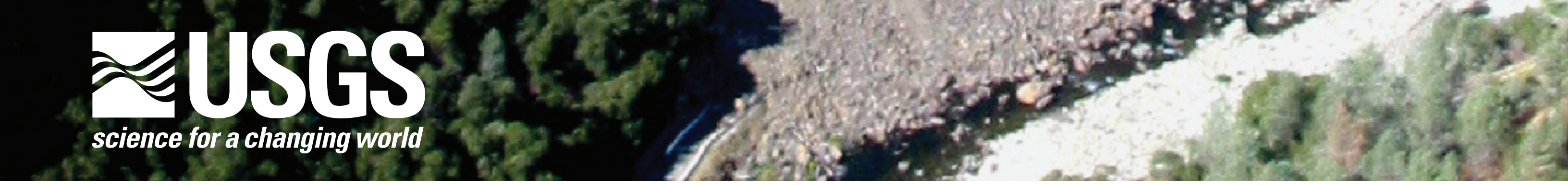

Real-Time Monitoring of Landslides

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Landslides cause fatalities and property damage throughout the Nation. To reduce the impact from hazardous landslides, the U.S. Geological Survey develops and uses real-time and near-real-time landslide monitoring systems. Monitoring can detect when hillslopes are primed for sliding and can provide early indications of rapid, catastrophic movement. Continuous information from up-to-the-minute or real-time monitoring provides prompt notification of landslide activity, advances our understanding of landslide behavior, and enables more effective engineering and planning efforts.

During the exceptionally wet spring of 2006, thousands of tons of rock crashed onto one of the main highways leading into Yosemite National Park in the mountainous Sierra Nevada of California (fig. 1). These rocks, emanating from the massive Ferguson rockslide perched upslope, buried the highway and encroached into the Merced River. After 92 days, the highway was temporarily rerouted to the opposite side of the river. Nevertheless, geologists and land managers remained concerned—if the entire rock mass slid rapidly and blocked the river, it could cause upstream inundation and, potentially, downstream flooding.

To help reduce the threat posed by this rockslide, the U.S. Geological Survey (USGS), in cooperation with other agencies, acted quickly to provide continuous near-real-time monitoring of rockslide activity. Spider units, developed for remote monitoring of active volcanoes, were airlifted by helicopter and positioned on the active slide (fig. 1, inset). These spider units contain high-precision Global Positioning System (GPS) units capable of detecting small movements of the rockslide. Data from these remote spider units are transmitted by radio to USGS computers (fig. 2). Graphs of slide movement, available over the Internet, display current activity to geologists, geotechnical engineers, and emergency managers at the U.S. Forest Service, the National Park Service, and the California Department of Transportation.

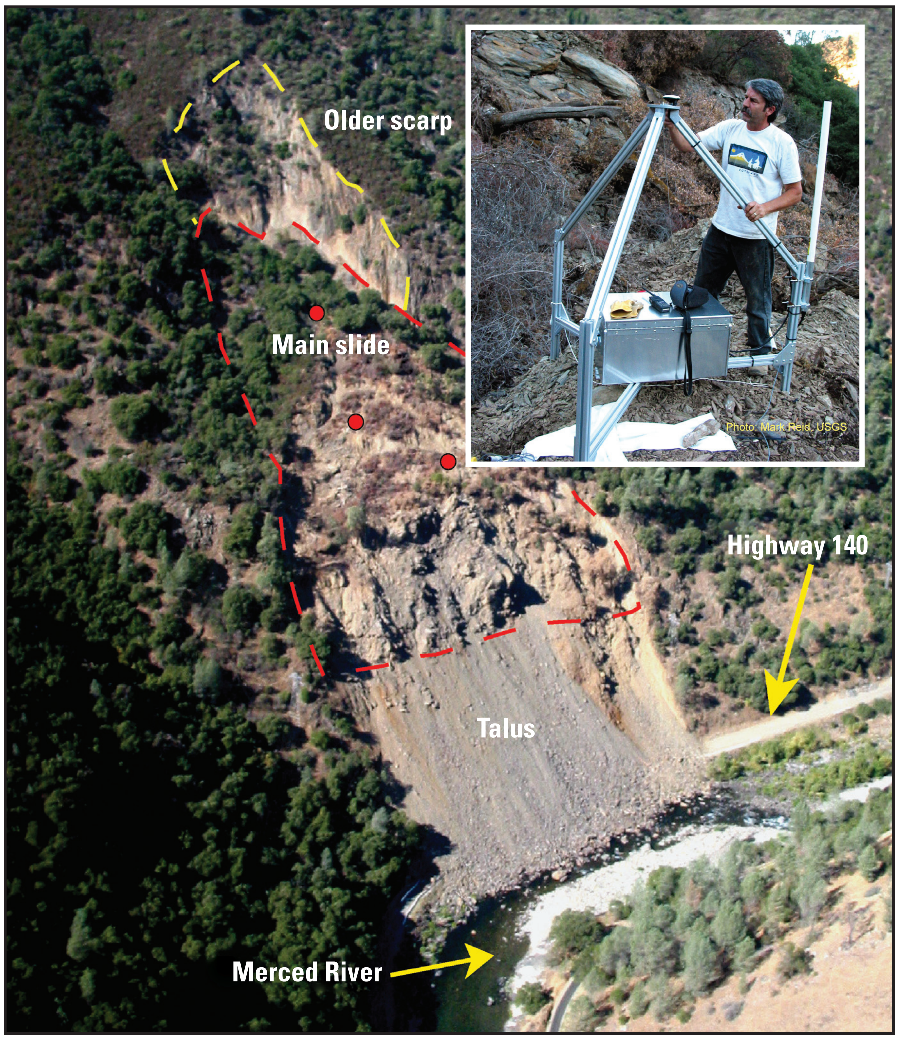

Figure 1. *Massive rockslide that buried California State Route 140 leading into Yosemite National Park, California, in 2006. Red dots are locations of spider monitoring units. Inset—Spider monitoring unit, containing Global Positioning System (GPS) receiver and radio telemetry, installed via helicopter to detect continuing movement of the rockslide. (Photos: Mark Reid, U.S. Geological Survey)*

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How do we monitor landslides?

The causes, speeds, and potential destructiveness of landslides vary widely, so there is no standard monitoring setup that will work universally. Selected monitoring strategies are tailored to fit specific landslide behaviors. Some landslides move slowly, traveling only a few inches (centimeters) in many days. Other landslides can transform suddenly into mud or debris flows that travel thousands of feet (hundreds to thousands of meters) in a matter of minutes and cause massive destruction and fatalities. Many landslides move only during or following extended periods of infiltration from rain or melting snow when groundwater pressures increase.

Some landslide events are reactivations of preexisting slides where ground sensors can be placed precisely. Others are first-time slides where triggering hydrologic conditions need to be monitored in anticipation of movement. Depending on field conditions, sensors may be installed to detect precipitation, soil moisture and groundwater pressures, and (or) slide displacement and acceleration.

Ground-based remote monitoring systems consist of more than just field sensors; they employ data acquisition units to record sensor measurements, remote telemetry (such as radio, satellite, or cell phone links), automated data processing, and displays of current conditions (often via the Internet). Because there is always some delay between sampling remote conditions and displaying these conditions to users, the term "near-real-time monitoring" is commonly used for observations that are delayed slightly (typically minutes to hours) but are still close enough in time to represent current field conditions.

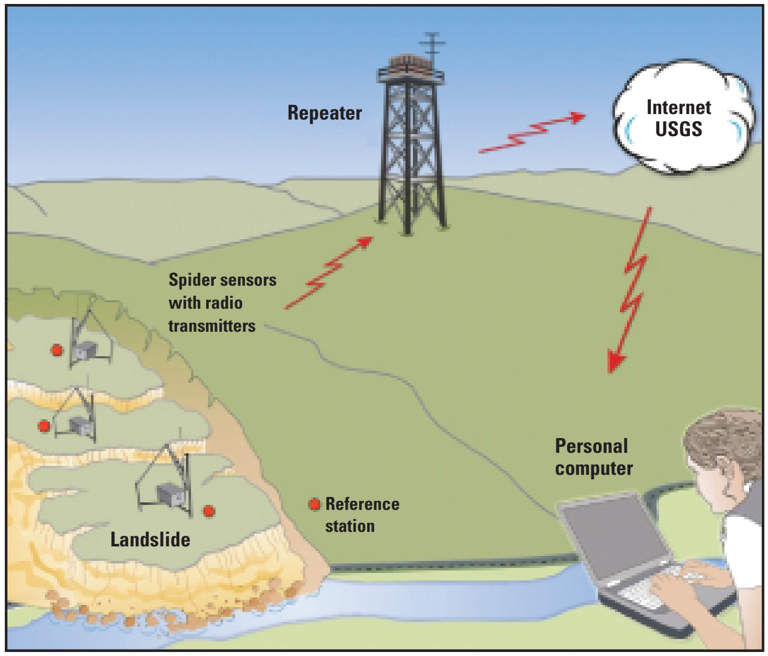

Figure 2. *Network for transmission of real-time landslide monitoring data. (Illustration: Lisa Faust, U.S. Geological Survey)*

Why is it necessary to collect real-time data from remote landslides? The immediate detection of landslide activity provided by real-time systems can be crucial in making timely decisions about safety. Traditional field observations, even if taken regularly, cannot detect changes at the moment they occur. Moreover, active landslides can be hazardous to work on, and large movements often occur during storms when visibility is poor. The continuous data provided by remote real-time monitoring permits a better understanding of dynamic landslide behavior that, in turn, enables engineers to create more effective designs to prevent or halt landslides.

At the Ferguson rockslide monitored by the USGS, the GPS-enabled spiders detected continued movement for years after the road closure. Large sections of the slide moved over 30 feet (10 meters) between 2006 and 2010, and the slide accelerated following even modest rainstorms each winter and spring over that time period. Near-real-time data, provided over the Internet, enabled land managers to rapidly modify safety alert levels for the public, and continuous data have aided in the design of a long-term highway solution.

The USGS operates remote near-real-time monitoring to keep an eye on a wide variety of hillslopes prone to hazardous landslides (fig. 3). For example, winter rains on steep burned slopes in southern California can quickly create rapidly moving debris flows. Flows from these wildfire-scarred slopes can inundate extensive urban areas and harm residents. At these sites, the USGS installs and monitors sensors to detect debris-flow occurrence, size, and speed. Once the burned hillslopes become stabilized by the regrowth of vegetation in 1–3 years, the USGS relocates monitoring equipment to other newly burned areas susceptible to debris flows. In Colorado, intense summer thunderstorms and steep, easily erodible cliffs induce frequent debris flows. In this natural laboratory setting, the USGS conducts long-term monitoring aimed at understanding debris-flow initiation processes (fig. 4).

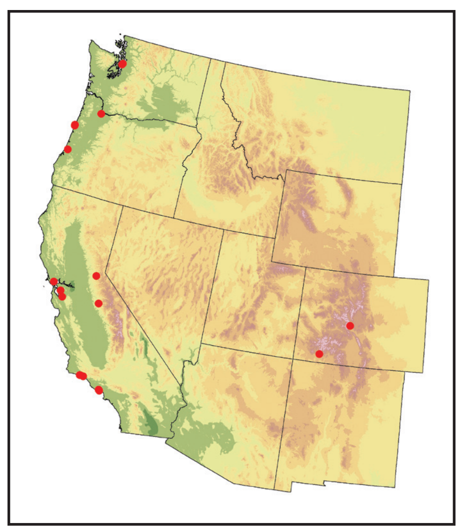

Figure 3. *Current U.S. Geological Survey near-real-time landslide monitoring sites in the western United States. Active and recent sites can be viewed at http://landslides.usgs.gov/monitoring.*

Throughout mountainous areas in the Pacific coastal states of Washington, Oregon, and California, intense winter storms can trigger widespread shallow landslides and debris flows. Extensive landsliding generated by a single strong storm can devastate large areas, yet the amount of rain needed to trigger shallow landsliding varies from region to region. At multiple sites in the Pacific coastal mountains, USGS near-real-time systems detect the rainfall and soil moisture conditions that can initiate abundant landslides. Currently, monitoring sites installed in the landslide-prone hills of Portland, Oregon, the forests of western Oregon (fig. 5), and the slopes of the San Francisco Bay area of California record changes in soil moisture that could trigger landsliding.

Figure 4. *Scientists installing sensors to measure flow depth in a channel repeatedly swept by debris flows; Colorado. (Photo: Jeff Coe, U.S. Geological Survey)*

Figure 5. *Placing near-surface sensors to measure soil moisture favorable for triggering shallow landsliding; western Oregon. (Photo: Rex Baum, U.S. Geological Survey)*

On other hillsides, large, slow-moving landslides can pose an ongoing threat to homes, property, water reservoirs, and highways, including U.S. Highway 50 in California and U.S. Highway 101 in Oregon. Many of these slides are dormant during drier times and reactivate during extended wet periods. USGS near-real-time monitoring can detect destabilizing groundwater pressures that drive slide movement (fig. 6). If slow-moving slides fail rapidly and catastrophically, or if they spawn fast-moving debris flows, they can inflict immense damage (fig. 7). Rapid movement of some landslides is preceded by gradual acceleration. Monitoring can determine landslide speed and acceleration, thereby providing early indication of catastrophic movement.

Scientists at the USGS have developed real-time monitoring and other tools that improve the understanding of where, when, and how landslides occur. Data from their research have lead to advances in predictive understanding:

- Identifying the exceptionally brief periods of intense rainfall that trigger debris flows on recently burned hillslopes.
- Distinguishing the cumulative destabilizing effects of a series of storms on hillslopes prone to shallow landsliding.
- Discovering that small fluctuations in atmospheric pressure can induce additional movement in an active landslide.
- Quantifying the rapid acceleration leading to catastrophic movement of destructive, deeper landslides.

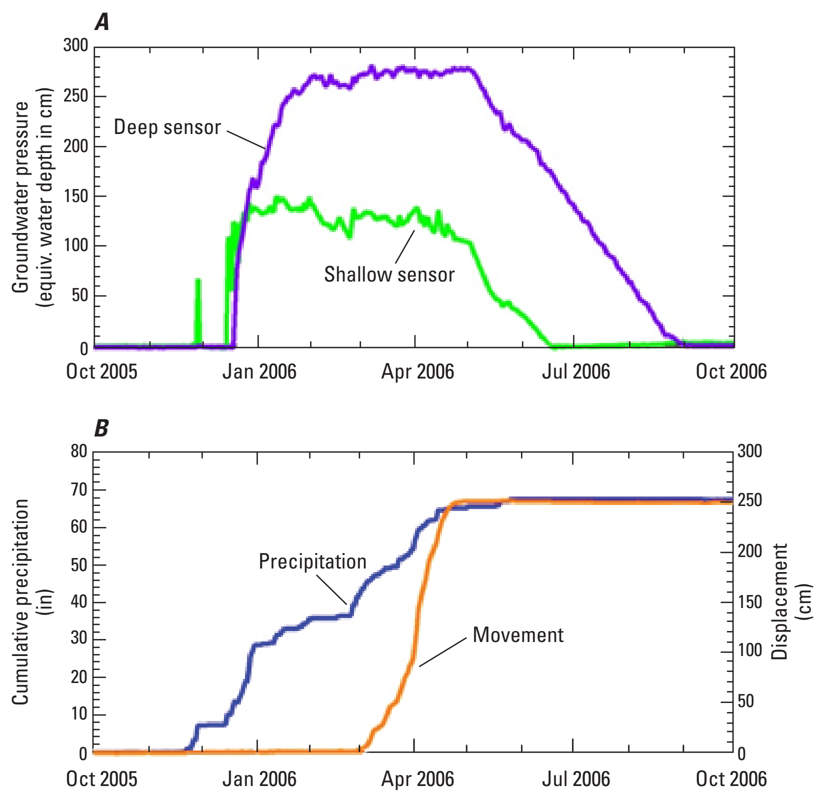

Figure 6. *Graphs showing (A) elevated groundwater pressures and (B) slow movement (displacement) in response to precipitation at a monitored landslide along U.S. Highway 50, California. In figure 6A, the shallow sensor measures groundwater pressure near the ground surface, whereas the deep sensor measures pressure at depth near the slide surface. Movement occurs after deep groundwater pressures become elevated. (From http://landslides.usgs.gov/monitoring/hwy50/yearly.php)*

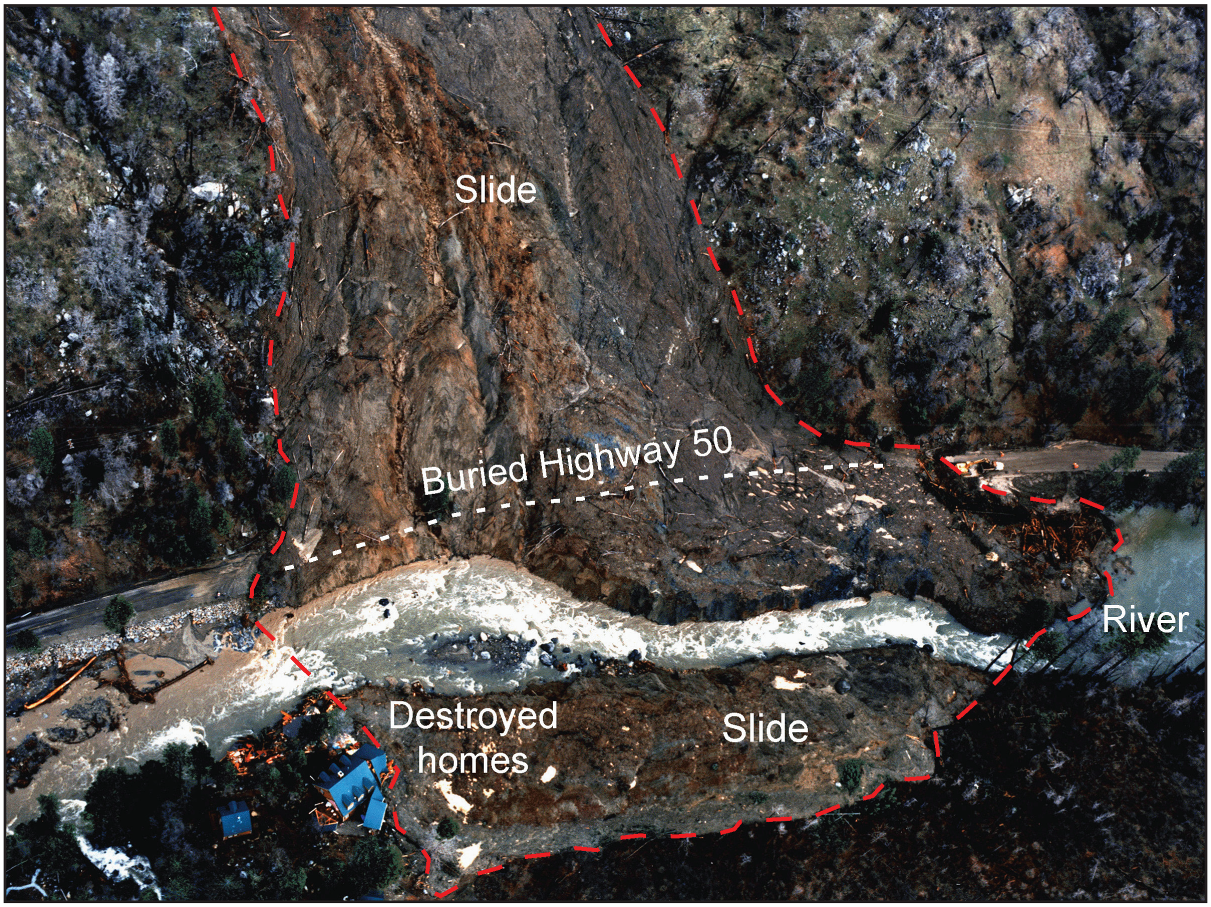

Figure 7. *Massive landslide that failed catastrophically, blocked U.S. Highway 50, and temporarily dammed the South Fork of the American River near Placerville, California, in 1997. The U.S. Geological Survey monitors a nearby landslide perched upslope of U.S. Highway 50. (See http://landslides.usgs.gov/monitoring/hwy50) (Photo: Lynn Harrison, Caltrans)*

For More Information

National Landslide Information Center
U.S. Geological Survey
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Denver, CO 80225
1-800-654-4966
NLIC@usgs.gov
http://landslides.usgs.gov

Real-Time Monitoring

http://landslides.usgs.gov/monitoring

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Cooperating Agencies

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- California Geological Survey
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- County of San Mateo, California
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