Project: Update on conditions through 2008 at the Springhill landslide, North Salt Lake, Utah			
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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

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

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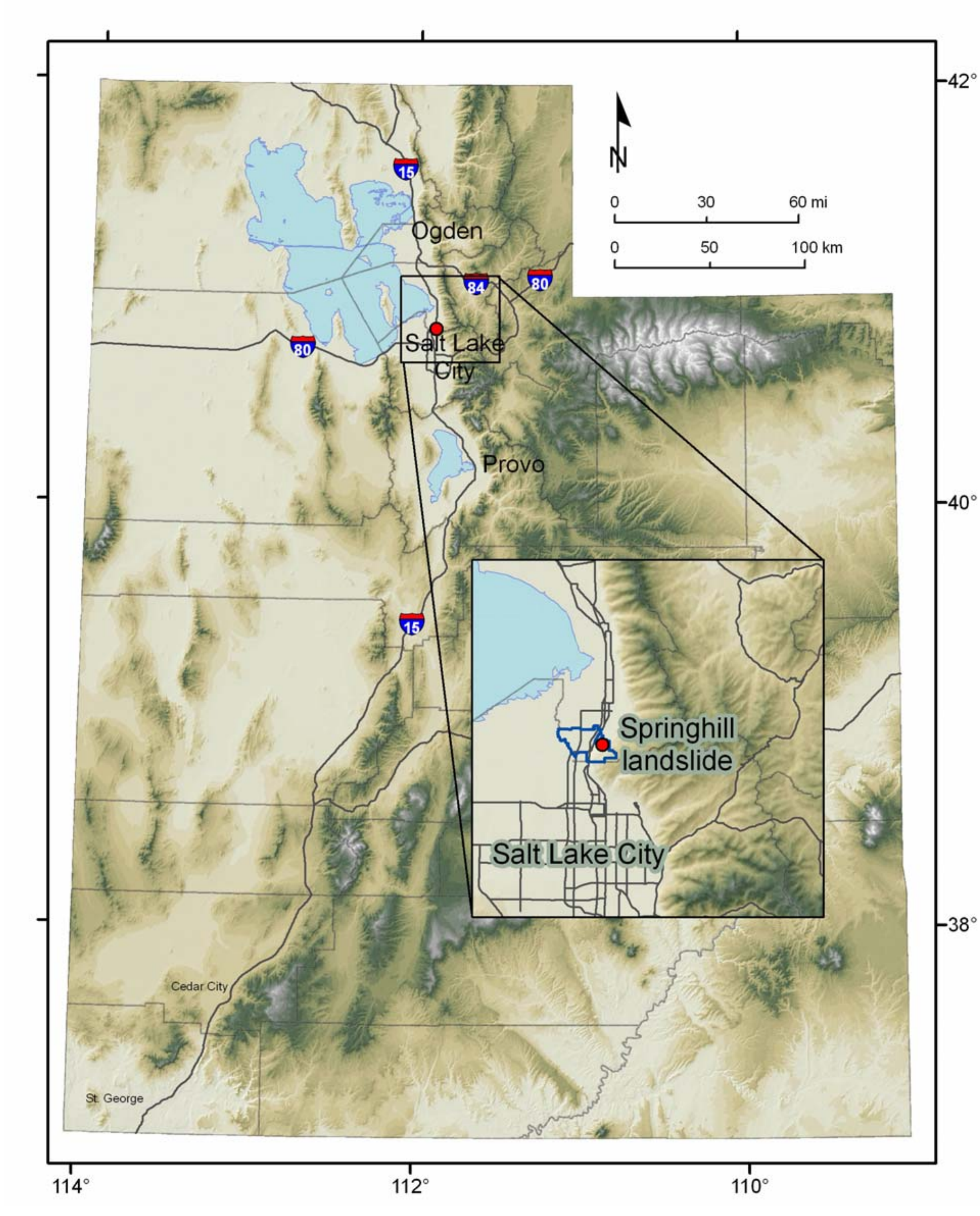

Figure 1. *General location of the Springhill landslide in North Salt Lake. Boundary of North Salt Lake shown in inset map (blue line).*

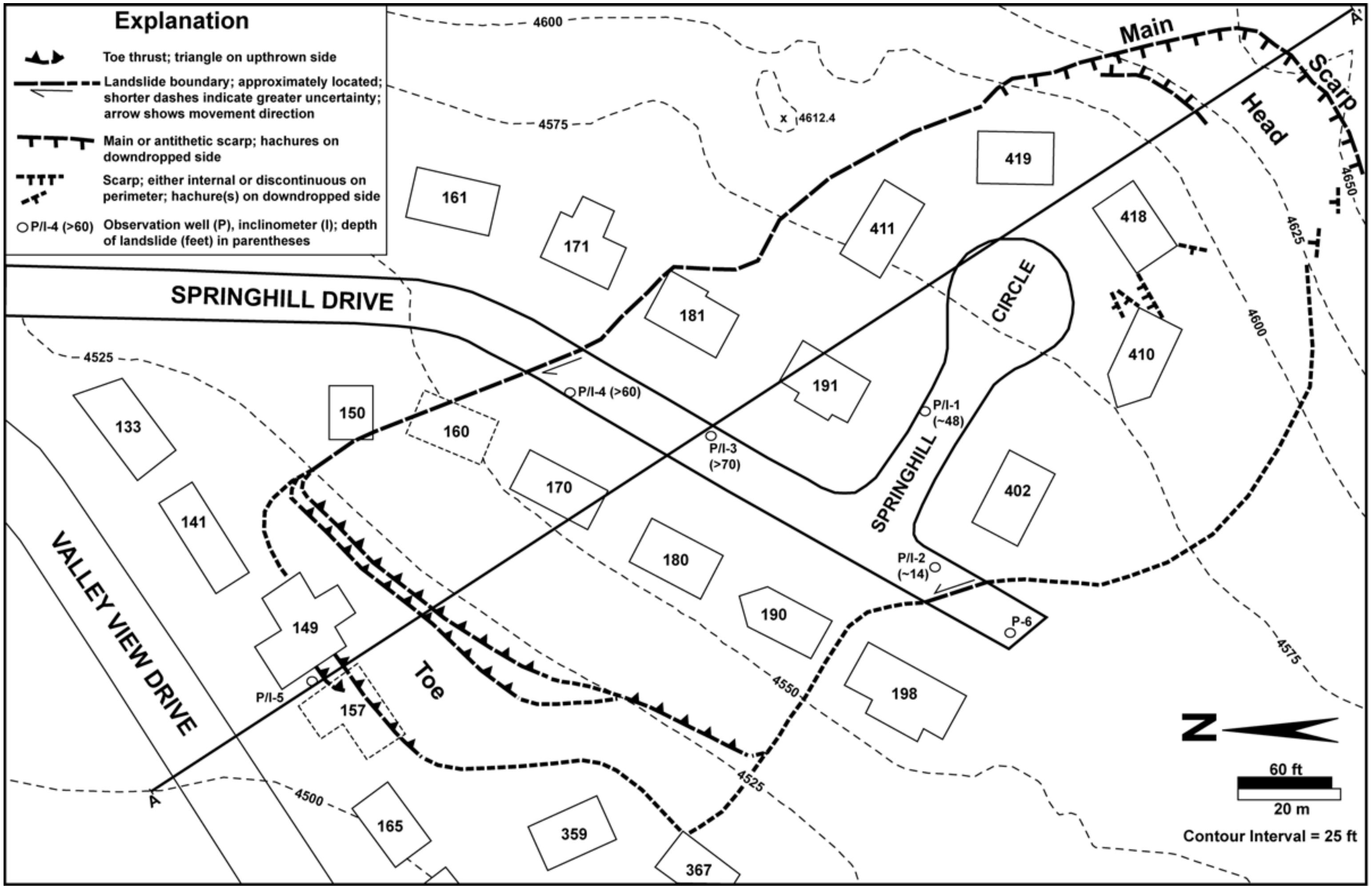

Figure 2. *Map of the Springhill landslide. Base map modified from Terracon (1998). A trace of the Wasatch fault zone (not shown on map, see figure 5 for approximate location) is inferred to cross the landslide in the backyards of the lots immediately southeast of Valley View Drive. Geologic cross section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

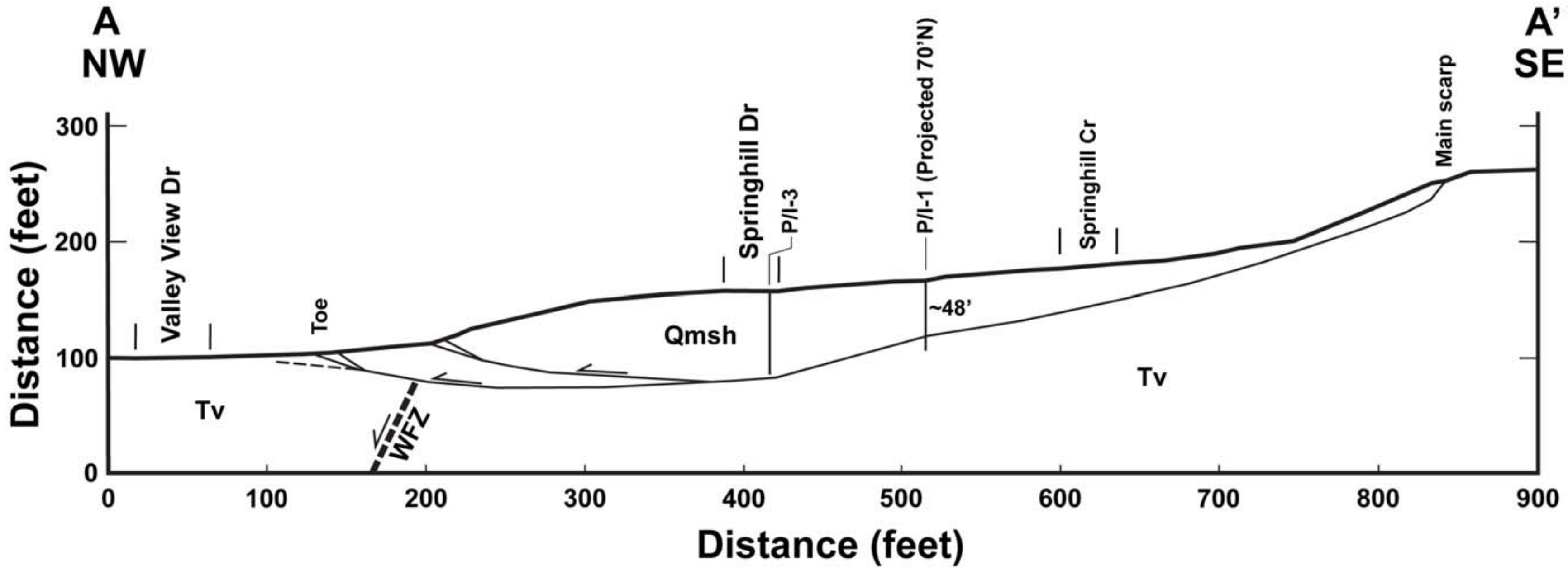

Figure 5. *Geologic cross section of Springhill landslide based on depths from inclinometers and slope-stability analysis. Landslide (Qmsh) overlies weathered Tertiary volcanic rocks (Tv). Basal slide-plane splays intersect the ground surface at four locations (see figure 2). Approximate location of 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.*

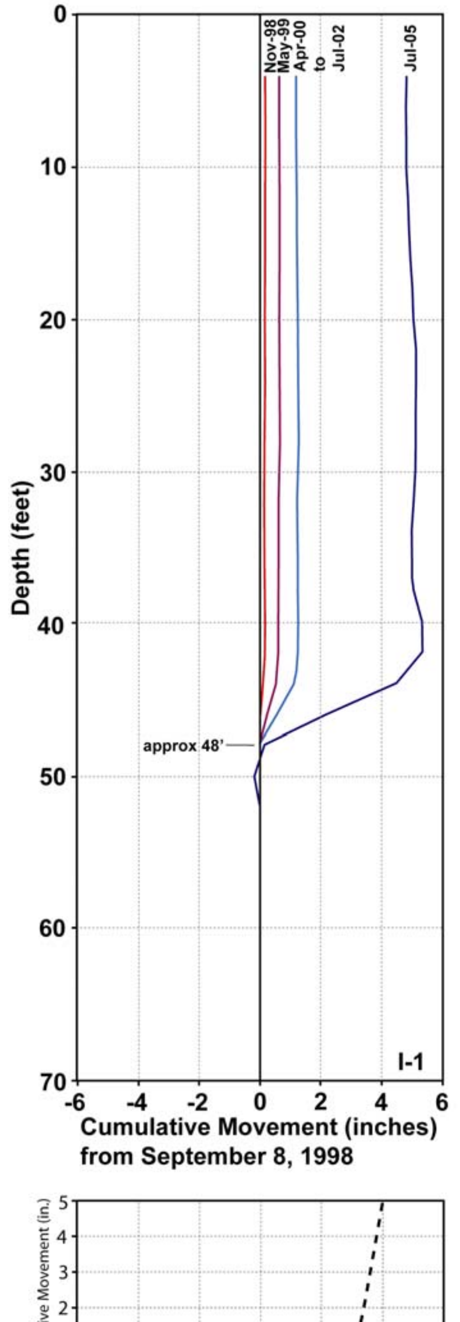

Figure 6. *Plots for inclinometer I-1 in Springhill Circle. Upper plot shows cumulative movement versus depth between September 1998 and July 2005. Landslide depth is about 48 feet (15 m.) Lower plot shows cumulative movement versus time. Dashed part of curve is inferred based on surface observations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

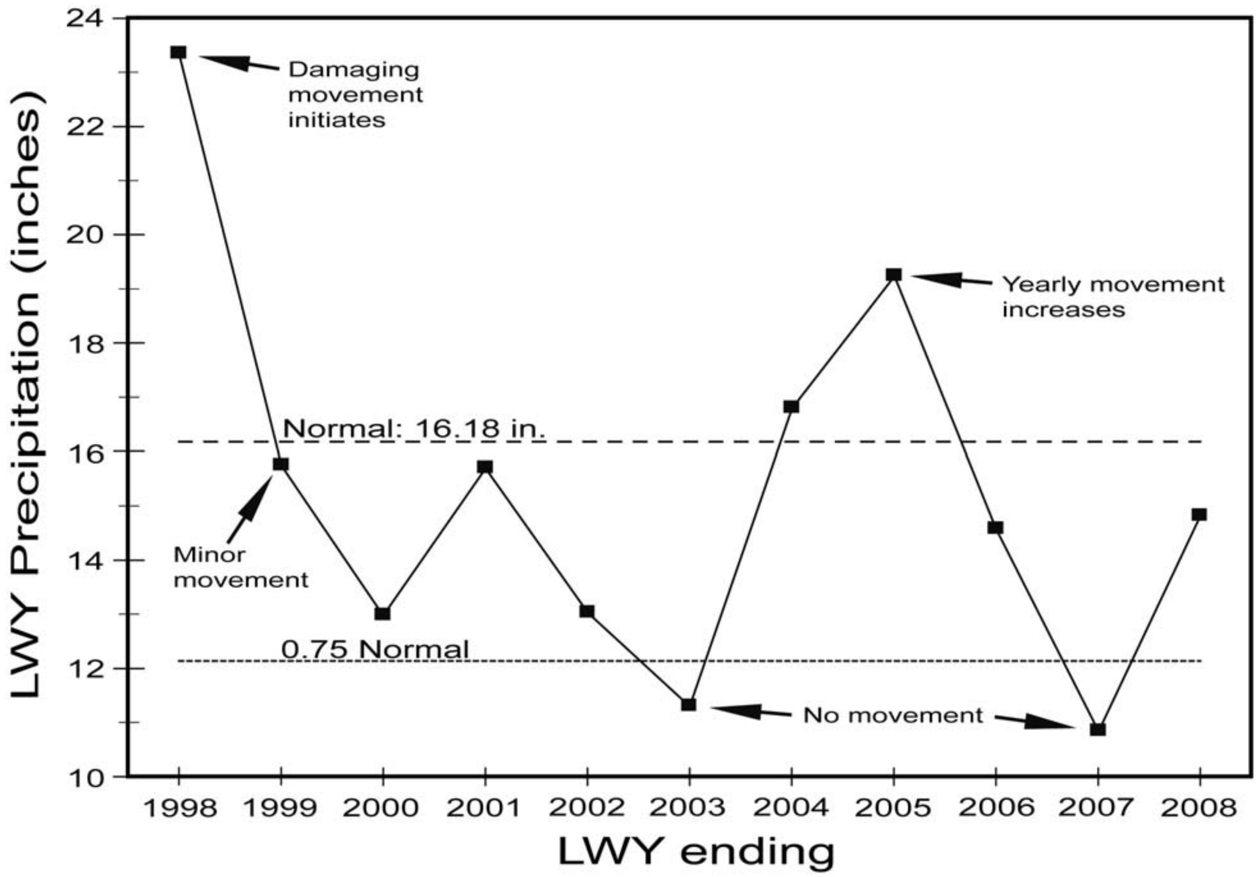

Figure 8. *Salt Lake City precipitation for landslide water years (LWY) ending between 1998 and 2008 annotated with movement history of the Springhill landslide. Damaging movement initiated in 1998 during the second-wettest LWY on record dating back to 1875 in Salt Lake City. Minor movement of landslide 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).*

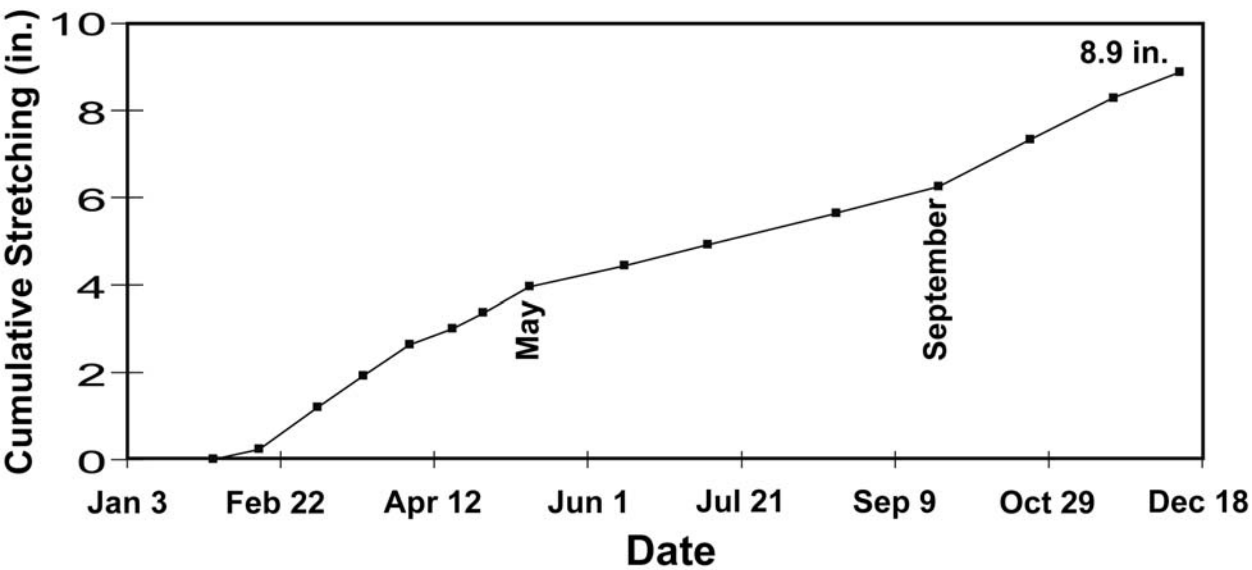

Figure 9. *Cumulative stretching across main scarp zone in 2008. Total stretching was about 8.9 inches (23 cm). Changes in the rate of movement occurred in May and September, separated by periods during which movement occurred at a nearly constant rate. A gradual increase in the rate of movement also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

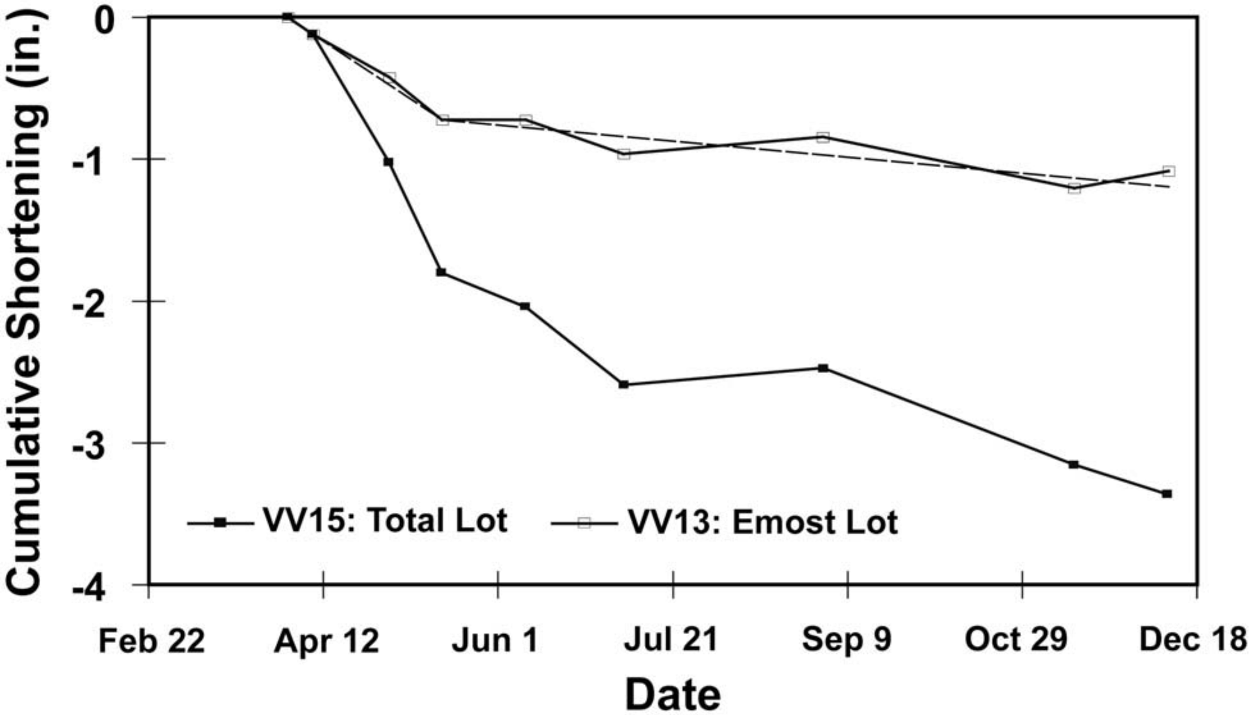

Figure 10. *Cumulative shortening across the toe thrust system at lot 157 Valley View Drive between April and December 2008. Upper curve shows cumulative shortening across southeasternmost two toe thrusts (figure 2). Lower curve shows cumulative shortening across entire toe thrust system, which was about 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.*

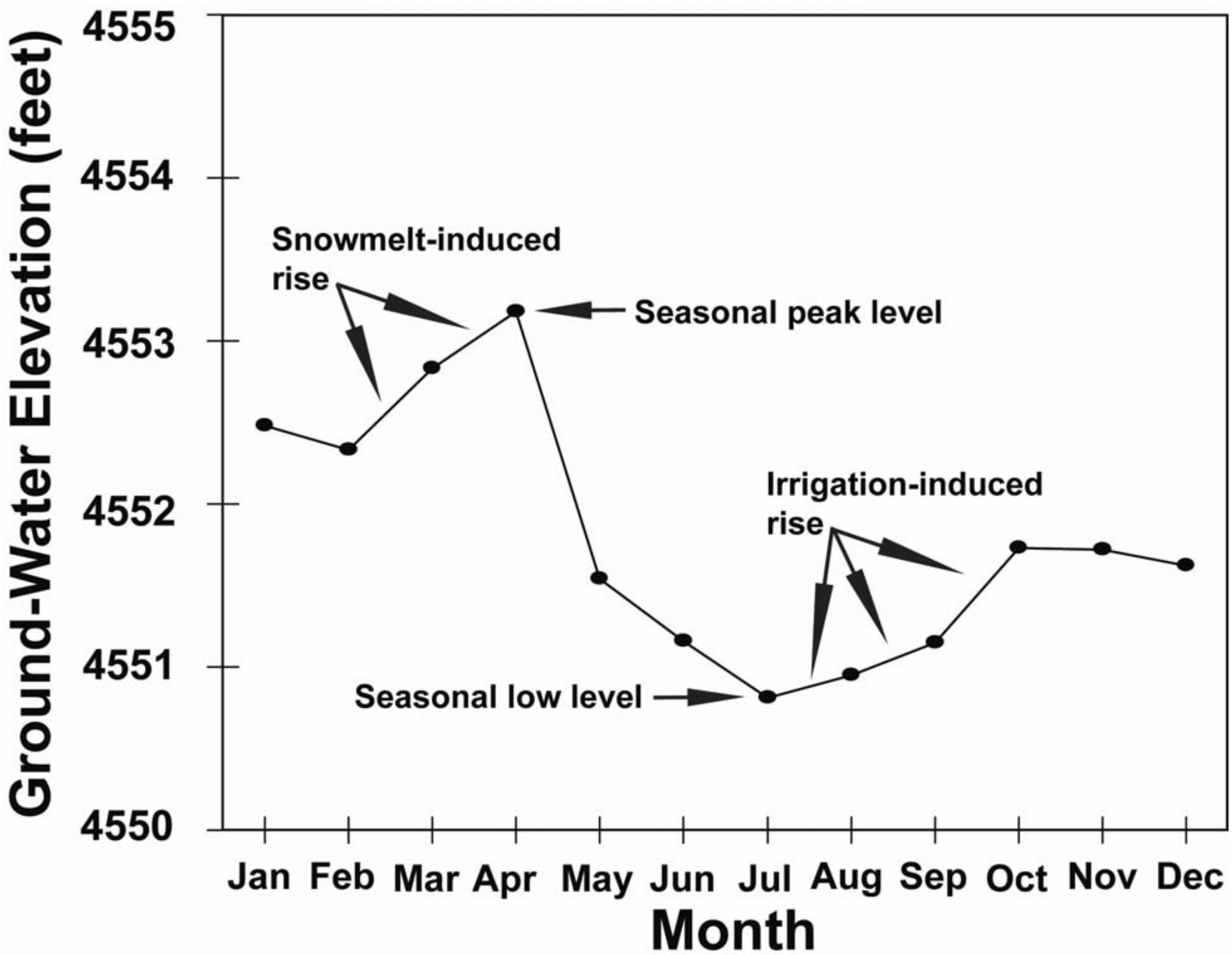

Figure 11. *Seasonal fluctuation in ground-water level in observation well P-4 in 2006. Rise in ground-water level between February and April to seasonal peak level is due mostly to infiltration of snowmelt. Seasonal low ground-water level occurs in response to dry hot weather and evapotranspiration. 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.*

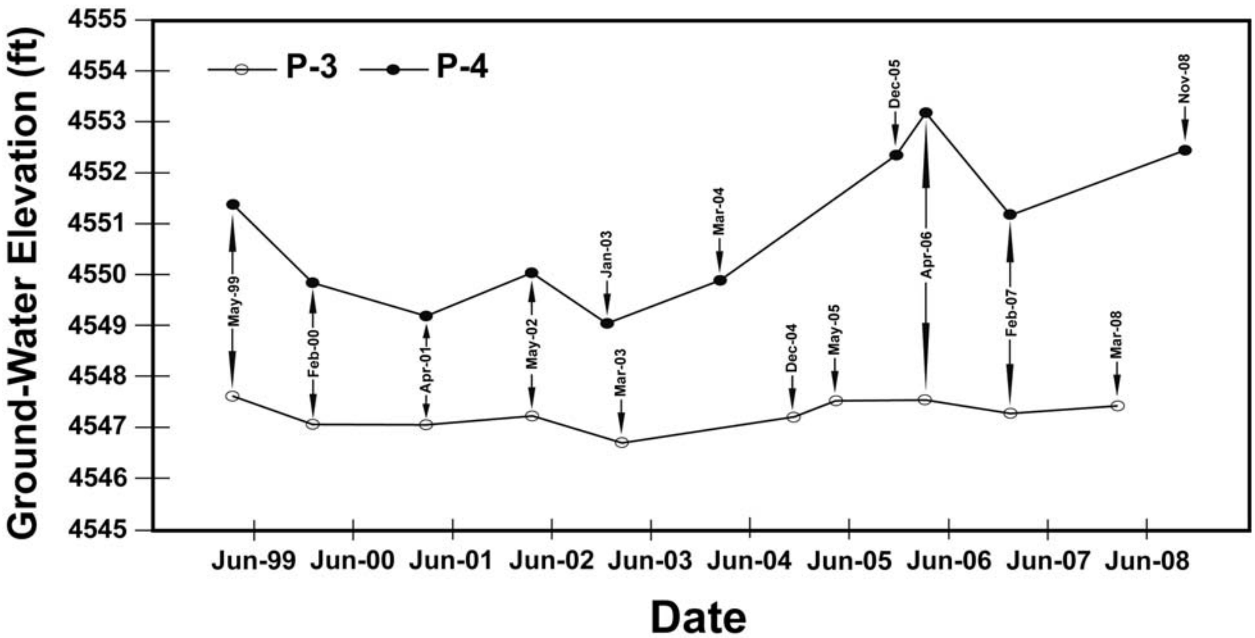

***Figure 12**. Fluctuations in seasonal peak ground-water levels (SPGWL) in observation wells P-3 and P-4 between 1999 and 2008. The SPGWL coincides with the lowest stability of the landslide during the year, and thus is a basis for assessing the relative stability of the landslide. High SPGWLs since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

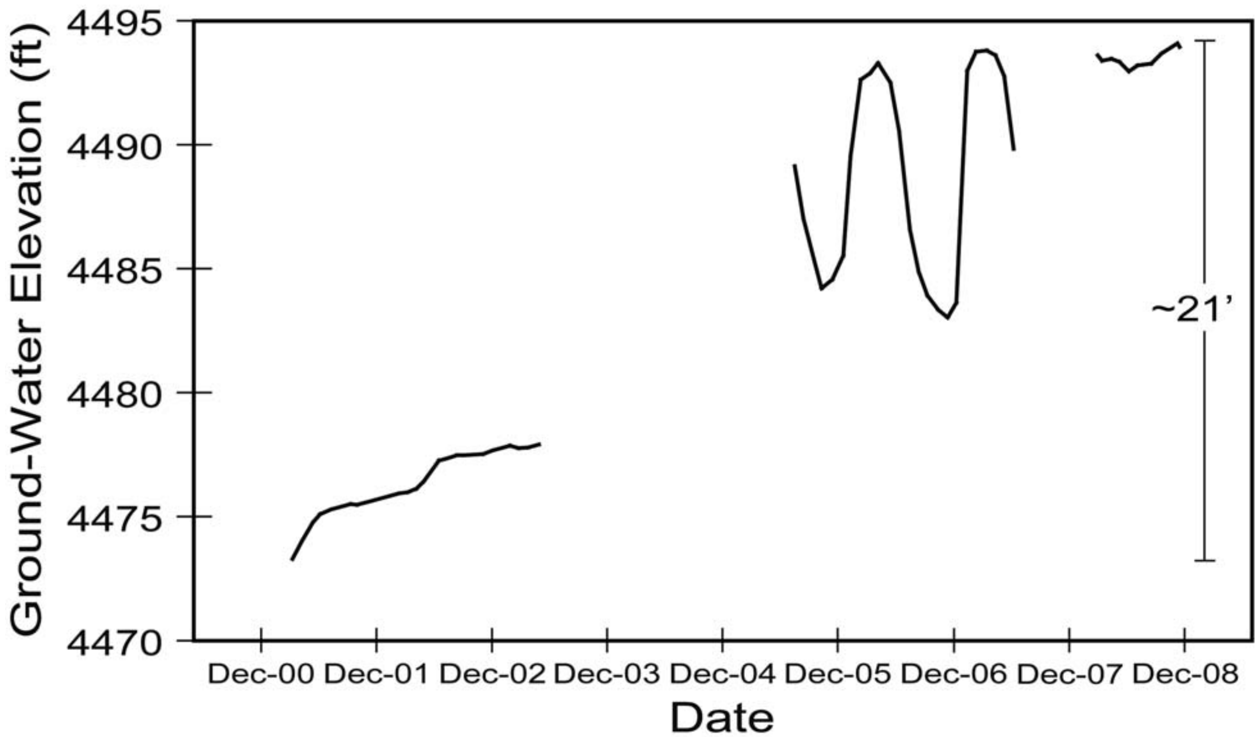

Figure 13. *Rise in ground-water level in observation well P-5 near toe of the landslide since 2001. Observation well was dry when initially installed in 1998 until March 2001. Between March 2001 and April 2006 the ground-water level rose nearly 20 feet (6 m). Ground-water levels between 2005 and early 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.*