Section A
MASS WASTING

INTRODUCTION

This section summarizes the methods and results of a mass wasting assessment conducted on the Mendocino Redwood Company, LLC (MRC) ownership in the Willow Creek, Freezeout Creek, and Dutch Bill Creek watersheds. Throughout this report, ownership in these three watersheds will collectively be termed the Willow Creek Watershed Analysis Unit (Willow Creek WAU). This assessment is part of a Watershed Analysis initiated by MRC and utilizes watershed analysis modified methodology adapted from procedures outlined in the Standard Methodology for Conducting Watershed Analysis manual (Version 3.0, Washington Forest Practices Board).

The principle objectives of this assessment are to:

1) Identify the types of mass wasting processes active in the basin.
2) Identify the link between mass wasting and management related activities.
3) Identify where the mass wasting processes are concentrated.
4) Partition the ownership into zones of relative mass wasting potential (Mass Wasting Map Units) based on the likelihood of future mass wasting and sediment delivery to stream channels.

Additionally, the role of mass wasting sediment input to watercourses is examined. This information combined with the results of the surface erosion module will be used to construct a sediment input summary for the Willow Creek WAU, contained in the Sediment Input Summary section of this watershed analysis.

The products of this report are: a landslide inventory map (Map A-1), a mass wasting map unit (MWMU) map (Map A-2), a mass wasting inventory database (Table A-1), and a SHALSTAB (digital terrain slope stability model)(Dietrich and Montgomery, 1998) map (Map A-3) for the WAU. The basis for these products are: aerial photograph interpretation of 4 sets of aerial photographs (scales 1:12000 to 1:15840), dated 1978, 1987, 1996, and 2000, field observations during the summer of 2000, and interpretation of SHALSTAB data. Due to incompleteness of the MRCs 1987 aerial photograph set, select photographs from a 1990 photo set were used to complete coverage. The analysis was done without the use of historic aerial photographs (pre-1970s). Therefore the analysis presented is only representative for current mass wasting conditions (last 40 years).

The assembled information will enable forestland managers to make better forest management decisions to reduce management created mass wasting. The mass wasting inventory will provide the information necessary to understand the spatial distribution, causal mechanisms, relative size, and timing of mass wasting processes active in the basin with reasonable confidence.

The Role of Mass Wasting in Watershed Dynamics

Mass wasting is defined as the downslope movement of soil or rock material under the influence of gravity and water without the direct aid of other media such as air, or ice (Selby, 1993). Mass wasting is the dominant process in developing the morphology of steep, mountainous terrain. Mass wasting events are episodic and sometimes catastrophic in nature.

Mass wasting is a naturally occurring process, but can be accelerated by anthropogenic disturbances. Forest management practices can accelerate the natural frequency of mass wasting events by altering slope steepness, saturating soil and bedrock, altering soil cohesiveness, or removing root strength from a slope. Accelerated mass wasting can disrupt the dynamic equilibrium between hillslopes and channels, resulting in a decline of anadromous fish habitat.

Mass Wasting Influence on Stream Channels

Mass wasting is a natural process and provides a vital sediment link between hillslopes and stream channels. Mass wasting events are able to alter stream environments by increasing bed and suspended sediment loads, redistributing existing channel-bed sediments, introducing woody debris, changing channel morphology, damming and obstructing the channel, and in extreme cases scouring the channel to bedrock. Stream systems will adjust to major alterations downstream, as well as upstream of individual mass wasting events.

Mass Wasting Influence on Fish Habitat

In the Pacific Northwest where anadromous fish are present, mass wasting can have both beneficial and adverse effects on salmonid habitat. Beneficial effects include formation of new spawning, rearing, and over-wintering habitat due to addition of coarse gravels to the channel. The introduction of woody debris and boulders from landslides can increase cover and improve pool:riffle ratios. Adverse effects include filling of pools and scouring of riffles, blockage of fish access, disturbing side-channel rearing areas, and siltation of spawning gravels. The magnitude of these effects are dependent on the frequency, location, and intensity of mass wasting events, as well as the sediment transporting capabilities of a particular stream. Larger streams and rivers adjust to mass wasting perturbations faster than smaller streams.

Landslide Types and Processes in the Willow/Freezeout Creeks WAU

The terminology used to describe landslides in this report closely follows the definitions of Cruden and Varnes (1996). This terminology is based on two nouns, the first describing the material that the landslide is composed of and the second describing the type of movement. Landslides identified in the Willow Creek WAU were described using the following names: debris slides, debris torrents, debris flows, rockslides, and earth flows. These names are described in Cruden and Varnes (1996) with the exception of our use of debris torrent and debris flow.

Shallow-Seated Landslides

Debris slides, debris flows, and debris torrents are the shallow-seated landslide processes that were identified in the Willow Creek WAU. The material composition of debris slides, flows, or torrents is considered to be soil with a significant proportion of coarse material; 20 to 80 percent of the particles larger than 2 mm. Shallow-seated slides generally move quickly downslope and commonly break apart during failure. Shallow-seated slides commonly occur in converging topography where colluvial materials accumulate and subsurface drainage concentrates. Susceptibility of a slope to fail by shallow-seated landslides is affected by slope steepness, saturation of soil, soil strength (friction angle and cohesion), and root strength. Due to the shallow depth and fact that debris slides, flows, or torrents involve the soil mantle, these are landslide types that can be significantly influenced by forest practices.

Debris slides are, by far, the most common landslide type observed in the WAU. The landslide mass typically fails along a surface of rupture or along relatively thin zones of intense shear strain. The landslide deposit commonly slides a distance beyond the toe of the surface of rupture and onto the ground surface below the failure. While the landslide mass may deposit onto the ground surface below the area of failure, it generally does not slide more than the distance equal to the length of the failure scar. Landslides with deposits that traveled a distance below the failure scar would be defined by debris flow or debris torrent. Debris slides commonly occur on steep planar slopes, convergent slopes, along forest roads and on steep slopes adjacent to watercourses. They usually fail by translational movement along an undulating or planar surface of failure. Upon reaching a watercourse, by definition debris slides do not continue downstream.

A debris flow is similar to a debris slide with the exception that the landslide mass continues to “flow” down the slope below the failure a considerable distance on top of the ground surface. A debris flow is characterized as a mobile, potentially rapid, slurry of soil, rock, vegetation, and water. High water content is needed for this process to occur. Debris flows generally occur on both steep, planar hillslopes and confined, convergent hillslopes. Often a failure will initiate as a debris slide, but will change as its moves downslope to a debris flow. During this analysis these types of failures were mapped as debris flows.

Debris torrents are relatively rare, but have the greatest potential to destroy stream habitat and deliver large amounts of sediment. The main characteristic distinguishing a debris torrent is that the failure “torrents” downstream in a confined channel and scours the channel. As the debris torrent moves downslope and scours the channel, the liquefied landslide material increases in mass. A highly saturated soil is required for this process to occur. Debris torrents move rapidly and can potentially run down a channel for great distances. They typically initiate in headwall swales and torrent down intermittent watercourses. Often a failure will initiate as a debris slide, but will develop into a debris torrent upon reaching a channel. While actually a combination of two processes, these features were considered debris torrents.

Sediment Input from Shallow-Seated Landslides

The overall time period used for mass wasting interpretation and sediment budget analysis is thirty-two years. Sediment input to stream channels by mass wasting is quantified for three time periods (1969-1978, 1979-1987, 1988-2000). This is assumed because of the use of 1978, 1987/90, 1996, and 2000 aerial photographs and field observations in 2000. The evaluation is initiated at 1969 based on the earliest aerial photograph year of 1978 and the assumption that landslides farther back than about ten years are too difficult to detect, with much certainty, from aerial photographs. This is because landslide surfaces can re-vegetate quickly, making them too difficult to see. We acknowledge that we have likely missed some small mass wasting events during the aerial photograph interpretation. However, we assume we have captured the majority of the larger mass wasting events in this analysis. It is the large mass wasting events that provide the greatest sedimentation impacts. In the case of the landslides observed in the Willow Creek WAU, landslides greater than 300 cubic yards in size represented over 85% of the sediment delivery estimated. Landslides greater than 200 and 100 cubic yards in size represented approximately 90% and 97%, respectively of the sediment delivery estimated.

Sediment delivery estimates from mapped shallow-seated landslides were used to produce the total mass wasting sediment input. Some of the sediment delivery from shallow-seated landslides is the result of conditions created by deep-seated landslides. For example, a deep-seated failure could result in a debris slide or torrent, which could deliver sediment. Furthermore, over-steepened scarps or toes of deep-seated landslides may have shallow failures associated with them. These types of sediment delivery from shallow-seated landslides associated with deep-seated landslides are accounted for in the delivery estimates.

Deep-Seated Landslides

The two deep-seated landslide processes identified in the Willow Creek WAU are rockslides and earth flows. The failure dates of the deep-seated landslides generally could not be estimated with confidence and the landslides are likely to be of varying age with some landslides potentially being over 10,000 years old. Many of the deep-seated landslides are considered “dormant”, but the importance of identifying them lies in the fact that if reactivated or accelerated, they have the potential to deliver large amounts of sediment and destroy stream habitat. Accelerated or episodic movement in some landslides is likely to have occurred over time in response to seismic shaking or infrequent high rainfall events. Deep-seated landslides can be very large, exceeding tens to hundreds of acres.

Rockslides are deep-seated landslides with movement involving a relatively intact mass of rock and overlying earth materials. The failure plane is below the colluvial layer and involves the underlying bedrock. Mode of rock sliding generally is not strictly rotational or translational, but involves some component of each. Rotational slides typically fail along a concave surface, while translational slides typically fail on a planar or undulating surface of rupture. Rockslides commonly create a flat, or back-tilted bench below the crown of the scarp. A prominent bench is usually preserved over time and can be indicative of a rockslide. Rockslides can fail in response to triggering mechanisms such as seismic shaking, adverse local structural geology, high rainfall, or channel incision. The stream itself can be the cause of chronic movement, if it periodically undercuts the toe of a rockslide.

Earth flows are deep-seated landslides composed of fine-grained materials and soils derived from clay-bearing rocks. Earth flow materials consist of 80% or more of the particles smaller than 2mm. Materials in an earth flow also commonly contain boulders, some very large, which move downslope in the clay matrix. Failure in earth flows is characterized by spatially differential rates of movement on discontinuous failure surfaces that are not preserved. The “flow” type of movement creates a landslide that can be very irregularly shaped. Some earth flow surfaces are dominantly grassland, while some are partially or completely forested. The areas of grassy vegetation are likely due to the inability of the unstable, clay-rich soils to support forest vegetation. The surface of an earth flow is characteristically hummocky with locally variable slope forms and relatively abundant gullies. The inherently weak materials within earth flows are not able to support steep slopes, therefore slope gradients are low to moderate. The rates of movement vary over time and can be accelerated by persistent high groundwater conditions. Timber harvesting can have the effect of increasing the amount of subsurface water, which can accelerate movement in an earth flow. A principal source of anthropogenic created sediment from earthflows is often gully erosion resulting from concentrated or diverted water.

Sediment Delivery from Deep-Seated Landslides

A large, active deep-seated slide can deliver large volumes of sediment. Delivery generally occurs over long time periods compared to shallow-seated landslides, with movement delivering earth materials into the channel. These materials are then confined to the channel, resulting in an increased sediment load downstream of the failure. Actual delivery can occur by over-steepening of the toe of the slide and subsequent failure into the creek, or by the slide pushing out into the creek. Sediment delivery could also occur in a catastrophic manner. In such a situation, large portions of the landslide essentially fail and move into the watercourse “instantaneously”. These types of deep-seated failures are relatively rare and usually occur in response to unusual storm events or seismic ground shaking.

Movement of deep-seated landslides has definitely resulted in some sediment delivery in the Willow Creek WAU. Quantification of the sediment delivery from deep-seated landslides was not determined in this watershed analysis. Factors such as rate of movement, or depth of the deep-seated landslide are difficult to determine without in-depth geotechnical observations that were not included in this analysis. Sediment delivery to watercourses from deep-seated landslides (landslides typically $\geq$10 feet thick) can occur by several processes. Such processes can include surface erosion and shallow- or deep-seated movement of a portion or all of the deep-seated landslide deposit.

The ground surface of a deep-seated landslide, like any other hillside surface, is subject to surface erosion processes such as rain drop impact, sheet wash (overland flow), and gully/rill erosion. Fresh, unprotected surfaces that develop in response to recent or active movement could become a source of sediment until the bare surface becomes covered with leaf litter, re-vegetated, or soils developed.

Clearly, movement of a portion or all of a deep-seated landslide can result in delivery of sediment to a watercourse. To determine this the slide surface should be carefully explored for evidence of movement. However, movement would need to be on slopes immediately adjacent to or in close proximity to a watercourse and of sufficient magnitude to push the toe of the slide into the watercourse. A deep-seated slide that toes out on a slope far from a creek or moves only a short distance downslope will generally deliver little to a watercourse. It is also important to realize that often only a portion of a deep-seated slide may become active, though the portion could be quite variable in size. Ground cracking at the head of a large, deep-seated landslide does not necessarily equate to immediate sediment delivery at the toe of the landslide.

Use of SHALSTAB by Mendocino Redwood Company for the Willow/Freezeout Creeks WAU

SHALSTAB, a coupled steady state runoff and infinite-slope stability model, is used by MRC as one tool to demonstrate the relative potential for shallow-landslide hazard across the MRC ownership. A detailed description of the model is available in Dietrich and Montgomery (1998). In the watershed analysis mass wasting hazard is expanded beyond SHALSTAB. Inner gorge or steep streamside areas are mapped and designated as mass wasting map units. Relative areas of mass wasting and sediment delivery hazards are mapped using field and aerial photograph interpretation techniques. However, SHALSTAB output was used to assist in this interpretation of the landscape and mass wasting map units.

METHODS

Landslide Inventory

The mass wasting assessment relies on an inventory of mass wasting features collected through the review of aerial photographs and field observations. All aerial photograph sets used to interpret landslides are in color and are owned by MRC, with the 2000, 1996, and 1990/1987 sets at a photograph scale of 1:12,000, and 1:15,840 for the 1978 aerial photograph set. MRC collected data regarding characteristics and measurements of the identified landslides. Since mass wasting events were essentially “sampled”, we acknowledge that some landslides may have been missed, particularly small ones that may be obscured by vegetation. A description of select parameters inventoried for each landslide observed in the field and during aerial photograph interpretation is presented below and tabulated in Figure A-2. These parameters are similar to the type of information being collected by the California Division of Mines and Geology for the North Coast Watershed Assessment Program.

The landslide inventory work was done under the supervision of Certified Engineering Geologist, John Coyle.

Figure A-2. Description of Select Parameters used to Describe Mass Wasting in the Mass Wasting Inventory.

- Slide I.D. Number: Each landslide is assigned a number in the inventory. Since section lines and numbers of the Willow Creek WAU map were not available, landslides were numbered consecutively with their observation.
- Planning Watershed: Denotes the MRC planning watershed in which the landslide is located.
  - SF = Freezeout Creek
  - SW = Willow Creek
  - SD = Dutch Bill Creek
- MWMU # – Mass Wasting Map Unit in which landslide is located.
- Landslide Process:
  - DS = debris slide
  - DT = debris torrent
  - DF = debris flow
  - RS = rockslide
  - EF = earth flow
- Certainty: The certainty of identification is recorded.
  D - Definite, P - Probable; Q - Questionable.
- Approximate Failure Date: Minimum failure date is typically the photo year that the slide first appears on or the year observed in the field.
- Slope Form: Geomorphology of slope (D – divergent, P – planar, C – convergent).
- Physical Characteristics: Include average length, width, depth, and volume of individual slides.
- Sediment delivery and routing: Includes sediment delivered to streams (N - no sediment delivered; Y - sediment delivered), estimate of the percent of landslide mass delivered, the type of stream that sediment was delivered to (perennial or ephemeral).
- Land Use Association: Road, landing, or skid trail association.
- Deep seated landslides morphologic descriptions: toe, body, lateral scarps, and main scarp (see following for descriptions).

Landslides identified in the field and from aerial photograph observations are plotted on a landslide inventory map (Map A-1). Shallow-seated landslides are represented as a point on the map, and deep-seated landslides are shown as a polygon representing the landslide deposit. Following movement of a deep-seated failure, the geomorphic expression of the head and lateral scarps changes over time by erosional processes. Delineation of the landslide scarps as we see them today on aerial photographs does not truly represent the slide scarps at the time of failure, and mapping them becomes interpretive. Therefore, the deep-seated landslides identified and mapped in this analysis are strictly the landslide deposits.

Physical and geomorphic characteristics of shallow-seated landslides are categorized in a database including identification number, planning watershed, type of landslide, approximate failure date, slope gradient, length, width, depth, volume, sediment delivery, sediment routing, and associated land use (Table A-1). Landslide dimensions and depths can be variable for a given landslide, therefore length, width, and depth values that are recorded should be considered the estimated average of these attributes. The attributes of the deep-seated landslides received less attention in the landslide inventory than shallow-seated landslides mainly due to the fact that complicated geotechnical analyses would have to be done to estimate such features as depth, failure date, and sediment delivery. In conversion of the landslide masses from volumes to tons, we assume a uniform bulk density of 1.35 g/cc.

The certainty of landslide identification is also designated for each landslide. Three designations of certainty of identification are used: definite, probable, and questionable. Definite means the landslide definitely exists. Probable means the landslide probably is there, but there is some doubt (by the analyst) about its existence. Questionable means that the interpretation of the landslide identification may be inaccurate, the analyst has the least amount of confidence in the interpretation. Accuracy in identifying landslides on aerial photographs is dependent on the size of the slide, scale of the photographs, thickness of canopy, and logging history. Landslides mapped in areas recently logged or through a thin canopy are identified with the highest level of confidence. Characteristics of the particular aerial photographs used affects confidence in identifying landslides. For example, sun angle creates shadows that may obscure landslides, the print quality of some photo sets varies, and photographs taken at smaller scale makes identifying small landslides difficult. The landslide inventory results are considered a minimum estimate of sediment production. This is because landslides that were too small to identify on aerial photographs may have been missed, landslide surfaces could have reactivated in subsequent years and not been quantified, and secondary erosion by rills and gullies on slide surfaces is difficult to assess. However, small landslides cumulatively may not deliver amounts of sediment that would significantly alter total sediment delivery.

Dimensions (average length and width) for landslides not visited in the field were determined by measuring the failure as interpreted directly from aerial photographs and extrapolating the dimension to represent slope distance for a 70% slope gradient. The 70% slope gradient is assumed to be representative of average conditions for development of a shallow-seated landslide. To extrapolate depth to the shallow-seated landslides not visited in the field, the mean value of slide depths was extrapolated for shallow-landslides that were not visited in the field. It was determined that there was insignificant overall difference among depths of debris slides, flows, torrents, road-related failures, and non road-related failures. Therefore, the mean depth of 3 feet was calculated from all field verified shallow-seated landslide depths, regardless of shallow failure process type or land use association.

Two techniques were employed in order to extrapolate a sediment volume delivery percentage to shallow-seated landslides not visited in the field. Landslides that were determined to be directly adjacent to a watercourse were assigned 100% delivery. Landslides that were determined to deliver, but were not directly adjacent to a watercourse, were assigned the mean delivery percentage determined from shallow-seated landslides observed in the field.

The likelihood that some land use practice was associated with a shallow-seated slope failure was also noted. In this analysis, different silvicultural techniques were not recorded. This was because almost all of the Willow Creek WAU has been managed, both currently and historically, for timber production, and the effect of these different silvicultural practices was too difficult to confidently interpret. There have been too many different silvicultural activities over time for reasonable confidence in a landslide evaluation based on silviculture. The land use practices that were assigned to shallow-seated landslides were associations with roads, skid trails, or landings. It was assumed that a landslide adjacent to a road, landing, or skid trail was triggered either directly or indirectly by these land use practices. If a landslide appeared to be influenced by more than one land use practice, the more causative one was noted. If a cutslope failure did not cross the road prism, it was assumed that the failure would remain perched on the road, landing, or skid trail and would not deliver to a watercourse. Some surface erosion could result from a cutslope failure, this is assumed to be addressed in the road surface erosion estimates (Surface Erosion module).

Systematic Description of Deep-seated Landslide Features

Deep-seated landslides were only interpreted by reconnaissance techniques (aerial photograph interpretation rather than field observations). Reconnaissance mapping criteria consist of observations of four morphologic features of deep seated landslides -- toe, internal morphology, lateral flanks, main scarp--and vegetation (after McCalpin 1984 as presented by Keaton and DeGraff, 1996, p. 186, Table 9-1). The mapping and classification criteria for each feature are presented in detail below.

Aerial photo interpretation of deep seated landslide features in the Gualala watershed in Sonoma County suggest that the first three morphologic features above are the most useful for inferring the presence of deep-seated landslides. The presence of tension cracks and/or sharply defined and topographically offset scarps are probably a more accurate indicator of recent or active landslide movement. These features, however, are rarely visible on aerial photos.

Sets of four descriptions have been developed to classify each deep-seated landslide characteristic. The four descriptions are ranked in descending order from characteristics of active landslides to dormant to relict landslides. One description should characterize the feature most accurately. Nevertheless, some overlap between classifications is neither unusual nor unexpected. We recognize that some deep-seated landslides may lack evidence with respect to one or more of the observable features, but show strong evidence of another feature. If there is no expression of a particular geomorphic feature (e.g. lateral flanks), the classification of that feature is considered “indeterminate”. If a deep-seated landslide is associated with other deep-seated landslides, it may also be classified as a landslide complex.

In addition to the classification criteria specific to the deep-seated landslide features, more general classification of the strength of the interpretation of the deep-seated landslide is conducted. Some landslides are obscured by vegetation to varying degrees, with areas that are clearly visible and areas that are poorly visible. In addition, weathering and erosion processes may also obscure geomorphic features over time. The quality of different aerial photograph sets varies and can sometimes make interpretations difficult. Owing to these circumstances, each inferred deep-seated landslide feature is classified according to the strength of the evidence as definite, probable or questionable.

Finally, based on all the feature descriptions of a landslide, an assessment is made as to whether a deep-seated landslide is “active”, or of “indeterminate activity”. The range of interpretation of activity level allowed here is restricted in recognition of the limitations of aerial photo interpretation. It is expected that few deep-seated landslides will show unmistakable evidence of activity, in part because movement is usually slow. Most deep-seated landslides will probably be of indeterminate activity based on typical aerial photo observations.

At the project scale (THP development and planning), field observations of deep-seated landslide morphology and other indicators by qualified professionals are expected to be used to reduce uncertainty of interpretation inherent in reconnaissance mapping. Field criteria for mapping deep-seated landslides and assessment of activity are presented elsewhere.

Deep Seated Landslide Morphologic Classification Criteria:

I. Toe Activity

1. Steep streamside slopes with extensive unvegetated to sparsely vegetated debris slide scars. Debris slides occur on both sides of stream channel, but more prominently on side containing the deep-seated landslide. Stream channel in toe region may contain coarser sediment than adjacent channel. Stream channel may be pushed out by toe. Toe may be eroding, sharp topography/geomorphology.
2. Steep streamside slopes with few unvegetated to sparsely vegetated debris slide scars. Debris slides generally are distinguishable only on streamside slope containing the deep-seated landslide. Stream channel may be pushed out by toe. Sharp edges becoming subdued.
3. Steep streamside slopes that are predominantly vegetated with little to no debris slide activity. Topography/geomorphology subdued.
4. Gently sloping stream banks that are vegetated and lack debris slide activity. Topography/geomorphology very subdued.

II. Internal Morphology

1. Multiple, well defined scarps and associated angular benches. Some benches may be rotated against scarps so that their surfaces slope back into the hill causing ponded water, which can be identified by different vegetation than adjacent areas. Hummocky topography with ground cracks. Jack-strawed trees may be present. No drainage to disorganized drainage.
2. Hummocky topography with identifiable scarps and benches, but those features have been smoothed. Undrained to drained but somewhat subdued depressions may exist. Poorly established drainage.
3. Slight benches can be identified, but are subtle and not prominent. Undrained depressions have since been drained. Moderately developed drainage to

established drainage but not strongly incised. Subdued depressions but are being filled.

4. Smooth topography. Body of slide typically appears to have failed as one large coherent mass, rather than broken and fragmented. Developed drainage well established, incised. Essentially only large undrained depressions preserved and would be very subdued. Could have standing water. May appear as amphitheater slope where slide deposit is mostly or all removed.

III. Lateral Flanks

1. Sharp, well defined. Debris slides on lateral scarps fail onto body of slide. Gullies/drainage may begin to form at boundary between lateral scarps and sides of slide deposit. Bare spots are common or partially unvegetated.
2. Sharp to somewhat subdued, rounded, essentially continuous, might have small breaks; gullies/drainage may be developing down lateral edges of slide body. May have debris slide activity, but less prominent. Few bare spots.
3. Smooth, subdued, but can be discontinuous and vegetated. Drainage may begin to develop along boundary between lateral scarp and slide body. Tributaries to drainage extend onto body of slide.
4. Subtle, well subdued to indistinguishable, discontinuous. Vegetation is identical to adjacent areas. Watercourses could be well incised, may have developed along boundary between lateral scarp and slide body. Tributaries to drainage developed on slide body.

IV. Main Scarp

1. Sharp, continuous geomorphic expression, usually arcuate break in slope with bare spots to unvegetated; often has debris slide activity.
2. Distinct, essentially continuous break in slope that may be smooth to slightly subdued in parts and sharp in others, apparent lack of debris slide activity. Bare spots may exist, but are few.
3. Smooth, subdued, less distinct break in slope with generally similar vegetation relative to adjacent areas. Bare spots are essentially non-existent.
4. Very subtle to subdued, well vegetated, can be discontinuous and deeply incised, dissected; feature may be indistinct.

V. Vegetation

1. Less dense vegetation than adjacent areas. Recent slide scarps and deposits leave many bare areas. Bare areas also due to lack of vegetative ability to root in unstable soils. Open canopy, may have jack-strawed trees; can have large openings.
2. Bare areas exist with some regrowth. Regrowth or successional patterns related to scarps and deposits. May have some openings in canopy or young broad-leaf vegetation with similar age.

3. Subtle differences from surrounding areas. Slightly less dense and different type vegetation. Essentially closed canopy; may have moderately aged to old trees.
4. Same size, type, and density as surrounding areas.

This classification scheme is only to be used to provide some reconnaissance level interpretations of deep seated landslides prior to actual field observations. The lower the number designation is each of the four morphological characteristics might suggest more recent activity by the landslide, but not always. Furthermore, a landslide may be active or have recent movement yet not show characteristics representing the low number descriptions in this classification. This classification can only be used to develop hypothesis about potential landslide activity prior to field observations.

Landslides and Landslide Hazard in Willow and Freezeout Creeks Not within Mendocino Redwood Company Property

A reconnaissance level interpretation of landslides and shallow-seated landslide hazard was done in the watersheds of Willow and Freezeout Creeks on land that was not within the MRC ownership in these watersheds. This presentation is to provide a context for the mass wasting issues for the watersheds compared to just MRC property. Shallow-seated landslide risk was also determined by use of SHALSTAB data for both watersheds. Landslides off the MRC property were primarily identified from maps in the Geology and Planning in Sonoma County (1980) report. However, an aerial photograph interpretation was conducted from aerial photographs available from the California Department of Forestry and Fire Protection for 2000 (1:24000). The aerial photograph interpretation was to identify any large shallow-seated landslides (due to small scale photos) or additional deep seated landslides not mapped in the Sonoma County report (1980) plus observe potential activity of the deep seated landslides already mapped.

Mass Wasting Map Units

Mass Wasting Map Units (MWMUs) are delineated by partitioning the landscape into zones characterized by similar geomorphic attributes, shallow-seated landslide potential, and sediment delivery potential to stream channels. A combination of aerial photograph interpretation, field investigation, and SHALSTAB output were utilized to delineate MWMUs. The MWMU designations for the Willow Creek WAU are only meant to be general characterizations of similar geomorphic and terrain characteristics related to shallow-seated landslides. Deep-seated landslides are also shown on the MWMU map (Map A-2). The deep-seated landslides have been included to provide land managers with supplemental information to guide evaluation of harvest planning and subsequent needs for geologic review. The landscape and geomorphic setting in the Willow Creek WAU is certainly more complex than generalized MWMUs delineated for this evaluation. The MWMUs are only meant to be a starting point for gauging the need for site-specific field assessments.

The delineation of each MWMU described is based on landforms present, mass wasting processes, sensitivity to forest practices, mass wasting hazard, delivery potential, hazard potential, and forest management related trigger mechanisms for shallow-seated landslides. In the MWMU description the mass wasting process section is a summary of the landslide types found in the MWMU. Sensitivity to forest practice and mass wasting hazard is, in part, a subjective call by the analyst based on the relative landslide hazard and influence of forest practices. Sediment delivery potential is based on proximity of MWMU to watercourses and the likelihood of earth materials generated by mass wasting in the unit to reach a watercourse. If greater than 66% of the landslides in a MWMU deliver sediment then the MWMU is designated as having a high delivery potential. If between 33% and 66% of the landslides in a MWMU deliver sediment then the MWMU is designated as having a moderate delivery potential, <25% delivery would be a low delivery potential. The hazard potential is based on a combination of the mass wasting hazard and delivery potential (Figure A-1.). Finally in the MWMU description the trigger mechanisms are a list of forest management practices that may have the potential to create mass wasting in the MWMU.

Figure A-1. Ratings for Potential Hazard of Delivery of Debris and Sediment to Streams by Mass Wasting (letters designate hazard: L= low, M= moderate, H = high)(Version 3.0, Washington Forest Practices Board, 1995).

Mass Wasting Potential

		Low	Moderate	High
Delivery Potential	Low	**L**	**L**	**M**
	Moderate	**L**	**M**	**H**
	High	**M**	**M**	**H**

RESULTS

Mass Wasting Inventory

A Landslide Inventory Data Sheet (Table A-1) was used to record attributes associated with each landslide. The spatial distribution and location of landslides is shown on Map A-1.

Table A-1. Landslide Inventory for the Willow Creek WAU.

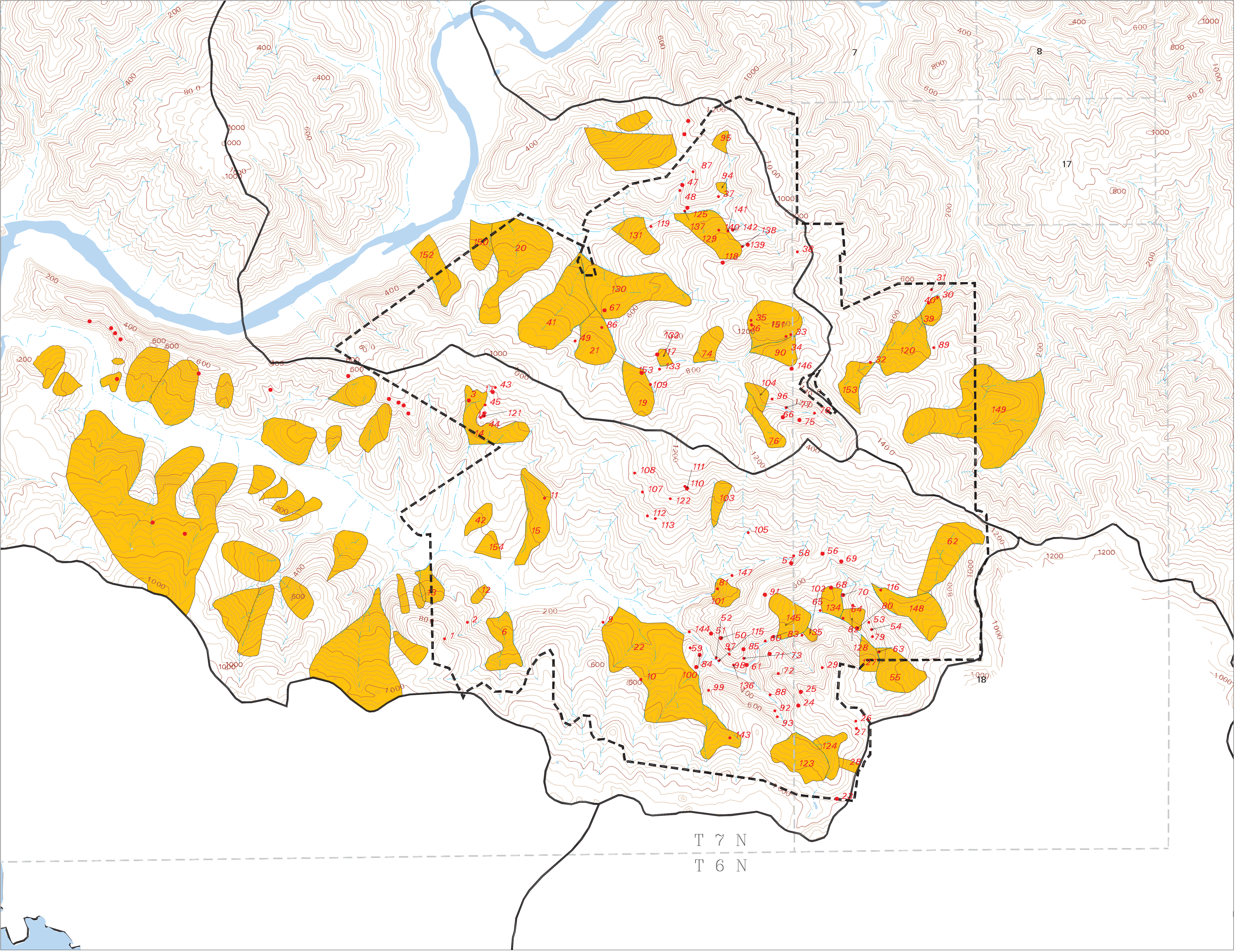
Slide Number	Plng WS	MWMU	Landslides		Approx. Failure Date	Field Checked	Slope Gradient (%) Field	Slope Form	Average Landslide Dimensions (feet)			Vol (cu. Yds)	Sediment Delivery	Delivery (%)	Delivery Volume (cu. yds.)	Delivery Mass (tons)	Sediment Routing	Land Use Assoc.	Deep Seated Landslide Morphologcal Descriptions						DSL Area (Acres)	Comments
			Process	Certainty					Length	Width	Depth								Toe	Body	Lat. Scarps	Main Scarps	Veg.	Complex		
1	SW	4	DS	D	90	N		C	32	16	3	57	Y	74	42	57	ephemeral									
2	SW	4	DS	D	90	N		C	48	16	3	85	Y	74	63	85	ephemeral									
3	SW	7	DS	D	90	N		C	112	112	3	1394	Y	74	1032	1393	ephemeral									on possible deep-seated slide. failure into gully.
6	SW		EF	P					1300	600									4	3	3	4	4	N	22.85	
9	SW	3	DS	D	90	N		P	32	48	3	171	Y	100	171	231	ephemeral									
10	SW	4	DS	D	90	N		P	16	16	3	29	Y	74	21	29	ephemeral									
11	SW	7	DS	Q	90	N		C	32	32	3	114	Y	74	85	114	ephemeral									
12	SW		RS	D					620	280									3	2	3	3	4	N	3.62	
13	SW		RS	P					1160	600									3	2	3	3	4	N	12.43	
14	SW		EF	D					1080	1820									4	2	3	2	3	Y	32.78	EF complex-multiple DS on scarp
15	SW		EF	D					2100	580									4	3	3	3	4	Y	33.2	EF complex
17	SW	8	DS	D	90	N		C	73	64	3	519	N	0	0	0										DS in melange. grassy
18	SW	8	DS	D	90	N		P	16	16	3	29	N	0	0	0										
19	SF		RS	Q					1160	620									2	3	3	4	4	N	21.64	
20	SF		EF	P					2300	900									3	2	3	4	4	N	67.03	
21	SF		RS	P					680	480									3	3	3	3	4	N	28.06	
22	SW		EF	P					2800	1050									3	3	3	3	4	Y	145.6	
23	SW	8	DS	D	87	N		P	279	64	3	1985	N	0	0	0		road								initiates at county road, onto property
24	SW	4	DT	D	87	N		C	990	25	3	2750	Y	74	2035	2747	ephemeral	skid								
25	SW	5	DS	D	87	N		P	297	32	3	1056	Y	74	781	1054	ephemeral	road								
26	SW	8	DS	Q	87	N		C	99	24	3	265	N	0	0	0		road								could not locate in field
27	SW	8	DS	Q	87	N		C	99	32	3	354	N	0	0	0		road								could not locate in field
28	SW		RS	D					450	380									3	2	5	3	4	N	3.6	active - ground cracks
29	SW	4	DS	D	87	N		P	83	48	3	444	N	0	0	0		road								
30	SD	4	DS	Q	90	N		P	50	32	3	178	Y	74	132	178	perennial									terrace above inner gorge
31	SD	4	DS	P	90	N		P	50	16	3	89	N	0	0	0										midslope
32	SD	4	DS	Q	90	N		P	50	64	3	358	Y	74	265	358	ephemeral									
33	SF	3	DS	D	90	N		P	37	20	3	82	Y	100	82	111	ephemeral									
34	SF	3	DS	Q	90	N		P	32	16	3	56	Y	100	56	76	ephemeral									
35	SF	8	DS	Q	90	N		P	17	32	3	60	Y	100	60	81	ephemeral									
36	SF	8	DS	Q	90	N		P	34	32	3	121	Y	100	121	163	ephemeral									
37	SF	8	DS	Q	90	Y	62	P	45	30	3	150	Y	10	15	20	ephemeral									
38	SF	8	DS	P	90	N		C	53	25	3	149	N	0	0	0										
39	SD		RS	P					540	540									3	3	3	3	4	N	8.29	
40	SD	3	DS	D	90	N		P	38	30	3	126	Y	74	93	126	ephemeral									fill failure
41	SF		RS	P					1770	1230									3	3	3	4	4	N	67.78	
42	SW		EF	P					960	320									4	3	5	4	4	N	8.61	
43	SW	8	DS	D	90	N		C	22	16	3	39	N	0	0	0										DS in melange. grassy
44	SW	8	DS	D	90	N		P	17	18	3	35	N	0	0	0										DS in melange. grassy
45	SW	8	DS	D	90	N		P	9	24	3	23	N	0	0	0										DS in melange. grassy
47	SF	3	DS	P	90	N		C	124	56	3	770	Y	100	770	1040	ephemeral									
48	SF	3	DS	Q	90	N		C	106	40	3	473	Y	100	473	639	ephemeral									
49	SF	8	DS	Q	90	N		P	27	24	3	71	Y	74	53	71	ephemeral									
50	SW	4	DT	D	87	N		C	286	64	3	2035	Y	74	1506	2033	perennial									slide=256'longX64'wide. runout=240'X10'
51	SW	4	DS	D	87	N		C	303	50	3	1684	Y	74	1246	1682	perennial									toe reaches creek
52	SW	1	DS	Q	87	N		C	27	16	3	48	Y	100	48	65	perennial									inner gorge
53	SW	4	DS	D	87	N		C	141	32	3	503	N	0	0	0										
54	SW	4	DT	D	78	Y	94	C	60	40	3	267	Y	90	240	324	perennial	road								slide=60'LX40'w. runout=110'LX6'w
55	SW		RS	Q					1200	730									3	2	3	3	4	N	28.49	
56	SW	5	DS	D	90	Y	58	P	120	50	3	667	N	0	0	0		road								field estimate 10 yrs old
57	SW	4	DS	D	97	Y	79	C	130	35	3	506	Y	40	202	273	ephemeral	road								
58	SW	3	DS	D	2000	Y	85	C	20	30	3	67	Y	100	67	90	ephemeral	road								directly into creek
59	SW	5	DS	D	2000	Y	106	P	10	30	8	89	Y	100	89	120	perennial	road								streambank failure
60	SW	1	DS	D	2000	Y	80	C	25	65	3	181	Y	100	181	244	perennial									inner gorge
61	SW	1	DS	D	95	Y	65	C	160	50	3	889	Y	100	889	1200	perennial	road								legacy road failure. Inner gorge
62	SW		EF	D					1300	1360									2	1	2	3	3	N	40.89	active EF. 12" deep gullies near toe.
63	SW	2	DS	P	87	N		C	57	24	3	151	Y	100	151	204	ephemeral									streamside
64	SW	4	DS	Q	87	Y	84	C	48	40	3	213	N	0	0	0		road								fill failure
65	SW		RS	Q					680	570									3	3	3	2	4	N	10.3	
66	SF	4	DS	D	87	Y	87	P	230	148	3	3782	Y	60	2269	3064	ephemeral	road								fill failure
67	SF	8	DS	Q	87	N		P	193	32	3	685	Y	74	507	684	perennial									slight vegetation 87 photo
68	SW	4	DS	D	87	N		C	174	56	3	1084	Y	74	802	1082	perennial									
69	SW	5	DS	D	87	N		C	175	200	3	3888	Y	74	2877	3884	ephemeral									stream undercut
70	SW	2	DS	Q	87	N		P	68	128	3	972	Y	100	972	1312	perennial									inner gorge
71	SW	5	DF	D	87	N		P	245	48	3	1308	Y	74	968	1307	perennial									
72	SW	4	DS	Q	87	N		C	39	64	3	280	N	0	0	0										
73	SW	4	DS	Q	87	N		C	59	72	3	475	N	0	0	0										
74	SF		RS	Q					1030	380									3	3	5	3	3	N	12.62	
75	SF	4	DF	D	90	Y	92	P	280	42	3	1307	Y	90	1176	1588	ephemeral	road								fill failure
76	SF		EF	P					1350	300									4	3	3	4	4	N	13.07	
77	SF	2	DS	Q	87	N		C	50	45	3	252	Y	100	252	341	ephemeral									steep slope

Table A-1 (continued). Landslide Inventory for the Willow Creek WAU.

Slide Number	Plng WS	MWMU	Landslides		Approx. Failure Date	Field Checked	Slope Gradient (%)	Slope Form	Average Landslide Dimensions (feet)			Vol (cu. Yds)	Sediment Delivery	Delivery (%)	Delivery Volume (cu. yds.)	Delivery Mass (tons)	Sediment Routing	Land Use Assoc.	Deep Seated Landslide Morphologcal Descriptions						DSL Area (Acres)	Comments
			Process	Certainty			Field		Length	Width	Depth								Toe	Body	Lat. Scarps	Main Scarps	Veg.	Complex		
78	SF	2	DS	P	87	N		C	76	25	3	211	Y	100	211	285	ephemeral									
79	SW	4	DS	P	87	N		P	96	20	3	212	Y	74	157	212	ephemeral									
80	SW	2	DS	P	82	N		P	160	60	3	1067	Y	74	790	1066	ephemeral									some vegetation on 1987 photo
81	SW	2	DS	P	87	N		C	58	60	3	386	Y	100	386	521	ephemeral									
82	SW	2	DS	P	87	Y	113	P	45	30	3	150	Y	100	150	203	perennial									steep streamside
83	SW	1	DS	P	87	N		C	52	90	3	520	Y	100	520	702	ephemeral									could not locate in field due to age. Inner gorge
84	SW	4	DF	P	87	N		C	248	90	3	2481	Y	100	2481	3350	perennial									failure is in draw
85	SW	4	DF	Q	80	N		P	262	83	3	2421	Y	74	1791	2418	ephemeral									moderate veg. regrowth - 87 photo
86	SF	4	DS	D	96	Y	72	P	80	45	3	400	Y	25	100	135	perennial	road								complex of multiple debris slides
87	SF	4	DS	P	87	N		C	117	30	3	389	N	0	0	0		road								
88	SW	2	DS	D	96	N		P	53	15	3	89	Y	100	89	120	ephemeral									steep streamside
89	SD	8	DS	Q	96	N		C	129	40	3	571	N	0	0	0										
90	SF		RS	P					620	810									3	3	3	3	4	N	14.04	
91	SW	4	DS	D	96	Y	64	C	114	57	3	722	N	0	0	0		road								shadowy in photo. road impassible
92	SW	5	DS	D	96	N		P	109	50	3	604	Y	100	604	815	ephemeral									
93	SW	4	DF	D	96	N		C	146	36	3	584	Y	100	584	789	ephemeral									
94	SF		RS	Q					200	340									3	3	5	2	4	N	1.93	
95	SF		RS	Q					580	260									3	3	3	4	4	N	4.36	
96	SF	4	DF	P	96	N		C	133	15	3	222	Y	74	164	222	ephemeral									
97	SW	5	DS	Q	96	N		P	67	24	3	178	N	0	0	0										steep slope
98	SW	5	DS	Q	96	N		D	67	24	3	179	N	0	0	0										steep slope
99	SW	4	DS	D	96	N		C	113	40	3	500	Y	74	370	500	ephemeral									
100	SW	4	DS	D	87	Y	88	C	100	83	5	1537	Y	90	1383	1868	ephemeral									
101	SW		RS	D					470	500									2	3	3	2	4	N	9.84	
102	SW		RS	P					480	350									3	3	3	2	4	N	2.38	
103	SW		EF	P					1520	530									4	3	3	4	4	N	9.76	
104	SF		RS	P					310	630									3	2	5	3	4	N	6.89	
105	SW	4	DS	D	99	Y	69	P	20	40	2.5	74	Y	15	11	15	perennial	road								fill failure adjacent to culvert on county road. delivers to MRC
107	SW	4	DS	D	95	Y	43	P	50	50	3	278	N	0	0	0		road								cutbank slide. revegetating
108	SW	8	DS	D	98	Y	64	P	25	27	1.5	38	N	0	0	0		road								DS in grassy melange area
109	SF	3	DS	P	95	Y	89	C	30	45	2	100	N	0	0	0		road								
110	SW	4	DS	D	99	Y	79	C	25	45	3	125	N	0	0	0		road								in swale of older slide #SW111
111	SW	4	DS	P	80	Y	74	P	120	80	4	1422	Y	30	427	576		road								in HW swale of slide SW 111
112	SW	8	DS	D	98	Y	43	P	25	15	2	28	N	0	0	0		road								DS in melange terrain
113	SW	4	DS	D	90	Y	48	P	65	75	2	361	N	0	0	0		road								DS in melange terrain. est. 10yrs old in field
115	SW	1	DS	D	2000	Y	100	C	40	70	2	207	Y	100	207	280	perennial									meander bend. Inner gorge
116	SW	3	DS	D	2000	Y	105	D	50	35	3	194	Y	100	194	263	perennial									DS on divergent nose of meander bend
117	SF	4	DS	D	98	Y	57	C	230	55	4	1874	Y	40	750	1012	perennial	land								skid trails downslope of landing
118	SF	4	DS	D	98	Y	59	C	170	45	3	850	N	0	0	0		road								toe makes road impassible
119	SF	4	DS	D	98	Y	82	C	70	59	3	459	Y	50	229	310	perennial	road								
120	SD		RS	Q					1800	820									4	3	3	3	4	N	39.15	
121	SW	8	DS	D	98	N		P	31	62	3	216	N	0	0	0										failure between DS 18 & 44. DS in melange. grassy
122	SW	4	DS	D	98	N		P	32	45	3	158	N	0	0	0										DS in melange. grassy
123	SW		RS	Q					890	1390									3	3	3	3	4	N	32.98	
124	SW		RS	P					710	1120									3	3	5	4	4	N	13.39	
125	SF	8	DS	D	90	Y	98	C	75	58	4	644	Y	90	580	783	perennial									trees on unit surface
127	SW		RS	Q					590	590									3	3	3	4	4	N	9.76	
128	SW		RS	D					470	360									2	2	3	3	4	N	6.93	
129	SF		RS	D					2030	930									2	2	2	2	4	N	30.7	likely active-hummocky surface with multiple DS
130	SF		RS	D					2100	910									4	3	3	2	4	N	62.6	
131	SF		RS	D					1250	720									3	3	3	4	4	N	17.99	
132	SF		RS	D					510	300									3	3	2	3	4	N	3.57	
133	SF	1	DS	Q	78	N		C	55	33	3	201	Y	100	201	272	perennial									inner gorge
134	SW	2	DS	D	90	Y	104	C	29	47	3	151	Y	90	136	184	perennial									streambank failure
135	SW	2	DS	D	98	Y	112	P	22	27	3	66	Y	100	66	89	perennial									
136	SW	4	DS	D	95	Y	88	C	38	29	4	163	Y	85	139	187	perennial									
137	SF	2	DS	D	99	Y	120	P	18	32	3	64	Y	100	64	86	perennial									steep streamside
138	SF	4	DS	D	94	Y	68	C	45	37	3	185	N	0	0	0		road								DS nested on RS. veg regrowing
139	SF	8	DS	D	99	Y	62	C	105	38	5	739	N	0	0	0		skid								many skids across slide. road gone at scarp
140	SF	8	DS	D	99	Y	52	P	8	143	3	127	N	0	0	0		road								fill failure on RS
141	SF	8	DS	D	99	Y	33	P	10	115	2	85	N	0	0	0		road								fill failure on RS
142	SF	8	DS	D	99	Y	49	P	10	125	3	139	N	0	0	0		road								fill failure on RS
143	SW	4	DS	Q	78	N		C	147	44	3	717	Y	74	530	716	ephemeral									
144	SW	2	DS	P	78	N		C	103	37	3	425	Y	74	315	425	perennial									likely high % delivery
145	SW		RS	D					1100	580									3	2	3	2	4	N	21.61	
146	SF	8	DS	P	78	N		C	241	48	3	1284	N	0	0	0		road								
147	SW	2	DS	Q	78	N		C	78	35	3	304	Y	74	225	304	perennial									high % delivery likely
148	SW		EF	P					1280	730									3	3	3	3	4	Y	33.69	
149	SD		EF	P					2070	1830									3	3	3	3	4	N	142.61	
150	SF		RS	D					1090	470									3	2	3	3	4	N	17.28	

Table A-1 (continued). Landslide Inventory for the Willow Creek WAU.

Slide Number	Plng WS	MWMU	Landslides		Approx. Failure Date	Field Checked	Slope Gradient (%) Field	Slope Form	Average Landslide Dimensions (feet)			Vol (cu. Yds)	Sediment Delivery	Delivery (%)	Delivery Volume (cu. yds.)	Delivery Mass (tons)	Sediment Routing	Land Use Assoc.	Deep Seated Landslide Morphologcal Descriptions						DSL Area (Acres)	Comments
			Process	Certainty					Length	Width	Depth								Toe	Body	Lat. Scarps	Main Scarps	Veg.	Complex		
151	SF		RS	P					1100	1450									2	2	3	3	4	N	34.64	
152	SF		RS	P					1410	500									3	3	3	3	4	N	26.64	contours do not represent slide very well
153	SF	8	DS	D	98	N		P	205	96	3	2184	Y	74	1616	2181	perennial	road	3	3	5	3	4	N		
153	SD		EF	Q					1020	420									3	3	3	3	4	Y	16.56	
154	SW		RS	Q					650	400									3	3	5	4	4	N	8.16	



Willow Creek / Freezeout Creek Watershed Analysis Unit

Map A-1
Mass Wasting Inventory

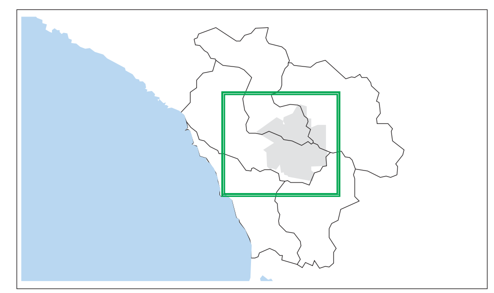
Large Deep-Seated Landslides

Shallow-Seated Landslides
- < 500 cubic yards
- 500 - 5000 cubic yards
- > 5000 cubic yards

Flow Class
- Class I
- Class II
- Class III

MRC Ownership

Planning Watershed Boundary



0 1/2 1 Mile

A total of 104 shallow-seated landslides (debris slides, torrents or flows) were identified and characterized in the Willow Creek WAU. A total of 43 deep-seated landslides (rockslides or earth flows) were mapped in the Willow Creek WAU. A considerable effort was made to field verify as many landslides as possible to insure greater confidence in the results. A total of 36% of the identified shallow-seated landslides were field verified. From this level of field observations, extrapolation of landslide depth and sediment delivery was performed with a reasonable level of confidence. The difference between the mean depth of road-related shallow landslides and the mean depth of non road-related shallow landslides was calculated and determined to be insignificant. Therefore, a mean depth of 3 feet was assigned to all shallow landslides that were not visited in the field. The mean sediment delivery percentage assigned to shallow landslides determined to deliver sediment, but not visited in the field, is 74%. Deep-seated landslides did not have depth or sediment delivery statistics calculated.

The temporal distribution of the 104 shallow-seated landslides observed in the Willow Creek WAU is listed in Table A-2. The spatial distribution by landslide process is shown in Table A-3.

Table A-2. Shallow-Seated Landslide Summary for the Willow Creek WAU Divided into Time Periods.

Planning Watershed	1969-1978 Landslides	1979-1987 Landslides	1988-2000 Landslides
Willow Creek	4	27	37
Freezeout Creek	2	5	24
Dutch Bill Creek	0	0	4

Table A-3. Slide Summary by Type and Planning Watershed for MRC Ownership in the Willow Creek WAU.

Watershed	Debris Slides	Debris Torrents	Debris Flows	Rock Slides	Earth Flows	**Total**	*Road Assoc.*
Willow Creek	61	3	4	14	8	**90**	*20*
Freezeout Creek	29	0	2	15	2	**48**	*13*
Dutch Bill Creek	5	0	0	2	2	**9**	*0*

The majority of landslides observed in the Willow Creek WAU are debris slides and rockslides. Only a few of the rockslides are known to be active in the Willow Creek WAU, the remaining are assumed to be dormant features. Of the 104 shallow-seated landslides in the Willow Creek, 33 are determined to be road-related. This is approximately 1/3 of the total number of shallow-seated landslides.

Three debris torrents and and 6 derbis flows were observed in the Willow Creek WAU. This is approximately 3 and 6 percent, respectively, of the total shallow landslides observed in the Willow Creek WAU. Debris torrents or flows are not common in the Willow Creek WAU, but do occur and are processes that should be taken into account in relation to forest management practices.

Ninety one percent of the shallow landslides inventoried were initiated on slopes greater than 60% gradient, eight landslides occurred on slopes with gradients in the 40s and 50s and one landslide on a slope of 33%. Those nine landslides are attributed to skid trails or road practices and may have been influenced to some degree by the unstable nature of the mélange terrain present in the WAU. Some of them are mid-slope failures in grassland topography that do not deliver any sediment. The majority of inventoried landslides originated in convergent topography where subsurface water tends to concentrate. However some also occurred on areas of steep, planar topography where sub-surface water can be concentrated at the base of slopes, in localized topographic depressions, or by subsoil geologic structures. Few landslides originated in divergent topography, where sub-surface water is routed to the sides of ridges. These observations were, in part, the basis for the delineation of the Willow Creek WAU into Mass Wasting Map Units.

Mass Wasting Map Units

The landscape was partitioned into seven Mass Wasting Map Units (MWMU) representing general areas of similar geomorphology, landslide processes, and sediment delivery potential by shallow-seated landslides (Map A-2). The delineation for the MWMUs was based on qualitative observations and interpretations from aerial photographs, field evaluation, and SHALSTAB output. The units are to be used by forest managers to assist in making decisions that will minimize future mass wasting sediment input to watercourses. Deep-seated landslides are also shown on the MWMU map (Map A-2). The deep-seated landslides have been included to provide land managers with supplemental information to guide evaluation of harvest planning and subsequent needs for geologic review.

Shallow-seated landslide characteristics considered in determination of map units are size, frequency, delivery to watercourses, and spatial distribution. Hillslope characteristics considered are slope form (convergence, divergence, planar), slope gradient, magnitude of stream incision, and overall geomorphology. The range of slope gradients was determined from USGS 1:24000 topographic maps and field observations. Hillslope and landslide morphology varies within each individual Mass Wasting Map Unit and the boundaries are not exact. This evaluation is not intended to be a substitute for site-specific field assessments. Site-specific field assessments will still be required in some MWMUs and deep-seated landslides or specific areas of some MWMUs to assess the risk and likelihood of mass wasting impacts from a proposed management action. The Mass Wasting Map Units are compiled on the entitled Mass Wasting Map Unit Map (Map A-2).

MWMU Number: 1

Title: Steep slopes along low-gradient watercourses

Materials: Shallow soils formed from weathered marine sedimentary rocks. Often bedrock slopes with a veneer of colluvial or alluvial soil deposits. Also, may be comprised of soil deposits of the toe of deep-seated landslides.

Landform Description: Characterized by steep slopes or inner gorge topography adjacent to low gradient watercourses. Slope form is generally planar or convex with slope gradients typically exceeding 65%. The upper extent of the unit is variable, often delineated by a break in slope. Landslides in this unit generally deposit sediment directly into Class I and II streams. Small areas of incised terraces may be locally present. Due to the highly erosive nature of the melange terrain, inner gorge in this terrain may be intermittent. Steep streamside slopes or inner gorge slopes that are controlled by bedrock exhibit greater stability at steeper slope angles, though slopes underlain by thick soils are gentler.

Slope: >65% to vertical, (mean slope of observed mass wasting events is 99%, range: 65-120%)

Total Area: 105 acres; 2.1 % of the total WAU area.

MW Processes: *1 road-associated landslide*

- 1 debris slides

18 non-road associated landslides

- 18 debris slides

Non Road-related Landslide Density: 0.17 landslides per acre for the past 32 years

Forest Practices Sensitivity: High sensitivity to roads due to steep slopes adjacent to watercourses, high to moderate sensitivity to harvesting and forest management due to steep slopes next to watercourses. Localized areas of steeper slopes have an even higher sensitivity to forest practices.

Mass Wasting Potential: High; localized potential for landslides in both unmanaged and managed conditions.

Delivery Potential: High

Delivery Criteria Used: Steep slopes adjacent to stream channels, all landslides delivered sediment into streams.

Hazard-Potential Rating: **High**

Forest Management Related Trigger Mechanisms:

- Sidecast fill material placed on steep slopes can initiate debris slides or flows in this unit.
- Concentrated drainage from roads onto unstable areas can initiate debris slides or flows in this unit.
- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can expose potential failure planes creating debris slides, torrents or flows in this unit.
- Sidecast fill material created from skid trail construction placed on steep slopes can initiate debris slides or flows in this unit.
- Concentrated drainage from skid trails onto unstable areas can initiate debris slides or flows in this unit.
- Cut-slope of skid trails can remove support of slope creating debris slides, torrents or flows in this unit.
- Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.
- Concentrated drainage from roads can increase groundwater, accelerating movement of rockslides or earth flows and over-steepening inner gorge slopes.
- Removal of vegetation above these slopes can result in loss of evapo-transpiration and thus increase pore water pressures that could create debris slides in this unit.

Confidence: High confidence for susceptibility of landslides and sediment delivery in this unit. Moderate to low confidence in placement of this unit, particularly the upper boundary, because of variable materials of mélange terrain and lack of continuous, bedrock-controlled slopes. This unit is locally variable and exact boundaries are better determined from field observations.

MWMU Number: 2

Title: Steep slopes adjacent to intermittent or ephemeral streams.

Materials: Shallow soils formed from weathered marine sedimentary rocks with localized areas of thin to thick colluvial deposits.

Landform Description: Characterized by steep slopes along intermittent or ephemeral streams. Slope form is largely concave with gradients >70%. The upper extent of this unit is typically about 120 feet from the watercourse (based on maximum observed debris slide length of 112 feet; mean landslide length is 49 feet). Landslides in this unit commonly are debris slides that deposit sediment directly into Class II and III watercourses. Occasionally the debris slides can form debris torrents that can transport material down the slope through and out of this unit. This unit typically extends upstream from MWMU 1. The area within this unit is highly correlated to potential landslide hazard areas defined by SHALSTAB (using a log q/t threshold of –2.8).

Slope: >70% (mean slope of observed mass wasting events is 93%, range: 85%-105%)

Total Area: 108 acres; 2.1 % of total WAU area

MW Processes: *2 road-associated landslides*

- 2 Debris slides

7 non-road associated landslides

- 7 Debris slides

Non Road-related Landslide Density: 0.06 landslides per acre for the past 32 years

Forest Practices Sensitivity: High sensitivity to roads due to steep slopes adjacent to watercourses, high to moderate sensitivity to harvesting and forest management due to steep slopes next to watercourses. Localized areas of steeper and/or convergent slopes may have an even higher sensitivity to forest practices.

Mass Wasting Potential: High, due to the steep converging topography of the slope in both unmanaged and managed conditions.

Delivery Potential: High

Delivery Criteria Used: Steep slopes adjacent to stream channels, 87% of landslides observed in this unit delivered sediment to watercourses.

Hazard-Potential Rating: **High**

Forest Management Related Trigger Mechanisms:

- Sidecast fill material placed on steep slopes can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads onto unstable areas can initiate debris slides, torrents or flows in this unit.
- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can over-steepen the slope creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can remove support of the toe or expose potential failure planes of rockslides or earth flows.
- Sidecast fill material created from skid trail construction placed on steep slopes can initiate debris slides, torrents or flows.
- Concentrated drainage from skid trails onto unstable areas can initiate debris slides, torrents or flows.
- Cut-slope of skid trails can remove support of the toe or expose potential failure planes of rockslides or earth flows.
- Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.
- Loss of evapo-transpiration from forest harvest can increase groundwater levels initiating or accelerating movement in rockslides or earth flows or aid in the initiation of debris slides, torrents or flows.

Confidence: High confidence for susceptibility of unit to landslides and delivery of sediment. Moderate confidence in placement of this unit. This unit is highly localized and exact boundaries are better determined from field observations. Within this unit there are areas of low gradient slopes that are less susceptible to mass wasting.

MWMU Number: 3

Title: Steep, dissected and convergent topography

Materials: Shallow soils formed from weathered marine sedimentary rocks with localized thin to thick colluvial deposits.

Landform Description: Steep gradient hillslopes typically converging on confined watercourse channels. The topography has dissected or strongly convergent slope forms, though very steep planar terrain also occurs in this unit. This unit is associated with steep colluvial hollows or headwater swales. All debris torrents and all but one debris flow mapped in the entire Willow Creek WAU originate in MWMU 3. Some of the headwater swales in this unit transition into active gully erosion. Identification of the terrain that fits this unit is a description of high-risk sites for shallow seated landslides. Slopes are greater than 65%, with slopes greater than 80% the greatest risk. Strong topographic convergence or multiple convergent depressions combined with shallow soils typify this terrain. However the lower 1/3 of long steep planar slopes will also be associated with this unit. Often there are seeps, springs or an unusual amount of water present or there is evidence of recent or historic landslides associated with the steep or convergent topography. Tension cracks, jack strawed trees, scraps or benches with scattered tree blowdown can also indicate unit 3 terrain.

Slope: >65%, (mean slope of observed mass wasting events is 74% range: 43 %-94%)

Total Estimated Area: 697 ac., 13.7% of the total WAU

MW Processes: *19 road associated landslides*

- 17 Debris slides, 1 Debris torrent, 1 Debris flow

22 *non-road associated slides*

- 17 Debris slides,1 Debris torrent, 4 Debris flows

Non Road-related Landslide Density: 0.03 landslides per acre for the past 32 years

Forest Practices Sensitivity: High sensitivity to road building, moderate to high sensitivity to harvesting and forest management practices due to moderately steep slopes within this unit. Localized areas of steeper and/or convergent slopes can have higher sensitivity to forest practices.

Mass Wasting Potential: High

Delivery Potential: High

Delivery Criteria Used: The converging topography directs mass wasting down slopes toward watercourses. Delivery potential may be high based on relatively high potential for debris flows and torrents. Failures in headwater swales can torrent or flow down watercourses. Approximately 66% of landslides in this unit delivered sediment.

Hazard-Potential Rating: **High**

Forest Management Related Trigger Mechanisms:

- Sidecast fill material placed on steep slopes can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads onto unstable areas can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads can increase groundwater, accelerating movement of rockslides or earth flows in this unit.
- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can over-steepen the slope creating debris slides in this unit.
- Cut-slope of roads can over-steepen the slope creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can remove support of the toe or expose potential failure planes of rockslides or earth flows.
- Sidecast fill material created from skid trail construction placed on steep slopes can initiate debris slides, torrents or flows.
- Concentrated drainage from skid trails onto unstable areas can initiate debris slides, torrents or flows.
- Cut-slope of skid trails can remove support of the toe or expose potential failure planes of rockslides or earth flows.
- Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.
- Loss of evapo-transpiration from forest harvest can increase groundwater levels initiating or accelerating movement in rockslides or earth flows or aid in the initiation of debris slides, torrents or flows.

Confidence: High, some areas within this unit could have higher susceptibility to landslides and higher delivery rates due to localized areas of steep slopes with weak soils, and unusually adverse ground water conditions.

MWMU Number: 4

Title: Non-dissected topography

Materials: Shallow to moderately deep soils formed from weathered marine sedimentary rocks.

Landform Description: Moderate to moderately steep hillslopes with planar, divergent or broadly convergent slope forms with isolated areas of steep topography or strongly convergent slope forms. Generally a midslope region differentiated from unit 7 by containing relatively competent bedrock.

Slope: >35%, (mean slope of observed mass wasting events 82%, range: 58%- 106%)

Total Area: 316 acres, 6.2% of the total WAU

MW Processes: *3 road-associated landslides*

- 3 Debris slides

5 non-road associated slides

- 4 Debris slides
- 1 Debris flow

Non Road-related Landslide Density: 0.02 landslides per acre for the past 32 years

Forest Practices Sensitivity: Moderate to low sensitivity to road building, moderate to low sensitivity to harvesting and forest management practices due to moderate slope gradients and non-converging topography within this unit. Localized areas of steeper slopes have and even higher sensitivity to forest practices

Mass Wasting Potential: Moderate

Delivery Potential: Moderate

Delivery Criteria Used: Sediment delivery in this unit is localized to landslides that occur adjacent to watercourses, or have long run-outs to a watercourse. Approximately 62% of landslides in this unit delivered sediment.

Hazard-Potential Rating: **Moderate**

Forest Management Related Trigger Mechanisms:

•Sidecast fill material placed on steep slopes can initiate debris slides, torrents or flows in this unit.
•Concentrated drainage from roads onto unstable areas can initiate debris slides, torrents or flows in this unit.
•Concentrated drainage from roads can increase groundwater, accelerating movement of rockslides or earth flows in this unit.
•Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
•Cut-slope of roads can over-steepen the slope creating debris slides in this unit.
•Cut-slope of roads can over-steepen the slope creating debris slides, torrents or flows in this unit.
•Cut-slope of roads can remove support of the toe or expose potential failure planes of rockslides or earth flows.
•Sidecast fill material created from skid trail construction placed on steep slopes can initiate debris slides, torrents or flows.
•Concentrated drainage from skid trails onto unstable areas can initiate debris slides, torrents or flows.
•Cut-slope of skid trails can remove support of the toe or expose potential failure planes of rockslides or earth flows.
• Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.
•Loss of evapo-transpiration from forest harvest can increase groundwater levels initiating or accelerating movement in rockslides or earth flows or aid in the initiation of debris slides, torrents or flows.

Confidence: High, some areas within this unit could have higher susceptibility to landslides and higher delivery rates due to localized areas of steep slopes with weak soils, and adverse groundwater conditions.

MWMU Number:	5
Description:	Low relief topography
Material:	Moderately deep to deep soils, formed from weathered marine sedimentary rocks. Also stream terrace deposits of the lower Willow Creek stream channel.
Landforms:	Characterized by low gradient slopes generally less than 30%, although in some places slopes can be steeper. This unit occurs on ridge crests, low gradient side slopes, and well-developed terraces of lower Willow Creek. This unit can have some localized areas of moderately steep (>35%), concave topography which can be more prone to mass wasting processes. Shallow-seated landslides seldom occur and usually do not deliver sediment to stream channels. Deep gullies exist in this unit and primarily originate in MWMU units 3,6, and 7 and are propagating upslope into unit 5.
Slope:	<30% (based on field observations)
Total Area:	498 acres, 9.8% of WAU area
MW Processes:	*No observed shallow-seated landslides*
Non Road-related Landslide Density:	0 landslides per acre for past 32 years.
Forest Practices Sensitivity:	Low sensitivity to road building and forest management practices due to low gradient slopes
Mass Wasting Potential:	Low
Delivery Potential:	Low
Delivery Criteria Used:	Sediment delivery in this unit is low. Delivery which occurs is primarily associated with gully erosion.
Hazard-Potential Rating:	**Low**

Forest Management Related Trigger Mechanisms:

- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Concentrated drainage from roads and skid trails can initiate or accelerate gully erosion, which can increase the potential for mass wasting processes.

Confidence: Moderate, due to inexactness of boundary locations between this MWMU unit and units 7, 4, and where earth flows of unit 6 are mapped as questionable deep-seated landslides. High confidence in mass wasting potential and sediment delivery potential ratings.

MWMU Number: 6

Title: Identified Earth Flow Complexes

Materials: Fine-grained soils and clays derived highly weathered and sheared marine sedimentary rocks and melange terrain. Soils contain >80% particles less than 2mm in size with rock fragments, some very large, within the soil matrix.

Landform Description: Boundaries of this unit correspond to mapped earth flows, regardless of state of activity. Characterized by hummocky moderate gradient slopes with localized areas of steep or flat topography. Slopes commonly contain areas of backtilted topography, creating ponded water. Ground surfaces in this unit commonly contain areas of grassy vegetation, which may be attributed to a long history of cattle grazing , and the inability of the clay-rich soil to support dense forests. Gullies are abundant in this unit. Rate of movement within earth flows typically is variable and likely fluctuates seasonally according to groundwater conditions. Unit 6 is composed of both individual earth flows and earth flow complexes with many scarps and benches that can create a step-like profile.

Slope: No field-verified mass wasting slope values.

Total Area: 405 acres; 7.9% of the total WAU.

MW Processes: *2 non-road associated landslides*

- 2 Debris slides

Non Road-related Landslide Density: 0.005 landslides per acre for past 32 years.

Forest Practices Sensitivity: High sensitivity to roads, harvesting, and forest management practices on active earth flow surfaces. Moderate sensitivity to roads, harvesting, and forest management practices on non-active earth flow surfaces due to localized areas of variable topography. Potential forest practices in this unit should be assessed on a very local scale due to variable topography and differing rates of movement within an earth flow.

Mass Wasting Potential: High

Delivery Potential: High

Delivery Criteria Used: Many of the earth flows in the Willow/Freezeout Creek WAU have the toe or lateral edges along watercourses. If earth flow movement occurs the landslides will deliver sediment.

Hazard Potential Rating: **High**

Forest Management Related Trigger Mechanisms:

- Sidecast fill material placed on locally steep slopes can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads onto unstable areas can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads can increase groundwater, accelerating movement of earth flows of this unit.
- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can over-steepen the slope creating debris slides in this unit.
- Concentrated drainage from skid trails onto unstable areas can initiate debris slides, torrents or flows in this unit.
- Loss of evapo-transpiration from forest harvest can increase groundwater levels initiating or accelerating movement of earth flows of this unit or aid in initiation of debris slides, torrents or flows.
- Concentrated drainage from roads and skid trails can initiate or accelerate gully erosion, which can increase the potential for mass wasting processes.
- Cut-slope of skid trails can remove support of the toe or expose potential failure planes of earth flows.
- Sidecast fill material created from skid trail construction placed on locally steep slopes can initiate debris slides, torrents or flows.
- Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.

Confidence: Confidence in delineation of unit is consistent with confidence level in mass wasting inventory mapping of deep-seated earth flows. Moderate confidence in hazard potential rating due to variability in geomorphology of unit 6.

MWMU Number: 7

Title: Accelerated Creep Terrain

Materials: Fine-grained soils from highly weathered and sheared marine sedimentary rocks and melange terrain. Soils contain blocks of rock, some very large, within the soil matrix. Very large rock blocks are generally hard and commonly known as "knockers".

Landform Description: Characterized by hummocky slopes with localized areas of steep or flat topography. Ground surfaces in this unit commonly contain areas of grassy vegetation, which may be attributed to a long history of cattle grazing or the inability of the clay-rich soil to support dense forests. Gullies were observed in the headwalls of some drainages. Unit 7 is identified by "rumpled" look of ground surface, similar to unit 6, but lacking scarps and benches. This unit will transition to Unit 6 when earth flows are present.

Slope: 30-70%; mean slope of observed mass wasting events is 58%, range is 33-98%. If the single 98% slope landslide is excluded, mean is 52%, range is 33-64%.

Total Area: 3074 acres; 60.3% of the total WAU

MW Processes:

10 road associated landslides
10 debris slides

1 skid trail associated landslide
1 debris slide

14 non-road associated landslides
14 debris slides

Non Road-related Landslide Density: 0.005 landslides per acre for the last 32 years

Forest Practices Sensitivity: Moderate sensitivity to roads, harvesting, and forest management practices particularly where localized areas of steep slopes exist.

Mass Wasting Potential: Moderate

Delivery Potential: Moderate

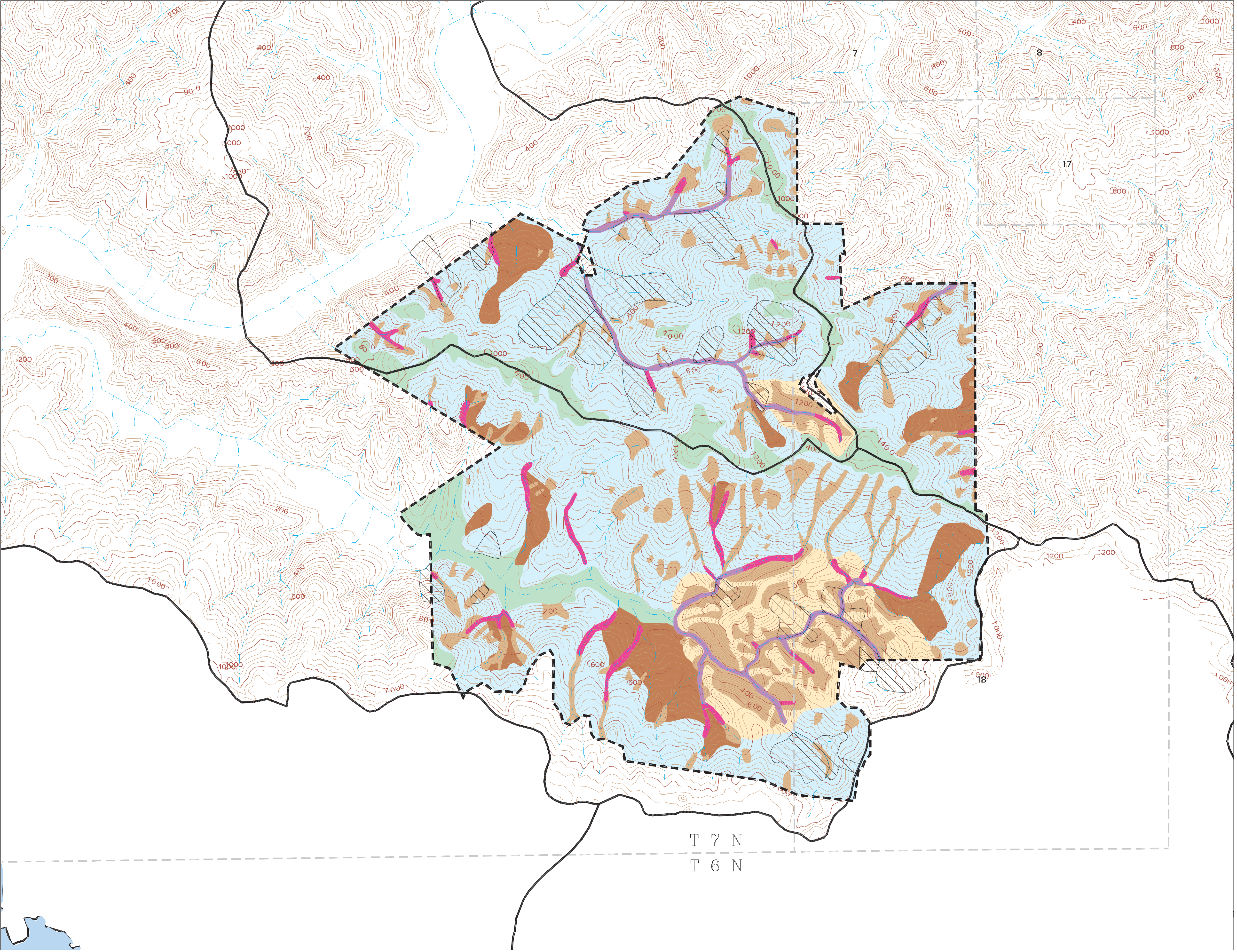
Delivery Criteria Used: 28% of shallow landslides in this unit delivered sediment.

Hazard Potential Rating: **Moderate**

Forest Management Related Trigger Mechanisms:

- •Sidecast fill material placed on locally steep slopes can initiate debris slides, torrents or flows in this unit.
- •Concentrated drainage from roads onto unstable areas can initiate debris slides, torrents or flows in this unit.
- •Concentrated drainage from roads can increase groundwater, accelerating movement of rockslides in this unit.
- •Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- •Cut-slope of roads can over-steepen the slope creating debris slides in this unit.
- •Concentrated drainage from skid trails onto unstable areas can initiate debris slides, torrents or flows in this unit.
- •Loss of evapo-transpiration from forest harvest can increase groundwater levels initiating or accelerating movement of rockslides in this unit or aid in initiation of debris slides, torrents or flows.
- •Concentrated drainage from roads and skid trails can initiate or accelerate gully erosion, which can increase the potential for mass wasting processes.
- •Cut-slope of skid trails can remove support of the toe or expose potential failure planes of earth flows.
- •Sidecast fill material created from skid trail construction placed on locally steep slopes can initiate debris slides, torrents or flows.
- • Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.

Confidence: Moderate confidence in the delineation of this unit due to similarities of terrain of this unit with that of units 4,5, and 6.



Willow Creek / Freezeout Creek Watershed Analysis Unit

Map A-2
Mass Wasting Map Units

Unit 1: Steep slopes along low gradient watersourses

Unit 2: Steep slopes adjacent to select intermittent or ephemeral streams

Unit 3: Steep dissected or convergent topography

Unit 4: Non-dissected topography

Unit 5: Low relief topography

Unit 6: Identified earthflow complexes

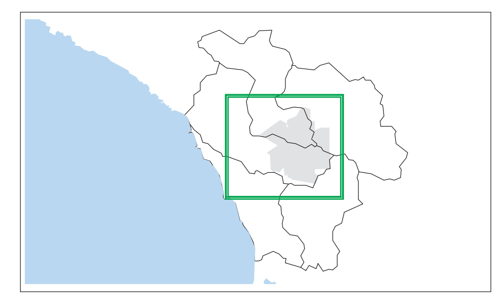
Unit 7: Accelerated creep terrain

Rockslides

Flow Class
- Class I
- Class II
- Class III

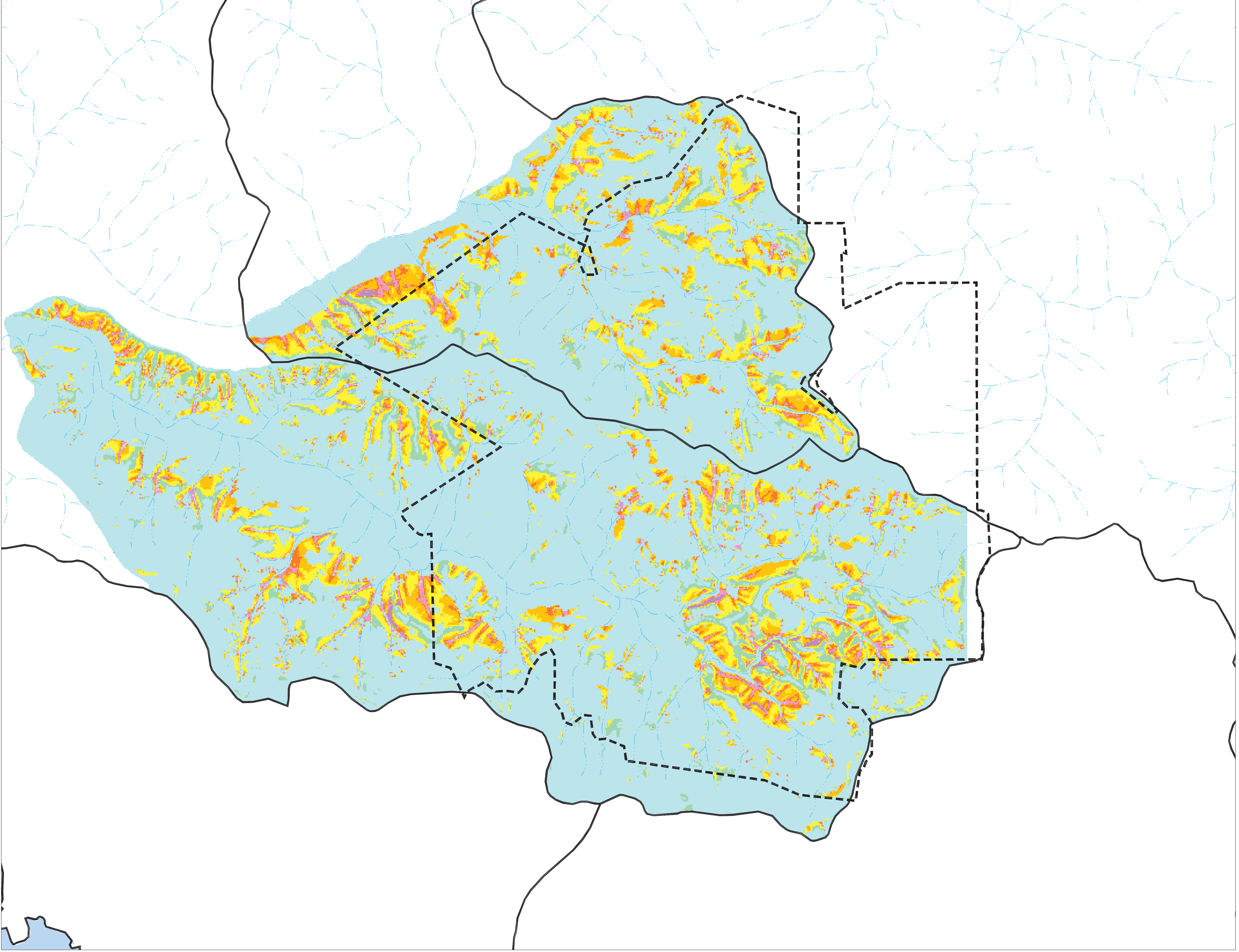
MRC Ownership

Planning Watershed Boundary



0 1/2 1 Mile

September 17, 2001



Willow Creek / Freezeout Creek Watershed Analysis Unit

Map A-3

Shallow Landslide Model SHALSTAB

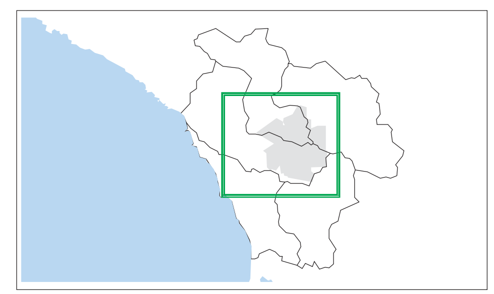
- MRC Ownership
- Planning Watershed Boundary

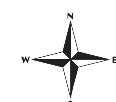
Value of log(q/T)

- -10.1 to -9.9
- -9.9 to -3.1
- -3.1 to -2.8
- -2.8 to -2.5
- -2.5 to -2.2
- -2.2 to 9.8
- 9.8 to 10.1

Flow Class

- Class I
- Class II
- Class III





0 1/2 1 Mile

March 15, 2001

Sediment Input from Mass Wasting

Sediment delivery was estimated for shallow-seated landslides in the Willow Creek WAU. Landslides were determined to have either no sediment delivery or to deliver all or a percentage of their total volume. Of the shallow-seated landslides mapped by MRC in this watershed analysis, 65 percent of the landslides delivered some amount of sediment (Table A-4).

Table A-4. Total Shallow-Seated Landslides Mapped for each Watershed in the Willow Creek WAU. (Road Associated Landslides are Included).

Planning Watershed	Total Slides	Landslides with Sediment Delivery	Landslides with No Sediment Delivery
Willow Creek	68	44	24
Freezeout Creek	31	21	10
Dutch Bill Creek	5	3	2
sum	104	68	36
percentage	100%	65%	35%

Mass wasting was separated into three time periods for data analysis. The first time period is for mass wasting that occurred from 1969-1978, the second time period assessed is from 1979-1987, and the third time period assessed is from 1988-2000. The cut-off dates from each of the time periods are based on the date of aerial photographs used to interpret landslides (1978, 1987/1990, 1996, and 2000) and field observations (2000). While the available aerial photograph years did not allow for perfect ten-year time periods for mass wasting assessment, the time periods were reasonable close to ten-year periods. The periods used in this analysis are useful to provide a general idea of the relative magnitude of sediment delivery for the time periods analyzed particularly the sediment delivery rate estimates.

Approximately 42,000 tons of mass wasting sediment delivery was estimated for the time period 1969-2000 in the Willow Creek WAU. This equates to about 160 tons/sq. mi./yr. Of the total estimated amount, approximately 1300 tons (3% of total) occurred from 1969-1978, approximately 27,000 tons (63% of total) occurred from 1979-1987,and 14,00 tons (34% of total) occurred in the 1988-2000 time period (Table A-5).

For the Willow Creek and Freezeout Creek planning watersheds, sediment input from mass wasting was highest during the 1979-1987 period (Table A-5)(Chart A-1). For the Dutch Bill Creek planning watershed, sediment input was only observed within the 1988-2000 time period, due to few observed landslides in a relatively small amount of MRC ownership.

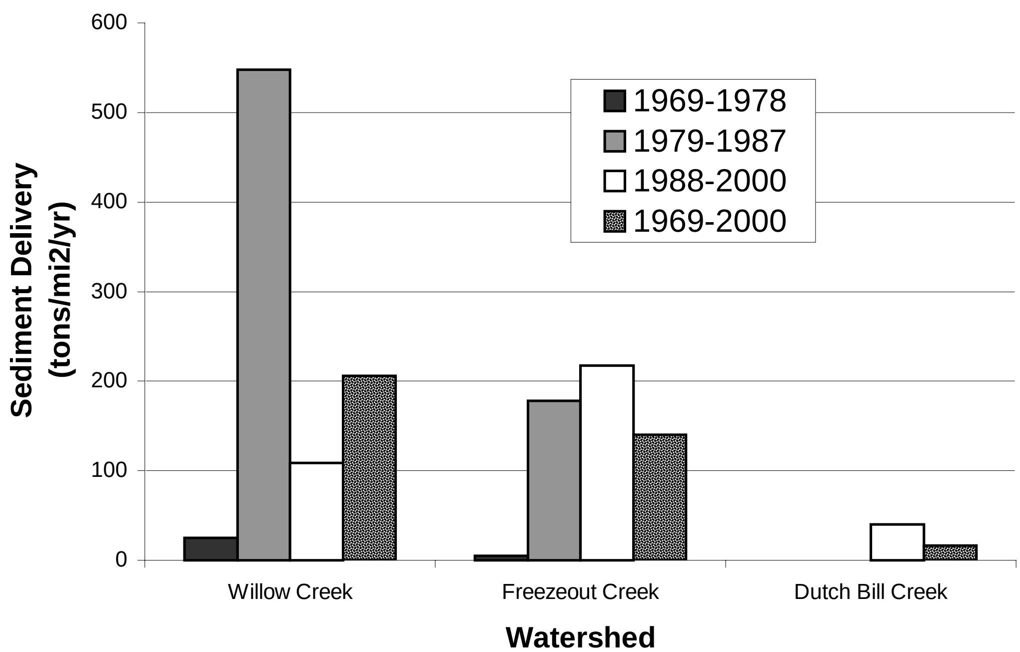
The highest sediment input from mass wasting occurs in the Willow Creek planning watershed. The higher sediment delivery appears to be due to a combination of extensive tractor yarding, and a long history of intense forest management prior to forest practice rules, and a few very large landslides that contributed a high amount of sediment in those planning watersheds. In particular, the high sediment delivery estimate for the

Willow Creek planning watershed from 1979-1987 is mainly from a few, voluminous landslides which may have occurred during the significant storms of 1981/1982. In contrast, Dutch Bill Creek planning watershed has an extremely low mass wasting input. The low input for Dutch Bill Creek, on Mendocino Redwood Company property is attributable to a low number of mapped landslides (5).

Table A-5. Estimated Sediment Volume Input by Watershed for MRC Ownership. Data are Reported in Tons of Sediment Delivered. (*Data based on limited sampling and should only be considered as relative quantities for comparison*).

Planning Watershed	1969-1978	1979-1987	1988-2000
Willow Creek	1100	23000	6500
Freezeout Creek	200	4000	7000
Dutch Bill Creek	0	0	500
Total	1310	27000	14000

Chart A-1. Total Mass Wasting Sediment Input Rate (tons/yr/sq. mi.) from Landslides for MRC Ownership Shown by Watershed and Time Period. (*Data based on limited sampling and should only be considered as relative quantities for comparison*).



Road associated mass wasting was found to contribute approximately 10,000 tons (40 tons/sq. mi./yr) of sediment over the 32 years analyzed (1969-2000) in the Willow

Creek WAU (Table A-6). This represents approximately 23% of the total mass wasting inputs for the Willow Creek WAU for 1969-2000. In the Freezeout Creek planning watershed, road associated landslide sediment delivery was the major sediment source, contributing 54% of the Freezeout Creek delivery. However, in the Willow Creek planning watershed, only 12% of the sediment delivery is from road associated landslides.

Table A-6. Road Associated Sediment Delivery for Shallow-Seated Landslides for the Willow Creek WAU by Watershed, 1969-2000.

Watershed	Road Associated Mass Wasting Sediment Delivery (tons)	Percent of Total Sediment Delivery
Willow Creek	4000	12%
Freezeout Creek	6000	54%
Dutch Bill Creek	0	0%
Total	**10,000**	**23%**

Sediment Input by Mass Wasting Map Unit (MWMU)

Total mass wasting sediment delivery for the Willow Creek WAU, from mass wasting estimates, was separated into respective mass wasting map units. It should be noted that not all planning watersheds contain all eight MWMUs.

The mass wasting map unit with the highest sediment delivery is MWMU 3 (Table A-7); which is estimated to deliver 23,000 tons of sediment over the last thirty-two years, 54% of the total sediment input. Combining the streamside units (MWMU 1 and 2) would yield 9,000 tons, 21% of the total sediment input. MWMU 4 is estimated to have delivered a moderate amount of sediment (6000 tons) suggesting its moderate landslide hazard. No delivery was estimated for MWMU 5 due to the fact that it is a low hazard area with very gently sloping to flat topography and typically does not deliver landslide material except in extraordinary events.

Mass wasting sediment delivery for MWMUs 6 and 7 are artificially low due to the fact that we did not attempt to quantify deep seated landslide sediment inputs or accelerated creep inputs. Only the shallow-seated landslides that were observed in these units were quantified.

Table A-7. Total Sediment Delivery for Shallow-seated Landslides of Mass Wasting Map Units in the Willow Creek WAU (1969-2000). (*Data based on limited sampling and should only be considered as relative quantities for comparison*).

MWMU

	1	2	3	4	5	6	7
Sediment Delivered (tons)	6500	2500	24000	6000	0	1500	3000
% of total delivered	16%	6%	54%	14%	0%	4%	7%

Mass Wasting within the Context of the Willow and Freezeout Creeks Watersheds

There appears to be a greater concentration of area with a high risk of shallow-seated landslides in the upper areas of the MRC ownership of Willow Creek, compared to the lower watershed area on the State Park, due to concentration steep topography there. The landslides mapped within the Willow and Freezeout Creeks watersheds confirm this. A few very large shallow landslides were mapped in the lower watershed areas of Willow and Freezeout Creeks. The majority of shallow-seated landslides are located in the steep swales at the heads of watercourses. The remainder of the large shallow-seated landslides mapped in the lower portion of the Willow Creek watershed are found on very steep slopes on the what appears to be the outside of an ancient meander bend. Furthermore, SHALSTAB output shows that throughout Willow and Freezeout Creeks the greatest hazard for shallow-seated landslides exists at the head and along the margins of watercourses in steep topography (Map A-3).

Deep-seated landslides (earth flows or rockslides) are very prevalent throughout both Willow and Freezeout Creeks. This prevalence is for both on and off the MRC ownership. Furthermore, many of the deep-seated landslides appear to have morphological characteristics suggesting recent activity, particularly in lower Willow Creek.

CONCLUSIONS

In natural forest environments of the California Coast Ranges, mass wasting is a common occurrence. In the Willow Creek WAU this is due to relatively steep slopes, the weak rocks (weathered interbedded sandstone, shale and melange terrain), locally thick colluvial soils, legacy timber harvest practices, and the occurrence of high intensity rainfall events. The topography of the Willow Creek WAU is unique when compared to that of MRC ownership in other Coast Range watersheds. The presence of significant mélange terrain here explains the abundance of the grassy, earth flow topography which overall is less steep than slopes of other MRC watersheds.

Mass wasting features of variable magnitude are observable throughout the Willow Creek WAU. The vast majority of the landslides visited in the field during this assessment occurred on slopes greater than 60%, in areas of convergent and or very steep planar topography.

Approximately 1/3 of the number of shallow-seated landslides are road associated in the Willow Creek WAU, though road related mass wasting only represented 23% of the sediment delivery. The reason that the sediment delivery proportion is so low is due to an abundance of mid-slope road associated failures that do not deliver sediment. MWMU 3 has the highest risk of road associated mass wasting sediment delivery. Roads prove to be a significant factor in the cause of shallow-seated mass wasting events in this unit. Better road construction practices combined with design upgrades of old roads will lower the amount over time.

MWMU 3 represented the greatest mass wasting sediment delivery for any one unit, providing 54% of the sediment delivered from 1969-2000. Streamside mass wasting (combining MWMU 1 and 2) yields 21% of the total sediment input. The combined delivery for MWMUs 5, 6, and 7 comprises 24% of the total shallow seated landslide sediment delivery, while encompassing most of the landscape in the WAU.

Mass wasting sediment input is estimated to be at least 158 tons/sq. mi./ yr. over the 1969-2000 time period for the entire Willow Creek WAU. Overall, in the Willow Creek WAU, sediment delivery from mass wasting was highest in the Willow Creek planning watershed in the 1979-1987 time period. This area was particularly high due to legacy harvest practices, compounded by the occurrence of a few very large landslides that significantly increased the sediment delivery amounts that may have been triggered by particularly large storms of the 1981-1982 winter. The forest harvesting technique utilized in the 1950's and 1960's was tractor skidding of logs. This skidding was performed on steep slopes and often in streamside environments and inner gorges, compacting and destabilizing the soil, increasing the frequency of mass wasting. Evidence of past harvesting practices can be seen in upper Willow Creek, where portions of rail lines still exist within the stream channel.

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