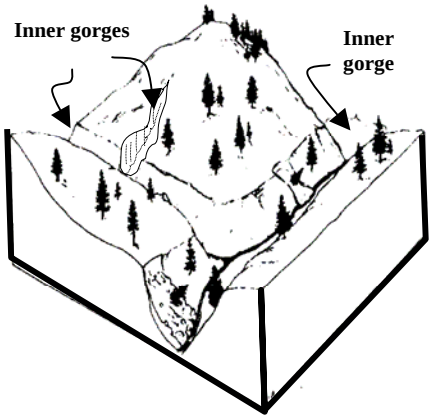
Appendix B: Form A-2
Skamokawa Landform Descriptions

Landform # 1 – Inner Gorges – Very High Hazard



Description: Rule-identified inner gorges are steep-sided (>70%), commonly flat-bottomed canyons or gullies that are formed by a combination of fluvial and mass-wasting processes. The upper boundary on either side of an inner gorge is the first break in slope of at least 10° at the crest of the inner walls. Inner gorges can be symmetrical or asymmetrical in cross-section, and are commonly discontinuous in lateral extent. Debris slides, debris flows, slope ravel, and small rotational failures frequently originate within inner gorges. In addition, colluvial evacuations from bedrock hollows or other convergent slopes upstream from inner gorges can evolve into scouring debris flows during major storms/floods. Inner gorge walls can revegetate rapidly, masking recent slope failures on air-photos and on the ground.

Gradient of Sidewalls: >70% field-measured, or >60% DEM-measured; field-measured slopes are commonly steeper than those determined from the DEM.
Material: Inner gorges form in soil and other unconsolidated surficial deposits over all rock types within this watershed.
Total Landform Area: 1588.2 acres

Mass Wasting Process: Inner gorges form due to a combination of stream incision, scouring by debris flows, and sidewall landslides. Oversteepened walls of inner gorges often fail as debris slides, slope ravel, or small rotational slumps and can produce debris flows. Failure most often occurs within unconsolidated surficial deposits or at the soil-bedrock interface.

Forest Practice Sensitivity: Roots from trees that stand in and along inner gorges can extend into the gully walls and significantly impede mass wasting by providing increased soil strength (Krogstad, 1995). Timber harvest, road and landing construction, and other activities that reduce root strength on steep slopes can greatly decrease slope stability. Roads and landings can destabilize inner gorge walls by undercutting and oversteepening them; sidecast and road/landing fill can also load slopes excessively. Furthermore, roads and landings can trigger landslides by capturing, rechanneling or pooling surface runoff and shallow groundwater, resulting in saturation of road fill or thin soils.

Trigger Mechanisms: Mass wasting on these naturally unstable slopes is triggered by soil saturation (particularly by artificial diversion of surface and ground water), loss of root strength, and oversteepening and loading of slopes. These mechanisms can be caused by timber harvest, road and landing construction or improper drainage especially during periods of intense and/or prolonged precipitation. Of the landslides identified within this unit, 39% were identified within clear-cuts and 6% were road-related.

Mass Wasting Potential: **Very High,** 71 landslides were mapped in 1588.2 acres of discretely mapped inner gorges over a 33 year air photo period, yielding an overall landslide frequency rate of 1354.7; the LFR is 76.3 for road related landslides, and 1278.4 for all other land uses (see LHZ protocol).

Delivery Potential/Criteria: **Moderate,** 71 landslides (100%) with a total area of 6.5 acres delivered sediment/debris from discreetly mapped inner gorges in this WAU. Inner gorges commonly contain steep slopes that are proximal to water; thus, it is likely that landslides in these features will deliver sediment to streams and/or other public resources. Delivery criteria are based on field and photo observations of visible sedimentation, proximity of streams, and unobstructed routes of delivery. This unit has an overall landslide area rate for delivery of 123.1; the LAR is 16.2 for road related landslides, and 106.9 for all other land uses (see LHZ protocol).

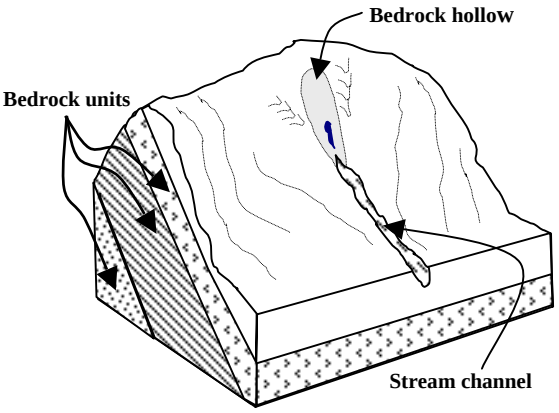
Overall Hazard Rating: **Very High,** based on analyst professional judgment, LHZ protocol, and standard Forest Practices Rules.

Confidence: **High,** based on excellent photo quality and coverage, and adequate field verification.

Comments: Further field investigation is necessary in areas where steep inner gorge walls are adjacent to toes of deep-seated landslides. It is likely that more inner gorges exist in the Skamokawa WAU than have been mapped, therefore a review in the field of stream channels and small drainage features located under dense canopy is recommended. The LFR and LAR numbers presented here are underestimates of the total impact of inner gorges in this WAU, as landforms # 10 and # 11 both contain many mapped landslides occurring in inner gorges that are not mapped individually. Inner gorges are defined by rule in WAC 222-16-010 and described in more detail in the Forest Practices Board Manual, Section 16.

Appendix B: Form A-2
Skamokawa Landform Descriptions

Landform # 2 – Bedrock Hollows – Very High Hazard



Description: Rule-identified bedrock hollows are steep (>70% at the steepest point), elongate inverted spoon-shaped areas of convergent topography with concave profiles. Bedrock hollows are also called colluvium-filled bedrock hollows, zero-order basins, swales, bedrock depressions, or hollows. These features can exist on any steep hillslope and within other landforms. They seldom contain channels but commonly drain directly into inner gorges or other channels downslope. Colluvial debris that accumulates in these steep convergent areas is prone to saturation by shallow groundwater, making bedrock hollows highly susceptible to slope failures. Bedrock hollows revegetate and refill with soil, which can mask their presence on air-photos and on the ground. However, even subdued hollows can be prone to destructive landslides.

Gradient at Steepest Point: >70% field-measured, or >60% DEM-measured; field-measured slopes are typically steeper than those determined from the DEM.
Material: Bedrock hollows can form in soil and other unconsolidated surficial deposits over all rock types within this watershed.
Total Landform Area: 208.0 acres

Mass Wasting Process: Steep hollows or swales in bedrock or other resistant materials are depositional sites for colluvial soils and debris. The convergent nature of these hollows concentrates shallow groundwater resulting in occasionally saturated soils, increased pore pressures, slope loading, and low effective soil strength. These areas are naturally unstable and any activity that results in further soil saturation, loss of root strength, and/or oversteepening of slopes will increase the probability of hollows evacuating as debris slides, debris flows, and other shallow landslides. Failures occur within unconsolidated surficial deposits or at the soil-bedrock interface.

Forest Practice Sensitivity: Roots from trees that stand adjacent to and within bedrock hollows can significantly impede mass wasting by providing increased soil strength (Krogstad, 1995). Timber harvest, road and landing construction, and other activities that degrade root strength on steep slopes can greatly reduce slope stability. Roads/landings can destabilize bedrock hollows by oversteepening them and by channeling water into them; sidecast and road/landing fill can also oversteepen and load slopes excessively. Timber harvest can increase soil saturated by loss of canopy interception, evapotranspiration, and increased effect of rain-on-snow events.

Trigger Mechanisms: Mass wasting on these naturally unstable slopes is triggered by soil saturation (particularly by artificial diversion of surface and ground water), loss of root strength, and oversteepening and loading of slopes. These mechanisms can be caused by timber harvest, road and landing construction or improper drainage, especially during periods of intense and/or proloned precipitation. Of the landslides identified within this unit, 7% were identified within clear-cuts and 48% were road-related.

Mass Wasting Potential: **Very High,** 54 landslides were mapped in 208.0 acres of discretely mapped bedrock hollows over a 33 year air photo period, yielding an overall landslide frequency rate of 7868.0; the LFR is 3788.3 for road related landslides, and 4079.7 for all other land uses (see LHZ protocol).

Delivery Potential/Criteria: **Very High,** 47 landslides (87%) with a total area of 12.5 acres delivered sediment/debris to public resources from discretely mapped bedrock hollows in this WAU. Bedrock hollows contain steep slopes that are commonly upstream from water; thus, it is likely that landslides in these features will deliver sediment to streams and/or other public resources. Delivery criteria are based on field and photo observations of visible sedimentation, proximity of streams, and unobstructed routes of delivery. This unit has an overall landslide area rate for delivery of 1814.8; the LAR is 1249.0 for road related landslides, and 565.8 for all other land uses (see LHZ protocol).

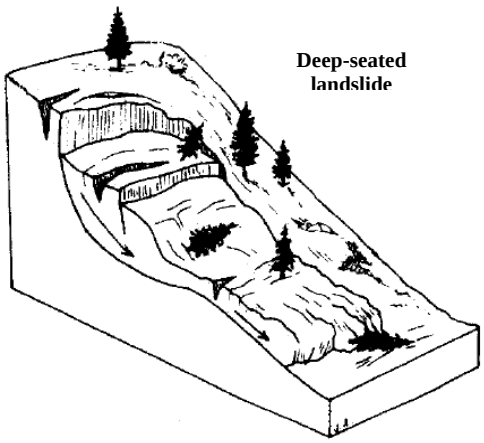
Overall Hazard Rating: **Very High,** based on LHZ protocol and Forest Practices Rules.

Confidence: **High,** based on excellent photo quality and coverage, and adequate field verification.

Comments: Great care should be taken not to channel excess water into bedrock hollows. It is likely that many more rule-identified bedrock hollows exist in the Skamokawa WAU than have been mapped. The LFR and LAR numbers presented here are underestimates of the total impact of bedrock hollows in this WAU, as landforms # 10 and # 11 both contain many mapped landslides occurring in bedrock hollows that are not mapped individually. Bedrock hollows are defined by rule in WAC 222-16-010 and described in more detail in the Forest Practices Board Manual, Section 16.

Appendix B: Form A-2
Skamokawa Landform Descriptions

Landform # 8 – Active Deep-Seated Landslides – Very High Hazard



Description: This map unit consists of deep-seated landslides that have evidence of recent movement, such as fresh headscarps, oversteepened toes, crevassed ground, jackstrawed or split trees, recent shallow landsliding, and/or distinct lateral boundaries (side scarps). This landform includes rotational and translational landslides and earthflows, with slip planes that are chiefly below maximum tree rooting depth (i.e., > about 10 ft). Weakened, fractured, and recently mobilized soil and bedrock materials of deep-seated landslides are also extremely susceptible to shallow landslides. Many active deep-seated landslides extend directly into stream channels and have the potential to deliver large volumes of sediment/debris to streams and other public resources.

Gradient: 18 to 109% (46% average)
Material: Deep-seated landslides can form in all rock types within this WAU.
Total Landform Area: 799.7 acres

Mass Wasting Process: Deep-seated landslides can mobilize large amounts of sediment by failing along slip surfaces that are tens to hundreds of feet deep and many acres in area. These large-scale slope failures can occur extremely quickly (seconds to minutes) or gradually over many years, moving either continuously or sporadically. While deep-seated landslides most commonly occur independently of human influence, they can be destabilized or reactivated by forest practices that undercut or oversteepen their toes, channel water onto them, or load them to excess. Furthermore, the weathered, weakened, fractured, and recently mobilized soil and bedrock materials that compose deep-seated landslides are extremely susceptible to shallow landslides, such as debris slides and debris flows.

Forest Practice Sensitivity: Deep-seated landslides can be destabilized or reactivated by forest practices that undercut or oversteepen their toes, load them excessively, channel water onto them, or otherwise change their surface or subsurface hydrology. The bodies of many deep-seated landslides are supported from below; any forest practice that undercuts or oversteepens their toes can dramatically increase movement rates. Dumping of road material (end-haul, sidecast, etc.) or other artificial loading of deep-seated landslides can increase mass movement or otherwise destabilize these features. In addition, diversion of water onto deep-seated landslides can increase pore-water pressure within the landslide, effectively lubricating slip surfaces and potentially loading the landslide mass. Furthermore, timber harvest has the potential to increase hydraulic pressure within a landslide by decreasing the canopy's capacity to intercept rain and transpire water vapor.

Trigger Mechanisms: Movement of these inherently unstable features can be triggered by both natural causes (such as earthquakes or intense and/or prolonged precipitation or rain-on-snow events); or by forest practices that change landslide hydrology (such as surface water diversion or canopy removal) or landslide structure (such as undercutting or oversteepening of slopes, or loading of slopes).

Mass Wasting Potential: **High**, 19 shallow landslides were mapped in 799.7 acres of active deep-seated landslides over a 33-yr airphoto period, yielding an overall landslide frequency rate of 720.0. The LFR for road related landslides is 37.9, and 682.1 for all other land uses (see LHZ protocol).

Delivery Potential/Criteria: **High**, 10 shallow landslides (53%) with a total area of 5.4 acres delivered sediment/debris from this landform unit. Deep-seated landslides can mobilize large volumes of sediment through large-scale slope failure. Furthermore, many deep-seated landslide toes extend directly into stream channels. Delivery criteria are based on field and photo observations of direct delivery into and proximity to streams, as well as unobstructed routes of delivery. This unit has an overall landslide area rate for delivery of 206.1; the LAR is 7.7 for road related landslides, and 198.4 for all other land uses (see LHZ protocol).

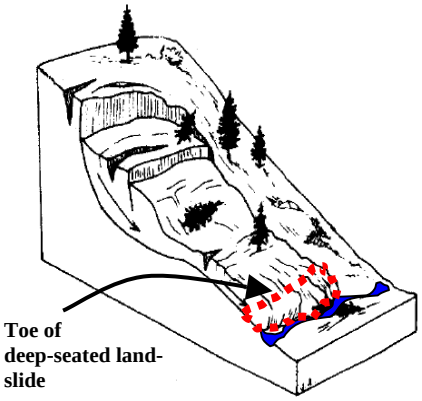
Overall Hazard Rating: **Very High**, based on analyst professional judgment and the LHZ protocol.

Confidence: **Moderate**, based on excellent photo quality and coverage, but limited field verification.

Comments: Within active deep-seated landslides, particular attention should be paid to headscarps, marginal streams, and toes that extend directly into stream channels. Many deep-seated earthflows throughout the basin were mapped as dormant or relict. However, as observed in the field these earthflows may become reactivated and behave as active landslides at any time. Be aware that these landslides are not included in landforms # 8 or # 9, but can potentially become mass-wasting hazards and deliver large volumes of sediment to public resources. See Map A-1 and Table A-1 for locations of mapped earthflows.

Appendix B: Form A-2
Skamokawa Landform Descriptions

Landform # 9 – Toes of Deep-Seated Landslides > 65% – Very High Hazard



Description: Rule-identified toes of deep-seated landslides are the hummocky deposits located at the lowest extents of large landslides (see description for LF # 8). They are commonly oversteepened (and thus unstable) due to the downhill accumulation of landslide material; oversteepening can be intensified by stream undercutting. This landform is steep (>65%) and often displays evidence of movement such as crevassed ground, jackstrawed or split trees, and stretched roots. This terrain can contain areas of recent shallow landsliding. The weakened, fractured, and recently mobilized soil and bedrock debris of deep-seated landslide toes are also susceptible to secondary/superimposed deep-seated landslides.

Gradient: >65% field-measured, or >55% DEM-measured; field-measured slopes are typically steeper than those determined from the DEM.
Material: Deep-seated landslides can form in all rock types within this WAU. The toes of deep-seated landslides consist of broken and recently mobilized soil and bedrock materials. The materials in these typically unsorted deposits can range in consistency from clays and silts to large (many meters across) blocks of transported bedrock.
Total Landform Area: 733.3 acres

Mass Wasting Process: Deep-seated landslides can mobilize large amounts of sediment by failing along slip surfaces that can be tens to hundreds of feet deep and many acres in area. The materials that compose the toe deposits of these landslides are extremely susceptible to shallow landslides and small rotational failures, particularly where they are undercut by streams. Furthermore, toe-marginal streams can rapidly cut inner gorges into these nonresistant toe deposits; occasionally, slopes gentler than 60% fail within these stream channels. Some toes of deep-seated earthflows can fail at substantially lower angles (<20%) and, although not covered by this landform unit, should also be field-inspected carefully.

Forest Practice Sensitivity: Toes of deep-seated landslides can be destabilized or reactivated by forest practices that further undercut or oversteepen them, load them excessively, channel water onto them, or otherwise change their surface or subsurface hydrology. The bodies of many deep-seated landslides are supported from below; any activity that undercuts or oversteepens their toes can dramatically increase movement of the entire slide mass above. Dumping of road material or other artificial loading of deep-seated landslides can increase mass movement or otherwise destabilize these features. In addition, diversion of water onto deep-seated landslides can increase pore-water pressure within the landslide, effectively lubricating slip surfaces and potentially loading the landslide mass. Furthermore, timber harvest has the potential to increase hydraulic pressure within a landslide by decreasing the canopy's capacity to intercept rain and transpire water vapor.

Trigger Mechanisms: Movement of these inherently unstable features can be triggered by both natural causes (such as earthquakes or intense and/or prolonged precipitation or rain-on-snow events) or by forest practices that change landslide hydrology (such as surface water diversion or canopy removal) or landslide structure (such as loading, undercutting, or oversteepening of slopes).

Mass Wasting Potential: **Very High**, 30 shallow landslides were mapped in 733.3 acres of rule-identified toes of deep-seated landslides over a 33-yr air-photo period, yielding an overall landslide frequency rate of 1239.8. There were no road related shallow landslides mapped in this unit.

Delivery Potential/Criteria: **Very High**, 29 landslides (97%) with a total area of 23.3 acres delivered sediment/debris from this landform unit. Deep-seated landslides can mobilize large volumes of sediment through large-scale slope failure. Virtually every rule-identified toe of a deep-seated landslide in the Skamokawa WAU is adjacent to a stream. Delivery criteria are based on field and photo observations of direct delivery into and proximity to streams, as well as unobstructed routes of delivery. This unit has an overall landslide area rate for delivery of 960.9.

Overall Hazard Rating: **Very High,** based on LHZ protocol and Forest Practices Rules.

Confidence: **Moderate**, based on good photo quality and lidar coverage, but limited field verification.

Comments: Particular attention should be paid to toes of active deep-seated landslides that extend directly into stream channels. All toes of deep-seated landslides in or near streams or inner gorges, regardless of gradient, should require a field review. Also, there are many deep-seated earthflows that have been mapped throughout the basin. The toes of these earthflows are often considerably gentler than 65% but are particularly prone to failure where undercut by streams. Be aware that these features are not included in landforms # 8 or # 9, but can potentially become mass-wasting hazards and deliver large volumes of sediment to public resources. See Map A-1 and Table A-1 for locations of mapped earthflows.

Appendix B: Form A-2
Skamokawa Landform Descriptions

Landform # 10 – Highly Incised Terrain – Very High Hazard

Description: This landform unit consists of high relief uplands that are characterized by large tracts of deeply incised drainages separated by steep ridges. Slopes in this widespread landform are steep; more than half of the slopes are >50%, and about a quarter are >70% (~2000 acres). The ridge tops in this unit tend to be deeply weathered, and the steep slopes are mantled by thin, poorly developed soils. Thin soils that are not strongly anchored to incompetent, poorly consolidated, and weathered bedrock units and abundant rainfall make highly incised terrain susceptible to debris slides, debris flows, and other shallow landslides. While landslides initiate on all slope forms in this landform, areas where surface or groundwater is concentrated, contributing to increased pore-water pressure in the soil, are particularly susceptible. Roots from trees that stand on steep slopes play a significant role in stabilizing the soils mantling bedrock in this landform.

This map unit contains many rule-identified landforms: convergent headwalls, bedrock hollows, and inner gorges are the initiation points for many debris slides and flows. Almost 75% of the 467 landslides observed in this landform began in landforms that are rule-identified, based on air photos and GIS data examination; many of the remaining slides also probably started in rule-identified landforms that were obscured by canopy or fell below the resolution of the DEM. However, rule-identified convergent headwalls, bedrock hollows and inner gorges in this landform were too numerous to map individually in a reasonable time.

Gradient: Variable – average slope of landslide initiation is 68% (DEM-measured; such measurements commonly underestimate actual slope gradients in the field by 10% or more.)
Material: Highly incised terrain forms mostly in areas underlain by resistant marine sandstones but this unit is also mapped over small regions of basalt and marine siltstone. Slope movement generally begins at the soil-bedrock interface, but can also occur within unconsolidated surficial deposits.
Total Landform Area: 8376.3 acres

Mass Wasting Process: Debris slides, debris flows, and other shallow landslides occur on steep slopes mantled with thin soils, commonly sliding at the soil-bedrock interface. While landslides initiate on all slope forms in this landform, areas where surface or groundwater is concentrated are particularly susceptible. Rock types within this landform are commonly weak and/or affected by deep weathering, which contributes to mass wasting on these slopes

Forest Practice Sensitivity: Roots from trees that stand on steep slopes can significantly impede mass wasting by forming an interwoven root mat, providing greatly increased slope strength (Krogstad, 1995). Timber harvest, road and landing construction, and other activities that reduce root strength on these slopes can greatly reduce slope stability. Timber harvest can also increase pore-water pressure in the soil by loss of canopy interception and evapotranspiration. Roads and landings can destabilize steep slopes by undercutting and oversteepening them; sidecast and road (or landing) fill can also load slopes excessively. Furthermore, roads/landings can trigger landslides by capturing surface runoff and shallow groundwater, causing saturation of fill material or adjacent thin soils. Many roads in this landform are built on ridgetops where weathering of the underlying bedrock is particularly deep and intense. Failure of these ridgetop roads can reach steep channels and become large destructive debris flows.

Trigger Mechanisms: Mass wasting on these slopes is triggered by loss of root strength, soil saturation (particularly by artificial diversion of surface and ground water), and oversteepening and loading of slopes. These triggering mechanisms can be caused by intense and/or prolonged precipitation, timber harvest, road/landing construction, and improper drainage.

Mass Wasting Potential: **Very High**, 467 landslides were mapped in 8376.3 acres of highly incised terrain over a 33-yr air-photo period, yielding an overall landslide frequency rate of 1689.5. The LFR for road-related landslides is 463.1, and 1226.4 for all other land uses (see LHZ protocol).

Delivery Potential/Criteria: **High**, 425 landslides (91%) with a total area of 96.1 acres delivered sediment/debris from this landform unit. This landform contains slopes that are commonly upslope from water; thus, it is likely that landslides on these slopes will deliver sediment to streams and/or other public resources. Delivery criteria are based on field and photo observations of visible sedimentation, proximity of streams, and unobstructed routes of delivery. This unit has an overall landslide area rate for delivery of 347.7; the LAR is 152.4 for road related landslides, and 195.3 for all other land uses (see LHZ protocol).

Overall Hazard Rating: **Very High**, based on the LHZ protocol.

Confidence: **High**, based on excellent photo quality and coverage, and adequate field verification.

Comments: This landform is composed of broad regions of similar topography, slopes and rock type, and not specific gradient, convergence, or geologic thresholds. For these reasons, this landform will be difficult to identify in the field without the aid of Map A-2.

Appendix B: Form A-2
Skamokawa Landform Descriptions

Landform # 11 – Steep Bedrock-Capped Ridges – Very High Hazard

Description: Steep-sided ridges capped by resistant bedrock have formed between the Columbia River and the interior of the Skamokawa WAU, and are mostly composed of (capped by) resistant volcanic flow rocks (basalt) standing in high relief above other weaker bedrock units. Slopes in this landform are steep: more than two-thirds of the slopes are >50%, and more than one-third are >70%. These bedrock ridges exhibit deep weathering profiles and tend to weather into lower-cohesion soils (though with some clay) with little internal strength. Many debris slides and flows originate along these high relief ridges, with the slides occurring mostly within the weathering profile of the basalt. Bedrock hollows and associated inner gorges are common in this unit, but were not mapped individually.

Gradient: Variable – average slope of landslide initiation is 72% (DEM-measured; such measurements commonly underestimate actual slope gradients in the field by 10% or more.)
Material: Steep bedrock-capped ridges occur where resistant Columbia River basalts form high, steep-sided ridges. Movement generally begins at the soil-bedrock interface, but can also occur within unconsolidated surficial deposits.
Total Landform Area: 511.3 acres

Mass Wasting Process: Debris slides, debris flows, and other shallow landslides occur on steep slopes with thin soil mantles generally at the edges of basalt-capped ridges, commonly sliding at the soil-bedrock interface. While landslides initiate on all slope forms in this steep landform, areas where surface or groundwater is concentrated are particularly susceptible. Rock types within this landform are commonly affected by deep weathering and exhibit a sharp strength/permeability contrast at the soil-bedrock interface. These factors contribute to mass wasting on these slopes.

Forest Practice Sensitivity: Roots from trees that stand on steep slopes can significantly impede mass wasting by forming an interwoven root mat, providing greatly increased slope strength (Krogstad, 1995). Timber harvest, road and landing construction, and other activities that reduce root strength on these slopes can greatly reduce slope stability. Timber harvest can also increase pore-water pressure in the soil by loss of canopy interception and evapotranspiration. Roads and landings can destabilize steep slopes by undercutting and oversteepening them; sidecast and road (or landing) fill can also load slopes excessively. Furthermore, roads/landings can trigger landslides by capturing surface runoff and shallow groundwater, causing saturation of fill material or adjacent soils. Many roads in this landform are built on ridgetops where weathering of the underlying bedrock is particularly deep and intense. Failure of these ridgetop roads can reach steep channels and become large destructive debris flows. The interface between soil or weathered rock and more coherent bedrock in this landform is a ready-made slip plane for landsides because it exhibits such a sharp strength/permeability contrast. Any forest practices that could dramatically increase pore-water pressure at this interface should be scrutinized.

Trigger Mechanisms: Mass wasting on these slopes is triggered by soil saturation (particularly by artificial diversion of surface and ground water), oversteepening and loading of slopes, and loss of root strength. These triggering mechanisms can be caused by intense and/or prolonged precipitation, timber harvest, road/landing construction, and improper drainage.

Mass Wasting Potential: **Very High**, 41 landslides were mapped in 511.3 acres of steep bedrock capped ridges over a 33-yr airphoto period, yielding an overall landslide frequency rate of 2429.9. The LFR for road-related landslides is 533.4, and 1896.5 for all other land uses (see LHZ protocol).

Delivery Potential/Criteria: **High**, 30 landslides (73%) with a total area of 5.8 acres delivered sediment/debris from this landform unit. This landform contains slopes that are commonly upslope from water; thus, it is likely that landslides on these slopes will deliver sediment to streams and/or other public resources. Delivery criteria are based on field and photo observations of visible sedimentation, proximity of streams, and unobstructed routes of delivery. This unit has an overall landslide area rate for delivery of 341.7; the LAR is 124.2 for road related landslides, and 217.5 for all other land uses (see LHZ protocol).

Overall Hazard Rating: **Very High**, based on the LHZ protocol.

Confidence: **Moderate**, based on good photo quality and lidar coverage, but limited field verification.

Appendix B: Form A-2
Skamokawa Landform Descriptions

Landform # 12 – Scarps of Land-Shaping Deep-Seated Landslides – Very High Hazard

Description: This map unit includes the scarps of very large (up to tens of square miles) relict deep-seated landslides that have shaped the topography and overall character of large sections of the WAU. The scarps are areas that have been oversteepened due to past landslide motion. The scarp slopes are mantled by thin soils that are not strongly anchored to incompetent and weathered bedrock. These conditions, plus abundant rainfall, make scarps of land-shaping deep-seated landslides susceptible to debris slides, debris flows, and other shallow landslides. While landslides begin on all slope forms in this landform, areas where surface or groundwater is concentrated, contributing to increased pore-water pressure in the soil, are particularly susceptible. Roots from trees that stand on these steep slopes play a significant role in stabilizing the soils mantling bedrock in this landform. Bedrock hollows and associated inner gorges can form in this unit, but were not mapped individually.

Gradient: Variable – average slope of shallow landslide initiation is 70% (DEM-measured; such measurements commonly underestimate actual slope gradients in the field by 10% or more.)
Material: Scarps of land-shaping deep-seated landslides can form in all rock types within this WAU.
Total Landform Area: 1770.3 acres

Mass Wasting Process: Secondary debris slides, debris flows, and other shallow landslides occur on oversteepened scarp slopes mantled with thin soils and commonly slide at the soil-bedrock interface. While landslides initiate on all slope forms in this landform, areas where surface or groundwater is concentrated are particularly susceptible.

Forest Practice Sensitivity: Roots from trees that stand on the oversteepened slopes of scarps can significantly impede mass wasting by forming an interwoven root mat, providing greatly increased slope strength (Krogstad, 1995). Timber harvest, road and landing construction, and other activities that reduce root strength on these slopes can greatly reduce slope stability. Timber harvest can also increase pore-water pressure in the soil by loss of canopy interception and evapotranspiration. Roads and landings can destabilize steep slopes by undercutting and oversteepening them; sidecast and road (or landing) fill can also load slopes excessively. Furthermore, roads/landings can trigger landslides by capturing surface runoff and shallow groundwater, causing saturation of fill material or adjacent soils.

Trigger Mechanisms: Mass wasting on these slopes is triggered by soil saturation (particularly by artificial diversion of surface and groundwater), oversteepening and loading of slopes, and loss of root strength. These triggering mechanisms can be caused by intense and/or prolonged precipitation, timber harvest, road/landing construction, and improper drainage.

Mass Wasting Potential: **Very High**, 129 secondary shallow landslides were mapped in 1770.3 acres of scarps of land-shaping deep-seated landslides over a 33-yr air-photo period, yielding an overall landslide frequency rate of 2208.2. The LFR for road-related landslides is 222.5, and 1985.7 for all other land uses (see LHZ protocol).

Delivery Potential/Criteria: **High**, 84 secondary shallow landslides (65%) with a total area of 22.3 acres delivered sediment/debris from this landform unit. While some of the scarps in this landform contain slopes that are upslope from water and provide a direct path for delivery of sediment and debris to streams and/or other public resources, other scarp forms do not allow a direct path to streams; delivery potential should be made on a scarp-by-scarp basis. Delivery criteria are based on field and photo observations of visible sedimentation, proximity of streams, and unobstructed routes of delivery. This unit has an overall landslide area rate for delivery of 382.0; the LAR is 27.6 for road related landslides, and 354.4 for all other land uses (see LHZ protocol).

Overall Hazard Rating: **Very High**, based on the LHZ protocol.

Confidence: **Moderate**, based on good photo quality and lidar coverage, but limited field verification.

Comments: See the Skamokawa LHZ Project report section 3.3, Slope Processes, for further description of land-shaping relict deep-seated landslides.

Appendix B: Form A-2
Skamokawa Landform Descriptions

Landform # 13 – Slopes Steeper Than 40% – Moderate Hazard

Description: This map unit includes all slope forms (convergent, divergent and planar) that are steeper than 40%, and that are not otherwise included in another map unit in the Skamokawa WAU. Thin soils that are not strongly anchored to incompetent, poorly consolidated, and weathered bedrock units, plus abundant rainfall, make steep slopes susceptible to debris slides, debris flows, and other shallow landslides. While landslides begin on all slope forms in this landform, areas where surface or groundwater is concentrated, contributing to increased pore-water pressure in the soil, are particularly susceptible to failure. Roots from trees that stand on steep slopes play a significant role in stabilizing the thin soils mantling bedrock in this landform.

Gradient: >40% (DEM-measured; such measurements commonly underestimate actual slope gradients in the field by 10% or more.)
Material: Slopes steeper than 40% are mapped in all rock and soil types within this WAU. Movement generally begins at the soil-bedrock interface, but can also occur within unconsolidated surficial deposits.
Total Landform Area: 4219.9 acres

Mass Wasting Process: Debris slides, debris flows, and other shallow landslides occur on steep slopes mantled with thin soils, commonly sliding at the soil-bedrock interface. While landslides initiate on all slope forms in this landform, areas where surface or groundwater is concentrated are particularly susceptible. Rock types within this watershed are commonly weak and/or affected by deep weathering, which contributes to mass wasting on these slopes

Forest Practice Sensitivity: Roots from trees that stand on slopes >40% can significantly impede mass wasting by forming an interwoven root mat, providing greatly increased slope strength (Krogstad, 1995). Timber harvest, road and landing construction, and other activities that reduce root strength on these slopes can greatly reduce slope stability. Timber harvest can also increase pore-water pressure in the soil by loss of canopy interception and evapotranspiration. Roads and landings can destabilize steep slopes by undercutting and oversteepening them; sidecast and road (or landing) fill can also load slopes excessively. Furthermore, roads/landings can trigger landslides by capturing surface runoff and shallow groundwater, causing saturation of fill material or adjacent thin soils.

Trigger Mechanisms: Mass wasting on these slopes may be triggered by loss of root strength, soil saturation (particularly by artificial diversion of surface and groundwater), and oversteepening and loading of slopes. These triggering mechanisms can be caused by intense and/or prolonged precipitation, timber harvest, road/landing construction, and improper drainage.

Mass Wasting Potential: **High**, 34 landslides were mapped in 4219.9 acres of slopes steeper than 40% in this map unit (excluding other higher-hazard landform units) over a 33-yr air-photo period, yielding an overall landslide frequency rate of 244.2. The LFR for road-related landslides is 64.6, and 179.5 for all other land uses (see LHZ protocol).

Delivery Potential/Criteria: **Low**, 28 landslides (82%) with a total area of 7.3 acres delivered sediment/debris from this landform unit. This landform contains slopes that are commonly upslope from water; thus, it is likely that landslides on these slopes will deliver sediment to streams and/or other public resources. Delivery criteria are based on field and photo observations of visible sedimentation, proximity of streams, and unobstructed routes of delivery. This unit has an overall landslide area rate for delivery of 52.7; the LAR is 28.8 for road related landslides, and 23.9 for all other land uses (see LHZ protocol).

Overall Hazard Rating: **Moderate**, based on analyst discretion and the LHZ protocol.

Confidence: **Moderate**, based on excellent photo quality and coverage, GIS tools, but limited field verification.

Comments: This landform was delineated by selecting slopes with DEM-derived gradients >40% that were not already accounted for by landforms having higher hazard ratings. The slope-gradient criterion was based on a series of statistical analyses of landslide attributes in the Skamokawa WAU.

Appendix B: Form A-2
Skamokawa Landform Descriptions

Landform # 18 – Low Gradient Hillslopes – Low Hazard

Description: This map unit includes all hillslopes between 10 and 40% gradient that have low landslide potential, and so are not likely to deliver sediment to streams or otherwise damage public resources. However, this unit may contain unmapped inner gorges, bedrock hollows, deep-seated landslides, or other higher hazard map units that were either hidden by dense forest canopy of not resolved by the 10-m DEM. Of particular concern in this unit are unmapped or dormant/relict, relatively gentle (<40% gradient) earthflows. It is important to understand that some of these features can become activated with even minor climatic and/or land-use perturbation, and have the potential to deliver enormous amounts of sediment to fish-bearing streams and other public resources. Examples are evident at landslide # 544, which heads on the Grays Bay/Skamokawa divide and toes in a tributary of Jim Crow Creek; and at landslide # 637, which toes in a tributary of Kelly Creek. Both landslides partially reactivated from previously dormant states during the winter of 2005-'06 and delivered sediment downstream into these creeks; both exhibit very subdued topography, with average gradients <23%. Due to their subdued topographic expression, dormant and even potentially active earthflows could have been overlooked during landslide mapping, especially in areas outside of lidar coverage and under heavy forest canopy. Therefore, users should take great care to look out for classic features of earthflow activity in the field (including fresh scarps and cracks, minor slumps, jackstrawed trees, stretched roots, split old growth stumps, streams that are newly incised through soft sediments, etc).

Gradient: Between 10 and 40% (Gradients were determined using 10-m DEM, which can result in some mapping errors.)
Material: Low gradient slopes in this WAU generally form in less resistant marine siltstone and sandstones, or in weathered and fractured Eocene basaltic volcanics.
Total Landform Area: 23,723.8 acres

Mass Wasting Process: Although rare because of the gentle slopes, debris slides, debris flows, shallow undifferentiated landslides, and deep-seated landslides can occur within this landform (or encroach upon it from adjacent areas).

Forest Practice Sensitivity: Mass wasting on these naturally stable slopes is unlikely, but can possibly be caused by human activities. Harvest-related activities that could contribute to landsliding on this landform would generally be the result of poor management practices (and likely involve violations of forest practice rules). Such activities might cause alterations of stream channels by damming or diversions (with road fill, blocked culverts, into ditches or onto road surfaces for excessive distances); creation of large undrained areas that could saturate fill or natural slope materials on hillslopes; or by sidecast of excessive amounts of uncompacted, unstable material.

Trigger Mechanisms: Landslides are unlikely to begin on this landform or deliver sediment/debris to public resources unless there has been failure of roads, drainage structures, etc. (plugged culvert, sidecast fill failure, overused skidding trail, etc.). Poor management practices can cause mass wasting to occur on almost any type of landform with any slope gradient even if the landform is not inherently unstable.

Mass Wasting Potential: **Low**, based on LHZ protocol Level I analysis and air-photo analysis.

Delivery Potential/Criteria: **Low**, based on LHZ protocol Level I analysis and air-photo analysis. Distance from stream channels and topography inhibits the transport of landslide debris to public resources.

Overall Hazard Rating: **Low**, based on LHZ protocol.

Confidence: **Moderate**, based on excellent photo quality and coverage and GIS tools, but limited field verification and the possibility of unmapped earthflows.

Comments: 43 landslides were mapped on this landform, 33 of which delivered sediment/debris to streams. Of the 43 landslides recognized, 11 were road related. The causes of the remaining landslides are unverified, although it is possible that they occurred in steeper areas that were not accurately resolved by the 10-m DEM.

Appendix B: Form A-2
Skamokawa Landform Descriptions

Landform # 19 – Flat Areas – Low Hazard

Description: This map unit includes slope forms that are gentler than 10% in gradient, dominantly lowland landforms such as valley bottoms, floodplains, and flat terrace surfaces, but also ridges and noses, that have low landslide potential, and so are not likely to deliver sediment to streams or otherwise public resources. However, this unit may contain unmapped inner gorges, bedrock hollows, deep-seated landslides, or other higher hazard map units that were either hidden by dense forest canopy of not resolved by the 10-m DEM.

Gradient: Variable, 0 to 10% (Gradients were determined using 10-m DEM, which can result in some mapping errors.)
Material: Valley bottoms are composed most commonly of alluvial and colluvial (including landslide) deposits. Ridgetops and other flat areas can be composed of any the rock units that exist within this watershed.
Total Landform Area: 6211.1 acres

Mass Wasting Process: Although extremely rare because of the very gentle slope gradients, debris slides, debris flows, shallow undifferentiated landslides, and deep-seated landslides can occur within this landform (or encroach upon it from adjacent areas).

Forest Practice Sensitivity: Mass wasting on these naturally stable slopes is unlikely, but can possibly be caused by human activities. Harvest-related activities that could contribute to landsliding on this landform would generally be the result of poor management practices (and likely involve violations of forest practice rules). Such activities might cause alterations of stream channels by damming or diversions (with road fill, blocked culverts, into ditches or onto road surfaces for excessive distances); creation of large undrained areas that could saturate fill or natural slope materials on hillslopes; or by sidecast of excessive amounts of uncompacted, unstable material.

Trigger Mechanisms: Landslides are unlikely to begin on this landform or deliver sediment/debris to public resources unless there has been failure of roads, drainage structures, etc. (plugged culvert, sidecast fill failure, overused skidding trail, etc.). Poor management practices can cause mass wasting to occur on almost any type of landform with any slope gradient even if the landform is not inherently unstable.

Mass Wasting Potential: **Low**, based on LHZ protocol Level I analysis and air-photo analysis.

Delivery Potential/Criteria: **Low**, based on LHZ protocol Level I analysis and air-photo analysis. Distance from stream channels and gentle topography inhibit the transport of landslide debris to public resources.

Overall Hazard Rating: **Low**, based on LHZ protocol.

Confidence: **High**, based on excellent photo quality and coverage, GIS tools, and field verification.

Comments: 4 small landslides were mapped on this landform, all of which delivered sediment/debris to streams. One of these landslides was road related, and the other three originated on steep cutbanks of Wilson Creek that were too small to map as discrete landforms.