CALIFORNIA DEPARTMENT OF CONSERVATION | CALIFORNIA GEOLOGICAL SURVEY
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NOTE 50
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# Factors Affecting Landslides in Forested Terrain

Landslides and geomorphic features related to landsliding have been mapped by the Department of Conservation's California Geological Survey (CGS) on forest lands within numerous northern California watersheds under contract with the Department of Forestry and Fire Protection (CAL FIRE; see CGS Note 40). Landslide terminology used on the maps, and presented in this document, was developed in conjunction, and is compatible with, ongoing U.S. Forest Service (USFS) and California Department of Water Resources (DWR) mapping on forest lands. Descriptions presented here are excerpted from Bedrossian (1983). Definitions are consistent with those presented in Varnes (1978) and Cruden and Varnes (1996).

Factors affecting landslide potential are described according to the geological conditions, drainage characteristics, slope gradient and configuration, vegetation, removal of underlying support, and other conditions specific to each landslide related category (Figures 1-6). Management objectives and guidelines for each landslide-related category were developed primarily from field experience, recommendations made by CGS geologists during the Timber Harvesting Plan review process, practices currently required under the Z'Berg-Nejedly Forest Practice Act (Public Resources Code, 2013) and the California Forest Practice Rules (California Code of Regulations, 2013), and mitigation measures recommended in numerous geologic reports prepared for CAL FIRE, DWR, and the USFS. The guidelines address each landslide-related category and provide recommendations for forest practices related to road construction, logging, and site preparation.

## LANDSLIDE TERMINOLOGY

Landslide terminology described here includes translational/rotational slide, earthflow, debris slide, debris flow/torrent track, debris slide amphitheater/slope, and inner gorge. The terms debris slide amphitheater and inner gorge refer to geomorphic features that were formed, in part, as a result of debris slide processes. Although they may be subject to continued debris slide activity, these features should not be misinterpreted as landslides. In addition, many landslides are, in reality, complex landslides subject to more than one type of landslide process. Accordingly, the management implications for such areas may be more complex than inferred here.

Most landslides are classified as active or dormant. The active or probably active slides are those which are presently moving or have recently moved, as indicated by the presence of distinct topographic slide features such as sharp barren scarps, cracks, and tipped (jackstrawed) trees. Major revegetation has not occurred on slides in the active category. Dormant slides show little evidence of recent movement; slide features have been modified by weathering and erosion and vegetation generally is well established. Although some large-scale landsliding may have developed under conditions different from today, the causes of failure may remain and movement could be renewed.

### Translational/Rotational Slide

Definition. The translational/rotational slide is characterized by a somewhat cohesive slide mass and a failure plane that is relatively deep when compared to that of a debris slide of similar areal extent. The sense of the motion is linear in the case of a translational slide and is arcuate or "rotational" in the case of the rotational slide (Figure 1). Complex versions involving rotational heads with translation or earthflow downslope are quite

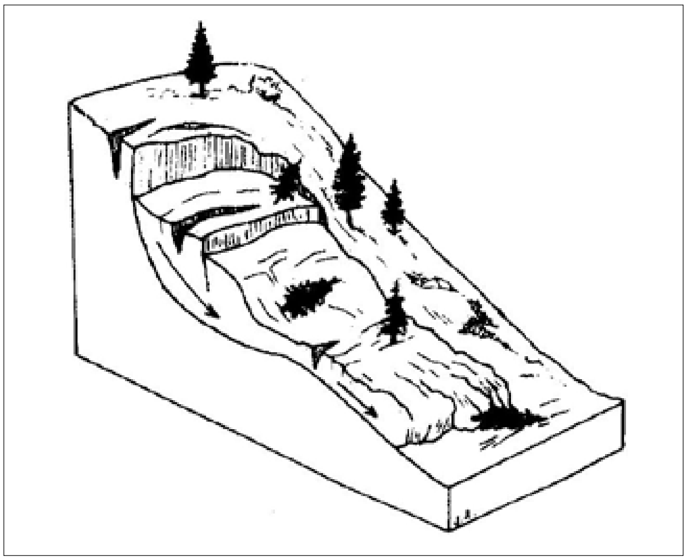

Figure 1. Diagrammatic sketch of a translational/rotational landslide. Drawing by Janet Appleby Richard Kilbourne and Thomas Spittler; modified from Varnes (1978)

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common. When movement occurs along a planar joint or bedding discontinuity, the translation may be referred to as a block glide.

Factors affecting landslide potential. Translational/rotational slides generally occur in relatively cohesive, homogeneous soils and rock. The soil mantle may be greater than 5 feet thick, but sliding is not restricted to the zone of weathering. Failure commonly occurs along bedrock bedding planes that are deep-seated and dip in the same direction as the slope surface. In saturated conditions, incompetent clayey bedrock material may fail under overburden weight and high pore pressures, resulting in a deep-seated rotational-type failure. Translational slides commonly are controlled structurally by surfaces of weakness such as faults, joints, bedding planes, and contacts between bedrock and overlying deposits.

Impaired drainage of slide deposits may be indicated at the surface by numerous sag ponds with standing water, springs, and patches of wet ground. Phreatophytic (wet site) vegetation may be widespread and jackstrawed trees are common. The concentric, downward movement of slide materials generally exposes a near vertical scarp in the head region and, occasionally, along the lateral margins of the slide. Slide materials are characterized by hummocky topography consisting of rolling, bumpy ground, frequent benches, and depressions. The toe of the slide may be steep where slide material has accumulated.

Although the removal of root support is not likely to affect the overall stability of the slide mass, large clear-cuts (relative to slide size) could raise the ground water table and induce instability. Steep crownscarps and margins of the translational/ rotational slide and toe areas of large slides may be subject to debris sliding. The removal of toe materials on smaller slides may reactivate the entire slide area.

Management objectives. The major management objectives for mitigating potential problems on translational/ rotational slides are to: minimize water concentration on the steep scarp and lateral margins of the slides, avoid undercutting of the toe areas, minimize loading the upper bench of the slide, and avoid the activation of debris sliding on steep scarp and toe areas.

Management guidelines. To enhance stability, roads and landings across translational/rotational slides should be carefully located to unload the crown area and load the toe. Where possible, benches should be utilized. Surface water should be diverted away from the slide mass and scarp areas, and long-term maintenance should be considered in the planning of site specific drainage problems. In some situations, the engineered drainage of fill materials may be required, and cut and fill slopes should be seeded. In order to avoid creating debris sliding, debris slide measures for road construction should be applied to steep scarps and toes of large slides. Consultation with a Certified Engineering Geologist is recommended in melange terrain, where large slides show activity, and in the design of road drainage.

During logging, ground disturbance in the slide area should be minimized. Along the edge of the slides, vegetation removal and physical changes should be limited to avoid the concentration of water on slide materials and the endlining of logs from outside the slide area should be considered when feasible. On large slides, water courses immediately adjacent to the slide often form inner gorges and therefore should be considered as part of the potentially unstable slide mass. Because removal of vegetation could raise the groundwater level and result in the local concentration of surface water, the size of the slide and the amount and condition of existing vegetation should be considered in determining the size and type of proposed harvest. During site preparation, physical disturbances on scarp areas and toes, where debris sliding may occur, should be minimized and overall root mass should be maintained.

## Earthflow

Definition. An earthflow is a landslide resulting from slow to rapid flowage of saturated soil and debris in a semiviscous, highly plastic state. After initial failure, the earthflow may move, or creep, seasonally in response to destabilizing forces.

Factors affecting landslide potential. Earthflows are composed of clay-rich materials that swell when wet, causing a reduction in intergranular friction. When saturated, the finegrained, clay-rich matrix may carry larger, more resistant boulders with them in slow, creeping movements.

Slide materials erode easily, resulting in gullying and irregular drainage patterns. The irregular, hummocky ground characteristic of earthflows is generally bare of conifers; grasslands and meadows predominate. Failures commonly occur on slopes that are gentle to moderate (Figure 2), although they may also occur on steeper slopes where vegetation has been removed. Undercutting of the toe of an earthflow is likely to reactivate downslope movement.

Management objectives. Because earthflow materials are so easily erodible, the main objective is to minimize the physical disturbance of the slide by 1) avoiding the concentration of water onto the slide mass and 2) avoiding deep cut slopes into slide deposits.

Management guidelines. Road construction across earthflows should be avoided whenever possible. Likewise, earthflows are not appropriate locations for landing sites. When conditions necessitate road construction, the road should be carefully designed and located to use benches, avoid wet areas and seeps, and where possible, follow contour. The road should be single lane in width and outsloped

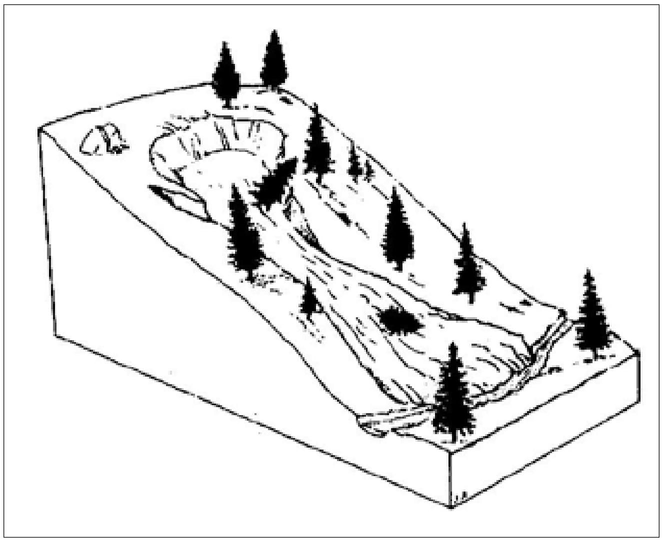

Figure 2. Diagrammatic sketch of an earthflow. Drawing by Janet Appleby and Richard Kilbourne; modified from Varnes (1978).

to avoid cutting into and concentrating water on slide materials. Areas exposed during road construction should be reseeded to minimize surface erosion. Winter construction and use is not advisable, and continued maintenance of drainage is recommended for major road construction across all earthflows.

During timber harvesting, ground disturbance should be minimized and the use of heavy equipment avoided. In logging areas adjacent to an earthflow, water should be drained from the slide to prevent gullying and reactivation of earthflow movement. Natural drainages on the earthflow should not be disrupted, for example, by the use of heavy equipment while being crossed to reach an adjacent logging site.

## Debris Slide

Definition. A debris slide is characterized by unconsolidated rock, colluvium, and soil that has moved downslope along a relatively shallow translational failure plane (Figure 3). Debris slides form steep, unvegetated scars in the head region and irregular, hummocky deposits (when present) in the toe region. Debris slide scars are likely to ravel and remain unvegetated for many years. Revegetated scars can be recognized by the even-faceted nature of the slope, steepness of the slope, and the light bulb-shaped form left by many midand upper-slope failures.

Factors affecting landslide potential. Debris slides are most likely to occur on slopes greater than 65 percent where unconsolidated, non-cohesive, and rocky colluvium overlie a shallow soil/bedrock interface. The shallow translational slide surface is usually less than 15 feet deep. The probability of sliding is low where bedrock is exposed, except, where weak bedding planes and extensive bedrock joints and fractures parallel the slope.

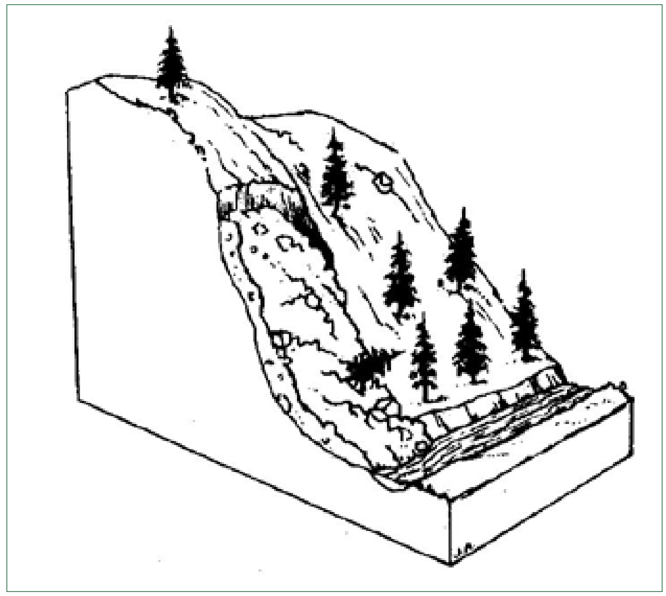

Figure 3. Diagrammatic sketch of a debris slide. Drawing by Janet Appleby and Richard Kilbourne; modified from Varnes (1978)

The presence of near surface bedrock creates a shallow, impervious slide plane that restricts the vertical movement of water and tends to concentrate subsurface water flow parallel to the slope. For this reason, sliding often occurs during high intensity storms. Springs may be present where water has concentrated along the slide plane. Because the removal of root support is likely to change the slope hydrology and shear strength of debris slide deposits, the vegetative cover where present is important to slope stability.

Management objectives. Because debris slides are characterized by unconsolidated materials above a shallow slide plane, the main management objectives are to: retain root support, minimize water flow along the soil/rock interface, avoid the undercutting of materials to the slide plane, and minimize the weighting of unconsolidated materials on steep slopes.

Management guidelines. Road construction across debris slides should be avoided where possible and existing roads used. Where active or potentially active slides on slopes over 65 percent must be crossed, the registered professional forester should consult a Certified Engineering Geologist in the preparation of the road design. Planning of the road should take into consideration a careful evaluation of both road and landing locations. Full bench cuts should be used across the slide where soils are most shallow and cut materials endhauled to minimize sidecast. If filling is necessary, fill materials should be retained during the road use and pulled before winter storms begin. Where possible, the road grade should be arched across the slide to drain water away from the slide. Where water must be drained onto the slide, energy dissipators should be used to reduce water impact on slide deposits. The undercutting of slide materials should be avoided in areas that are already buttressed; cribbing, retaining walls and/or riprap should be used where necessary. All small areas of unstable soil and debris should be removed from the roadcuts and cut and fill slopes seeded where vegetation will grow.

During logging, silvicultural practices should be designed to maintain maximum root support. In general, equipment exclusion zones and cable yarding are recommended. Site preparation burning should be designed to retain a maximum litter layer and some residual vegetation.

## Debris Flow/Torrent Track

Definition. Debris flow and debris torrent tracks are characterized by long stretches of bare, generally unstable stream channel banks that have been scoured and eroded by the extremely rapid movement of water-laden debris (Figure 4). They commonly are caused by debris sliding or the failure of fill materials along stream crossings in the upper part of a drainage during high intensity storms.

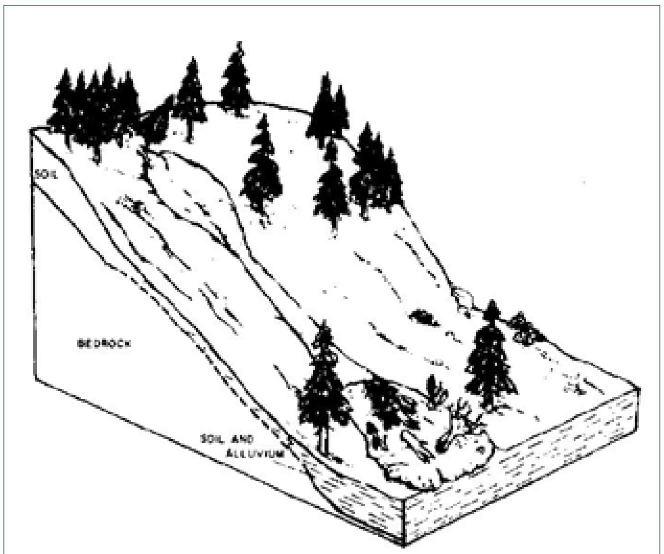


Figure 4. Diagrammatic sketch of a debris flow/torrent track. Drawing by Janet Appleby and Richard Kilbourne

Factors affecting landslide potential. Debris flow/torrent tracks are formed by the failure of water-charged soil, rock, colluvium, and organic material down steep stream channels. They are often triggered by debris slide movement on adjacent hill slopes and by the mobilization of debris accumulated in the stream channels themselves. Debris flows and torrents commonly entrain large quantities of inorganic and organic material from the stream bed and banks. Occasionally, the channel may be scoured to bedrock. When momentum is lost, scoured debris may be deposited as a tangled mass of large organic debris in a matrix of sediment and finer organic material. Such debris may be reactivated or washed away during subsequent events. The erosion of steep debris slide-prone streambanks below the initial failure may cause further failure downstream. The potential for failure is largely dependent upon the quantity and stability of soil and organic debris in a stream channel and the stability of adjacent hill slopes. The location of roads and landings upslope also affects landslide potential.

Management objectives. The main management objectives in mitigating areas containing debris flow/torrent tracks are to protect water quality and to avoid or minimize the possibilities of reactivating debris flow and debris torrent failures.

Management guidelines. Road and landing construction should be avoided across debris flow/torrent tracks. Where possible, scour-resistant crossings, such as low water crossings and rock fills, should be used.

In planning the harvesting of slopes adjacent to debris flow/torrent tracks, consideration should be given to the stability of the channel slopes. Soils exposed by logging operations adjacent to the tracks should be stabilized. Although an equipment exclusion zone around the track is recommended, the removal of logged debris below the stream transition line may be appropriate in some circumstances. A suitable overstory and understory should be left on slopes adjacent to the track.

## Debris Slide Amphitheater/Slope

Factors affecting landslide potential. Debris slide amphitheaters and slopes are characterized by generally well vegetated soils and colluvium above a shallow soil/bedrock interface. The slopes may contain areas of active debris sliding or bedrock exposed by former debris sliding (Figure 5). Slopes near the angle or repose may be relatively stable except where weak bedding planes and extensive bedrock joints and fractures parallel the slope angle. Although the slopes often are smooth, steep (generally greater than 65 percent), and unbroken by benches, they are characteristically dissected by closely-spaced incipient drainage depressions. In many places, perennial channels within the amphitheaters and slopes are deeply incised with steep walls of rock or colluvial debris. The presence of bedrock or impervious material at shallow depths may concentrate subsurface waterflow, and springs may be present where permeable zones above the restrictive layer are saturated.

The presence of linear or teardrop-shaped, even-aged stands of trees, beginning at small scarps or spoon-shaped depressions, is indicative of former debris slide activity. Because soil and colluvial materials are shallow, the vegetative cover, where present, is important to slope stability and the removal of root support could change slope hydrology.

For these reasons, the intensity of road networks and the location of roads and drainage structures are particularly

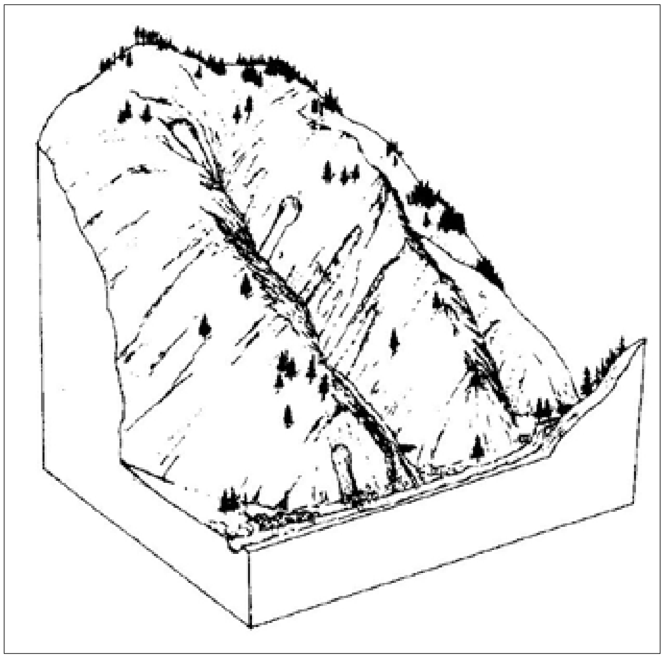

Figure 5. Diagrammatic sketch of a debris slide amphitheater and debris slide slopes. Drawing by Janet Appleby and Richard Kilbourne

important to slope stability in debris slide amphitheaters and on debris slide slopes. Areas adjacent to active slides have increased potential for sliding. The placement of fill materials on steep, unconsolidated upslope deposits also increases landslide potential.

Management objectives. The major management objectives in mitigating slope stability problems on debris slide amphitheaters and slopes are to: to retain root support, minimize water concentration in areas where soils are well-developed, and avoid large, continuous openings on steep slopes at any given period of time.

Management guidelines. Prior to road and landing construction, areas of active and potentially active debris slide movement should be identified. In areas of active and potentially active sliding, debris slide guidelines should be applied. In other areas where slopes are 65 percent or greater, the number and total length of roads should be minimized. Roads should also be located to avoid the crossing of active slides and the undercutting of buttressed slide materials.

During logging, a substantial vegetative cover should be retained by minimizing the size and continued downslope extent of vegetative openings and/or by using patch cuts. In areas with active sliding, equipment exclusion zones are recommended. On steep slopes, skyline and cable methods of logging should be used with a minimum number of blind leads. The amount of slash accumulated in deeply incised stream channels should also be minimized to reduce the chances of initiating debris flows and torrents.

During site preparation for replanting, burns should be designed to retain a maximum litter layer and residual vegetation. Equipment exclusion zones should be used around active slides.

## Inner Gorge

Definition. An inner gorge is a geomorphic feature formed by coalescing scars originating from landsliding and erosional processes caused by active stream erosion. The feature is identified as that area of stream bank situated immediately adjacent to the stream channel, having a side slope of generally over 65 percent, and being situated below the first break in slope above the stream channel (Figure 6).

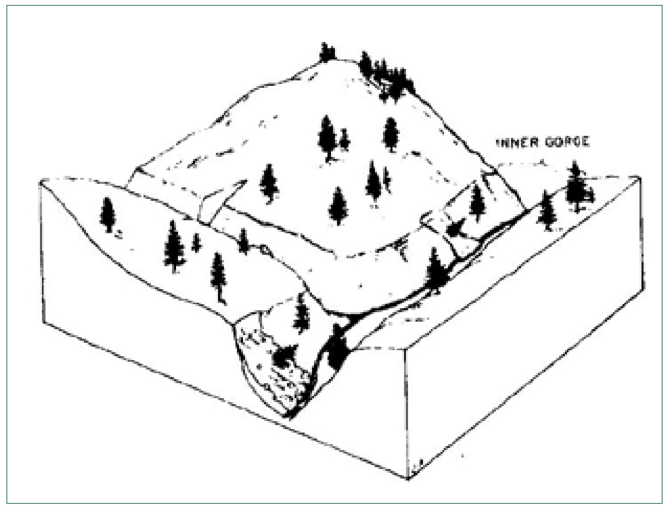


Figure 6. Diagrammatic sketch of the inner gorge. Drawing by Janet Appleby and Richard Kilbourne

Factors affecting landslide potential. Inner gorges are formed dominantly by debris slide processes that have been activated by the downcutting of stream channel bottoms. They commonly form along toes of large upslope landslides undercut by stream erosion. Where bedrock is exposed, the inner gorge may be stable. Where shallow, permeable, noncohesive soils and colluvium overlie impervious bedrock and/or slide plane materials, subsurface water flow may be concentrated along the steep streambank slopes and springs may be present. Slope stability is affected by high intensity storms and by the undercutting of stream banks by the rise in the stream water level. Roadcuts, as well as streambank erosion, are likely to activate or reactivate downslope movement. The addition of fill and/or concentration of water from roads and landings above the inner gorge could also increase landslide potential. Because unvegetated scars are likely to ravel, root support and vegetation are important to the overall slope stability.

Management objectives. The main objectives in mitigating slope stability problems in the inner gorge are to: protect water quality, protect riparian vegetation, and minimize the reactivation of debris slide failures.

Management guidelines. Where possible, road construction should be avoided within the inner gorge. Likewise, the inner gorge is an inappropriate location for landing sites. Where roads must cross the inner gorge, they should be located in rock gorge areas or other areas of stable ground, or structural supports should be used. Crossings should be engineered and designed for temporary use, that is, fill materials removed upon completion of logging and/or during the winter season. Water should be directed away from unstable inner gorge slopes and roads constructed along the upper break in slope should be full-benched and outsloped where possible to disperse water drainage and minimize failure of fill materials into the watercourse. Culverts installed within the inner gorge should be large enough to pass debris as well as water. When installed, the culverts should follow the longitudinal profile of the stream channel in order to minimize erosion of unstable stream banks. During logging, an equipment exclusion zone within the inner gorge is recommended. In addition, trees should be felled away from the stream channel. A suitable overstory and understory should be retained to provide root support and unmerchantable timber that could reach the stream should be removed or stabilized. Debris below the stream transition line should also be removed. Where possible, exposed soils should also be stabilized.

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