Chapter 5

5 Landslides

Landslide is a general term for a wide variety of down slope movements of earth materials that result in the perceptible downward and outward movement of soil, rock, and vegetation under the influence of gravity. The materials may move by falling, toppling, sliding, spreading, or flowing. Some landslides are rapid, occurring in seconds, whereas others may take hours, weeks, or even longer to develop. Although landslides usually occur on steep slopes, they also can occur in areas of low relief. Landslides can occur as ground failure of river bluffs, cut and-fill failures that may accompany highway and building excavations, collapse of mine-waste piles, and slope failures associated with quarries and open-pit mines. While gravity is the primary reason for landslides, there can be other contributing factors, including:

- Saturation, by snowmelt or heavy rains, that weaken rock or soils on slopes
- Erosion by rivers, glaciers, or ocean waves that create over-steepened slopes
- Topography of slope – its shape, size, degree of slope and drainage
- Stress from earthquakes magnitude 4.0 and greater can cause weak slopes to fail
- Volcanic eruptions that produce loose ash deposits and debris flows
- Excess weight, from accumulation of rain or snow, from stockpiling of rock or ore, from waste piles, or from manmade structures, may cause weak slopes to failure
- Human action, such as construction, logging or road building that disturbs soils and slopes

5.1 Landslide Hazards and Risk

5.1.1 Landslide Profile in Washington

The State of Washington Hazard Mitigation Plan identifies six landslide provinces. Stevens County is part of the Okanogan Highlands Province. This landslide province extends from the slopes of the North Cascades in the west to the Selkirk Mountains in the northeast corner of the state. The primary slope stability problem in this province is in the sediments within and along the boundary of the highlands. Thick sections of sediments along the valleys of the Columbia, Spokane, and Colville Rivers are the result of repeated damming of the Columbia River by lobes of the continental ice sheet and repeated catastrophic floods from breached dams.

The occurrence of new landslides and the reactivation of old landslides increased dramatically with the filling of reservoirs behind the Grand Coulee and Chief Joseph dams. Drawdowns for flood control and power generation also trigger new landslides and/or reactivate and extend old ones. Some of the landslide complexes extend for thousands of feet along the lakeshores, have head scarps in terraces 300 feet or more above reservoir level and extend well below its surface. With landslide activity common along hundreds of miles of shoreline, one hazard in such a setting is water waves generated by fast-moving landslide masses.

Stevens County is identified as one of the jurisdictions that have the greatest vulnerability for landslides in the State of Washington Hazard Mitigation Plan due to its Lake Roosevelt shoreline.
5.1.2 Stevens County Landslide Profile

The primary factors that increase landslide risk are slope and certain soil characteristics. In general, the potential for landslide occurrence intensifies as slope increases on all soil types and across a wide range of geological formations.

Landslides may occur on slopes steepened by man during construction, or on natural ground never disturbed. However, most slides occur in areas that have had sliding in the past. All landslides are initiated by factors such as weaknesses in the rock and soil, earthquake activity, the occurrence of heavy snow or rainfall, or construction activity that changes a critical factor involved with maintaining stability of the soil or geology of the area. A prime example of this includes previously stable slopes where home construction utilizing independent septic systems are added. The increased moisture in the ground, when coupled with an impermeable layer below the septic systems has led to surface soil movements and mass wasting.

Landslides can be triggered by natural changes in the environment or by human activities. Inherent weaknesses in the rock or soil often combine with one or more triggering events, such as heavy rain, snowmelt, or changes in ground water level. Late spring-early summer is slide season, particularly after days and weeks of greater than normal precipitation. Long-term climate change may result in an increase in precipitation and ground saturation and a rise in ground-water level, reducing the shear strength and increasing the weight of the soil.

Stream and riverbank erosion, road building or other excavation can remove the toe or lateral slope and exacerbate landslides. Seismic or volcanic activity often triggers landslides as well. Urban and rural living with excavations, roads, drainage ways, landscape watering, logging, and agricultural irrigation may also disturb the solidity of landforms, triggering landslides. In general, any land use changes that affects drainage patterns or that increase erosion or change ground-water levels can augment the potential for landslide activity.

Figure 5.1. Potential Landslide Risk on the Deep Lake Boundary Road in Stevens County.

Landslides are a recurrent menace to waterways and highways and a threat to homes, schools, businesses, and other facilities. The unimpeded movement over roads, whether for commerce, public utilities, school, emergencies, police, recreation, or tourism, is essential to the normal
functioning of Stevens County. The slopes of the Colville Valley pose special problems to U.S. Highway 395. This route is the main transportation corridor through the County and has been impacted in the past by landslides resulting from road construction and heavy precipitation. The disruption and dislocation of these or any other routes caused by landslides can quickly jeopardize travel and vital services.

5.1.2.1 Geologic History of Stevens County

The eastern portion of the Okanogan Highlands contains the oldest sedimentary and metamorphic rocks of the state. Precambrian Belt Supergroup, Windermere Group, and Deer Trail Group metasedimentary rocks extend from British Columbia south to the Columbia River. The nation's second largest magnesium operations are located near Addy, in Stevens County. Dolomite and magnesite are mined from the Stensgar Formation dolomite of the Deer Trail Group. Precambrian dikes and sills cut these ancient rocks. In the vicinity of Spokane, mountains such as Mica Peak consist of Precambrian high-grade metasedimentary rocks.

Since the Precambrian, huge amounts of crust have been accreted to the North American continent. Everything west of the Precambrian rocks in northeastern Washington has been created through complex processes along an active continental margin or transported from elsewhere and stuck onto the continent of this region.

In the eastern highlands, Precambrian metasedimentary rocks are overlain by marine rocks representing each of the Paleozoic geologic time periods. The Cambrian record starts with sandstone (now quartzite) followed by shales and then limestones that grade into rocks of the Ordovician Period. Cambrian trilobites indicate relatively shallow seas. During the Ordovician, dark shales full of graptolites indicate deeper water conditions. All these rocks were subjected to metamorphism during Jurassic through Eocene time.

Cambrian rocks, in particular, are important sources of mineral wealth. Near Metaline Falls, Pend Oreille County, large Mississippi Valley-type zinc deposits were mined by room-and-pillar mining methods. Closed in 1977, the mines were noted for large calcite crystals and palygorskite. At Metaline Falls, the argillaceous Cambrian-Ordovician Metaline Formation was mined by open-pit methods for the manufacture of portland cement. All Paleozoic and some younger rocks have been repeatedly folded into a northeast-trending regional structure called the Kootenay Arc, which extends northeastward for 150 miles into British Columbia and contains numerous lead-zinc mines. In Stevens County, Cambrian Addy Formation quartzite is mined for its silicon content, and near Northport, Devonian argillite includes interbedded barite.

Two-mica granites rich in uranium host formerly productive uranium mines on the Spokane Indian Reservation. Weathering of such granites has released uranium into younger sediments, including a small peat bog near Colville. Radon gas is also generated by the two-mica Cretaceous granites and poses a hazard to humans.

The Eocene Epoch had a profound effect on the geology of the land. It was during this time that the Okanogan Highlands were subject to tectonism, plutonism, volcanism, sedimentation, development of gneiss domes, and epithermal precious metal deposition. Overprinted on the Okanogan Highlands are massive gneiss domes and north-south trending grabens. Stresses due to Tertiary extension and strike-slip faulting were relieved by concurrent ductile deformation in the form of spectacular domes.

The Okanogan Highlands were covered by great ice sheets during the Pleistocene Epoch. As the ice sheets retreated to the north, lakes formed in the valleys of the Columbia and Pend Oreille Rivers. Along the Canadian boundary, terrace deposits indicate lake levels 2,000 feet above current sea level. Melt waters filled these lakes with sand, silt, and clay (WA DNR 2007).
5.1.2.2 Landslide Prone Landscapes in Stevens County

Many areas have specific landslide concerns. Areas that are generally prone to landslides are:

- On existing landslides, old or recent
- On or at the base or top of slopes
- In or at the base of minor drainage hollows
- At the base or top of an old fill slope
- At the base or top of a steep cut slope

There are many homes, roads and other resources at risk in Stevens County because of their juxtaposition to one or more of these characteristics. The probability of future occurrence of landslide hazard events, including those caused by severe local storms, is low. Individual assessments of landslide-prone areas that would cause disruption in Stevens County are detailed in subsequent sections of this plan.

Soil factors that increase the potential for landslide are soils developed from parent materials high in schist and granite, and soils that are less permeable containing a resistive or hardpan layer. These soils tend to exhibit higher landslide potential under saturated conditions than do well drained soils. To identify the high-risk soils in Stevens County, the NRCS State Soils Geographic Database (STATSGO) layer was used to identify the location and characteristics of all soils in the County. The specific characteristics of each major soil type within the County was reviewed. Soils with very low permeability that characteristically have developed a hardpan layer or have developed from schist and granite parent material were selected as soils with potentially high landslide risk potential. High-risk soils magnify the effect slope has on landslide potential. Soils identified as having high potential landslide risk are further identified only in areas with slopes between 14° and 30° (25-60%). It is these areas that traditionally exhibit the highest landslide risk due to soil characteristics within a given landscape.

To portray areas of probable landslide risk due to slope related factors, slope models were used to identify areas of low, moderate and high risk. This analysis identified the low risk areas as slopes in the range of 20°-25° (36-46%), moderate as 26°-30° (48-60%) and high risk as slopes in the range of 31°-60° (60-173%). Slopes that exceeded 60° (173%) were considered low risk due to the fact that sliding most likely had already occurred relieving the area of the potential energy needed for a landslide. From the coverage created by these two methods it is possible to depict areas of risk and their proximity to development and human activity. With additional field reconnaissance the areas of high risk were further defined by overlaying additional data points identifying actual slide locations, thus improving the resolution by specifically identifying the highest risk areas. This method of analysis is similar to a method developed by the Clearwater National Forest in north central Idaho (McClelland et al. 1997).
Figure 5.2. Landslide Prone Landscapes Analysis.
5.1.2.3 Past Events

Stevens County does not have many documented landslides. Those that have occurred are generally associated with the Lake Roosevelt shoreline or damage and/or blockage of a roadway. There are several recent reports of mudslides and landslides along the moderate to steep slopes found along U.S. Highway 395. No significant landslides have been recorded in Stevens County since 1953.

April 8, 1944 - A four to five million cubic yard landslide from Reed Terrace generated a 30-foot wave, 5,000 feet away on the opposite shore of the lake about 98 miles above Grand Coulee Dam.

April 10 – 13, 1952 – A 15 million cubic yard landslide three miles below the Kettle Falls Bridge created a 65-foot wave that struck the opposite shore of the lake. People observed some waves six miles up the lake.

February 1953 – A series of landslides about 100 miles upstream from Grand Coulee Dam generated a number of waves that crossed the lake and hit the opposite shore 16 feet above lake level. On average, observed waves crossed the 5,000-foot wide lake in about 90 seconds.

April – August 1953 – Landslides originating in Reed Terrace caused waves in the lake at least 11 different times. The largest wave to hit the opposite shore was 65 feet high and observed six miles away. Velocity of one of the series of waves was about 45 miles per hour.

5.1.2.4 Landslide Vulnerability

While a large areas of Stevens County is at high risk to landslides (Figure 5.2), most of this area occupies the rural mountainous regions. Home and business development in the County has been mainly on lands not at significant risk to landslides.

Much of the populated areas in Stevens County are at risk to flooding, which often results in damaging landslides. Flash floods typically carry large amounts of debris, silt, and rocks that are deposited in downstream floodplains. Additionally, soil saturation ensuing from prolonged periods of rain or flooding can lead to slope instability. Cut and fill slopes, even those well outside of the flood plain, are particularly at risk to slides and/or slumping as a result of soil saturation.

The primary slope stability problem is associated with the sediments within and along the boundary of Lake Roosevelt. The occurrence of new landslides and the reactivation of old landslides increased dramatically with the filling of reservoirs behind the Grand Coulee Dam, i.e. Lake Roosevelt. Drawdowns for flood control and power generation also trigger new landslides and/or reactivate and extend old ones. Some of the landslide complexes along Lake Roosevelt extend for thousands of feet along the lakeshores, have head scarp in terraces 300 feet or more above reservoir level and extend well below its surface. With landslide activity common along hundreds of miles of shoreline, one hazard in such a setting is water waves generated by fast-moving landslide masses.

5.1.2.5 Assets at Risk to Landslides

Using the parcel information and asset values maintained by the Stevens County Assessor’s office, overlaid with the Landslide Prone Landscapes map developed by Northwest Management, Inc. and Stevens County, we have completed an assessment of the assets at risk to damage from landslides in Stevens County. Stevens County has over $1.4 million worth of improvements and 218,436 acres within the landslide impact zones mapped in Figure 5.2.
Table 5.1. Summary of Assets at Risk in Landslide Impact Zones.

<table>
<thead>
<tr>
<th>Impact Zone</th>
<th>Number of Structures</th>
<th>Number of Acres</th>
<th>Total Improvement Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addy-Blue Creek</td>
<td>188</td>
<td>12,098</td>
<td>$15,077,205</td>
</tr>
<tr>
<td>Cedonia-Hunters</td>
<td>4</td>
<td>8,394</td>
<td>$13,780</td>
</tr>
<tr>
<td>East Chewelah</td>
<td>30</td>
<td>11,633</td>
<td>$1,769,552</td>
</tr>
<tr>
<td>Evans-Aladdin</td>
<td>82</td>
<td>34,648</td>
<td>$4,588,760</td>
</tr>
<tr>
<td>Gifford-Maud</td>
<td>36</td>
<td>14,000</td>
<td>$3,262,289</td>
</tr>
<tr>
<td>Loon Lake-Ford</td>
<td>1,975</td>
<td>61,291</td>
<td>$105,534,322</td>
</tr>
<tr>
<td>Onion Creek-Boundary</td>
<td>122</td>
<td>35,959</td>
<td>$4,730,565</td>
</tr>
<tr>
<td>Orient-Dulwich</td>
<td>31</td>
<td>10,415</td>
<td>$1,794,975</td>
</tr>
<tr>
<td>South-Fruitland</td>
<td>3</td>
<td>12,579</td>
<td>$2,770</td>
</tr>
<tr>
<td>West Colville</td>
<td>77</td>
<td>17,419</td>
<td>$5,796,615</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,548</strong></td>
<td><strong>218,436</strong></td>
<td><strong>$142,570,833</strong></td>
</tr>
</tbody>
</table>

The cost of clean up and repairs of roadways is difficult to estimate due to the variable circumstances with each incident including size of the slide, proximity to a State or County shop, and whether the slide occurred on the cut slope or the fill slope. Other factors that could affect the cost of the damage may include culverts, streams, and removal of debris. This type of information is impossible to anticipate; thus, no repair costs for damaged roadways have been estimated.

Numerous communities in Stevens County could be affected by landslides; however, Loon Lake is the only population center located directly within an identified Landslide Impact Zone. Nevertheless, landslides often cause road closures that may isolate rural communities for an extended period of time.

The South-Fruitland and Loon Lake-Ford Impact Zones are considered high risk due to unstable soil types usually due to an underlying hardpan. Landslides in this type of impact zone will typically consist of small slumps along toe slopes or in disturbed areas such as construction sites or cut and fill slopes of roads. Although not generally catastrophic, these types of slides generally occur more frequently.

The Addy-Blue Creek, Cedonia-Hunters, East Chewelah, Evans-Aladdin, Gifford-Maud, Onion Creek-Boundary, Orient-Dulwich, and West Colville Landslide Impact Zones are considered high risk due to increased slope and higher risk (schist or granite) underlying parent material. Slides in these impact zones are more likely to be larger and more damaging as weaknesses in the underlying rock formations give way. Although infrequent, this type of slide has the potential to not only block, but destroy road corridors, dam waterways, and demolish structures. The highest risk areas in these impact zones are typically at the higher elevations where slopes exceed 25% grade and along the Lake Roosevelt shoreline. There are numerous homes in each of these impact zones; however, for the most part, they are widely scattered. Thus, single slide events will not likely impact the entire population, but rather individual structures. Most of State Route 25 and sections of the Flowery Trail Road (Chewelah Mountain area) and U.S. 395 (Addy and Loon Lake), could be at risk from slides initiating in these impact zones. Past events have shown that areas along the Lake Roosevelt shore are not only at increased risk from slides directly, but could also be impacted by slides in other areas as high velocity waves crash into opposite shorelines anywhere from 16 to 65 feet above the normal high water level.
Figure 5.3. Landslide Impact Zones in Stevens County.
5.1.2.6 Countywide Landslide Hazard Mitigation Strategies

A number of techniques and practices are available to reduce and cope with losses from landslide hazards. Careful land development can reduce losses by avoiding the hazards or by reducing the damage potential. The following are a number of approaches used individually or in combination to reduce or eliminate losses and decrease landslide risk.

5.1.2.6.1 Establish a Countywide landslide hazard identification program

Establish a Countywide landslide hazard identification program by documenting all landslides, bank failures, “washouts”, and manmade embankment failures. Each failure should be located on a map with notations about time of failure, repair (if made), and descriptions of the damaged area. This could become a County directive to the road and bridge crews.

5.1.2.6.2 Restricting development in Landslide Prone Landscapes

Land-use planning is one of the most effective and economical ways to reduce landslide losses by avoiding the hazard and minimizing the risk. This is accomplished by removing or converting existing development or discouraging or regulating new development in unstable areas. Buildings should be located away from known landslides, debris flows, steep slopes, streams and rivers, intermittent-stream channels, and the mouths of mountain channels. In the State of Washington, restrictions on land use generally are imposed and enforced by local governments by land-use zoning districts and regulations.

5.1.2.6.3 Standardizing codes for excavation, construction, and grading

Excavation, construction, and grading codes have been developed for construction in landslide prone areas; however, there is no nationwide standardization. Instead, State and local government agencies apply design and construction criteria that fit their specific needs. The Federal Government has developed codes for use on Federal projects. Federal standards for excavation and grading often are used by other organizations in both the public and private sectors.

5.1.2.6.4 Protecting existing development

Control of surface-water and ground water drainage is the most widely used and generally the most successful slope-stabilization method. Stability of a slope can be increased by removing all or part of a landslide mass or by adding earth buttresses placed at the toes of potential slope failures. Restraining walls, piles, caissons, or rock anchors are commonly used to prevent or control slope movement. In most cases, combinations of these measures are used.

5.1.2.6.5 Post warnings of potentially hazardous areas and educate the public about areas to avoid

Such areas may include (a) existing / old landslides, (b) on or at the base of a slope, (c) in or at the base of a minor drainage hollow, (d) at the base or top of an old fill or steep cut slope, and (e) on developed hillsides where leach field septic systems are used. In addition to identifying these at-risk landscapes, it will also serve to begin an educational dialog with landowners in Stevens County, enlightening residents and visitors to the risks associated with landslides.
5.1.2.6.6 Utilizing monitoring and warning systems

Monitoring and warning systems are utilized to protect lives and property, not to prevent landslides. However, these systems often provide warning of slope movement in time to allow the construction of physical measures that will reduce the immediate or long-term hazard. Site-specific monitoring techniques include field observation and the use of various ground motion instruments, trip wires, radar, laser beams, and vibration meters. Data from these devices can be sent via telemetry for real-time warning. Development of regional real-time landslide warning systems is one of the more significant areas of landslide research (Fragaszy 2002, USGS 2004).

5.1.2.6.7 Public Education

Residents can increase their personal awareness by becoming familiar with the land around the home and community. People can learn whether landslides or debris flows have occurred in the area by contacting local officials, state geological surveys or departments of natural resources, USGS maps, and university departments of geology. Slopes where landslides or debris flows have occurred in the past are likely to experience them in the future.

Educate the public about telltale signs that a landslide is imminent so that personal safety measures may be taken. Some of these signs include:

- Springs, seeps, or saturated ground in areas that have not typically been wet before.
- New cracks or unusual bulges in the ground, street pavements or sidewalks.
- Soil moving away from foundations, and ancillary structures such as deck-sand patios tilting and/or moving relative to the house.
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb.
- Broken water lines and other underground utilities.
- Leaning telephone poles, trees, retaining walls or fences.
- Sunken or dropped-down roadbeds.
- Rapid increase in a stream or creek water levels, possibly accompanied by increased turbidity (soil content).
- Sudden decrease in creek water levels even though rain is still falling or just recently stopped.

Residents or County representatives who live and work in landslide prone areas should follow these recommendations prior to a storm event:

- Watch the patterns of storm-water drainage on slopes and note places were runoff water converges, increasing flow over soil-covered slopes. Watch the hillsides around your home and community for any signs of land movement, such as small landslides or debris flows or progressively tilting trees.
- Develop emergency response and evacuation plans for individual communities and for travel routes. Individual homeowners and business owners should be encouraged to develop their own evacuation plan (USGS 2004).
5.1.3 Individual Community Assessments

The Loon Lake-Ford Landslide Impact Zone encompasses the communities of Loon Lake, Deer Lake, and Tum Tum. The following assessment addresses the potential risks associated with this Impact Zone. No other communities are located directly within a Landslide Impact Zone.

5.1.3.1 Loon Lake-Ford Landslide Impact Zone

The Loon Lake-Ford Landslide Impact Zone encompasses the communities of Deer Lake, Loon Lake, and Tum Tum as well as numerous scattered residences in the general area. Furthermore, State Routes 291, 231, and 292 and U.S. Highway 395 could be impacted by this high landslide risk area.

5.1.3.1.1 Landslide Potential

Many of the slopes and hillsides in this impact zone are comprised by material deposited by past landslides. In fact, much of the lower slopes near the valley floors are alluvial fans created by sediment being carried downstream and deposited at the mouths of the numerous small drainages. The presence of this material indicates the historic occurrence of high-energy, short duration floods and debris flows in these chutes in response to severe climatic conditions, such as thunderstorms and rain-on-snow events. These events are historically infrequent, with recurrence cycles on the order of years to decades. However, they can result in significant damage to buildings and infrastructure, disrupts travel, reduce water quality, and jeopardize safety.

The largest landslides typically occur where human development or disturbance has exposed landslide-prone sediments to steep topography. Today, initiation and reactivation of landslides is closely tied to unusual climatic events and land-use changes. Even small landslide activity on the upper slopes can transform into high-energy debris flows that endanger roads, buildings, and people below. Landslide debris is highly unstable when modified through natural variations in precipitation, artificial cuts, fills, and changes to surface drainage and ground water (Weisz et al. 2003).

Wildfires in this impact zone could cause a domino effect of multiple hazards. Higher intensity fires not only remove most of the vegetation, but they also cause soils to become hydrophobic or water repellent for a period of time after the fire. This combination leads to unusually high runoff after rain showers or during the spring runoff season. As streams and rivers begin to reach and exceed flood stage, bank failures and channel migration are common. Road building and other soil disturbances tend to exacerbate this effect leading to even more severe land and soil slides.

5.1.3.1.2 Community Risk Assessment

Individual homes and communities in the Loon Lake – Ford Impact Zone are at low to moderate risk to landslide activity. Homes and travel routes that have been constructed at the mouths of drainages and through alluvial deposits are at an increased risk of being affected by landslide activity. These historic deposits are a strong indicator of debris flows in the future. Furthermore, these deposits tend to be unstable and somewhat prone to movement. There are nearly 2,000 structures in this impact zone with a value exceeding $105 million.

Debris flow activity and the resulting alluvial sediment deposition is associated with soil saturation and precipitation events. As mentioned, landslide events are generally associated with large precipitation events. The probability of these events occurring during normal weather
conditions is quite low. However during large precipitation events, residents and county representatives should monitor these areas for landslide activity.

The potential for debris flows and landslides would dramatically escalate in the event of a large wildland fire event that denudes the steeper slopes of vegetative cover. The loss of the vegetative cover reduces slope stability by removing much of the organic matter that helps absorb and intercept precipitation and anchor the soil.

5.1.3.1.3 Mitigation Activities

Landslides are difficult to deal with effectively on a small scale. Often they occur as a result of flooding, wildfire, or human development. The countywide mitigation activities detailed in Section 5.1.2.6 would help mitigate the landslide risk in the Loon Lake – Ford Impact Zone as well.

5.2 Secondary Hazards

5.2.1 Fire Related Debris Flows

Wildland fires are inevitable in the western United States where burnable vegetation exists. Expansion of human development into forested areas has created a situation where wildfires can adversely affect lives and property, as can the flooding and landslides that potentially occur in the aftermath of the fires. Post-fire landslide hazards include fast-moving, highly destructive debris flows that can occur in the years immediately after wildfires in response to high intensity rainfall events. Flows that are generated over longer time periods are generally accompanied by root decay and loss of soil strength. Post-fire debris flows are particularly hazardous because they can occur with little warning, can exert great impulsive loads on objects in their paths, can strip vegetation, block drainage ways, damage structures, and endanger human life. Wildfires could potentially result in the destabilization of pre-existing deep-seated landslides over long time periods.

5.2.1.1 Conditions for fire-related debris-flow occurrence

In a recent study of the erosion response of recently burned basins in the intermountain west, the USGS found that not all basins produce debris flows; most burned watersheds respond to even heavy rainfall events by flooding. However, those watersheds that do produce destructive debris flows can be readily identified by a combination of geologic, topographic, and rainfall characteristics. The factors that best determine the probability of debris-flow occurrence are:

- The percent of area burned in each basin at both high and moderate severities,
- The average storm rainfall intensity,
- The measure of sorting of the grain-size distribution of the burned soil,
- The percent of soil organic matter (by weight),
- The soil permeability,
- The soil drainage, and
- The percent of the basin with slopes great than or equal to 30%.

The results from post-fire erosion rates show that the majority of post-fire erosion results from summer thunderstorms rather than frontal storms or snowmelt (MacDonald et al. 2004).
Thunderstorm events producing 0.25 inches of precipitation an hour have been used as a threshold for flash flooding in severely burned areas of Western Montana.

5.2.1.2 Mitigation Activities for Fire-Related Debris Flows

There are a number of mitigation activities that can be implemented following large wildland fires in order to help rehabilitate the site. Rehabilitation efforts help speed the ecological recovery of the burned area while reducing the potential for rapid runoff, rilling, gullying, and development of destructive debris flows. These efforts also help reduce the loss of soil productivity and water quality, while reducing the threat to human life and property. In the event of large-scale fire events, a complete Burned Area Emergency Recovery (BAER) plan should be completed in order to address the unique features of the burn. The following is a partial list of components that would likely be included in a BAER plan.

- Directional tree felling, and contour log terracing along drainages and slopes with high burn severity in order to reduce overland and in stream channel flow. This can help reduce the amount of runoff and potential to initiate rilling and downstream mud and debris flows.
- Aerially seed moderate to high burn areas to provide short-and long-term vegetative cover to reduce water yield and sedimentation.
- Apply straw mulch to high severity burn areas where soils are well drained, occurring on gentle slopes and are protected from the wind. Mulch will slow runoff and help to prevent erosion. Topsoil will be protected and soil moisture will be maintained to promote biological activity in the soil.
- Install straw bale check dams in steep drainages in order to trap sediment.
- Place flood hazard warning signs in areas prone to flash-flooding.
- Install straw wattles in a checkerboard fashion along the contour of hillsides. The wattles serve as soil erosion and runoff control measure on steep slopes with a high degree of water repellency. Waddles can help stabilize the slope, minimize soil erosion and capture sediment.
- Clear, reinforce, and if needed, replace undersized culverts and stream crossings within the burn area to prevent washout along roads. Since water yield will be dramatically higher in the post-burn condition, drainage systems need to be restructured in order to accommodate the increase in flow.