SECTION 9: LANDSLIDES

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Why are Landslides a Threat to the City of Glendale?

Landslides are a serious geologic hazard in almost every state in America. Nationally, landslides cause 25 to 50 deaths each year. The best estimate of direct and indirect costs of landslide damage in the United States ranges between $1 and $2 billion annually. In California, landslides are a significant problem, in part because of the region's seismic activity, and in part because the region is underlain by weak soils and rocks, especially when saturated. Some landslides result in private property damage, whereas other landslides impact transportation corridors, fuel and energy conduits, and communication facilities. They can also pose a serious threat to human life.

The San Gabriel Mountains are located in the central part of the Transverse Ranges, where they rise abruptly to heights of more than 7,000 feet above the valley floor (several peaks are more than 9,000 feet high and Mount Baldy is the highest at 10,064 feet). Bounded by the San Andreas fault system on the north and the Sierra Madre fault zone on the south, the mountains are essentially a large block of the Earth's crust that has been squeezed up and thrust over the valley floor by north-south compression along the Big Bend portion of the San Andreas tectonic plate boundary. Tectonic forces that initiated the rise of the mountains are thought to have started about 3.5 million years ago, at a time when scientists now believe there was a change in the relative motion of the Pacific and North American tectonic plates from strike-slip (slipping horizontally past one another) to transpressive (oblique movement that is a combination of strike-slip and compression). Uplift of the mountains accelerated in mid-Pleistocene time, about 500,000 years ago, and continues today (Wright, 1991). The current rate of uplift, in the context of geologic time, is one of the fastest in the world.

The steep southern flank of the San Gabriel Mountains is deeply incised by gorges and canyons that drain south into the La Cañada Valley, where they have been channelized, conveying their flows south to Verdugo Wash. The three canyons that are located mostly within city of Glendale limits include Ward, Dunsmore, and Cooks. Several other streams draining the San Gabriel Mountains that are also channelized through the La Crescenta area and into the northern portion of Glendale; these include the Eagle Canyon, Pickens, Hills and Winery Canyon channels (see Plate H-1 in Appendix H). Nearly all the tributaries flowing northerly and easterly out of the Verdugo Mountains and westerly out of the San Rafael Hills also empty into Verdugo Wash. South of the mountains, Verdugo Wash turns to the west-southwest and joins the Los Angeles River near the junction of Highway 134 with the 5 Freeway (Interstate 5). Drainage from the southwestern slope of the Verdugo Mountains flows directly across the alluvial fan and into the Los Angeles River. As discussed further in Section 8, Verdugo Wash has been confined to a man-made channel through most of Glendale to reduce the potential for it to flood the city.

Nearly half of the land in Glendale consists of steep hillslopes and rugged mountains. These areas have for the most part been preserved in their near natural state, while most of the development in the city occurs in the flat to gently sloping alluvial surfaces at the base of the mountains. However, some development (primarily residential) is present in and adjacent to steep hillsides. These areas include the canyons within the Verdugo Mountains and the San Rafael Hills, and the alluvial fans situated at the front of the San Gabriel and Verdugo Mountains. Such areas are locally vulnerable to slope instability, particularly in winters of heavy rainfall and in winters following wildfires.

What is a Landslide?

Landslides are downslope movements of relatively large landmasses, either as nearly intact bedrock blocks, or as jumbled mixes of bedrock blocks, fragments, debris, and soil. Landslides are a type of "mass wasting" which denotes any down slope movement of soil and rock under the direct influence of gravity. The term "landslide" encompasses events such as rock falls, topples, slides, spreads, and flows, and in general, landslides can be broken down into two categories: 1) rapidly moving (generally known as debris flows), and 2) slow moving. Rapidly moving landslides or debris flows pose the greatest risk to human life, and people living in or traveling through areas prone to rapidly moving landslides are at increased risk of serious injury. Slow moving landslides can cause significant property damage, but are less likely to result in serious human injuries.

Geologists also describe the type of movement of a landslide as either 1) translational (where movement occurs along a flat surface), 2) rotational (where sliding material moves along a curved surface) or 3) wedge (where movement occurs on a wedge-shaped block formed by intersecting planes of weakness, such as fractures, faults and bedding). The size of a landslide usually depends on the geology and the initial cause of the landslide. Landslides vary greatly in their volume of rock and soil, the length, width, and depth of the area affected, frequency of occurrence, and speed of movement. Slow-moving landslides can occur on relatively gentle slopes and can cause significant property damage, but are far less likely to result in serious injuries than rapidly moving landslides. Rotational and translational slides are generally slow moving and can be deep; whereas wedge failures generally occur suddenly and are shallow. Slumps are small rotational slides that are generally shallow.

Landslides can be initiated by rainfall, earthquakes, volcanic activity, changes in ground water, disturbance and change of a slope by man-made construction activities, or any combination of these factors. Landslides can also occur underwater, causing tidal waves and damage to coastal areas. The potential for slope failure is dependent on many factors, including slope height, slope steepness, shear strength and orientation of the underlying geologic unit, as well as moisture content. For example, water can increase the plasticity of weak clays lining joints or shears, forming planes of weakness along which a landmass can fail.

For engineering of earth materials, these factors are combined in calculations to determine if a slope meets a minimum safety standard. The generally accepted standard is a factor of safety of 1.5 or greater (where 1.0 is equilibrium, and less than 1.0 is failure). Natural slopes, graded slopes, or graded/natural slope combinations must meet these minimum engineering standards where they impact planned homes, subdivisions, or other types of developments. Slopes adjacent to areas where the risk of economic losses from landsliding is small, such as parks and mountain roadways, are often allowed a lesser factor of safety. From an engineering perspective, landslides are generally unstable (may be subject to reactivation), and may be compressible, especially around the margins, which are typically highly disturbed and broken. The headscarp area above the landslide mass is also unstable, since it is typically oversteepened, cracked, and subject to additional failures. Although existing landslides are not widespread in the Glendale area, it is probable that many of the steeper hillsides do not meet the minimum factor of safety, and slope stabilization may be needed if development reaches these areas.

Failure of a slope occurs when the force that is pulling the slope downward (gravity) exceeds the strength of the earth materials that compose the slope. They can move slowly, (millimeters per year) or can move quickly and disastrously, as is the case with debris-flows. Debris-flows can travel down a hillside of speeds up to 200 miles per hour (more commonly, 30 – 50 miles per hour), depending on the slope angle, water content, and type of earth and debris in the flow. These flows are initiated by heavy, usually sustained, periods of rainfall, but sometimes can happen as a result of short bursts of concentrated rainfall in susceptible areas. Burned areas charred by wildfires are particularly susceptible to debris flows, given certain soil characteristics and slope conditions.

What is a Debris Flow?

This type of failure is the most dangerous and destructive of all types of slope failure. A debris flow (also called mudflow, mudslide, and debris avalanche) is a rapidly moving slurry of water, mud, rock, vegetation and debris. Larger debris flows are capable of moving trees, large boulders, and even cars. This type of failure is especially dangerous as it can move at great speeds, is capable of crushing buildings, and can strike with very little warning. As with soil slips, the development of debris flows is strongly tied to exceptional storm periods of prolonged rainfall. Failure occurs during an intense rainfall event, following saturation of the soil by previous rains.

A debris flow most commonly originates as soil slip in the rounded, soil-filled "hollow" at the head of a drainage swale or ravine. The rigid soil mass is deformed into a viscous fluid that moves down the drainage, incorporating into the flow additional soil and vegetation scoured from the channel. Debris flows also occur on canyon walls, often in soil-filled swales that do not have topographic expression. The velocity of the flow depends on the viscosity, slope gradient, height of the slope, roughness and gradient of the channel, and the baffling effects of vegetation. Even relatively small amounts of debris can cause damage from inundation and/or impact (Ellen and Fleming, 1987; Reneau and Dietrich, 1987). Recognition of this hazard led FEMA to modify its National Flood Insurance Program to include inundation by "mudslides."

Watersheds that have been recently burned typically yield greater amounts of soil and debris than those that have not burned. Erosion rates during the first year after a fire are estimated to be 15 to 35 times greater than normal, and peak discharge rates range from 2 to 35 times higher. These rates drop abruptly in the second year, and return to normal after about 5 years (Tan, 1998). In addition, debris flows in burned areas are unusual in that they can occur in response to small storms and do not require a long period of antecedent rainfall. These kinds of flows are common in small gullies and ravines during the first rains after a burn, and can become catastrophic when a severe burn is followed by an intense storm season (Wells, 1987). The United States Geological Survey (USGS), as part of its National Landslide Hazards Program, is currently developing tools and methodologies to identify and quantify slope stability hazards posed by burned watersheds. Such tools will help communities with emergency planning and in dealing with post-fire rehabilitation (USGS, 2001).

Historic Southern California Landslides:

Historically, there have been many landslides in the southern California area. Landslides recorded in the 20th century alone caused losses of more than $5 billion (in 2000 dollars). Many of these landslides have occurred after particularly wet winters, others in response to strong ground shaking during an earthquake. Some of the most dramatic of these cases are briefly described below.

1956 Portuguese Bend Landslide, Palos Verdes:
Cost: $14.6 million (2000 dollars), on California Highway 14 in the Palos Verdes Hills. The Portuguese Bend landslide is a reactivated ancient slide that began its modern movement in August 1956, when displacement was noticed at its northeast margin. Movement gradually extended downslope so that the entire eastern edge of the slide mass was moving within 6 weeks. By the summer of 1957, the entire slide mass was sliding towards the sea.

1969 Glendora, Los Angeles County:
Cost: $26.9 million (2000 dollars), in Los Angeles County. The winter of 1969 was one of the wettest on record in the southern California area. The rain caused many of the canyons at the base of the San Gabriel Mountains to overflow, causing debris flows that damaged 175 houses in the Glendora area alone.

1977-1980 Monterey Park and Repetto Hills, Los Angeles County:
Cost, $14.6 million (2000 dollars); 100 houses damaged due to debris flows.

1978 Bluebird Canyon, Orange County:
Cost: $52.7 million (2000 dollars); 60 houses destroyed or damaged. On October 2, 1978, a portion of the Bluebird Canyon slope gave way, in great part due to the unusually heavy rains in March that may have contributed to initiation of the landslide. Although the 1978 slide area was approximately 3.5 acres, it is suspected to be a portion of a larger, ancient landslide.

1979 Big Rock, California, Los Angeles County:
Cost: approximately $1.08 billion (2000 dollars; rockslide causing damage to California Highway 1.

1980 Southern California slides:
Cost: $1.1 billion in damage (2000 dollars). Heavy winter rainfall in 1979-90 caused damage in six southern California counties. A sequence of five days of continuous rain that started on February 8 dropped more than 7 inches of water by February 14. Slope failures began to develop by February 15 and then very high-intensity rainfall occurred on February 16. As much as 8 inches of rain fell in a 6-hour period in many locations. Records and personal observations in the field on February 16 and 17 showed that the mountains and slopes literally fell apart on those last two days.

1983 San Clemente, Orange County:
Cost: $65 million (2000 dollars), California Highway 1. Litigation associated with this landslide ultimately cost approximately $43.7 million (2000 dollars).

1983 Big Rock Mesa, Malibu, Los Angeles County:
Cost: $706 million (2000 dollars) in legal claims; 13 houses condemned and 300 more threatened due to rockslide triggered by intense rainfall.

1978-1979, 1980 San Diego County:
Experienced major damage from storms in 1978, 1979, and 1979-80, as did neighboring areas of Los Angeles and Orange County, California. One hundred and twenty landslides were reported to have occurred in San Diego County during these 2 years. Rainfall for the rainy seasons of 78-79 and 79-80 was 14.82 and 15.61 inches (37.6 and 39.6 cm) respectively, compared to a 125-

year average (1850-1975) of 9.71 inches (24.7 cm). Significant landslides occurred in the Friars Formation, a unit known to be slide-prone. [Of the nine landslides that caused damage in the northern part of San Diego County in excess of $1 million, seven occurred in the Friars Formation, and two in the Santiago Formation.]

1994 Northridge Earthquake Landslides:
As a result of the magnitude 6.7 Northridge earthquake, more than 11,000 landslides occurred over an area of 10,000 km^2. Most were in the Santa Susana Mountains and in mountains north of the Santa Clara River Valley. The landslides destroyed dozens of homes, blocked roads, and damaged oil-field infrastructure.

March 1995 Los Angeles and Ventura Counties:
Above normal rainfall triggered damaging debris flows, deep-seated landslides, and flooding. Several deep-seated landslides were triggered by the storms, the most notable being the La Conchita landslide, which in combination with a local debris flow, destroyed or badly damaged 11 to 12 homes in the small town of La Conchita, about 20 km west of Ventura. There also was widespread debris-flow and flood damage to homes, commercial buildings, and roads and highways in areas along the Malibu coast that had been devastated by wildfire two years before.

2005 Landslide in La Conchita, Ventura County
Cost – undetermined yet. On January 10, 2005 a landslide struck the sea-side community of La Conchita destroying 36 homes and killing 10 people. The landslide occurred in an area known for prior landslide activity (more recently in 1995), and was the direct result of intense rainfall in the area, compounded by weak sediments and steep slopes.

2005 Blue Bird Canyon Landslide, Laguna Beach, Orange County
Cost – undetermined yet, but probably in the billions, in great part due to litigation. On June 1, a landslide began moving in the area, almost certainly in response to the extremely wet winter rains earlier that year, in January and February. This landslide occurred in the same general area as the 1978 landslides. More than two dozen homes were damaged.

Conditions Conducive to Slope Failures

Locations at risk from landslides or debris flows include the following:

- ✓ On or close to steep hills;
- ✓ Steep road-cuts or excavations;
- ✓ Existing landslides or places of known historic landslides (such sites often have tilted power lines, trees tilted in various directions, cracks in the ground, and irregular-surfaced ground);
- ✓ Steep areas where surface runoff is channeled, such as below culverts, V-shaped valleys, canyon bottoms, and steep stream channels;
- ✓ Fan-shaped areas of sediment and boulder accumulation at the outlets of canyons; and
- ✓ Canyon areas below hillside and mountains that have recently (within 1-6 years) been subjected to a wildland fire.

The conditions leading to failure can be varied. The most common of these are described in detail below.

Natural Conditions:

Natural processes can cause landslides or re-activate historical landslide sites. The removal or undercutting of shoreline-supporting material along bodies of water by currents and waves produces countless small slides each year. Seismic tremors can trigger landslides on slopes historically known to have landslide movement. Earthquakes can also cause additional failure (lateral spreading) that can occur on gentle slopes above steep streams and riverbanks.

Weathering and the decomposition of geologic materials produces conditions conducive to landslides, while human activity often further exacerbates many landslide problems. Many landslides are difficult to mitigate, particularly in areas of large historic movement with weak underlying geologic materials.

Rock falls occur when blocks of material come loose on steep slopes. Weathering, erosion, or excavations, such as those along highways, can cause falls where the road has been cut through bedrock. They are fast moving with the materials free falling or bouncing down the slope. In falls, material is detached from a steep slope or cliff. The volume of material involved is generally small, but large boulders or blocks of rock can cause significant damage.

As the list of historical landslides suggests, landslides are often triggered by periods of heavy rainfall. Earthquakes, subterranean water flow and excavations may also trigger landslides. Certain geologic formations are more susceptible to landslides than others. Human activities, including locating development near steep slopes, can increase susceptibility to landslide events. Landslides on steep slopes are more dangerous because movements can be rapid.

Wildland fires in hills covered with chaparral are often a precursor to debris flows in burned out canyons. The extreme heat of a wildfire can create a soil condition in which the earth becomes impervious to water by creating a waxy-like layer just below the ground surface. Since the water cannot be absorbed into the soil, it rapidly accumulates on slopes, often gathering loose particles of soil in to a sheet of mud and debris. Debris flows can often originate miles away from unsuspecting persons, and approach them at a high rate of speed with little warning.

Impacts of Development:

As communities continue to modify the terrain and influence natural processes, it is important to be aware of the physical properties of the underlying soils as they, along with climate, create landslide hazards. Even with proper planning, landslides will continue to threaten the safety of people, property, and infrastructure, but without proper planning, landslide hazards will be even more common and more destructive. The increasing scarcity of build-able land, particularly in urban areas, increases the tendency to build on geologically marginal land. Additionally, hillside housing developments in southern California are prized for the view lots that they provide.

Thus, although landslides are a natural occurrence, human impacts can substantially affect the potential for landslide failures to occur. Proper planning and geotechnical engineering can be exercised to reduce the threat of safety of people, property, and infrastructure. Grading for road construction and development can increase slope steepness. Grading and construction can decrease the stability of a hill slope by adding weight to the top of the slope, removing support at the base of the slope, and increasing water content. Other human activities effecting landslides include excavation, drainage and groundwater alterations, and changes in vegetation.

Excavation and Grading:

Slope excavation is common in the development of home sites or roads on sloping terrain. Grading these slopes often results slopes steeper than the pre-existing natural slopes. Since slope steepness is a major factor in landslides, these steeper slopes can be at an increased risk for landslides. The added weight of fill placed on slopes can also result in an increased landslide hazard. Small landslides can be fairly common along roads, in either the road cut or the road fill sections. Landslides occurring below new construction sites are indicators of the potential impacts stemming from excavation.

Alterations to Drainage and Groundwater Systems:

Water flowing through or above ground is often the trigger of landslides. Any activity that increases the amount of water flowing into landslide-prone slopes can increase landslide hazards. Broken or leaking water or sewer lines can be especially problematic, as can water retention facilities that direct water onto slopes. However, even lawn irrigation in landslide-prone locations can result in damaging landslides. Ineffective storm water management and excess runoff can also cause erosion and increase the risk of landslide hazards. Drainage can be affected naturally by the geology and topography of an area. Development that results in an increase in impervious surface impairs the ability of the land to absorb water and may redirect water to other areas. Channels, streams, ponding, and erosion on slopes all indicate potential slope problems.

Road and driveway drains, gutters, downspouts, and other constructed drainage facilities can concentrate and accelerate runoff flow. Ground saturation and concentrated velocity flow are major causes of slope problems and may trigger landslides.

Changes in Vegetation:
Removing vegetation from very steep slopes can increase landslide hazards. Areas that experience wildfire and land clearing for development may have long periods of increased landslide hazard. Also, certain types of non-native ground covers require extensive irrigation to remain green. As a result, clearing and replacement of native ground covers with non-native covers can lead to an increase in slope failures.

Landslide Hazard Assessment

Hazard Identification:

Identifying hazardous locations is an essential step towards implementing more informed mitigation activities. Evidence of past slope failures are found throughout the mountain and foothill regions of the City of Glendale. The crystalline rock of the San Gabriel Mountains, weakened by fracturing, shearing, and crushing along numerous fault zones, particularly near the range front, combined with the moderate to extremely steep slopes that have resulted from rapid uplift of the mountains, are important elements that create the setting for the development of slope failures. Similar conditions are present in the Verdugo Mountains and the San Rafael Hills, where rocks are highly weathered and slope gradients of 30 degrees or steeper are common.

Significantly, however, areas of gross instability such as large deep-seated landslides have not been mapped in the Glendale area, primarily because the highly fractured crystalline rocks that underlie the San Gabriel and Verdugo Mountains and the San Rafael Hills rarely fail as large cohesive units. Three small landslides (Qls) of probable Holocene age have been mapped on the slopes of the Verdugo Mountains and the San Rafael Hills. Because the bedrock in these areas is highly fractured and weathered, the slides consist of small blocks and rock fragments rather than large cohesive masses. These landslides are shown on Plates H-2 and H-11. Numerous other smaller landslides have also occurred in the area, but their size is too small to show on the maps that accompany this report. Large prehistoric landslides have been mapped in the San Gabriel Mountains just to the east of the city, but not in the Glendale area. The distribution of existing landslides in the Glendale area and vicinity was compiled from various publications, including Morton and Streitz, (1969), Crook et al. (1987), and Dibblee, (1989a, 1989b, 1991a, 1991b, 2002).

Areas of surficial instability are common along the steep slopes and canyons of the San Gabriel Mountains, Verdugo Mountains and San Rafael Hills. Unfortunately detailed maps showing previous sites of surficial slope failures, such as small landslides, slumps, soil slips, and rockfalls have not been compiled or published for the Glendale area. However, an unpublished engineering geology report records several talus rockfalls on steep slopes and roadcuts in the

Verdugo Mountains (R. T. Frankian & Associates, 1968). The common occurrence of rockfalls can also be inferred by the abundant talus at the base of steep slopes and in canyons of the San Gabriel Mountains.

The Southern California Area Mapping Project (SCAMP), a cooperative effort between the US Geological Survey (USGS) and the California Geological Survey (CGS), has produced a series of Debris-Flow Occurrence Maps, at a scale of 1:100,000, that predict in a general way areas that will be prone to debris flows in normally vegetated hillsides (SCAMP, 2001). The maps are based on their studies of recent El Nino events, specifically relating the relationships between rainfall thresholds, terrain, and past debris flow events. Their studies indicate that in upland areas underlain by sedimentary rock and fractured crystalline rock (such as that found in the mountains of Glendale), essentially all past debris flows have occurred on slopes with gradients of 26 degrees or steeper. The mapped debris flow susceptibility areas in the San Gabriel Mountains include most slopes steeper than 26 degrees, but do not include the heads of the large alluvial fans at the base of the mountains because the flood control dams and debris basins that have been built in these areas are thought to be adequate to contain flows from unburned areas.

However, flows can overwhelm flood control structures during periods of extreme rainfall on a recently burned hillside. For instance, during winters of exceptional rainfall (such as 1934, 1969, 1978, and 1980), debris flows caused widespread property damage and loss of life in communities in and near the base of the San Gabriel Mountains, with areas below burned watersheds receiving the bulk of the damage. For example, in November 1933, there was a large fire in the Montrose-La Crescenta area that burned more than 5,000 acres. Then, on January 1, 1934, intense rainfall fell on the same area that had burned. La Crescenta and Glendale received the brunt of the damage. Several people died, swept away by debris-ladden flows that overtopped the canyons in the area. Streets were clogged with debris, and several bridges were washed out (see Plate H-9). In 1978, several canyons within burned watersheds near the Glendale area overtopped their debris basins (Davis, 1980). These canyons include Zachau Canyon located north of Sunland, Shields Canyon north of La Crescenta, and Rubio Canyon north of Altadena. In 1980, the Rubio basin again overflowed, partially inundating one home and threatening several others (Davis, 1980). Therefore, if the right conditions are met, such as high rainfall within burned watersheds, the possibility that debris flows will overtop basins in the Glendale area cannot be precluded.

A recent detailed study of burned watersheds (including in the San Gabriel Mountains during and after the 1997-1998 winter rains) indicate that less than half of the drainage basins produced debris flows, although the debris flows that did occur were most frequently in response to the initial heavy rainfall. In addition to rainfall and slope steepness, the study highlights the many other factors that contribute to the formation of post-fire debris flows, including the underlying rock type, the shape of the drainage basin, and the presence or absence of water-repellent soils. The goal of these studies is a better understanding of the processes and conditions that generate this hazard, an understanding that is needed in order for communities to make appropriate decisions on public safety and slope mitigation (Cannon, 2001).

Vulnerability and Risk:

Vulnerability assessment for landslides will assist in predicting how different types of property and population groups will be affected by a hazard. Data that includes specific landslide-prone and debris flow locations in the city can be used to assess the population and total value of property at risk from future landslide occurrences.

The potential for slope failure is dependent on many factors and their interrelationships. Some of the most important factors include slope height, slope steepness, sheer strength, and orientation of weak layers in the underlying geologic unity, as well as pore water pressures.

Joints and shears, which weaken the rock fabric, allow penetration of water leading to deeper weathering of the rock along with increasing the pore pressures, increasing the plasticity of weak clays, and increasing the weight of the landmass. For engineering of earth materials, these factors are combined in calculations to determine if a slope meets a minimum safety standard. The generally accepted standard is a factor of safety of 1.5 or greater (where 1.0 equilibrium, and less than 1.0 is failure).

Although existing landslides are not widespread in the area, it is probable that many of the steeper hillsides do not meet the minimum factor of safety and slope stabilization may be needed if development reaches these areas. Natural slopes, graded slopes, or graded/natural slope combinations must meet minimum engineering standards where they impact planned homes, subdivisions, or other types of developments. Slopes adjacent to areas where the risk of economic losses from landsliding is small, such as parks and mountain roadways, are often allowed a lesser factor of safety.

While a quantitative vulnerability assessment (an assessment that describes number of lives or amount of property exposed to the hazard of landslides) has not yet been conducted for city of Glendale, there are many qualitative factors that point to potential vulnerability. Landslides can impact major transportation arteries, blocking residents from essential services and businesses. Past landslide events have caused major property damage or significantly impacted city residents, and continuing to map city landslide and debris flow areas will help in preventing future loss.

Factors included in assessing landslide risk include population and property distribution in the hazard area, the frequency of landslide or debris flow occurrences, slope steepness, soil characteristics, and precipitation intensity. This type of analysis could generate estimates of the damages to the City due to a specific landslide or debris flow event. At the time of publication of this plan, data were insufficient to conduct a risk analysis and the software needed to conduct this type of analysis was not available.

Community Landslide Issues

What is Susceptible to Landslides?

The City's mountain and foothill areas are vulnerable to the types of slope instability mentioned above. Steep-sided slopes along Verdugo Wash and other incised drainages may also be locally susceptible to slope instability. Table 9-1 below is a general summary of the geologic conditions in various parts of the city that provide the environment for slope instability to occur. These conditions usually include such factors as terrain steepness, rock or soil type, condition of the rock (such as degree of fracturing and weathering), internal structures within the rock (such as bedding, foliation, faults) and the prior occurrence of slope failures. Catalysts that ultimately allow slope failures to occur in vulnerable terrain are most often water (heavy and prolonged rainfall), erosion and undercutting by streams, man-made alterations to the slope, or seismic shaking. The summary in Table 9-1 was derived from the Geologic Map (Plate H-2), and other resources. The information in Table 9-1 was then used to prepare the Slope Instability Map for Glendale (Plate H-11).

Landslides can affect utility services, transportation systems, and critical lifelines. Communities may suffer immediate damages and loss of service. Disruption of infrastructure, roads, and critical facilities may also have a long-term effect on the economy. Utilities, including potable water, wastewater, telecommunications, natural gas, and electric power are all essential to service community needs. Loss of electricity has the most widespread impact on other utilities and on the whole community. Natural gas pipes may also be at risk of breakage from landslide movements as small as an inch or two. Some of these issues are discussed in more detail below.

Roads and Bridges:

It is not cost-effective to mitigate all slides because of limited funds and the fact that some historical slides are likely to become active again even with mitigation measures. The City alleviates problem areas by grading slides, and by installing new drainage systems on the slopes to divert water from the landslides.

This type of response activity is often the most cost-effective in the short-term, but is only temporary. Unfortunately, many property owners are unaware of slides and the dangers associated with them.

Table 9-1: General Slope Instability Potential within the City of Glendale

Area	Geologic Conditions	Types of Potential Slope Instability
San Gabriel Mountains	Steep to extremely steep rock slopes, most in excess of 40 degrees; Highly fractured, sheared, faulted, and crushed crystalline bedrock; Soils and loose debris in tributary drainages; Stream terrace deposits along major drainage channels; No known landslides in Glendale.	*Most Probable:* Rockfalls, soil slips on steep slopes, soil slumps on the edges of active stream channels, small to large debris flows. *Less Probable:* Large, deep-seated landslides.
San Rafael Hills (north of Highway 134)	Moderate to very steep rock slopes, most in excess of 26 degrees, many in excess of 40 degrees; Highly fractured and weathered crystalline rock; Soils and loose debris in tributary drainages and swales; Several small existing landslides.	*Most Probable:* Soil slips and slumps on moderate to steep slopes and in drainage swales, small debris flows, small slides or rockfalls, surficial soil failures on steep man-made slopes. *Less Probable:* Large, deep-seated landslides.
Verdugo Mountains	Moderately steep to extremely steep rock slopes, most between 26 and 40 degrees, with some slopes steeper then 40 degrees; Highly fractured, sheared, faulted, and crushed crystalline bedrock; Soils and loose debris in tributary drainages; A few remnant stream terrace deposits along major drainage channels; Several small existing landslides; Rockfalls common according to R.T. Frankian & Associates (1968).	*Most Probable:* Soil slips and slumps on moderate to steep slopes and in drainage swales, small debris flows, small slides or rockfalls, surficial soil failures on steep man-made slopes. *Less Probable:* Large, deep-seated landslides.
Major Drainage Channels – Verdugo Wash	Gentle to moderate sloping channel walls with steeper channel banks (26-40 degrees) in a few isolated areas; Poorly bedded Holocene alluvium consisting of silt, sand and gravel, with coarse sand, gravel and boulders near the mountain front; No mapped landslides.	Slope instability generally not an issue.
Valley Plain	Very gentle slopes, typically about 10 degrees or less; Poorly bedded Holocene and Pleistocene alluvium consisting of silt, sand and gravel; No mapped landslides.	Slope instability generally not an issue.

Lifelines and Critical Facilities:

Lifelines and critical facilities should remain accessible, if possible, during a natural hazard event. The impact of closed transportation arteries may be increased if the closed road or bridge is critical for hospitals and other emergency facilities. Therefore, inspection and repair of critical transportation facilities and routes is essential and should receive high priority. Losses of power and phone service are also potential consequences of landslide events. Due to heavy rains, soil erosion in hillside areas can be accelerated, resulting in loss of soil support beneath high voltage transmission towers in hillsides and remote areas. Flood events can also cause landslides, which can have serious impacts on gas lines that are located in vulnerable soils.

Landslide Mitigation Activities:

Landslide mitigation activities include current mitigation programs and activities that are being implemented by local or city organizations.

All proposed development projects require a site-specific geotechnical evaluation of any slopes that may impact the future use of the property. This includes existing slopes that are to remain, and any proposed graded slopes. The investigation typically includes borings to collect geologic data and soil samples, laboratory testing to determine soil strength parameters, and engineering calculations. Numerous soil-engineering methods are available for stabilizing slopes that pose a threat to development. These methods include designed buttresses (replacing the weak portion of the slope with engineered fill); reducing the height of the slope; designing the slope at a flatter gradient; and adding reinforcements such as soil cement or layers of geogrid (a tough polymeric net-like material that is placed between the horizontal layers of fill). Most slope stabilization methods include a subdrain system to remove excessive ground water from the slope area. If it is not feasible to mitigate the slope stability hazard, building setbacks are typically imposed.

For debris flows, assessment of this hazard for individual sites should focus on structures located or planned in vulnerable positions. This generally includes canyon areas; at the toes of steep, natural slopes; and at the mouth of small to large drainage channels. Mitigation of soil slips, earthflows, and debris flows is usually directed at containment (debris basins), or diversion (impact walls, deflection walls, diversion channels, and debris fences). A system of baffles may be added upstream to slow the velocity of a potential debris flow. Other methods include removal of the source material, placing subdrains in the source area to prevent pore water pressure buildup, or avoidance by restricting building to areas outside of the potential debris flow path.

There are numerous methods for mitigating rock falls. Choosing the best method depends on the geological conditions (i.e., slope height, steepness, fracture spacing, bedding orientation), safety, type and cost of construction repair, and aesthetics. A commonly used method is to regrade the slope. This ranges from locally trimming hazardous overhangs, to completely reconfiguring the slope to a more stable condition, possibly with the addition of benches to catch small rocks. Another group of methods focuses on holding the fractured rock in place by draping the slope with wire mesh, or by installing tensioned rock bolts, tie-back walls, or even retaining walls. Shotcrete is often used on the slope face to prevent raveling in highly fractured rock, but its primary purpose is to offer surface protection only. A third type of mitigation includes catchment devices at the toe of the slope, such as ditches, walls, or combinations of both. Designing the width of the catchment structure requires analysis of how the rock will fall. For instance, the slope gradient and roughness of the slope determines if rocks will fall, bounce, or roll to the bottom. Rock slope stabilization may also include the addition of drains in order to reduce water pressure within the slope (Wyllie and Norrish, 1996).

There are a number of options for management of potential slope instability in developed hillsides.

1. Complete a detailed survey and assessment of existing developments in areas recognized to be vulnerable to potential slope failures (for instance, the Verdugo Mountains, the San Rafael Hills, and at the base of the San Gabriel Mountains).
2. Protect existing development and population where appropriate by physical controls such as drainage, slope-geometry modification, protective barriers, and retaining structures.
3. Implement monitoring or warning systems. For instance, in the San Francisco Bay area, the USGS, in cooperation with the National Weather Service, operated a system for real-time warnings for storm-related slope failures (Keefer et al., 1987). Using a combination of tracking storm systems, measuring actual rainfall with a network of rain gauges, and comparing thresholds for the initiation of debris flows, they were able to issue Flash Flood/Debris Watches during the most intense storms (Wilson, 1997). This would be especially valuable for developments adjacent to burned watersheds.
4. Post warning signs in areas of potential slope instability
5. Encourage homeowners to use landscaping methods that help stabilize the hillsides.
6. Incorporate recommendations for potential slope instability into geologic and soil engineering reports for additions and new grading.
7. Educate the public about slope stability, including the importance of maintaining drainage devices. USGS Fact Sheet FS-071-00 (May, 2000) and the CGS Note 33 (November, 2001) provide public information on landslide and mudslide hazards. These are available on the internet (see Appendices A and B).

Landslide Mitigation Action Items

The landslide mitigation action items below provide direction on specific activities that the City, organizations, and residents of Glendale can undertake to reduce risk and prevent loss from landslide events. Each action item is followed by ideas for implementation, which can be used by the steering committee and local decision makers in pursuing strategies for implementation.

Short Term - Landslide #1:

Action Item: Improve knowledge of landslide hazard areas and understanding of vulnerability and risk to life and property in hazard-prone areas.

Ideas for Implementation:

- Update the landslide map for the city of Glendale to show areas where rockfalls, debris flows and surficial mass wasting events are reported, especially during wet winters.
- Develop public information to emphasize economic risk when building on potential or historical landslide areas.

Coordinating Organization: Hazard Mitigation Advisory Committee
Timeline: 1 -2 Years
Plan Goals Addressed: Protect Life and Property
Constraints: Pending Funding and Available Personnel

<u>Short Term - Landslide #2:</u>

Action Item: Encourage construction and subdivision design that can be applied to steep slopes to reduce the potential adverse impacts from development.

Ideas for Implementation:

- Increase communication and coordination between the City's Departments.

Coordinating Organization: Hazard Mitigation Advisory Committee
Timeline: 1 – 2 Years
Plan Goals Addressed: Increase awareness of mitigation issues through the coordination of all City resources and departments.
Constraints: Pending Funding and Available Personnel

<u>Short Term - Landslide #3:</u>

Action Item: Identify safe evacuation routes in high-risk debris flow and landslide areas.

Ideas for Implementation:

- Identify potential debris removal resources.
- Increase participation in regional committee planning for emergency transportation routes.
- Identify and publicize information regarding emergency transportation routes.

Coordinating Organization: Public Works, Engineering
Timeline: 1 – 3 Years
Plan Goals Addressed: Protection of Life and more efficient response of emergency personnel.
Constraints: Pending Funding and Available Personnel

Long Term - Landslide #1:

Action Item: Review local ordinances regarding building and development in landslide prone areas.

Ideas for Implementation:

- Create committee of local stakeholders to study issue and make recommendations to staff.

Coordinating Organization: Building and Safety
Timeline: 3 – 5 Years
Plan Goals Addressed: Protect Life and Property
Constraints: Pending Funding and Available Personnel

Long Term - Landslide #2:

Action Item: Limit activities in identified potential and historical landslide areas through regulation and public outreach.

Ideas for Implementation:

- Analyze existing regulations regarding development in landslide prone areas.
- Identify existing mechanisms for public outreach / develop new methods of outreach.

Coordinating Organization: Hazard Mitigation Advisory Committee, Public Affairs Department
Timeline: 3 – 5 Years
Plan Goals Addressed: Protect Life and Property
Constraints: Pending Funding and Available Personnel

Landslide Resource Directory

County Resources:

Los Angeles County Department of Public Works
900 S. Freemont Avenue
Alhambra, CA 91803
Ph: 626-458-5100

State Resources:

California Department of Conservation: Southern California Regional Office
655 S. Hope Street, #700
Los Angeles, CA 90017-2321
Ph: 213-239-0878
Fax: 213-239-0984

California Geological Survey
801 K Street

Sacramento, CA 95814
Ph: 916-445-1825
Fax: 916-445-5718

California Division of Forestry
1416 9th Street
PO Box 944246
Sacramento, CA 94244-2460
Ph: 916-653-5123

California Department of Water Resources
1416 9th Street
Sacramento, CA 95814
Ph: 916-653-6192

Governor's Office of Emergency Services (OES)
P.O. Box 419047
Rancho Cordova, CA 95741-9047
Ph: 916-845-8911
Fax: 916-845-8910

California Department of Transportation (Cal Trans)
120 S. Spring Street
Los Angeles, CA 90012
Ph: 213-897-3656

Federal Resources and Programs:

Federal Emergency Management Agency (FEMA) – Region IX
1111 Broadway, Suite 1200
Oakland, CA 94607
Ph: 510-627-7100
Fax: 510-627-7112

Natural Resource Conservation Service (NRCS)
PO Box 2890
Washington, DC 20013
Ph: 202-690-2621

US Geological Survey, National Landslide Information Center
345 Middlefield Road
Menlo Park, CA 94025
Ph: 650-853-8300

Publications:

Olshansky, Robert B., Planning for Hillside Development (1996) American Planning Association.
This document describes the history, purpose, and functions of hillside development and regulation and the role of planning, and provides excerpts from hillside plans, ordinances, and guidelines from communities throughout the US.

Olshansky, Robert B. & Rogers, J. David, Unstable Ground: Landslide Policy in the United States (1987) Ecology Law Quarterly.
This is about the history and policy of landslide mitigation in the US.

Public Assistance Debris Management Guide (July 2000) Federal Emergency Management Agency.
The Debris Management Guide was developed to assist local officials in planning, mobilizing, organizing, and controlling large-scale debris clearance, removal, and disposal operations. Debris management is generally associated with post-disaster recovery. While it should be compliant with local and city emergency operations plans, developing strategies to ensure strong debris management is a way to integrate debris management within mitigation activities. The Guide is available in hard copy or on the FEMA website.

USGS Landslide Program Brochure. National Landslide Information Center (NLIC), United States Geologic Survey.
The brochure provides good, general information in simple terminology on the importance of landslide studies and a list of databases, outreach, and exhibits maintained by the NLLC. The brochure also includes information on the types and causes of landslides, rock falls, and earth flows.