APPENDIX A

MASS WASTING ASSESSMENT

Sinlahekin and South Fork Toats Coulee Watershed Analysis
Watershed Analysis Numbers 46 & 47

WAU #s 49-01-025; 49-01-030

Level 2 Watershed Assessment

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This assessment was performed in accordance with the Standard Methodology for Conducting Watershed Analysis, Chapter 222-22 WAC (Washington Forest Practices Board, 1997), Version 4.

Qualified Analyst   Date

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1. INTRODUCTION AND OVERVIEW

The mass wasting assessment of the South Fork Toats Coulee and Sinlahekin WAUs was conducted in accordance with the Washington Forest Practices Board Standard Methodology for Conducting Watershed Analysis (1997). The primary objective of the mass wasting analysis is to determine the spatial distribution of landslide hazards in the WAUs and to estimate the effects of forest practices on landsliding and the resulting delivery of sediment to streams and rivers, and to other public resources. The final product is a slope stability map that can be used as a guide to create forest management prescriptions.

2. SUMMARY OF GEOLOGIC AND PHYSIOGRAPHIC SETTING

The South Fork Toats Coulee and Sinlahekin WAUs are underlain by rocks originating during the Triassic through Cretaceous Periods (Mesozoic Era) and the Eocene Epoch. The headwaters and higher elevations of the South Fork Toats Coulee WAU consist of Triassic metamorphic orthogneiss with non-metamorphosed Cretaceous intrusives that occur along the eastern WAU boundary and in the northern portion on national forest lands. The eastern portion of the WAU, including the confluence of the South and Middle Forks, consists of non-metamorphosed Jurassic intrusives in Jurassic metamorphic orthogneiss. The headwaters of the Sinlahekin Creek consist of Triassic metamorphic orthogneiss with more recent Eocene volcanics and sedimentary rocks along both sides of the mainstem extending to the northern and southern watershed boundaries of Sinlahekin Creek. The northeastern portion of the WAU is underlain by unmetamorphosed Triassic intrusives and more recent Cretaceous intrusives that extend to the southern boundary of the WAU (Stoffel et. al. 1991).

Soils have derived from bedrock weathering, glaciation, deposition of volcanic ash, and mass wasting. Generally, volcanic ash and pumice occur on the northerly aspects of low and mid-elevations in the WAUs. The southern aspects are dominated by glacial till. The valley bottoms consist of stratified alluvial deposits, and the lower hillslopes contain deep colluvial deposits (USDA Forest Service 1995).

Elevations range from approximately 518 m (1,700 ft) around Blue Lake to over 2,530 m (8,300 ft) at the summit of Windy Peak. Both Toats Coulee and Sinlahekin creeks flow generally in an east-northeastern direction.

3. SUMMARY OF METHODS

The slope stability analysis of the South Fork Toats Coulee and Sinlahekin WAUs was conducted in accordance with the Washington Forest Practices Board Standard Methodology for Conducting Watershed Analysis (WFPB 1997) and with general theory and practice of slope stability science (Sidle et al. 1985; Swanston 1991; Benda et al. 1998). Mass wasting in the South Fork Toats Coulee and Sinlahekin WAUs was differentiated into the following categories: shallow-rapid landslides, deep-seated landslides, earthflows, debris flows in first- and second-order channels, and rock avalanches. Shallow landslides are generally considered to have depths of less than several meters. Landslide debris that mobilize and travel through (and generally scour) first- and second-order channels with gradients in excess of approximately 8° (14 percent) are classified as debris flows (Benda and Cundy 1990).

Hillslope characteristics were tabulated at each landslide site (typically using 1:24,000-scale topographic maps and 1:12,000 aerial photographs), including hillslope gradient, slope form, and landform, if appropriate. Field studies have revealed that the rate of landsliding increases with increasing hillslope gradients with the majority of failures occurring on hillslopes with gradient greater than 36° (73 percent) and very few slides occurring on hillsides less than 30° (58 percent) (Dragovich et al. 1993).

Each landslide was associated with forestry land uses and forest age categories according to criteria contained in Washington State's watershed analysis manual (WFPB 1997). Categories include: 1) clearcut (approximately less than 20-year-old trees); 2) second growth forests (20 to 50 years old); 3) mature forests; and 4) roads and/or landings. In addition, the occurrence of sediment delivery to stream channels (i.e., landslide deposits in channels) was also tabulated for each slide when they were visible on aerial photos. In addition to the use of aerial photography, field observations took place at various locations (constrained by road access). Field data included landslide type, hillslope gradient, triggering mechanism (i.e., land use and forest age association), slope form, and sediment delivery. Field data provided a check on the data collected using aerial photography.

4. SUMMARY OF ANALYSIS AND RESULTS

Eleven landslides were inventoried in the South Fork Toats Coulee and Sinlahekin WAUs using aerial photos from 1977 (high elevation), 1983, and 2000, and field surveys during September 2001 (see Map A-1 and Table A-1 [DNR Form A-1] in Section 10 – Supporting Information). Field observations obtained at various locations confirmed some of the data such as landslide type, hillslope gradient, initiation mechanisms, slope form, and sediment delivery. Several landslides that occurred outside of the WAUs were examined. The actual number of recent landslide scars in the South Fork Toats Coulee and Sinlahekin WAUs is likely greater than eleven because small slides, particularly those occurring in inner gorges or under forest canopy, are not always visible on aerial photographs. Of the eleven inventoried mass wasting features (not including slow moving earthflows), four were categorized as rockfalls and the remaining seven were categorized as shallow landslides. Five of the seven shallow failures occurred in convergent areas, landforms often referred to as bedrock hollows, swales, or unchanneled valleys (Dietrich and Dunne 1978; see Figure A-1 [Section 10 – Supporting Information]). It was not possible to obtain accurate estimates of slope gradient from aerial photography and topographic maps often underestimate hillslope gradients (Dragovich et al. 1993). To circumvent this limitation, measurements of slope gradients were obtained in the field at several landslide sites in the Redman Creek area located outside of the South Fork Toats Coulee and Sinlahekin WAUs. Measurements of hillslope gradient at the headscarps of three shallow failures ranged between 28° and 32° (53 and 62 percent).

Shallow landslides are concentrated in relatively steep terrain underlain by mechanically strong igneous rocks. These failures are common in the Pacific Northwest region, and they often trigger debris flows (Benda and Cundy 1990). Small, shallow slides and slumps located in inner gorges (Figure A-2 [Section 10 – Supporting Information]) occur sporadically throughout the South Fork Toats Coulee and Sinlahekin WAUs and they appear to be associated with locally steep topography rather than a specific lithology. Slow-moving earthflows (Figure A-3 [Section 10 – Supporting Information]), in contrast, appear to be preferentially located in the mechanically weaker Tertiary sedimentary and volcaniclastic rocks, or near contacts between different lithologies, such as volcaniclastics and harder metamorphic rocks. Rock cliffs and rockfall processes appear to be concentrated along oversteepened valley walls located primarily in hard metamorphic rocks. Although lithology is an important determinant in mass wasting, the topography, which partly reflects the mechanical strength of the rock, is the most important clue regarding the potential for different types of failures.

Overall, the South Fork Toats Coulee and Sinlahekin WAUs have a very low occurrence of landsliding. In particular, shallow failures that trigger debris flows and inner gorge slides and slumps are rare compared to watersheds located in wetter areas of the Pacific Northwest region. Landslide inventories in wet and steep parts of the Pacific Northwest often consist of hundreds of landslides and debris flows in areas equivalent in size to South Fork Toats Coulee and Sinlahekin WAUs (NCASI 1985). The primary reasons for the low occurrence of mass wasting in the WAUs are presumed to be the low annual rainfall and the general lack of high intensity winter rainfall. Precipitation falls mostly as snow during the winter months. The predominance of low-gradient topography (i.e., gradients less than 30°; 58 percent) also contributes to a low landslide rate. The low incidence of mass wasting probably also contributes to a relatively low overall erosion or coarse sediment yield rate in the WAUs.

5. DESCRIPTION OF MASS WASTING MAP UNITS

Five mass wasting map units (MWMU) were created for the South Fork Toats Coulee and Sinlahekin WAUs (see DNR Map A-2 in Section 10 – Supporting Information). The five mass wasting map units were created to differentiate among: 1) shallow landslides in steep, convergent areas that create debris flows in headwater channels (and deliver sediment to large channels); 2) small, shallow failures and deeper slumps in inner gorges; 3) rockfall avalanches; 4) slow-moving earthflows; and 5) all other features. The MWMU map should be used as a general guide because not all potentially unstable areas can be mapped from aerial photography and topographic maps. The map unit descriptions listed below are inherently more accurate than the map because they are not limited to certain places. The map unit descriptions apply to all areas in the South Fork Toats Coulee and Sinlahekin WAUs (mapped or unmapped) that have the stated physical characteristics. In addition, some map units, such as MWMUs #1 and #4, may contain unmapped areas of inner gorges (MWMU #2). Hence, the most appropriate and effective application of the slope stability analysis is by recognition of potentially unstable areas on the ground during timber harvest layout and road construction using the map unit descriptions described below and the map as a general guide.

The MWMU descriptions for the South Fork Toats Coulee and Sinlahekin WAUs are summarized below.

MWMU #1. This map unit is characterized by a potential for shallow-rapid landslides that can transition into debris flows in first- and second-order channels. Potential slide areas are concentrated in small, convergent landforms (swales, hollows) and channel heads that have gradients of 28° to 32° (53 to 62 percent) and shallow soils 1 to 2 m (3 to 7 ft). There is a high potential for delivery of sediment and woody debris to streams of any order. The map unit is mapped in polygons that represent a population of sites and individual sites need to be identified in the field using terrain diagnostics (Figure A-4 [Section 10 – Supporting Information]). Although tree root strength is potentially important (Burroughs and Thomas 1977), failure probability may be low because of low winter precipitation. Failures are likely to occur in these areas following wildfires (see Part I – Watershed Overview). This map unit may also contain unmapped inclusions of MWMUs #2 and #4. Field surveys will be needed to identify such inclusions. Shallow landslides and debris flows characterizing this map unit have been investigated by science staff of the Department of Natural Resources (Grizzel 1995; Schlichte, Ryan, and Donda 1995; Powell 1995; reports in Section 10 – Supporting Information).

MWMU #2. This map unit is characterized by shallow landslides, small rotational failures, and rockfalls located in inner gorges along streams of any order (Figure A-5 [Section 10 – Supporting Information]). Gorge relief may range from several meters to greater than 100 meters (328 ft). Slope gradient of slide prone areas is generally greater than 36° (73 percent) and soil thickness may vary between one and several meters (3 to 7 ft). Sediment and wood can be delivered to streams of any order but most commonly to large channels bordered by high relief gorges. MWMU #2 may also contain convergent (i.e., inclusions of MWMU #1), divergent, and planar landforms. MWMU #2 may contain significant areas of stable ground (i.e., lower slope) and areas that cannot deliver sediment because of benches and river terraces located below gorges that can intercept debris. More stable areas and areas contained in inner gorges that do not deliver sediment can be identified and excluded from MWMU #2 during field surveys. This map unit may contain inclusions of MWMU #4, or the toes of earthflows that originate from farther uphill. The ability to map all inner gorges was limited by dense forest canopy. Hence, it should be assumed that inner gorge landforms are located discontinuously along many of the streams in the South Fork Toats Coulee and Sinlahekin WAUs, and field surveys (during timber harvest layout, etc.) will be needed to assist in their identification.

MWMU #3. Map unit #3 is characterized by rock falls and rock avalanches, and infrequent, very coarse-textured, shallow landslides (Figure A-6 [Section 10 – Supporting Information]). The topography is dominated by rocky cliffs and associated talus deposits. MWMU #3 is highly dissected into gullies or swales, but the unit may also contain planar and divergent areas. All slope forms are potentially unstable. Actively eroding areas have slopes of 35° to 90° (>70 percent) and depositional areas have slopes generally between 30° and 40° (58 to 84 percent). Rock debris can be delivered directly to channels but more commonly to toeslopes of hillsides and riverine terraces. Vegetation coverage varies from none to fully covered, but most commonly, vegetation is sparse.

MWMU #4. Map unit #4 contains landforms that have earthflow characteristics, including springs, tipped and contorted trees, rolling, benchy, and chaotic topography, closed depressions, grabens (in soil or bedrock), and headscarps (Figure A-7 [Section 10 – Supporting Information]). In general, mapped areas indicate "suspect" terrain and these areas were not verified in detail in the field. This map unit contains all slope forms, and hillslope gradients may range from 5° to 30° (9 to 58 percent). Earthflows may contain closely spaced, small streams. Primary mode of failure appears to be soil creep, although several grabens indicate ground ruptures were also likely. Sediment from earthflows can be delivered to streams of all orders. Only a small number of earthflows were identified from aerial photography and in the field; additional field surveys will be needed to identify other (unmapped) sites. The thickness of soil or weathered bedrock is unknown but probably ranges between 5 and 100 m (16.5 and 328 ft).

MWMU #5. Map unit #5 encompasses all other terrain in the South Fork Toats Coulee and Sinlahekin WAUs not contained in MWMUs #1 through #4. This map unit contains all slope forms and gradient combinations, and includes ridgetops, valley floors, terraces, and moderate gradient hillslopes (generally less than 30°; 58 percent). MWMU #5 may also contain unmapped inclusions of MWMUs #1 through #4 that do not deliver sediment to streams. However, due to the difficulty of mapping slope stability features using aerial photography and often dense canopy, MWMU #5 may also contain significant unmapped inclusions of hazardous landforms, in particular MWMU #2, as well as earthflow terrain. Field surveys will be required to determine the location of any inclusions.

6. DESCRIPTION OF TRIGGER MECHANISMS

6.1 BACKGROUND

The triggering mechanisms for landslides in the South Fork Toats Coulee and Sinlahekin WAUs are similar to landslide triggering mechanisms throughout the Pacific Northwest (Sidle et al. 1985; Swanston 1991; Benda et al. 1998). The most important triggering mechanisms include topography (including slope gradient and curvature), geotechnical properties of soils and weathered bedrock or colluvium, depth of soil or colluvium, biotic factors such as vegetation roots and animal burrows, climate (including precipitation intensity and duration) and fire effects (discussed briefly in Part I – Watershed Overview).

Shallow failures, like those that occur in MWMUs #1 and #2, are most sensitive to the soil strength component contributed by trees and other plants because of their shallow failure planes. Deep failures (~>5 m [~>16.5 ft]) and earthflows are less sensitive to rooting strength than shallow failures. Vegetative rooting strength should have little influence on rockfall avalanches. Therefore, the effect of timber harvest (or wildfire) in reducing the mechanical strength of the soil would be most pronounced in areas prone to shallow failures (i.e., MWMUs #1 and #2). Shallow landslides are also triggered by intense precipitation, and precipitation can be effectively increased by road drainage diversions and by altering snowmelt patterns due to timber harvest.

Deep-seated landslides and earthflows may also be susceptible to increased precipitation from road drainage diversion and from altered snowmelt regimes (Swanston 1991). However, the linkage between forestry practices and the movement of deep-seated landslides and, in particular, earthflows located in bedrock are not well understood. Nevertheless, road construction that significantly alters hillslope topography or road drainage patterns, that increase flow to unstable areas, may contribute to increased failure potential. In the South Fork Toats Coulee and Sinlahekin WAUs, the form of failure seems to be dominated by slow soil deformation or creep, and hence, the risk posed by these features from a channel perspective appears to be quite limited. In addition, it is likely that earthflow toes may contribute to habitat by creating low-gradient, floodplain-dominated channels and/or wetlands upstream of their valley constrictions.

6.2 EMPIRICAL EVIDENCE IN SOUTH FORK TOATS COULEE AND SINLAHEKIN WAUs

The relatively few landslides documented during the watershed analysis (n = 12) are insufficient to develop quantitative linkages between forest management practices and slope instability in the

South Fork Toats Coulee and Sinlahekin WAUs. In the single case, a shallow landslide occurred within a recent clearcut and triggered a debris flow in Redman Creek (located outside of the South Fork Toats Coulee and Sinlahekin WAUs). There were also similar failures that occurred nearby in unharvested terrain (see Grizzel 1995 in Section 10 – Supporting Information). Loss of rooting strength in the clearcut in the Redman Creek basin likely contributed to the landslide, but there is insufficient information to determine the magnitude of the effect.

Large-scale clearcutting began in the South Fork Toats Coulee and Sinlahekin WAUs in the 1970s. A general lack of historical harvest may contribute to the few documented landslides in the WAUs. However, the prevalence of low gradient topography and low rainfall no doubt contribute to the observed low density of landslides. Despite the lack of data, the mass wasting map units are indexed according to their susceptibility to forest practices based primarily on well-understood concepts and other studies that have established causal relationships between forest practices and landsliding.

6.3 MASS WASTING MAP UNITS: SENSITIVITY TO FOREST PRACTICES

MWMU #1. This map unit is moderately to highly sensitive to clearcut timber harvesting (reduced rooting strength) and to road construction (fill failures and road drainage diversion). Partial harvesting may reduce management-related failure risk in convergent areas, but to an unknown degree. Partial harvesting should limit the contribution of timber harvest to landslide potential. Identification of the most unstable areas of convergent landforms (Benda et al. 1998) and application of leave areas may reduce the potentially destabilizing effect of timber harvest. Empirical data are limited to Redman Creek, a slide area located outside of the South Fork Toats Coulee and Sinlahekin WAUs.

MWMU #2. This unit is moderate to highly sensitive to clearcut timber harvesting (reduced rooting strength) and to road construction (fill failures and road drainage diversion). Partial harvesting may reduce management-related failure risk in convergent areas, but to an unknown degree. Partial harvesting should limit the contribution of timber harvest to landslide potential.

MWMU #3. This map unit is generally not sensitive to timber harvest but the areas mapped generally lack merchantable timber. Road construction may trigger rockfalls.

MWMU #4. Sensitivity is unknown but it is thought to be low since slope movement is dominantly in the form of soil creep. Highest sensitivity is presumed to be associated with road construction that undercuts earthflow toes (particularly near streams) and the diversion of significant drainage by road prisms. There is little empirical evidence in the South Fork Toats Coulee and Sinlahekin WAUs regarding the relationship between earthflow movement and timber harvest.

MWMU #5. Overall low sensitivity except in unmapped inclusions of the other four map units.

7. OTHER FORMS OF MASS WASTING: POTENTIAL RESPONSE TO WILDFIRES

Because wildfire is a natural disturbing agent in the South Fork Toats Coulee and Sinlahekin WAUs (Toats Coulee Watershed Analysis, Okanogan National Forest 1995), widespread surface erosion and gullying may occur following wildfires. Although there are no studies of post-fire erosion in the WAUs, there is an abundance of studies from other, similar mesic mountainous landscapes in the region that reveal a propensity of punctuated and intense erosion following fires due to hydrophobic soils and loss of rooting strength (Rice 1973; Klock and Helvey 1976; Scott and Williams 1978; Meyer et al. in press). There is no *a-priori* reason to believe the terrain in the South Fork Toats Coulee and Sinlahekin WAUs is not similarly sensitive to wildfires, including low intensity fires that are not necessarily stand-replacing events. Therefore, it seems likely that erosion and therefore sediment delivery to stream and valley floors occurs sporadically in time, driven in part by natural fire cycles. However, natural fire patterns may have been altered by widespread fire suppression during the last half century. This action may have caused some areas in the South Fork Toats Coulee and Sinlahekin WAUs to be more prone to intense stand-replacing fires and intense erosion. In addition, not all map units may be equally susceptible to post-fire surface erosion, gullying, and shallow landsliding. Although post-fire surface erosion, gullying, and landsliding may be the dominant erosion mechanisms in the South Fork Toats Coulee and Sinlahekin WAUs, that topic falls beyond the scope of this watershed analysis.

8. CONFIDENCE IN WORK PRODUCTS

A limitation in the assessment of mass wasting potential in the South Fork Toats Coulee and Sinlahekin WAUs is the low number of inventoried landslides (n = 12). This low number partly reflects the low level of forest management activity in the watersheds, but it also reflects a low natural susceptibility of landsliding because of the dominance of low-gradient topography and the absence of high intensity winter precipitation. The landslide mechanisms observed (i.e., shallow failures in hollows and inner gorges, debris flows in first- and second-order channels, earthflows, and rock avalanches) are well documented in the scientific literature. Therefore, the triggering mechanisms for these landslides are generally well known and that information was used to characterize the five mass wasting map units and to classify their susceptibility to forestry activities. Overall, there is a high to moderate confidence in the mass wasting assessment with respect to identifying failure types, triggering mechanisms, and sediment delivery potential. However, dense forest canopy that obscured much of the terrain during the landslide inventory and mapping procedure would have limited the number of slides that could be detected in the South Fork Toats Coulee and Sinlahekin WAUs. However, these slides will very likely be found in landforms described as susceptible to failure (i.e., MWMUs #1 to #4). In addition, because of dense forest canopy in much of the WAUs, it was not feasible to identify all slide prone areas, such as MWMUs #1 and #2. This limitation can be overcome by field surveys that search for slide prone areas (i.e., MWMUs #1 to #4) during timber harvest layout or road construction.

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10. SUPPORTING INFORMATION

This Section contains the following:

Figures A-1 through A-7 (MWMU illustrations and examples).
Tables A-1 and A-2. (DNR Forms A-1 and A-3, respectively).
DNR Form A-1 (Table A-1). Mass Wasting Inventory Data.
DNR Form A-2. Mass Wasting Map Unit Descriptions (multiple pages).
DNR Form A-3. Mass Wasting Summary Table (Table A-2).
DNR Map A-1. Mass Wasting Landslide Inventory.
DNR Map A-2. Mass Wasting Map Units and Hazard Potential Ratings.

Required components of the mass wasting module report.

Product	Section Presented
I. Title Page	Title Page
II. Table of Contents	Table of Contents
III. Maps:	
Map A-1. Mass Wasting Landslide Inventory	Section 10
Map A-2. Mass-Wasting Map Units and Hazard Potential Ratings	Section 10
IV. Summary Data:	
Form A-1. Mass Wasting Inventory Data	Section 10
Form A-2. Mass Wasting Map Unit Description	Section 10
Form A-3. Mass Wasting Summary Table	Section 10
Form A-4. Summary of Mass Wasting and Delivery Potential	Not Needed
V. Summary Text:	
Summary geologic and physiographic setting pertinent to mass wasting interpretations	Section 2
Study Methods	Section 3
Summaries of analysis and results	Section 4
Descriptions of mass wasting map units	Section 5
Description and explanation of mass wasting potential ratings	Section 6
Statement on trigger mechanisms	Section 6
Statement of author's confidence level	Section 8
VI. Supporting Information:	
DNR Geologic reports	Section 10

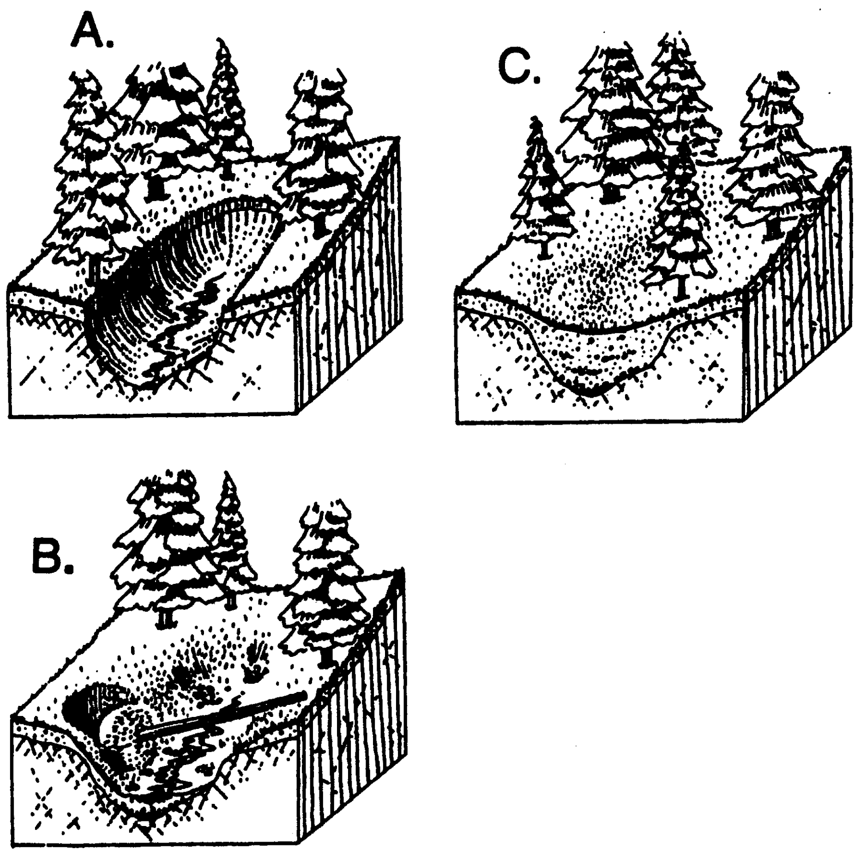

Figure A-1. An illustration of a landslide-prone bedrock hollow showing the refilling and fail cycle (adapted from Dietrich et al. 1988). This is the landslide-prone landform found in MWMU #1.

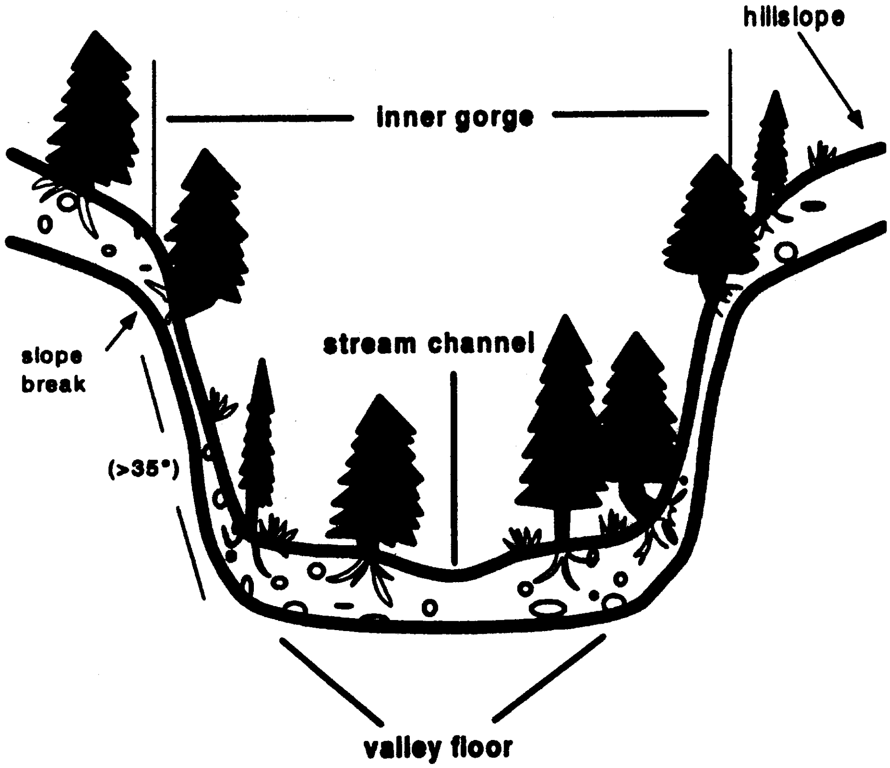

Figure A-2. An illustration of landslide-prone inner gorges located immediately adjacent to streams of all sizes in the South Fork Toats Coulee and Sinlahekin WAUs. Adapted from Benda et al. 1997. This landform defines MWMU #2.

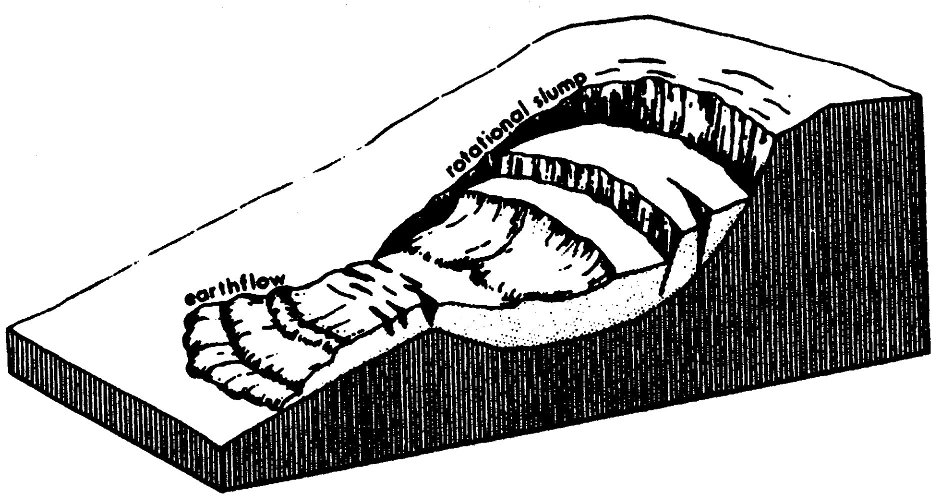

Figure A-3. An illustration of a deep-seated earthflow, similar to suspect terrain located in MWMU #4. Adapted from Selby 1993.

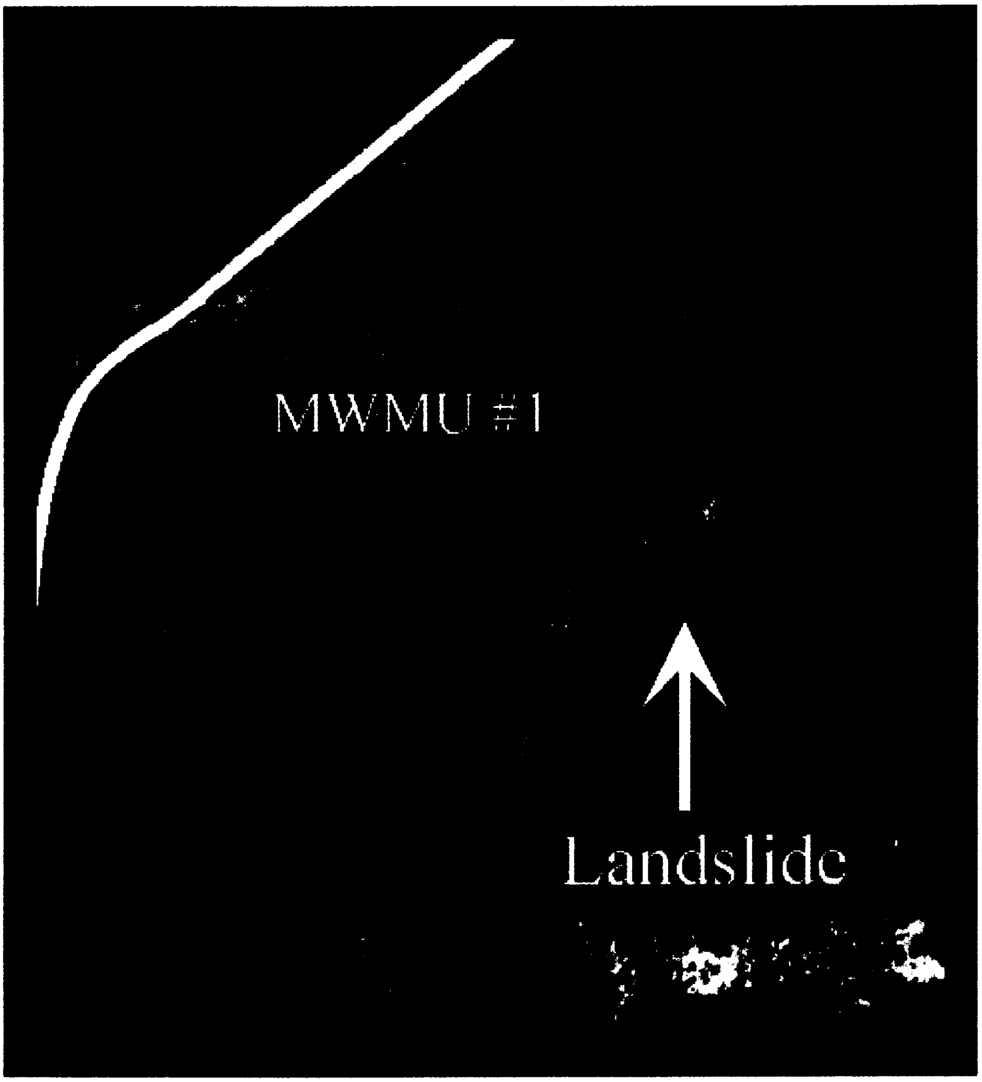

Figure A-4. An example of MWMU #1 in the South Fork Toats Coulee and Sinlahekin WAUs.

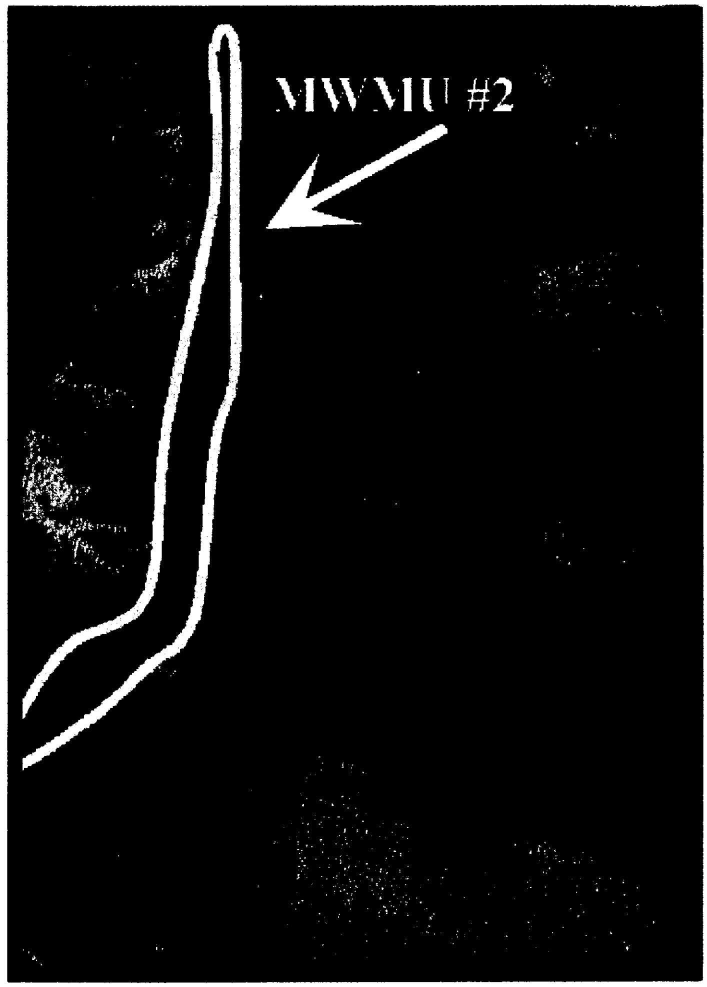

Figure A-5. An example of MWMU #2 inner gorge slopes in the South Fork Toats Coulee and Sinlahekin WAUs.

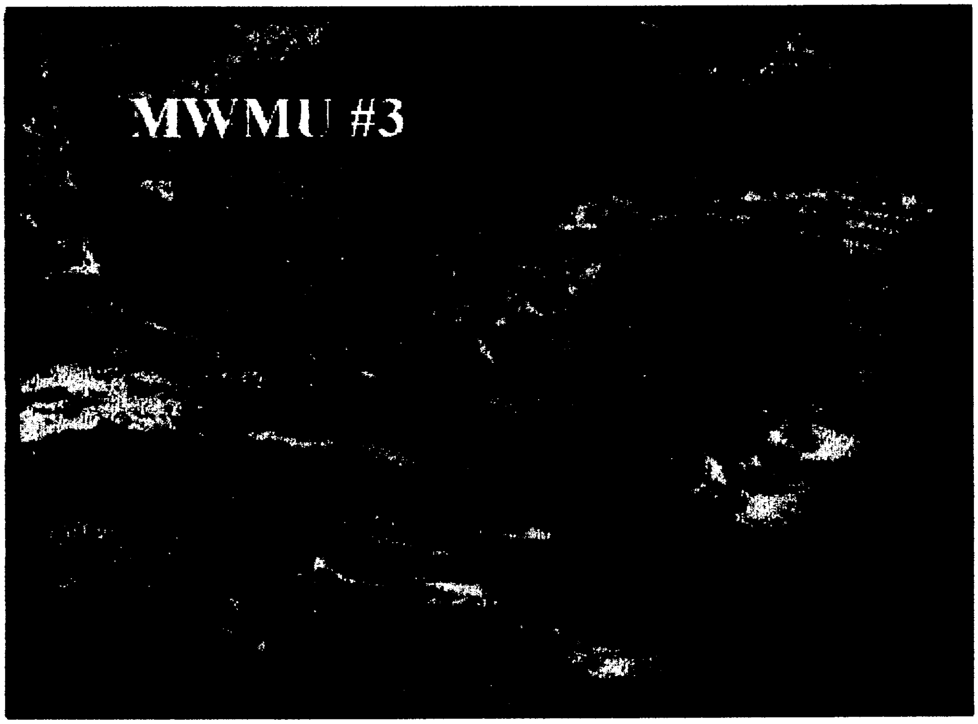

Figure A-6. An example of MWMU #3 rock avalanches in the South Fork Toats Coulee and Sinlahekin WAUs.

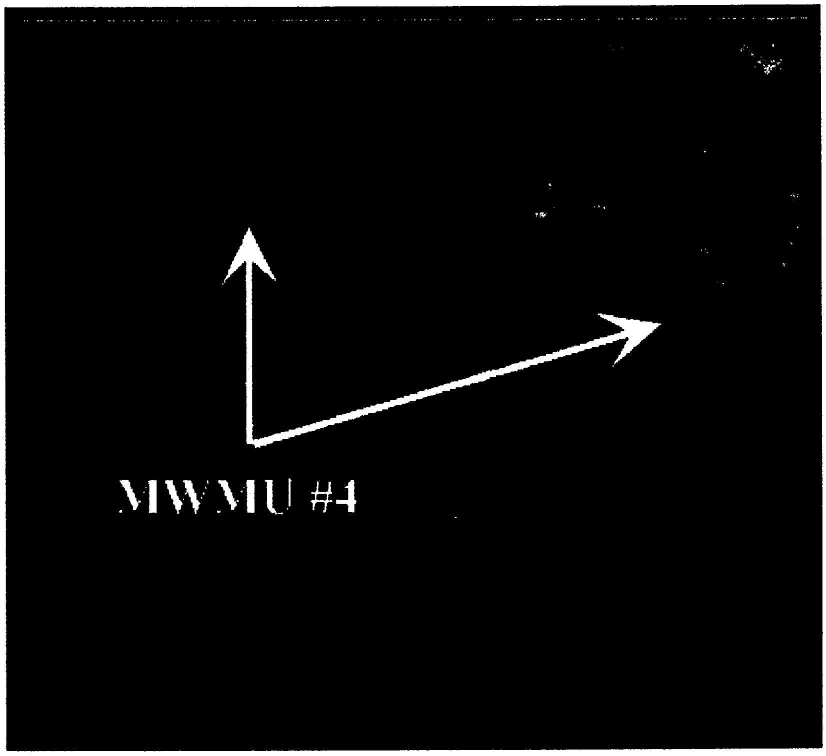

Figure A-7. An example of MWMU #4 earth flows in the South Fork Toats Coulee and Sinlahekin WAUs.

DNR FORM A-1. LANDSLIDE INVENTORY DATA.

Table A-1. DNR Form A-1, Landslide Inventory Data.

MWMU Number	Landslide I.D. Number	Landslide Type	Aerial Photo Year	Aerial Photo Number	Sediment Delivered to Stream (Y,N, order or stream name)	Associated Land Use Activity	Landform	Township (N)	Range (E)	Section
#3	1	rockfall	1983	21 56-370,371	N	none	hollow	37	25	se32
#3	2	rockfall	1983	1-57-123,124	N	none	hollow	37	25	ne32
#3	3	rockfall	1983	1-57-123,124	N	none	hollow	37	25	sw28
#3	4	rockfall	1983	1-57-123,124	N	none	hollow	37	25	sw28
#1	5	shallow-rapid	2000	69-29-232,233	1	clearcut	hollow	38	23	nw12
#1	6	shallow-rapid	2000	69-31-177,178	3	mature forest	hollow	37	24	se17
#2	7	shallow-rapid	2000	69-31-178,179	4	mature forest	inner gorge	37	24	se8
#1	8	shallow-rapid	2000	56-35-52,53	N	road	hollow	37	24	sw12
#2	9	shallow-rapid	1983	49-171,172	MF Toats Coulee	none	inner gorge	39	24	se19
#1	10	shallow-rapid	1977	24E-74,75	Sinlahekin Creek	non-forested	hollow	37	23	se1
#1	11	shallow-rapid	1977	24E-74,75	Sinlahekin Creek	mature forest	hollow	37	24	nw7

DNR FORM A-2. MASS WASTING MAP UNIT DESCRIPTION

DNR FORM A-2 MWMU #1

Description: MWMU #1 is mapped as a polygon that contains numerous unmapped bedrock hollows, channel heads of type 5 streams (first-order channels), inner gorges, and planar and divergent hillslopes. MWMU #1 is broadly mapped and landslide-prone hollows must be identified in the field. This map unit also contains significant areas of more stable ground, such as planar and divergent slopes.

Materials: Colluvium originating from igneous, metamorphic, and volcanic rocks.

Landform: Bedrock hollows, channel heads, and inner gorges along first-order streams.

Slope: 28° to 36+°.

Elevation: Variable.

Total Area: 4.8 and 2.6 km^2 (1,194 and 654 acres) in South Fork Toats Coulee and Sinlahekin WAUs, respectively, although the most unstable zone is confined to a relatively narrow zone along the axis of hollows, channel heads, and inner gorges. For guidance on delineating the most unstable zone of a bedrock hollow, see Appendix 1 in Benda et al. 1998. A relatively large proportion of the 7.4 km^2 should be found to be stable upon field surveys.

Mass Wasting Processes: Shallow landslides and debris flows.

Forest Practice Sensitivity: There were too few landslides in MWMU #1 to empirically determine sensitivity to forest practices. Based primarily on other field studies and slope stability theory, hillslopes located within MWMU #1 are susceptible to both timber harvesting and road building. Timber harvesting decreases the stability of these marginally-stable slopes by reducing or eliminating the apparent cohesion attributable to tree root strength. In addition, cable yarding logs over this area may disturb the ground and stumps, which may contribute to failure. Roads in this map unit may: 1) create areas of concentrated drainage; 2) overload already marginally stable slopes (sidecast material); 3) create oversteepened cut-bank slopes (>40°); and 4) reroute and concentrate drainage.

Delivery: Direct delivery to fish-bearing streams.

Delivery Criteria: For debris flows: Benda and Cundy 1990.

Delivered Hazard Rating: High.

Confidence: High.

DNR FORM A-2 MWMU #2

Description: Landslide-prone inner gorges along channels. Convergent forms most unstable. Relief may range from 10 m to greater than 100 m. Direct delivery to streams. Dense forest canopy in many areas of the watersheds precluded the accurate depiction and mapping of inner gorges. Hence, all stream courses should be assumed to be at least partially bordered by slide-prone inner gorges; the actual locations of inner gorges must be identified on the ground using field surveys.

Materials: Colluvium originating from igneous, metamorphic and volcanic rocks; may include glacial materials.

Landform: All slope forms, but convergent areas potentially most unstable.

Slope: $\geq 36^{o}$.

Elevation: Variable.

Total Area: 0.2 and 2.5 km^2 (53 and 623 acres) in South Fork Toats Coulee and Sinlahekin WAUs, respectively.

Mass Wasting Processes: Shallow-rapid landslides and possibly debris flows (relatively small volume failures)

Forest Practice Sensitivity: There were too few landslides in MWMU #2 to empirically determine sensitivity to forest practices. Based primarily on other field studies and slope stability theory, hillslopes located within MWMU #2 are sensitive to forest harvest and road construction. Timber harvest may reduce rooting strength and lead to a higher incidence of landsliding. In addition, roads in this map unit may: 1) create areas of concentrated drainage; 2) overload already marginally stable slopes; and 3) reroute and concentrate drainage.

Delivery: Direct delivery to streams.

Delivery Criteria: Proximity to channels. Note that terraces and floodplains may intercept slide debris rendering slide prone areas in inner gorges low hazard.

Delivered Hazard Rating: High.

Confidence: High.

DNR FORM A-2 MWMU #3

Description: This unit is characterized primarily by rock falls and rock avalanches located in mostly unvegetated bedrock cliffs and scree slopes.

Materials: Rocky cliffs.

Landform: All slope forms, but convergent areas potentially most unstable.

Slope: 35° to 90°.

Elevation: Variable.

Total Area: 19.1 km^2 (4,711 acres) in the Sinlahekin WAU, only.

Mass Wasting Processes: Rock avalanches.

Forest Practice Sensitivity: Because of the absence of significant soil and vegetation, sensitivity is low to forest harvest. However, road construction along cliffs could undermine rock walls and lead to localized rock avalanches.

Delivery: Some localized delivery of rock debris to streams.

Delivery Criteria: Proximity to streams; most rock debris should be intercepted by talus or scree slopes.

Delivered Hazard Rating: Low.

Confidence: Moderate.

DNR FORM A-2 MWMU #4

Description: Suspect earthflow terrain (ancient). Distinguishing characteristics include springs, tipped and contorted streams, rolling, benchy, and chaotic topography, closed depressions, grabens (in soil or bedrock), and headscarps. Soil displacement appears to be mainly by soil creep. These features need to be verified in the field by slope stability experts.

Materials: Identified sites located mainly in mechanically weak volcaniclastic rocks. In some locations, glacial sediments are also involved.

Landform: Suspect unit as mapped has indeterminate boundaries but landforms include those described above.

Slope: Variable.

Elevation: Variable.

Total Area: 4.1 and 9.2 km^2 (1,015 and 2,281 acres) in the South Fork Toats Coulee and Sinlahekin WAUs, respectively.

Mass Wasting Processes: Although ground ruptures and rotational failures may occur infrequently (no recent events observed on aerial photos or on the ground), soil displacement appears to be dominated by soil creep.

Forest Practice Sensitivity: Sensitivity to timber harvest is unknown because of the lack of failures and lack of widespread timber harvest on these features in the two WAUs. Since the dominant form of soil displacement appears to be soil creep, sensitivity to loss of rooting strength should be low. Highest sensitivity is presumed to be associated with road construction that undercuts the toes of earthflows in the vicinity of streams.

Delivery: Variable, depends on the location of earthflow toes with respect to stream channels.

Delivery Criteria: Should be determined in the field.

Delivered Hazard Rating: Low with respect to harvest. Moderate with respect to roads.

Confidence: Moderate.

DNR FORM A-2 MWMU #5

Description: MWMU #5 consists of all other terrain in the South Fork Toats Coulee and Sinlahekin WAUs not contained in MWMUs #1 through #4, and areas similar to MWMUs #1 through #4 that do not deliver to streams of any order. Generally, the unit consists of broad and gentle hillslopes and includes ridgetops and valley floors. This map unit has a low likelihood of landsliding, and consequently low potential for direct delivery of sediment to channels.

Materials: Bedrock and colluvium originating from igneous, metamorphic and volcanic rock; also includes unconsolidated glacial-derived sediments.

Landform: Broad and gentle hillslopes.

Slope: generally $\geq 30^{o}$, but can include all slope gradients.

Elevation: Variable.

Total Area: 171.3 and 154.1 km^2 (42,337 and 38,087 acres) in the South Fork Toats Coulee and Sinlahekin WAUs, respectively.

Mass Wasting Processes: Shallow-rapid and deep-seated landslides are rare.

Forest Practice Sensitivity: Low.

Delivery: No sediment delivery.

Delivery Criteria: Determine delivery potential in the field for any inclusions of MWMU #1 to #4 in this unit.

Delivered Hazard Rating: Low.

Confidence: High.

DNR FORM A-3. MASS WASTING SUMMARY TABLE

Table A-2. DNR Form A-3, Mass Wasting Summary Table.

ACTIVITY	MASS WASTING FEATURE				
	Shallow Rapid LS	Large Persistent Deep-Seated Failures	Rock Falls	Debris Flows(1)	Totals
Clear Cut 0-20 years	1			1	1
Clear Cut 20-50 years					
Partial Cut					
Road	1				1
Stream Crossing					
Landing					
Other Forest Practices					
Wildfire					
Mature Forest	3			1	3
Non-Forest Land Use	1			1	1
None	1		4		5
Totals	7		4		11

(1) Subset of shallow rapid landslides that developed into debris flows. Numbers are not included in totals.

(2) The low occurrence of slides does not provide sufficient information to assess associated landuse activity.