted when a through-going slip surface was finally established and the shear strengths along the slip surface were sufficiently reduced to allow significant landslide movement.

(a) (b)

(c) (d)

Figure 9. Building damage caused by Heather Drive landslide. (a) House at 1369 E. Heather Drive straddling the main scarp on August 26, 2001, view looking southeast. The house was demolished on August 27, 2001. (b) Basement and foundation at 1423 E. Heather Drive straddling the main scarp on September 5, 2001, view looking northeast. The house was moved off the foundation on August 25, 2001. (c) House at 1417 E. Heather Drive on the landslide head on August 28, 2001; view looking northeast. A splay of the main scarp caused substantial distress to the house and attached garage. (d) Front yard and house at 1393 E. Heather Drive (blue house on right) on the landslide head on August 27, 2001; view looking west along Heather Drive and the main scarp. The house was demolished on August 30, 2001.

Building and Utility Damage

Movement of the Heather Drive landslide severely damaged houses and lots (figure 9). Landslide movement damaged six houses at 1369 E., 1381 E., 1393 E., 1417 E., and 1423 E. Heather Drive, and 1456 Tartan Way (figure 2). Three of these houses were demolished due to landslide-related damage (1369 E., 1393 E., and 1417 E. Heather Drive) and three were moved off the landslide (1381 E. and 1423 E. Heather Drive and 1456 Tartan Way). The main scarp crossed the lots of 1431 E. (a garden lot) and 1445 E. Heather Drive, but did not damage the house at 1445 E. A small ground crack formed in the back yard at 1651 N. Emerald Drive, but did not significantly damage the lot.

Landslide movement also damaged or threatened underground utilities. Underground utilities connecting from Heather Drive to the houses on the north side of Heather Drive (1369 E. to 1445E., figure 2) were damaged by landslide movement beginning in mid-July 2001. Natural gas, electric, telephone, and cable lines were buried in the parking strip on the north side of Heather Drive and were threatened because the main scarp extends to Heather Drive at 1393 E. (figure 9). The electric and natural gas lines were relocated to the parking strip on the south side of Heather Drive, but the telephone and cable lines remain buried along the north side of Heather Drive (Scott Carter, Layton City, verbal communication, October 12, 2001). A 4-inch underground irrigation water line was present along the north boundary of 1369 to 1445 E. Heather Drive. Main-scarp movement damaged the line at 1369 E., causing leakage (Fred Meese, homeowner, verbal communication, August 20, 2001). The irrigation line was subsequently abandoned (Scott Green, Kays Creek Irrigation, verbal communication, August 20, 2001).

Direct Economic Loss

Homeowners, mortgage companies, utility companies, and Layton City incurred substantial economic loss as a result of the landslide movement. The initial loss estimates gathered by Layton City indicate that for five houses (1369 E., 1381 E., 1393 E., 1417 E., and 1423 E. Heather Drive), $450,000 was owed to mortgage companies by the homeowners, and the homeowner equity loss was $590,000 (Scott Carter, Layton City, verbal communication, October 8, 2001). Layton City costs for emergency response and assistance in the moving and demolition of houses were $28,000. These preliminary estimates indicate landslide-related losses will easily exceed $1 million. The above estimates do not include economic loss at 1456 Tartan Way and underground utility relocation costs along Heather Drive. Accurate loss estimates can be made when mortgage companies and homeowners complete final decisions regarding these properties.

SCOPE AND METHODS

Scott Carter, Layton City Community Development Director, requested this study and hazard assessment of the landslide. The landslide study area includes the area between South Fork Kays Creek and Heather Drive and between the church on 1325 E. Cherry Lane and Emerald Drive (figures 1 and 2 [SW1/4NE1/4 section 15, T. 4 N., R. 1 W., Salt Lake Base Line

and Meridian]). Fred Meese, the homeowner at 1381 E. Heather Drive, first reported the landslide movement and building distress to Layton City.

The scope of work included review of published geologic reports and maps, an unpublished consultant's landslide and soil report, an unpublished consultant's subdivision map, and aerial photographs (1985, scale 1:24,000). Several UGS geologists visited the site, collected movement data, and interviewed homeowners. Main-scarp movement was monitored by measuring the increase in distance between two wood stakes driven into the soil on either side of the scarp. If the wood stakes were loose, removed, or if the scarp height interfered with measurements between stakes, the stakes were reset and measured for a new baseline. Landslide toe displacement across the creek was monitored by measuring the decrease in distance between a fixed point on a tree trunk on the north creek bank and a stake on the landslide south of the creek. All measurements were made using a fiberglass tape and finish nails were used on the top of all wood stakes for accurate measurements. The estimated accuracy of this measurement technique is about 0.5 inch. The lower landslide grid was surveyed with a total station (Trimble TTS 500). Prefailure slope profiles were measured with a fiberglass tape, compass, and clinometer.

SUMMARY

The Heather Drive landslide is a reactivated rotational landslide in silty and clayey Lake Bonneville deposits of the Weber River delta. Shallow ground water is present in the landslide crown and head, and deeper confined ground water is present within or below the main body of the landslide. The landslide damaged lots and houses, and obstructed the flow in South Fork Kays Creek. The onset of landslide movement was gradual, possibly starting in 1998 or earlier, and the majority of landslide movement occurred between August 20 and 29, 2001. Vertical displacement across the main scarp ranged up to 9.5 feet, the lower landslide moved a minimum of 7.1 feet northward toward the creek, and toe displacement across the creek exceeded 4.1 feet. The landslide moved as an intact mass a relatively short distance downslope. The cause(s) of landslide movement in late summer during a dry year is unknown. No recognizable recent changes in slope-related driving and resisting forces or ground-water conditions exist, but ground-water conditions are poorly understood. Several years of above-normal precipitation, believed to have triggered other nearby landslides in 1997 and 1998, may have triggered initial movement. The Heather Drive landslide then may have moved at an extremely slow to very slow rate until the slip surface developed and shear strength was reduced sufficiently to accelerate movement in 2001.

Three houses were moved off the landslide and three were demolished due to landslide-related damage. The preliminary loss estimates indicate that direct landslide-related losses will exceed $1 million. Future movement could enlarge the landslide, placing additional houses, Heather Drive and underlying utilities, and South Fork Kays Creek at risk.

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REFERENCES

Ashland, F.X., 2001, Lessons learned from the 1998 Wasatch Front landslides [abs.], *in* Conference on Geologic Hazards in Utah - Practical Information for Geologists and Engineers, Salt Lake City, Utah, April 12-13, 2001, Program with Abstracts: Association of Engineering Geologists and American Society of Civil Engineers, p. 24-26.

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 of 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 36-41.

Baum, R.L., Johnson, A.M., and Fleming, R.W., 1988, Measurement of slope deformation using quadrilaterals: U.S. Geological Survey Bulletin 1842-B, p. B1-B23.

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.

Dames and Moore, 1977, Landslide and soils study - portions of the Heather Hills subdivision, East Layton, Utah: Salt Lake City, unpublished consultant's report for the Kier Corporation, 24 p.

Great Basin Engineering and Surveying Inc, 1975, Preliminary plan for Heather Hills subdivisions, Layton, Utah: Ogden, unpublished surveyor's plan, scale 1:1,200.

Giraud, R.G., 1999a, Reconnaissance of a landslide on the South Fork Kays Creek, Layton, Davis County, Utah, *in* McDonald, G.N., compiler, Technical reports of 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 52-59.

Giraud, R.G., 1999b, 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.

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

Kaliser, B.N., 1975, Geologic hazards, Davis County, Utah: Utah Geological and Mineralogical Survey Map Q 275, scale 1:24,000.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, p. 406-421.

Lowe, Mike, 1988, Natural hazards overlay zone - slope failure inventory, Kaysville quadrangle: Weber 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.

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 of 1998, Applied Geology Program: Utah Geological Survey Report of Investigation 242, p. 42-49.

University of Utah Seismograph Stations, 2001, Utah region earthquake listings: Online, <http://www.seis.utah.edu/catalog/utah.shtml>, accessed November 15, 2001.