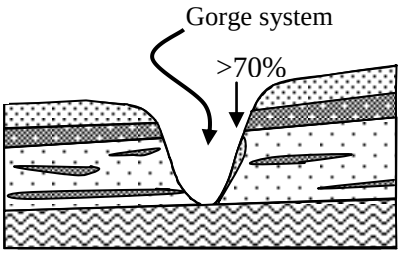
Lower Chehalis - Elizabeth Creek WAU
Appendix C – Form A-2 Landform Descriptions

Landform #1 – Inner Gorges - Slope gradients ≥ 70% – Very High Hazard

Description of Mass Wasting Unit: This landform consists of rule-identified inner gorges. These inner gorges are steep walled canyons or gullies eroded by stream action with evidence of mass wasting along their sidewalls. Inner gorges may be either symmetrical or asymmetrical in profile and are commonly intermittent in lateral extent. They are occasionally scoured by debris flows during storm events. Buried wood is often observed in the channels from previous mass wasting events. A 10° (18%) break in slope usually separates the upper margin of the inner gorge feature from the surrounding slope forms. Inner gorge scarp slopes re-vegetate rapidly which can mask their appearance on aerial photos. Inner gorges are present within and overlapping a wide range of other landforms including larger inner gorges, bedrock hollows, and terrace margins.



Slopes: Greater than 70%
Slope Shape: Convergent to concave-planar
Material: Marine sedimentary tuffaceous siltstones and sandstones (Astoria and Montesano Formations)
Elevation: 0 ft to 730 ft
Total Area: 477 acres

Mass Wasting Process: This landform contains primarily shallow undifferentiated landslides with a few debris flows and often contains toes of deep-seated landslides. Recent slope failures can be the result of elevated pore pressures in shallow soils draped over weakly cemented bedrock. Previous landslides that have occurred along portions of the inner gorge slopes are indicated by an accumulation of landslide debris and partially buried wood within the channel bottoms. These landslide deposits are often made apparent by the presence of even-aged alder.

Forest Practice Sensitivity and Trigger Mechanisms: Root strength decline within and adjacent to inner gorges has been found to be a factor in increasing rates of mass wasting (Krogstad, 1995). Trees adjacent to the inner gorge can have roots extending into the slopes providing slope stability. Forty-four percent of the 129 landslides in this landform were associated with clearcut to 15 year old timber. Roads and landings can have destabilizing effects by undercutting and over-steepening slopes. Destabilization can occur when roads cut across slopes; removing the hillslope buttressing effect and the replacement of over-steepened cut-slopes associated with road tread. Side cast from roads or landings can further over-steepen and weight slopes, promoting instability. Roads intercept and re-route shallow groundwater and channel it to point locations that saturate road fill that could trigger landslides.

Mass Wasting Potential: **Very High** for roads and timber harvest based on 128 slope failures in a landform covering 477 acres. This landform has a Landslide Frequency Rating of 5,710 including road-related landslides. The Landslide Frequency Rating without road-related landslides is 4,818

Delivery Potential/Criteria: **Very High.** The Landslide Area Rate of Delivery for this landform is 887 based on 122 "delivering" landslides totaling 19.9 acres including road-related landslides. The Landslide Area Rate of Delivery without road-related landslides is 608 based on 102 "delivering" landslides totaling 13.6 acres.

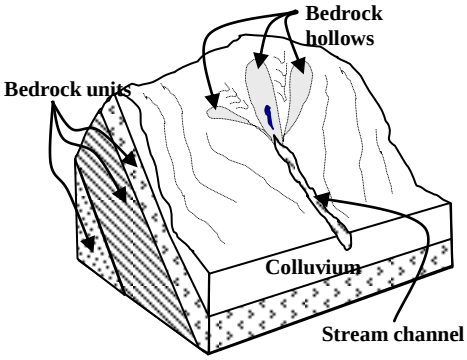
Overall Hazard Rating: **Very High** based on the LHZ Protocol, Table 5.

Confidence: Moderate level of confidence based on good photo coverage, poor Digital Elevation Model (DEM) accuracy, and limited field verification.

Comments: Computer-generated DEM slope values may be much lower than actual slopes, therefore there may be many rule-identified inner gorges that may have been inadvertently mapped within other landforms. Inner gorges, where connected in a complex, were often mapped as one inner gorge system instead of mapping each individually.

Landform #2 – Bedrock Hollows - Slope gradients ≥ 70% – Very High Hazard

Description of Mass Wasting Unit: This landform consists of rule-identified bedrock hollows. These hollows are steep, shallow spoon-shaped or elongate areas of convergent topography with concave profiles, sometimes broadly convergent. Bedrock hollows are also called colluvium-filled bedrock hollows, zero-order basins, swales, bedrock depressions, or simply hollows. These features can exist on any steep hillslope and within other landforms. They seldom contain channels but commonly drain directly into inner gorges. Colluvial debris that accumulates in these steep convergent areas is prone to saturation by shallow ground water making bedrock hollows highly susceptible to slope failures. Over time, bedrock hollows re-vegetate and refill with soil, which can mask their presence on air photos and on the ground.



Slopes: Greater than 70%
Slope Shape: Convergent to concave-planar
Material: Marine sedimentary tuffaceous siltstones and sandstones (Astoria and Montesano Formations), glacial deposits
Elevation: 35 ft to 810 ft
Total Area: 350 acres

Mass Wasting Process: This landform contains numerous shallow undifferentiated landslides, debris flows and debris slides. Bedrock hollows can occur in the scarps of deep-seated landslides. Old landslide features have been muted by soil accumulation within these landforms.

Forest Practice Sensitivity and Trigger Mechanisms: Root strength decline within and adjacent to bedrock hollows has been found to be a factor in increasing rates of mass wasting (Krogstad, 1995). Trees adjacent to the bedrock hollow can have roots extending into the slopes providing slope stability. Thirty-one percent of the 182 landslides in this landform were classified as occurring in 0-15 year old timber. Destabilization can occur when roads cut across slopes; removing the hillslope buttressing effect and the replacement of over-steepened cut-slopes associated with road tread. Side cast from roads or landings can further over-steepen and weight slopes, promoting instability. Roads intercept and re-route shallow groundwater and channel it to point locations that saturate road fill that could trigger landslides.

Mass Wasting Potential: **Very High** for roads and timber harvest based on 181 slope failures in a landform covering 350.1 acres. This landform has a Landslide Frequency Rating of 11,001 including road-related landslides. The Landslide Frequency Rating without road-related landslides is 6,564.

Delivery Potential/Criteria: **Very High.** The Landslide Area Rate of Delivery for this landform is 1,917 based on 165 "delivering" landslides totaling 31.5 acres including road-related landslides. The Landslide Area Rate of Delivery without road-related landslides is 843 based on 105 "delivering" landslides totaling 13.9 acres.

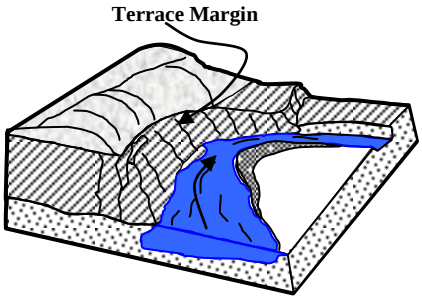
Overall Hazard Rating: **Very High** based on the LHZ Protocol, Table 5.

Confidence: Moderate level of confidence based on good photo coverage, poor DEM accuracy, and limited field verification.

Comments: Computer generated DEM slope values may be much lower than actual slopes. Due to mapping constraints, several small (<0.5 acre) bedrock hollows were merged into adjacent high hazard landforms such as Steep Gradient Hillslopes, Convergent Headwalls and other bedrock hollows where topographic features separating the landforms were less than 0.5 acres.

Landform #4 – River Terrace Margin - Very High Hazard

Description of Mass Wasting Unit: The Chehalis River has cut into marine sedimentary rocks and glacial deposits creating an unstable margin. During Pleistocene continental glacial retreat out of the Puget Sound area, meltwater flowed to the ocean at a much higher elevation than present river flows through the watershed. The slopes of siltstones and sandstones may have been undercut by the present day Chehalis River creating many shallow & deep-seated landslides. (Note: this landform may contain rule-identified landforms such as inner gorges and deep-seated landslide toes.)



Terrace undercut by river along toes of DSLS & planar slopes

Slopes: Greater than 25%
Slope Shape: Convergent to planar
Material: Marine sedimentary tuffaceous siltstones and sandstones (Astoria Formation), previously, mapped landslides in glacial deposits
Elevation: 10 ft to 345 ft
Total Area: 247 acres

Mass Wasting Processes: The Chehalis River, as well as roads and old railroads, have undercut adjacent upland slopes and caused mass wasting along slopes in the form of shallow undifferentiated landslides, debris slides, and deep-seated landslides. Springs from slopes above roads may cause road failures on the south side of the Chehalis River.

Forest Practice Sensitivity and Trigger Mechanisms: Root strength decline within and adjacent to terrace margins has been found to be a factor in increasing rates of mass wasting (Krogstad, 1995). Trees adjacent to and within the river terrace margin can have roots extending into the slopes providing slope stability. Stream bank and terrace face erosion undercutting this landform make it prone to mass wasting even under mature forested conditions, therefore, any disturbance resulting from timber harvest or road construction may further destabilize these slopes. Seven percent of the 43 landslides in this landform were associated with younger than 15 year old timber, likely due to very few clearcuts in this landform. Roads can destabilize slopes by undercutting and over steepening slopes. Side cast from roads can further over-steepen and weight slopes, promoting instability. Water management on roads is critical to prevent saturation of fills and side cast. Sixty-two percent of the 43 landslides within this landform were associated with roads.

Mass Wasting Potential: **Very High** for roads and timber harvest based on 43 slope failures in a landform covering 247.3 acres. This landform has a Landslide Frequency Rating of 3,699 with roads and 1,376 without road related landslides.

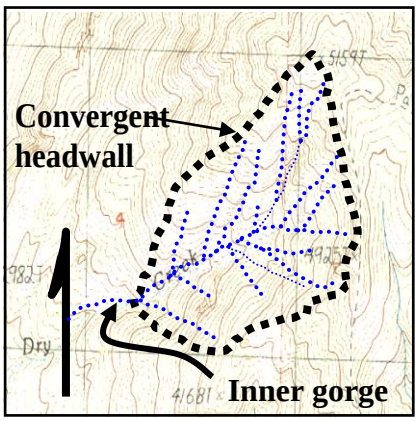
Delivery Potential/Criteria: **High.** The Landslide Area Rate of Delivery for this landform is based on 40 "delivering" landslides totaling 8.6 acres is 738 with roads and 15 "delivering" landslides totaling 2.7 acres is 235.7 without road related landslides.

Overall Hazard Rating: **Very High** based on the LHZ Protocol, Table 5.

Confidence: High for the entire unit based on observed direct delivery to typed waters and public roads, good photo coverage, partial LiDAR coverage, and field verification.

Comments: Computer generated DEM's slope values are much lower than actual slopes and can be verified by partial LiDAR coverage within this landform. Public roads within this landform experience repeated buckling and cracking of road surfaces, as well as frequent cover by shallow landslide deposition. Steep slopes and heavy vegetation coverage likely reduced observation of landslides in this landform.

Landform # 5 – Convergent Headwalls – Slope gradients ≥ 70% - Very High Hazard



Description of Mass Wasting Unit: This landform consists of rule-identified convergent headwalls with steep headwall basins located in the upper end of drainage systems. Convergent headwalls are broadly convergent and contain bedrock hollows that are commonly separated by steep knife-edge ridges.

Slopes: Greater than 70%
Slope Shape: Convergent to concave-planar
Material: Marine sedimentary tuffaceous siltstones and sandstones (Astoria Formation)
Elevation: 100 ft to 735 ft
Total Area: 102 acres

Mass Wasting Processes: This landform contains numerous shallow undifferentiated landslides on the steep slopes (>70%) of knife edge ridges. These shallow landslides leave little or no soil on steep slopes of loosely lithified (cemented) marine sedimentary bedrock.

Forest Practice Sensitivity and Triggering Mechanisms: Root strength decline within and adjacent to convergent headwalls has been found to be a factor in increasing rates of mass wasting (Krogstad, 1995). Trees adjacent to the convergent headwalls can have roots extending into the slopes providing slope stability. Sixty-seven percent of the 76 landslides were classified as occurring in 0-15 year old timber. This is assumed to be beyond the time when roots can still hold soils in place on steep ground and suggests that loss of root strength can adversely influence slope stability in this landform. Destabilization can occur when roads cut across slopes; removing the hillslope buttressing effect and the replacement of over-steepened cut-slopes associated with road tread. Side cast from roads or landings can further over-steepen and weight slopes, promoting instability. Roads intercept and re-route shallow groundwater and channel it to point locations that saturate road fill that could trigger landslides. Twenty percent of the 76 landslides within this landform were associated with roads.

Mass Wasting Potential: **Very High** for roads and timber harvest based on 75 slope failures in a landform covering 101.6 acres. This landform has a Landslide Frequency Rating of 15,707 including road-related landslides. The Landslide Frequency Rating without road-related landslides is 12566.

Delivery Potential/Criteria: **Very High.** The Landslide Area Rate of Delivery for this landform is 2,278 based on 74 "delivering" landslides totaling 10.9 acres including road-related landslides. The Landslide Area Rate of Delivery without road-related landslides is 1,499 based on 59 "delivering" landslides totaling 7.2 acres.

Overall Hazard Rating: **Very High** based on LHZ Protocol, Table 5.

Confidence: High based on good photo coverage and field verification of landslides and their direct delivery to streams.

Comments: Additional convergent headwalls may be present but were mapped as individual bedrock hollow and inner gorge landforms where a rule-identified convergent headwall was not immediately apparent through field observations or GIS.

Landform #7 – Active Scarps of Deep-Seated Landslides – Very High Hazard

Description of Mass Wasting Unit: This landform consists of head and interior scarps of previously failed deep-seated landslides with slopes greater than 30% (average of 70%). Many landslides within this landform are located on steep ground with shallow soils but some slopes fail at much gentler slope gradients due to the weathering characteristics of the bedrock. Small shallow undifferentiated landslides occur on the weakened materials in the headscarp areas. Slope failures within this landform could be reactivated by high pore water pressures due to prolonged storm events, or improper water management associated with harvest, road building, or poor road maintenance. This landform is often stream adjacent which greatly increases the likelihood of delivery.

Slopes: 30% and greater
Slope Shape: Convergent to planar
Material: Marine sedimentary tuffaceous siltstones and sandstones (Montesano and Astoria Formations)
Elevation: 100 ft to 700 ft
Total Area: 82 acres

Mass Wasting Process: The landslides within this landform were mostly shallow landslides (95%).

Forest Practice Sensitivity and Triggering Mechanisms: Timber harvest, road and landing construction, and other activities that reduce root strength can reduce slope stability. Roots from trees growing on slopes often impede mass wasting by forming an interlocking root mat that provides increased slope strength (Krogstad, 1995). Destabilization can also occur when roads cut across slopes; this removes buttressing sections that support a hill and replaces them with over-steepened cutslopes and road tread. Destabilization can occur when roads cut across slopes; removing the hillslope buttressing effect and the replacement of over-steepened cut-slopes associated with road tread. Side cast from roads or landings can further over-steepen and weight slopes, promoting instability. Roads intercept and re-route shallow groundwater and channel it to point locations that saturate road fill that could trigger landslides. Fifty-three percent of the landslides in this landform were associated with roads.

Mass Wasting Potential: **Very High** for roads and timber harvest based on 19 slope failures in a landform covering 81.6 acres. This landform has a Landslide Frequency Rating of 4,955 including road-related landslides. The Landslide Frequency Rating without road-related landslides is 2,347.

Delivery Potential/Criteria: **High.** The Landslide Area Rate of Delivery for this landform is 448 based on 4 "delivering" landslides totaling 1.7 acres including road-related landslides. The Landslide Area Rate of Delivery without road-related landslides is **Low** based on zero "delivering" landslides in this landform that were not associated with roads.

Overall Hazard Rating: **Very High** based on LHZ Protocol, Table 5. In this landform, the overall hazard rating is heavily influenced by road-related failures. The overall hazard rating for this landform without road related landslides is **Moderate.**

Confidence: Moderate level of confidence based on good photo coverage, poor DEM accuracy, and field verification.

Comments: Computer generated DEM slope values may be much lower than actual slopes. Many of the deep-seated landslide scarps in the WAU contain other very high hazard landforms, such as bedrock hollows. Deep-seated landslide scarp landforms were mapped around other landforms where the scarps included delivering landslides.

Landform #9 - Fluvial Erosion along Channels of the Chehalis River – Low Hazard

Description of Mass Wasting Unit: Fluvial erosion along channels of the Chehalis River. LHZ protocol for a level one analysis prescribes that floodplains are delineated as low hazard areas along with prairies and flats. These bank failures were calculated as having a very high hazard rating, but assigned a low hazard rating by judgment of the analyst based the occurrence of the landform within the floodplain. Alluvium found along the Chehalis River Surge Plain is highly susceptible to natural bank failure. Bank failures occur primarily along the outer edges of the meander bends, but a few are found along straight banks due to the daily rise and fall of the tides, which affects pore water pressure of the slopes adjacent to the river. Bank material delivers directly to the Chehalis River. This landform is unlikely to be impacted by forest practices, as it occurs entirely within the Chehalis River floodplain.

Slopes: Greater than 11%
Slope Shape: Convergent to planar
Material: Alluvium
Elevation: 0 ft to 45 ft
Total Area: 214 acres

Erosion Processes: Flood events carry additional fine-grained sediment that deposits on the naturally formed levees within the Chehalis River floodplain. Within the Chehalis River and associated sloughs and tributaries the incoming tide delivers an influx of sediment which vertically enhances and over-steepens levees. The rising tide saturates sediments on the edges of the river channel, causing increased pore pressure. The lateral support provided by the water during high tide is removed with the out-flowing tide, increasing the likelihood of the sometimes 10 ft tall and vertical banks with direct delivery to the river. As the river migrates back and forth across the floodplain through time, the meanders travel downstream impacting areas on both sides of the river. Typically, slope failures are found on the outside edges of meanders bends, but can also occur along straight banks after high flows. Frequent shallow calving of the banks occurs in the small-scale slumping, and sediment toppling. All of the landslides mapped in this landform were classified as shallow undifferentiated.

Forest Practice Sensitivity and Trigger Mechanisms: This landform occurs entirely within a riparian management zone (RMZ) and/or channel migration zone (CMZ). As such, it is unlikely to have continued forest management practices. Twenty percent of the landslides in this landform were associated with roads. Sediment delivery to the Lower Chehalis River, its sloughs and tributaries from slope failures within this landform is unavoidable, since erosion along river banks is a natural and common process. However, forest practices and other activities disturbing this landform increase the instability.

Mass Wasting Potential: Calculated as Very High based on 54 slope failures in a landform covering 214.1 acres. However the landform has a Landslide Frequency Rating of 5,366 including road-related landslides. The Landslide Frequency Rating without road-related landslides is 4,273.

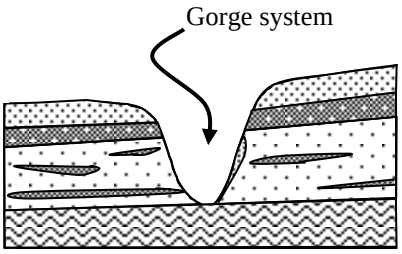
Delivery Potential/Criteria: Calculated as Very High**.** The Landslide Area Rate of Delivery for this landform is 1,832 based on 54 "delivering" landslides totaling 18 acres including 11road-related landslides. The Landslide Area Rate of Delivery without road-related landslides is 1,605 based on 43 "delivering" landslides totaling 16.2 acres.

Overall Hazard Rating: Low. Based on analyst override due to the location of bank failures within the Chehalis River floodplain and no potential for forest practices within this landform.

Confidence: High based on the number of landslides located in this landform, good photo coverage, good LiDAR coverage and field observations.

Comments: The mapped representation of this landform was drawn to include all streamside areas along the Chehalis River Surge Plain at a thickness of the widest observed failure. Although mapped entirely within the floodplain, this landform was included for consistency with previous LHZ reports (Serdar and Powell, 2008) and for completeness of product to include all analyst-derived unique features within the WAU.

Landform #10 – Non-Rule Identified Inner Gorges – Very High Hazard



Description of Mass Wasting Unit: This landform contains similar characteristics of rule-identified inner gorges with convergent slopes of 30-70%. They appear as gentle walled canyons or gullies on DEM slope maps and appear eroded by stream action with evidence of mass wasting along their sidewalls. These Non-Rule Identified Inner Gorges may be either symmetrical or asymmetrical in profile and are commonly intermittent in lateral extent.

Slopes: 30% to 70%
Slope Shape: Convergent to planar
Material: Marine sedimentary tuffaceous siltstones and sandstones (Astoria and Montesano Formations); and glacial outwash
Elevation: 30 ft to 660 ft
Total Area: 122 acres

Mass Wasting Process: This landform contains numerous shallow undifferentiated landslides. These features often contain streams.

Forest Practice Sensitivity and Trigger Mechanisms: Root strength decline within and adjacent to inner gorges has been found to be a factor in increasing rates of mass wasting (Krogstad, 1995) therefore trees adjacent to the inner gorge can have roots extending into the slopes of the gully providing slope stability. Destabilization can occur when roads cut across slopes; removing the hillslope buttressing effect and the replacement of over-steepened cut-slopes associated with road tread. Side cast from roads or landings can further over-steepen and weight slopes, promoting instability. Roads intercept and re-route shallow groundwater and channel it to point locations that saturate road fill that could trigger landslides Twenty-six percent of landslides in this landform were associated with roads.

Mass Wasting Potential: **Very High** for roads and timber harvest based on 57 slope failures in a landform covering 122.4 acres. This landform has a Landslide Frequency Rating of 9,910 including road-related landslides. The Landslide Frequency Rating without road-related landslides is 7,302.

Delivery Potential/Criteria: **Very High.** The Landslide Area Rate of Delivery for this landform is 1,427 based on 53 "delivering" landslides totaling 8 acres including road-related landslides. The Landslide Area Rate of Delivery without road-related landslides is 947 based on 38 "delivering" landslides totaling 5.5 acres.

Overall Hazard Rating: **Very High** based on LHZ Protocol, Table 5.

Confidence: Moderate level of confidence based on the number of landslides in this landform and limited field verification. Good photo coverage and limited field observations were used.

Comments: The majority of this landform is based on slope angles drawn from computer generated Slopestab and DEM's which have been identified in the field as being underrepresented. Field review of accessible mapped areas of this landform always determined slopes at or greater than 70% and were changed to rule identified landform designation. Rule-identified features such as inner gorges and bedrock hollows are likely included in this landform. Small areas of 10-40% slopes have been lumped into this landform.

Landform #11 – Steep Gradient Hillslopes (>60%) - Very High Hazard

Description of Mass Wasting Unit: Steep Gradient Hillslopes contain slopes >60% and are convergent to planar in shape. Thin soils that are not anchored to loosely lithified and weathered bedrock units, combined with the occurrence of heavy precipitation, make steep slopes susceptible to landsliding. Where present on higher ridges this landform is commonly located between mapped rule-identified inner gorges and bedrock hollows and may contain isolated areas of vertical bluffs. Some steep (>60%) deep-seated landslide head scarps have been mapped within this landform.

Slopes: Greater than 60%
Slope Shape: Convergent to Planar
Material: Marine sedimentary tuffaceous siltstones and sandstones (Montesano and Astoria Formations, conglomerate of the Montesano Formation, and glacial deposits
Elevation: 15 ft to 820 ft
Total Area: 878 acres

Mass Wasting Processes: Soil saturation, loss of root strength, and/or over-steepening of slopes in this landform can trigger debris slides, debris flows or small deep-seated landslides. Stream incision causes over steepening which results in shallow landsliding and delivery of sediment and debris to waterways.

Forest Practice Sensitivity and Trigger Mechanisms: Timber harvest, road and landing construction, and other activities that reduce root strength can reduce slope stability. Roots from trees growing on slopes >60% often impede mass wasting by forming an interlocking root mat that provides increased slope strength (Krogstad, 1995). Timber harvest can increase pore-water pressure in the soil by reducing canopy interception and evapotranspiration. Thirty-eight percent of the landslides in this landform were characterized as occurring in 0-15 year old timber. This is assumed to be beyond the time when roots can still hold soils in place on steep ground and suggests that loss of root strength can adversely influence slope stability in this landform. Destabilization can occur when roads cut across slopes; removing the hillslope buttressing effect and the replacement of over-steepened cut-slopes associated with road tread. Side cast from roads or landings can further over-steepen and weight slopes, promoting instability. Roads intercept and re-route shallow groundwater and channel it to point locations that saturate road fill that could trigger landslides. Twenty-eight percent of the landslides in this landform were characterized as being road-related.

Mass Wasting Potential: **Very High** for roads and timber harvest based on 127 slope failures in a landform covering 877.7 acres. This landform has a Landslide Frequency Rating of 3,078 including road-related landslides. The Landslide Frequency Rating without road-related landslides is 2,157.

Delivery Potential/Criteria: **High.** The Landslide Area Rate of Delivery for this landform is 454 based on 98 "delivering" landslides totaling 18.7 acres including road-related landslides. The Landslide Area Rate of Delivery without road-related landslides is 219 based on 69 "delivering" landslides totaling 9.1 acres.

Overall Hazard Rating: **Very High** based on the LHZ Protocol, Table 5.

Confidence: Moderate based on the number of landslides located in this landform, good photo coverage, under-represented DEM data, and limited field verification.

Comments: This landform was delineated primarily by selecting slopes with DEM-derived gradients >60% that were not already delineated as rule-identified landforms. The remotely-sensed slope angles have been identified in the field as being under-represented. Due to mapping constraints, rule-identified features such as inner gorges, toes of deep-seated landslides, and bedrock hollows that were <0.5 acres may have been merged into this landform.

Landform # 12 – Moderate Gradient Hillslopes (41 to 60%) – Very High Hazard

Description of Mass Wasting Unit: This landform consists of slopes found throughout the WAU and frequently adjacent to inner gorges and bedrock hollows. These slopes vary in shape (the majority being convergent and concave-planar) and have gradients between 41 and 60%. This landform includes head scarps and bodies of relict or dormant deep-seated landslides as well as other landslide processes that were not previously mapped.

Slopes: 41 to 60%
Slope Shape: All slope shapes are found within this landform
Material: Marine sedimentary tuffaceous siltstones and sandstones (Montesano and Astoria Formations), glacial deposits
Elevation: 15 ft to 845 ft
Total Area: 2,028 acres

Mass Wasting Process: Shallow undifferentiated landslides, debris flows, and deep-seated landslides occur within this map unit. Several earthflows have been mapped within this landform.

Forest Practice Sensitivity and Trigger Mechanisms: Timber harvest, road and landing construction and other activities that reduce root strength can reduce slope stability. Loss of root strength can increase rates of mass wasting, as can roads and landings that undercut or load or change the hydrology of these slopes. Roots from trees growing on slopes (41-61%) often impede mass wasting by forming an interlocking root mat, providing increased slope strength (Krogstad, 1995). Timber harvest can also increase pore-water pressure in the soil by reducing canopy interception and evapotranspiration. Thirty percent of the landslides in this landform were characterized as occurring in 0-15 year old timber. This is assumed to be beyond the time when roots can still hold soils in place on these slopes and suggests that loss of root strength can adversely influenced slope stability on this landform. Destabilization can occur when roads cut across slopes; removing the hillslope buttressing effect and the replacement of over-steepened cut-slopes associated with road tread. Side cast from roads or landings can further over-steepen and weight slopes, promoting instability. Roads intercept and re-route shallow groundwater and channel it to point locations that saturate road fill that could trigger landslides. Thirty percent of the landslides mapped were characterized as road-related.

Mass Wasting Potential: **Very High** for roads and timber harvest based on 123 slope failures in a landform covering 2,027.8 acres. This landform has a Landslide Frequency Rating of 1,290 including road-related landslides. The Landslide Frequency Rating without road-related landslides is 923.

Delivery Potential/Criteria: **High.** The Landslide Area Rate of Delivery for this landform is 156 based on 99 "delivering" landslides totaling 14.9 acres including road-related landslides. The Landslide Area Rate of Delivery without road-related landslides is 93 based on 74 "delivering" landslides totaling 8.9 acres.

Overall Hazard Rating: **Very High** based on the LHZ Protocol, Table 5. In this landform, the overall hazard rating is heavily influenced by road-related failures. The overall hazard rating for this landform without road related landslides is **Moderate.**

Confidence: Moderate level of confidence based on good photo coverage, under-represented DEM data, and limited field observations.

Comments: This landform was delineated by primarily selecting slopes with DEM-derived gradients 41-61%. The remotely-sensed slope angles have been identified in the field as being under-represented therefore small convergent or steeper features have been mapped within this landform.

Landform #14 - Flats - Low Hazard

Description of Mass Wasting Unit: This landform consists of valley and stream bottoms, flat terraces, prairies, flood plains, and wetlands with slopes that are gentler than 10% in gradient (DEM derived). Slopes exhibit a low landslide potential, and/or are not likely to deliver sediment to a stream, impact public safety or impact a public resource.

Slopes: 0 to 10%
Slope Shape: All slope shapes are found within this landform
Material: Alluvium and continental glacial deposits
Elevation: 0 ft to 345 ft
Total Area: 7,949 acres

Mass Wasting Process: Shallow landslides have not been observed within this landform. Areas adjacent to this landform that consist of steep slopes (>60% DEM) have the potential for slope failures depositing on this landform.

Forest Practice Sensitivity and Trigger Mechanisms: Typically, there is no evidence that forest practice activities increase slope failures.

Mass Wasting Potential: **Low** for road construction and timber harvest based on zero slope failures identified in a landform covering 7,948.9 acres. This landform has a Landslide Frequency Rating of zero including road-related landslides and without road-related landslides.

Delivery Potential/Criteria: **Low**. The Landslide Area Rate of Delivery for this unit is 0. No mass wasting features were noted within this landform.

Overall Hazard Rating: **Low** based on the LHZ Protocol, Table 5.

Confidence: Moderate level of confidence based on good photo coverage, very few landslides identified in aerial photos, and limited field observations.

Comments: Some areas may have been included within this landform that have slopes greater than 10% but these areas do not have a likelihood of slope failure or delivery.

Landform #15 - Ridge Tops and Noses – Low Hazard

Description of Mass Wasting Unit: This landform consists of ridge tops and noses of ridges with varying slope forms and gradients between 0 and 10% that exhibit a low landslide potential, and/or are not likely to deliver sediment to a stream, impact public safety or impact a public resource.

Slopes: 0 to 10%
Slope Shape: All slope shapes are found within this landform
Material: Marine sedimentary tuffaceous siltstones and sandstones (Montesano and Astoria Formations) and glacial deposits
Elevation: 85 ft to 710 ft
Total Area: 343 acres

Mass Wasting Process: Shallow landslides have not been observed within this landform. Areas adjacent to this landform that consist of steep slopes (>60% DEM) have the potential for slope failures migrating into this landform.

Forest Practice Sensitivity and Trigger Mechanisms: Poor forest management practices on this landform could cause mass wasting on slopes below ridge tops and noses. Side cast road construction and landings can cause instability by over-steepening slopes, weighting and undercutting them. Roads and landings can also capture runoff water or shallow groundwater and channel it to point locations that saturate fill and/or unconsolidated deposits triggering slope failures.

Mass Wasting Potential: **Low** for road construction and timber harvest based on no slope failures identified in a landform covering 343.0 acres. This landform has a Landslide Frequency Rating of zero.

Delivery Potential/Criteria: **Low**. The Landslide Area Rate of Delivery for this unit is 0. No mass wasting features were noted within this landform.

Overall Hazard Rating: **Low** based on the LHZ Protocol, Table 5.

Confidence: Moderate level of confidence based on good photo coverage but under-represented DEM data and limited field observations.

Comments: Some areas may have been included within this landform that have slopes greater than 10% but these areas do not have a likelihood of slope failure or delivery. This landform was mapped using DEM slope percent maps and may contain areas of steeper slopes due to the inaccuracy of the available DEM data.

Landform # 16 – Low Gradient Hillslopes (11 to 40%) – Low Hazard

Description of Mass Wasting Unit: This landform consists of all slope shapes and gradients between 11 and 40% that exhibit a low landslide potential, and/or are not likely to deliver sediment to a stream, impact public safety, or impact a public resource.

Slopes: 11 to 40%
Slope Shape: All slope shapes are found within this landform
Material: Marine sedimentary tuffaceous siltstones and sandstones (Montesano and Astoria Formations, conglomerate of the Montesano Formation, and glacial deposits
Elevation: 5 ft to 785 ft
Total Area: 2,994 acres

Mass Wasting Process: Deep-seated landslides dominate this landform, but shallow landslides can occur with a variety of slope shapes on slopes between 11 and 40%.

Forest Practice Sensitivity and Trigger Mechanisms: Timber harvest, road and landing construction and other activities that reduce root strength on slopes between 11 and 40% have the potential to reduce slope stability. Loss of root strength can increase rates of mass wasting, as can roads and landings that undercut or load or change the hydrology of these slopes. Roots from trees on slopes (11-40%) often impede mass wasting by forming an interlocking root mat, providing increased slope strength (Krogstad, 1995). Destabilization can occur when roads cut across slopes; removing the hillslope buttressing effect and the replacement of over-steepened cut-slopes associated with road tread. Side cast from roads or landings can further over-steepen and weight slopes, promoting instability. Roads intercept and re-route shallow groundwater and channel it to point locations that saturate road fill that could trigger landslides.

Mass Wasting Potential: **Low** for road construction and timber harvest based on no slope failures identified in a landform covering 2,993.6 acres. This landform has a Landslide Frequency Rating of zero.

Delivery Potential/Criteria: **Low**. The Landslide Area Rate of Delivery for this unit is 0. No mass wasting features were noted within this landform.

Overall Hazard Rating: **Low** based on the LHZ Protocol, Table 5.

Confidence: Moderate level of confidence based on good photo coverage but under-represented DEM data and limited field observations.

Comments: The majority of this landform is based on slope angles drawn from computer generated SLPSTAB and DEMs which have been identified in the field as being underrepresented.