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# GEOTECHNICAL REVIEW
# WC-187 PROPOSED HARVEST UNIT,
# T21N-R07W-SEC 11 and 12,
# GRAYS HARBOR COUNTY, WASHINGTON

**Final**

**Prepared for**

**Green Diamond Resource Company**

**Prepared by**

**LaManna Geosciences Inc.**

**June 27, 2014**

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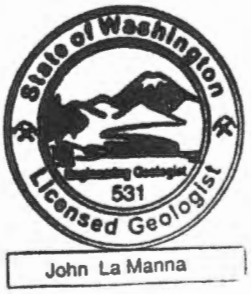
**THIS REPORT HAS BEEN PREPARED UNDER THE RESPONSIBLE CHARGE OF A STATE OF WASHINGTON LICENSED ENGINEERING GEOLOGIST**

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## PURPOSE AND SCOPE OF EVALUATION

This report presents the results of a geotechnical evaluation of proposed harvest unit (PHU) WC-187. The proposed forest practices will consist of even-age harvesting approximately 23.9 acres of timber. The PHU is shown relative to Shelton on the vicinity map (Figure 1).

This report was prepared by an engineering geologist licensed in the State of Washington who is a qualified expert according to the definition in Washington Administrative Code (WAC) 222-10-030(5). Green Diamond Resource Company (GDRCo) uses habitat conservation plan (HCP) prescriptions as alternatives to Standard Forest Practices and Watershed Analysis (GDRCo, 2012; Mahan, 2013). The HCP prescriptions prohibit timber harvest on unstable slopes that have the potential to deliver sediment to public resources. The goal of the geotechnical evaluation was to evaluate whether the proposed forest practices will cause or contribute to landslides. The conclusions presented in this report are based on a review of available information and a field reconnaissance of locations selected because they were judged to have the greatest potential for instability. The harvest boundary, as well as the topography, streams, and existing roads within and surrounding the PHU, is shown on Figure 2.

LaManna Geosciences Inc. (LGI) performed the field reconnaissance on May 12, 2014, accompanied by GDRCo personnel. LGI's services were provided under a consulting agreement dated January 1, 2014.

This evaluation was performed to (a) determine whether the PHU boundary excludes potentially unstable landforms that are likely to deliver sediment and/or debris to public resources or that threaten public safety; (b) determine whether potentially unstable landforms can be included in the PHU because they are likely to be stable or are unlikely to result in sediment delivery; (c) develop mitigation measures for reducing the likelihood that the proposed forest practices would cause or contribute to slope instability and for reducing the likelihood of sediment delivery to public resources. Specifically, LGI's scope of services consisted of the following components:

- Collect and review maps, reports, and other information pertinent to the PHU
- Interpret historical aerial photographs and output from a light detection and ranging (LiDAR) digital elevation model (DEM) of the PHU
- Prepare a geotechnical report summarizing the observations, opinions, and conclusions of the evaluation

## METHOD

LGI used a method that is consistent with the Washington State Forest Practices Rules (Title 222 WAC) and Section 16 of the Forest Practices Board Manual (Washington State Department of Natural Resources, 2004). LGI's method consisted of reviewing aerial photographs, LiDAR-derived topography, anecdotal information provided by GDRCo, and other available information, followed by field observations to identify potentially unstable slopes and landforms. LGI then judged the potentially unstable slopes and landforms for their potential to deliver sediment and debris to streams or to pose a threat to public safety. Where LGI judged that impacts are likely, mitigation measures were developed (e.g., excluding areas from harvest). LGI did not perform subsurface explorations, laboratory testing, and computer modeling of slope stability and delivery of sediment and debris.

## REVIEW OF AVAILABLE INFORMATION

LGI reviewed the information summarized in Table 1. The PHU is located in the West Fork Satsop Watershed Administrative Unit (WAU). A watershed analysis report has been prepared for this WAU.

**Table 1. Information Reviewed by LGI**

| Description | Data Source |
|---|---|
| PHU boundary | Shapefile and map from GDRCo |
| Existing roads and structures | (a) Shapefiles and map from GDRCo<br>(b) LiDAR DEM and aerial photographs<br>(c) Google Earth |
| Streams (typed waters) | (a) Shapefile and map from GDRCo<br>(b) LiDAR DEM; LGI adjusted stream locations to fit topography<br>(c) Information from GDRCo regarding water types |
| Topography from LiDAR Bare Earth DEM | LiDAR data from 2010; provided by GDRCo |
| Geology (1:100,000), GIS shapefiles | Department of Natural Resources<br>https://fortress.wa.gov/dnr/geology/?Site=wigm<br>http://www.dnr.wa.gov/ResearchScience/Topics/GeosciencesData/Pages/gis_data.aspx |
| Vicinity geography, topography, and improvements | (a) U.S. Geological Survey (USGS) Wynoochee Valley NW 7.5-minute quadrangle map (scale 1:24,000)<br>(b) USGS Larsen Creek 7.5-minute quadrangle map<br>(c) Google Earth |
| Soil survey | Natural Resources Conservation Service<br>http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx<br>Department of Natural Resources<br>http://fortress.wa.gov/dnr/app1/dataweb/dmmatrix.html |
| West Fork Satsop WAU watershed analysis report | Department of Natural Resources<br>http://fortress.wa.gov/dnr/forestpractices/wsasmt.cgi?wsaval=acme |
| DNR landslide inventory shapefile | Department of Natural Resources<br>http://fortress.wa.gov/dnr/app1/dataweb/dmmatrix.html |
| DNR slope stability map | Department of Natural Resources<br>http://fortress.wa.gov/dnr/app1/dataweb/dmmatrix.html |
| Precipitation zones | Department of Natural Resources<br>http://fortress.wa.gov/dnr/app1/dataweb/dmmatrix.html |
| 1946 aerial photographs | 10316 11-19 and -20; provided by GDRCo |
| 1956 aerial photographs | S.L.10W-15 and -16; provided by GDRCo |
| 1967 aerial photographs | GH-67-43C-6 through -8; provided by GDRCo |
| 1977 aerial photographs | OL-77 60C-9 through -11; provided by GDRCo |
| 1985 aerial photographs | OL-85 18-060-099 and -101; provided by GDRCo |
| 1994 orthophotograph | University of Washington<br>http://rocky2.ess.washington.edu/data/raster/doqs/wenatchee.html |
| 1995 aerial photographs | OLP-95 14-14-39 through -41; provided by GDRCo |
| 1999 aerial photographs | SW-C-99 60-37-156 through -158; provided by GDRCo |
| 2003 aerial photographs | OL-C-03 37-60-61 through -63; provided by GDRCo. |
| 2006 orthophotograph | National Agriculture Inventory Program (NAIP) |
| 2009 orthophotograph | NAIP |

| Description | Data Source |
|---|---|
| 2011 orthophotograph | NAIP |

### Precipitation Zones, Geology, and Soils

The entire PHU is located in the Rain Dominated precipitation zone. According to DNR maps, the PHU is situated on two geologic units (Figure 3). Most of the PHU is underlain by Eocene-age basalt flows and flow breccias of the Crescent Formation (Ev[cf]). Smaller portions of the PHU are underlain by Eocene-age marine sedimentary rocks of the Crescent Formation (Em[1c]). These rocks reportedly dip to the south in the vicinity of the PHU.

The Natural Resources Conservation Service soil map indicates that the PHU is underlain by one soil unit (i.e., Waketickeh-Fricaba complex, 60 to 100 percent slopes). The soil texture varies between extremely gravelly sandy loam and extremely cobbly sandy loam.

### Geomorphology, Surface Drainage, Improvements, and Public Safety

The PHU is located on a moderate- to steep-gradient west-facing slope. The elevation of the PHU varies between approximately 1,070 and 1,800 feet (ft). Within the PHU, slopes steeper than 70 percent are mostly associated with midvalley hill slopes and scarps of dormant deep-seated landslides (Figure 2).

The PHU drains into an unnamed tributary of the Little River, which is located west of the PHU. Identified improvements downstream of the PHU are summarized in Table 2.

**Table 2. Summary of Selected Improvements Downstream of the PHU**

| Improvement | Location | Ownership | Comments |
|---|---|---|---|
| 48-inch corrugated metal pipe | Section 14 (T21N-R07W), where 600 Road crosses the unnamed tributary<br>47°18'49.01"N<br>123°32'0.63"W | GDRCo | The average stream gradient is approximately 5.2 degrees for the 1,200-ft reach downstream of the PHU. This gradient is high enough to transport a debris flow from the PHU to the culvert should a debris flow occur. |
| Abandoned railroad trestle | Section 21 (T20N-R07W)<br>47°12'22.43"N<br>123°33'18.23"W | GDRCo | This trestle crosses the West Fork Satsop River a short distance downstream from the Canyon River confluence and about 12 miles downstream of the PHU. |
| Cougar-Smith Road Bridge and buildings | Section 33 (T210N-R07W)<br>47°10'46.60"N<br>123°33'35.36"W | GDRCo | This bridge crosses the West Fork Satsop River. The first buildings downstream of the PHU are located along the river in this area. Some of these buildings appear to be dwellings. The Satsop River meanders in an unconfined alluvial channel that is unlikely to transport a debris flow to these structures. |

The information in Table 2 indicates no significant hazard due to a debris flow that might originate in the PHU and reach a valuable structure located downstream of the PHU. However, sediment and debris from a landslide that might originate in the PHU during a storm or seismic event could contribute to sediment and debris from other sources and cause sedimentation, scour, and debris dams downstream of the PHU. If a debris dam forms against a bridge, lateral forces and subsequent deformations could damage the bridge or its abutments.

LGI did not verify whether water from the West Fork Satsop River or the Chehalis River is diverted for municipal, domestic, commercial, irrigation, livestock, or hatchery water supplies. However, water diversion appears likely. If water is being diverted, additional fine-sediment load associated with slope movements in the PHU could increase the requirements for maintenance and repairs of water diversion equipment or potentially affect the health of organisms that receive the diverted water.

Public resources could be affected by slope movements regardless of their cause. These public resources consist of water quality and fish and wildlife located on and downslope of the PHU.

No threats to public safety are apparent. LGI understands that all land located within 1 mile of the PHU is owned or managed by GDRCo and that GDRCo is not aware of any planned changes in future land uses. The PHU and all property within 1 mile are located on privately owned timber property that has limited access due to locked gates. In addition, GDRCo's security personnel periodically patrol the roads used to access the PHU.

### DNR Slope Stability Model

The DNR prepared a map that shows computer model predictions of slope stability for use as a reconnaissance screening tool. The map shows predicted locations of shallow-rapid-type landslides. The computer model predicts instability based mainly on slope steepness and convergence. The model does not predict delivery. As shown on the slope stability map, the PHU encompasses some areas of "high slope instability" and "medium slope instability" (Figure 4). In LGI's opinion, places where blue the pixels (representing high instability) coalesce into large blue areas should be field reviewed if they are in locations where delivery is likely. The PHU includes such areas.

### Watershed Analysis and DNR Landslide Inventory

West Fork Satsop Watershed Analysis Map A-1 is a mass wasting inventory map (Figure 5). This map appears to have been digitized into DNR's landslide inventory shapefile. Both of these landslide inventories show that previously mapped landslides in the vicinity of the PHU are located near stream channels.

## REVIEW OF LIDAR-DERIVED TOPOGRAPHY AND HISTORICAL AERIAL PHOTOGRAPHY

A LiDAR-derived oblique image of the topography in the vicinity of the PHU is displayed on Figure 6, which shows that the PHU is situated on a moderate to steep west-facing slope. Topographic and field observations reveal the scarps of dormant deep-seated landslides within and adjacent to the PHU boundary. The tops of the scarps are delineated on Figure 6.

There is good photographic coverage of the PHU from 1946 to 2011 (Figure 7). LGI's observations from these photographs are summarized in Table 3. Bare soil visible on these photographs may represent landslides, erosion, sedimentation, or soil disturbance due to heavy

equipment and log yarding. Photographs may underrepresent the extent of bare soil, because bare soil can be hidden by the tree canopy and shadows.

**Table 3. Observations from Historical Aerial Photographs**

| Year | Description |
|---|---|
| 1946 | The PHU is situated in an old-growth forest, and roads have not been constructed near the PHU. No significant mass wasting is visible with the PHU boundary. |
| 1956 | The 630 Road has been constructed. The northwestern portion of the PHU below the 630 Road and a small northeastern portion of the PHU have been harvested. Bare soil appears to be associated with side-cast and an inner gorge landslide or erosion. |
| 1967 | The entire PHU has been harvested. Bare soil appears to be associated with road side-cast, a 630 Road-related landslide, small inner gorge landslides, and yarding-related disturbance within the PHU boundary. |
| 1977 | The entire PHU is vegetated with young conifers. Bare soil appears to be associated with the 630 Road-related landslide first visible on the 1967 photograph, ravel on the cut slope of the 630 Road, and an unvegetated yarding-related disturbance within the PHU boundary. |
| 1985 | Bare soil appears to be associated with unvegetated side-cast, the side-cast landslide, excavation or failure of the cut slope of the 630 Road in the northern portion of the PHU, and possible small, shallow landslides within the PHU boundaries associated with the scarps of dormant deep-seated landslides. |
| 1994 | Bare soil appears light gray on this photograph and is associated with unvegetated side-cast and cut slopes along the 630 Road and an area within the PHU boundary associated with the scarp of a dormant deep-seated landslide. |
| 1995 | Bare soil appears white on this photograph. It appears to be associated with unvegetated side-cast, a landslide and cut slopes along the 630 Road, small areas within the PHU boundary that are associated with the scarp of a deep-seated landslide, and yarding-related disturbances observed on earlier photographs. |
| 1999 | This photograph was taken between 2 and 3 years after the unusual storm events during the winter of 1996–1997. Three areas with uneven tree canopy coincide with areas of bare soil observed on earlier photographs that appear to be related to yarding disturbances and possible small landslides or erosion on the scarp of a dormant deep-seated landslide. |
| 2003 | Three small areas of bare or sparsely vegetated soil are visible within the PHU boundary. They appear to be associated with a yarding disturbance and the scarp of a dormant deep-seated landslide. |
| 2006 | Recent harvest is visible south and west of the PHU. No bare soil is visible within the PHU boundary. |
| 2009 | This photograph was taken less than 1 year after the unusual storm event in January 2009 and less than 3 years after the unusual storm event in December 2007. One area of bare soil west of the PHU boundary appears to be a small inner gorge landslide. No areas of bare soil are visible within the PHU boundary. |
| 2011 | No areas of bare soil are visible within the PHU boundary. |

In summary, most bare soil is associated with unvegetated side-cast on the 630 Road. The photographs show one landslide that originated on the 630 Road and scoured a path that almost reached the unnamed fish-bearing stream west of the PHU. This landslide occurred between 1956 and 1967. The cut slope along the 630 Road at the northern side of the PHU became larger between 1977 and 1985 because the cut slope was quarried for rock and/or it slid or raveled. Some semi-persistent small areas of bare soil within the PHU boundary appear to have been related to erosion and soil disturbance due to yarding, or shallow landslides on the

scarps of dormant deep-seated landslides. These areas of bare soil apparently did not deliver sediment to typed water based on the review of photographs and field observations.

## FIELD OBSERVATIONS, OPINIONS, AND LANDFORMS

The PHU includes many steep slopes. The slopes that were excluded from the PHU appear to be potentially unstable and located where delivery appears likely. The cutting lines (i.e., the PHU boundary) are marked in the field with fluorescent red flagging and white Tyvek tags.

LGI's field observations are summarized in Table 4. Field measurements of slope gradients were made with a handheld clinometer, and most distances were estimated. LGI inferred many landform boundary locations, especially the inner gorges and deep-seated landslides, using slope gradients derived from the LiDAR DEM. The location numbers and landforms are shown on Figure 8.

**Table 4. Selected Field Observations**

| Location No. | Observations, Mitigation Measures, and Opinions |
|---|---|
| 1 | The cutting line (i.e., the PHU boundary) is located at the top of the slope break of the inner gorge (landform G1). The slope above the cutting line is divergent, with an 80 percent gradient. The gradient below the line is about 84 percent. The PHU in this area has conifers, vine maple, salal, Oregon grape, ferns, and in situ old-growth stumps. The PHU appears to be stable.<br>*Mitigation:* The mitigation is to exclude the inner gorge landform (G1) from the PHU. |
| 2 | A five-tree leave island, approximately 30 ft in diameter, was created to stabilize loose cobble-size side-cast and colluvium (landform E1). The leave island has a divergent slope with 85 to 88 percent gradients. The loose colluvium is buttressed by the leave trees and old-growth stumps. The PHU downslope of the leave island has an approximate gradient of 74 percent; above the leave island the gradient is about 77 percent. The PHU in this area has conifers, salal, huckleberry, ferns, Oregon Grape, in situ old-growth stumps, and abundant loose, angular, cobble-size basalt talus. The PHU appears to be stable in this area.<br>*Mitigation:* The mitigation is to leave trees within a 30-ft-diameter area of steep, loose colluvium. The root strength will help stabilize this colluvium. |
| 3 | Loose, angular, gravel to cobble-size basalt talus covers a planar to divergent hillslope (landform E2). The talus is visible as a 630 Road-related landslide on aerial photographs beginning in 1967. Slope gradients vary from approximately 50 percent near the lower side of the PHU to 70 percent near the road. The talus is vegetated with conifers up to 4 inches in diameter, alder up to 4 or 5 inches in diameter, ferns, and salal. No seepage or rule-identified landforms were observed on the talus-covered slope. The talus was not excluded from the PHU because it appears to be stable. The cut slope above the 630 Road at this location is about 30 ft high and may have been the source of the talus.<br>*Mitigation:* LGI recommends pulling back the top 10 ft of steep slope below the shoulder of the 630 Road for approximately 50 lineal ft, where the road is located above the talus slope. |
| 4 | The PHU boundary includes portions of a debris fan (landform F).[1] The fan has 40 and 62 percent slopes with conifers (some cedar), vine maple, in situ old-growth stumps (some stumps are partially buried), and logging debris (also partially buried). At the time of observation, the Ns stream had incised about 4 ft of the fan and was not flowing. The fan appears to be stable.<br>*Mitigation:* The mitigation is to exclude from the PHU the steep inner gorge (landform G2) along the Ns stream and steep side-cast slopes below the 630 Road that appear likely to deliver to the Ns stream. |
| 5 | This broad bedrock hollow (landform H2) has slope gradients up to 76 percent on the north side, 40 percent along the axis, and 82 percent on the south side. It has conifers (some cedar), vine maple, cascara, ferns, salal, in situ old-growth stumps (some on axis), and burnt logging debris (some on axis). |

[1] Fans are not potentially unstable landforms.

| Location No. | Observations, Mitigation Measures, and Opinions |
|---|---|
| | This hollow appears to be stable. Delivery across the road to the Ns stream is likely should a slide occur.<br>*Mitigation:* No mitigation is needed because this landform appears to be stable. |
| 6 | The cutting line is located above the top of the 630 Road cut slope, which locally displays landslide scars and ravel (landform E3). Slopes above the cutting line are planar to divergent, with gradients up to 88 percent and conifers, vine maple, salal, ferns, huckleberry, and, locally, in situ old-growth stumps.<br>*Mitigation:* The cutting line was placed one tree above the break-in slope at the top of the road cut. The roots of these leave trees will retard ravel at the top of the cut. Ravel and small landslides are unlikely to deliver to typed water at this location. |
| 7 | The cutting line is located in a broad area of convergence, with gradients up to 68 percent, conifers, vine maple, ferns, Oregon grape, in situ old-growth stumps, and logging debris. This area appears to be stable and is not a bedrock hollow with slope gradients greater than 70 percent.<br>*Mitigation:* No mitigation is needed because this area appears to be stable. |
| 8 | This is a broad bedrock hollow (landform H1) with gradients mostly between 75 and 92 percent and conifers, vine maple, ferns, salal, in situ old-growth stumps, and logging debris. No seepage or shallow landslides were observed in the PHU in this area. This landform appears to be stable. North of the cutting line are rock outcrop and a scar and deposit from a relatively recent shallow-rapid landslide.<br>Delivery of a slide that originates in H1 is unlikely because the steep slope below the 630 Road to the nearest typed water is about 200 ft long (slope distance) and planar.<br>*Mitigation:* The cutting lines do not exclude H1 because it appears to be stable. Unstable slopes north and west of the cutting lines are excluded. |
| 9 | There are two dormant deep-seated landslides at this location. The toe of the larger landslide has broadly divergent slopes up to 62 percent with conifers, vine maple, Oregon grape, salal, ferns, in situ old-growth stumps, and logging debris (landform T). The scarp of this dormant landslide is almost planar, with no observed hollows. There is no evidence of shallow landslides that originated on the scarp and delivered past the toe. The toe and scarp appear to be stable, notwithstanding the smaller landslide occurred in the toe of the larger.<br>The toe of the smaller landslide (also landform T) has broadly divergent and hummocky slopes, with gradients up to 63 percent and conifers, vine maple, ferns, Oregon grape, and salal. No seepage was observed. The scarp of the smaller landslide has a broadly convergent slope up to 82 percent, with conifers, vine maple, ferns, salal, in situ old-growth stumps, and logging debris. No seepage or shallow landslide scars were observed. Both the toe and the scarp appear to be stable.<br>The areas of bare soil or sparse vegetation observed on the aerial photographs do not appear to be associated with shallow-rapid landslides in this area and are probably related to soil disturbance due to yarding.<br>Should a shallow landslide occur on the toe (landform T), delivery appears unlikely because of the relatively long non-convergent slope situated between landform T and the nearest stream.<br>*Mitigation:* No mitigation is needed because (a) decreases in root strength due to harvest are unlikely to cause or contribute to a resurgence of movement on these dormant deep-seated landslides; and (b) the scarps do not appear likely to generate shallow-rapid landslides that could deliver to typed water. |
| 10 | The upper portion of this slope (landform H3) is almost planar, with gradients up to 84 percent; the lower portion is broadly convergent, with approximately 75 percent gradients. These slopes have conifers, vine maple, huckleberry, salal, in situ old-growth stumps, and logging debris. No seepage or shallow landslide scars were observed. This landform appears to be stable.<br>*Mitigation:* No mitigation is needed because this landform appears to be stable. |
| 11 | The north end of the steep scarp (landform E5) of a dormant deep-seated landslide has gradients of 95 percent; the south end of the scarp (landform E5) has gradients between 84 and 88 percent. The vegetation consists of conifers, ferns, salal, Oregon grape, vine maple, and in situ old-growth stumps. The scarp has three or four 30-ft-diameter steep, convergent shallow-rapid landslide scars.<br>The slope below the steepest portion of the scarp has an apron of loose gravel to cobble-size talus and lacks channels or convergences that could convey the talus as far downslope as the road. The field |

| Location No. | Observations, Mitigation Measures, and Opinions |
|---|---|
| | observations and photographs (Figure 7) indicate no landslides or areas of bare soil large enough to reach the road. Hence, delivery from E5 appears unlikely.<br>*Mitigation:* No mitigation is needed because delivery of sediment to typed water appears unlikely. |
| 12 | The cutting line is located on a planar to broadly convergent slope with gradients of 56 percent facing upslope and 74 percent facing downslope. The cutting line is located above the scarp of a probable dormant deep-seated landslide and an inner gorge (landform G4). Most of the PHU below the 630 Road has gradients less than 70 percent in this area.<br>*Mitigation:* No mitigation is needed because this area appears to be stable. |
| PB | The area of side-cast pull back discussed for location 3 is labeled PB on Figure 8. |

### Potentially Unstable Landforms

Landforms relevant to the PHU are shown on Figure 8. LGI inferred the landform boundaries from field observations and LiDAR-derived maps. These landforms are summarized in Table 5.

**Table 5. Summary of Potentially Unstable Landforms Identified in the PHU[2]**

| Landform | Map Symbol | Comments |
|---|---|---|
| Inner gorges | G1, G2, G3, G4 | Inner gorges with slopes steeper than 70 percent were excluded from the PHU. |
| Bedrock hollows | H1, H2, H3 | Bedrock hollows with slopes steeper than 70 percent were not excluded from the PHU because they appear to be stable. |
| Category E | E1, E2, E3, E4, E5 | The Category E landforms represent steep slopes that have indicators of instability. E1 was excluded because root strength could be beneficial; E2 was not excluded because it appears to be stable; E3 and E4 were excluded because they appear to be unstable; E5 was not excluded because delivery appears to be unlikely. |
| Toe of deep-seated landslide | T | Landform T was not excluded from the PHU because it appears to be stable and sediment delivery is unlikely. |

## IMPLEMENTATION AND MITIGATION

### Harvest

LGI understands that trees will be harvested in accordance with current forest practices rules, and forest practices will not take place beyond the cutting lines marked by the fluorescent red ribbon and white Tyvek tags observed by LGI. LGI recommends painting and/or notching the butts of selected trees along the cutting lines in the vicinity of potentially unstable landforms, low enough that the mark will not be removed if the tree is cut. This should be done after the Forest Practices Application is approved and shortly before harvest. At the same time, missing flags and tags can be replaced. Having trees marked on the butt may be useful if it becomes necessary to verify compliance with the cutting lines established for this project.

[2] The debris fan (landform F) is not included in this table because it is not a potentially unstable landform.

### Roads and Landings

LGI recommends pulling back historical side-cast at the location discussed in Table 4 and shown on Figure 8.

### Contractor Performance

LGI recommends that a qualified person confirm that the contractors' work is properly performed. Errors and negligence by contractors can create conditions that trigger complaints, erosion, and landslides.

## CONCLUSION

In LGI's opinion, potentially unstable landforms and unstable slopes that are likely to deliver sediment and debris to public resources have been excluded from the PHU in a manner consistent with the HCP prescription of "no harvest" on unstable slopes. The mitigation measures consist of specific no-harvest areas and one road-related prescription.

## REQUIRED STATEMENTS

The following are responses that address the requirements of WAC 222-10-030(1)(a), (b), and (c):

> *(1) In order to determine whether such forest practices are likely to have a probable significant adverse impact, and therefore require an environmental impact statement, the applicant must submit the following additional information, prepared by a qualified expert. The expert must describe the potentially unstable landforms in and around the application site and analyze:*
>
> *(a) The likelihood that the proposed forest practices will cause movement on the potentially unstable slopes or landforms, or contribute to further movement of a potentially unstable slope or landform;*

Response[3]:

- For the inner gorge landforms (G1, G2, G3, and G4), the likelihood is LOW.
- For the bedrock hollow landforms (H1, H2, and H3), the likelihood is LOW.
- For the toe of the deep-seated landslide landform (T), the likelihood is LOW.
- For Category E landform E1, the likelihood is HIGH.
- For Category E landform E2, the likelihood is LOW.
- For Category E landform E3, the likelihood is HIGH.
- For Category E landform E4, the likelihood is HIGH.
- For Category E landform E5, the likelihood is HIGH.

> *(b) The likelihood of delivery of sediment or debris to any public resources,*

Response[4]:

[3] Movement responses assume the proposed mitigations are implemented (i.e., likelihood of movement is LOW *assuming the proposed mitigations were properly implemented*).

[4] Delivery responses assume that a slope movement will occur on the landform for some reason (e.g., the likelihood of delivery is HIGH *if a landslide is assumed to occur for some reason*).

- For the inner gorge landforms (G1, G2, G3, and G4), the likelihood is HIGH.
- For the bedrock hollow landform H1, the likelihood is LOW.
- For the bedrock hollow landforms H2 and H3, the likelihood is HIGH.
- For the toe of the deep-seated landslide landform (T), the likelihood is LOW.
- For Category E landform E1, the likelihood is HIGH.
- For Category E landform E2, the likelihood is HIGH.
- For Category E landform E3, the likelihood is HIGH.
- For Category E landform E4, the likelihood is HIGH.
- For Category E landform E5, the likelihood is LOW.

*or in a manner that would threaten public safety*;

Response:

- For the inner gorge landforms (G1, G2, G3, and G4), the likelihood is LOW.
- For the bedrock hollow landforms (H1, H2, and H3), the likelihood is LOW.
- For the toe of the deep-seated landslide landform (T), the likelihood is LOW.
- For Category E landform E1, the likelihood is LOW.
- For Category E landform E2, the likelihood is LOW.
- For Category E landform E3, the likelihood is LOW.
- For Category E landform E4, the likelihood is LOW.
- For Category E landform E5, the likelihood is LOW.

*(c) Any possible mitigation for the identified hazards and risks.*

Response:

- For the inner gorge landforms (G1, G2, G3, and G4), the mitigation is to exclude these landforms from the PHU.
- For the bedrock hollow landforms (H1, H2, and H3), no mitigation is required.
- For the toe of the deep-seated landslide landform (T), no mitigation is required.
- For Category E landform E1, the mitigation is to exclude this landform from the PHU.
- For Category E landform E2, the mitigation is to pull back oversteepened side-cast as explained in Table 4 (location 3).
- For Category E landform E3, the mitigation is to exclude this landform from the PHU.
- For Category E landform E4, the mitigation is to exclude this landform from the PHU.
- For Category E landform E5, no mitigation is required.

## LIMITATIONS

The opinions expressed in this report have been developed using the degree of care and skill ordinarily exercised, under similar conditions, by reputable engineering geologists practicing in this or similar localities. The methods used are based on anecdotal information; observations of LiDAR-derived topography, aerial photographs, and surface expressions of slope movements at the time of this investigation; and judgments about stability and sediment delivery. This method

is limited by the completeness and accuracy of the information provided, the availability and clarity of photographs, access to and visibility of the ground surface, weather conditions, and available time. Consequently, the quality and extent of LGI's observations may vary. Other limitations include the lack of subsurface explorations (borings, backhoe test pits, piezometers, etc.), the lack of laboratory test data on soil and rock properties, and the absence of quantitative slope stability, storm event, and seismic modeling. Because the method LGI used does not predict slope stability, slope movement, and delivery with certainty, the opinions expressed herein cannot guarantee that landslides and delivery will not occur or that mitigation measures will perform as intended.

There are always risks related to landslides that current and future owners and land managers must accept when choosing to conduct forest practices on slopes. These risks arise from the limitations described; the use of improper harvest methods; the poor construction and maintenance of roads and drainage structures; the occurrence of forest fires, earthquakes, floods, extreme or unusual storm events, and climate change; and other causes.

This report was prepared for GDRCo for the location and purpose described herein and does not apply to other locations or other purposes. If there is a substantial lapse of time between the submission of this report and the start of work, or if conditions have changed due to natural causes or work at or adjacent to the PHU, LGI recommends that this report be reviewed to determine the applicability of its conclusions and recommendations. No warranty, expressed or implied, is made.

## REFERENCES

GDRCo (Green Diamond Resource Company). 2012. HCP Forest Practices Crosswalk. November 6.

Mahan, Donelle. 2013. Green Diamond Resource Company Crosswalk for Unstable Slopes. Letter from Donelle Mahan, Washington State Department of Natural Resources, to Eric Beach, Green Diamond Resource Company. January 23.

Washington State Department of Natural Resources. 2004. Forest Practices Board Manual. Section 16, Guidelines for Evaluating Potentially Unstable Slopes and Landforms.

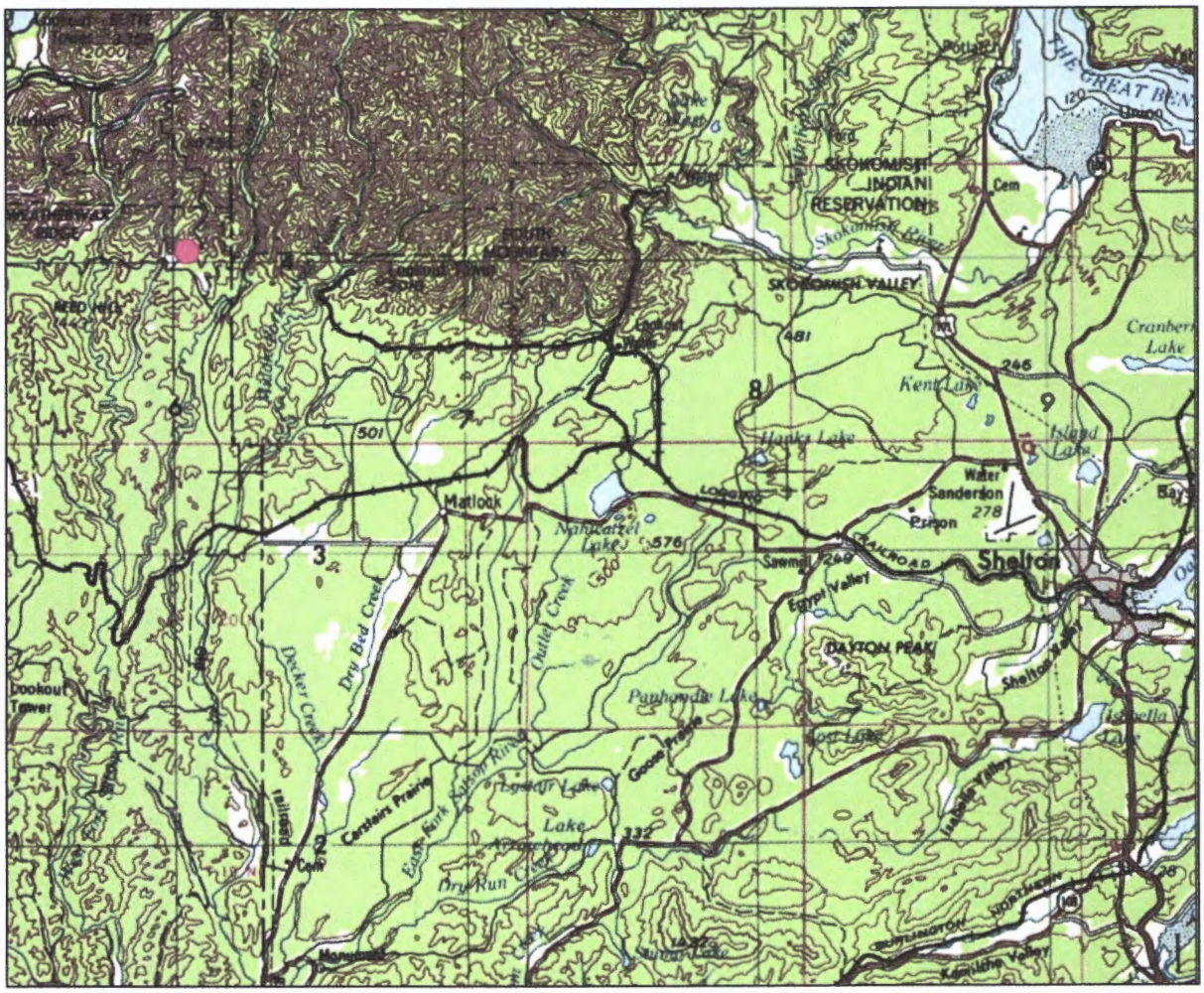


**Figure 1.** Vicinity map. Shown is the approximate location of the PHU (red circle) relative to Shelton, Washington. The PHU is located along an unnamed tributary of the Little River in Grays Harbor County, Washington. The Little River flows south into the Satsop River.

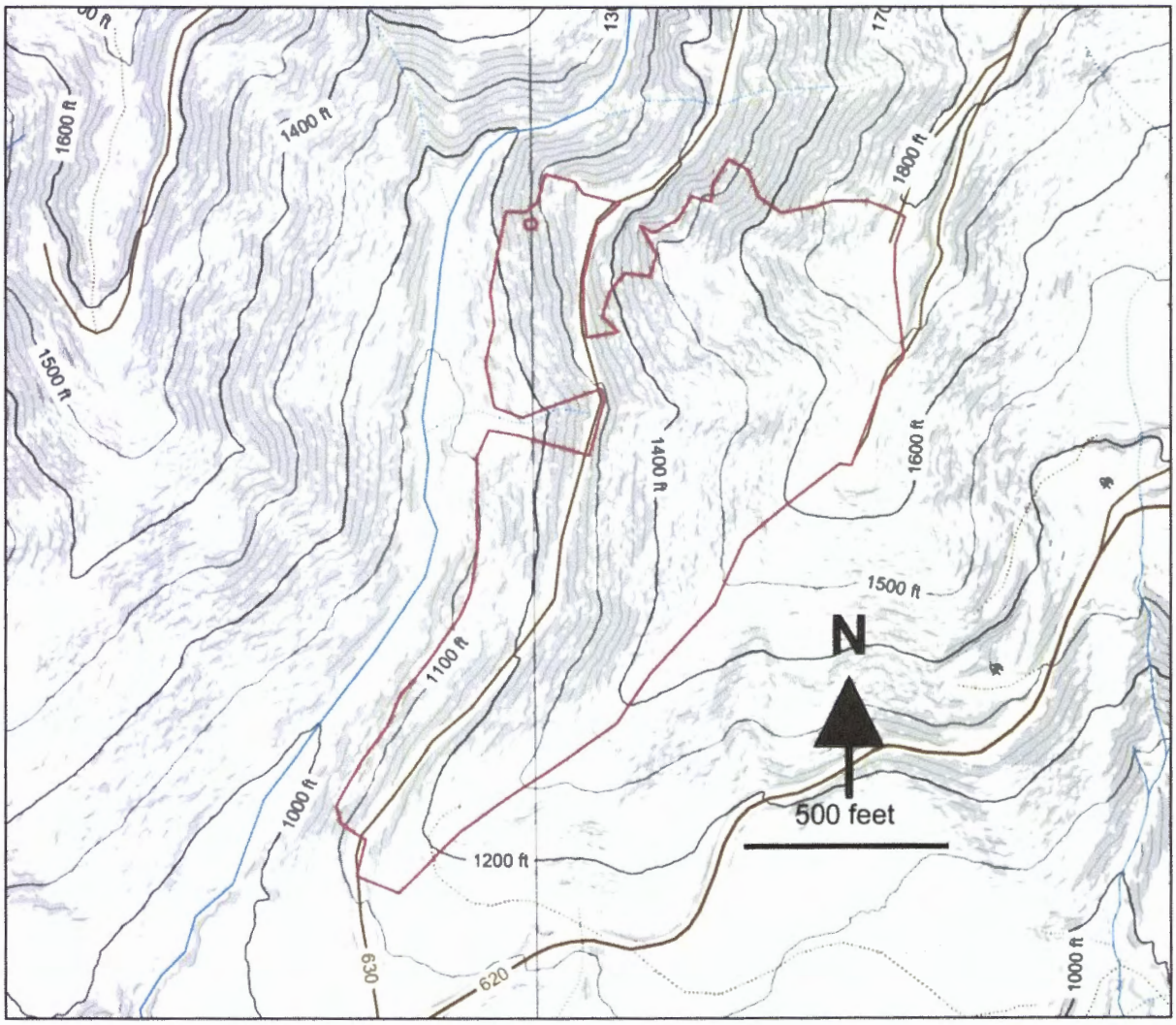


**Figure 2.** Topography map. Shown are topography (20-ft contours; slopes with gradients over 70 percent shaded gray); PHU boundary (red line); streams (solid and dotted blue lines); and existing roads (solid and dotted brown lines).

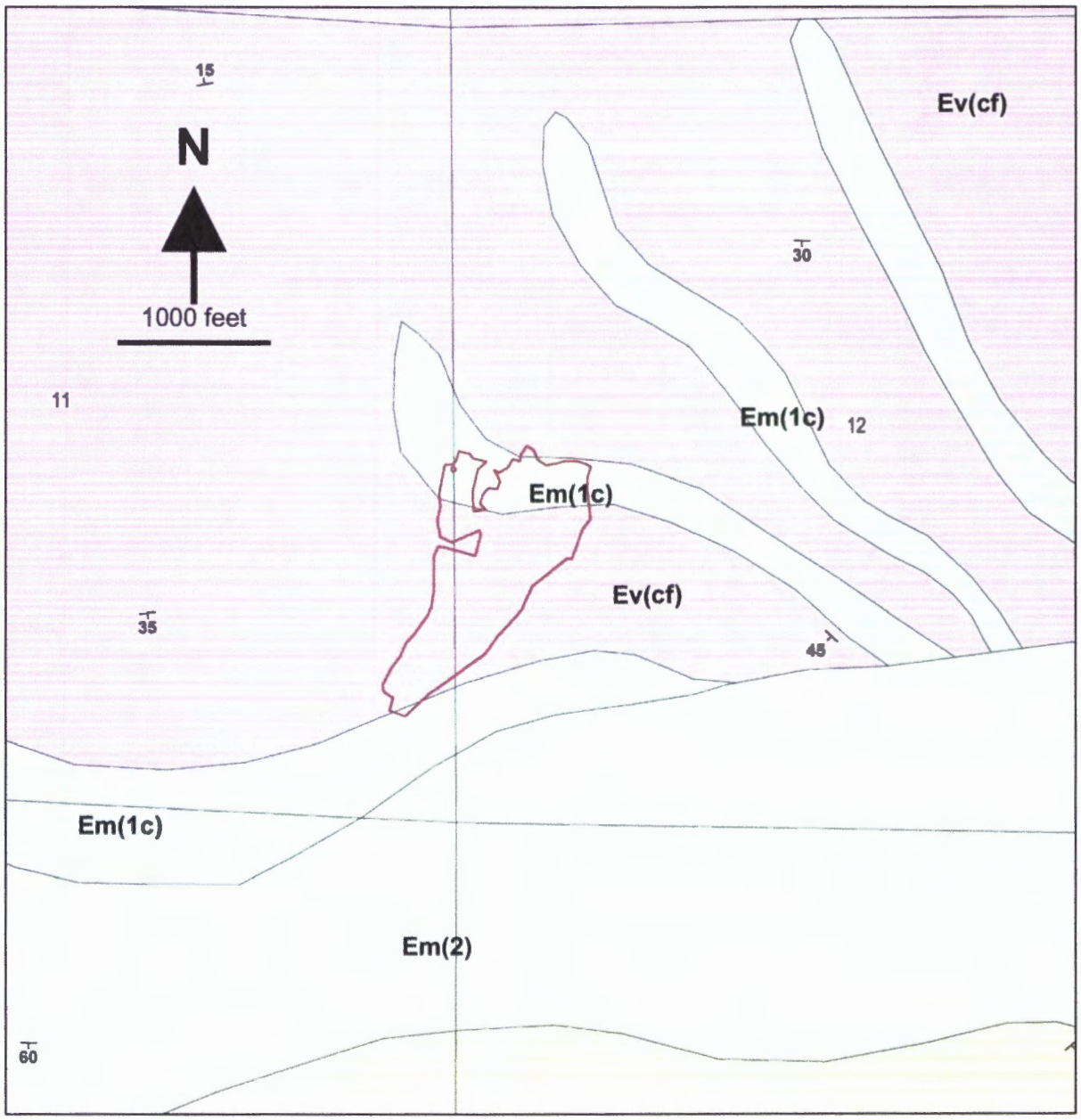


**Figure 3.** Geology map. Two geologic units, Ev(cf) and Em(1c), underlie the PHU.

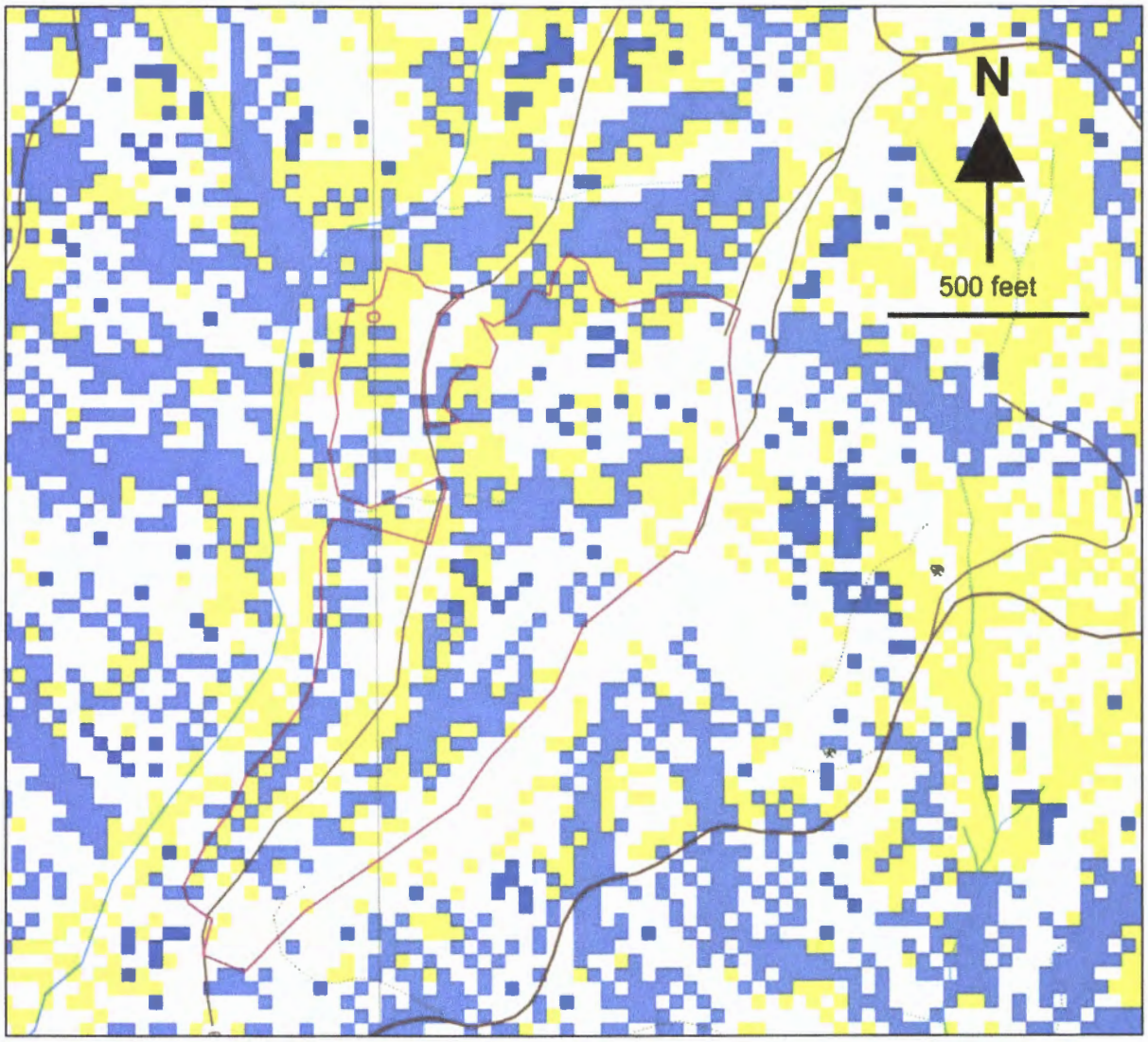


**Figure 4.** DNR slope stability map. The yellow pixels indicate moderate slope instability, and the blue pixels indicate high slope instability. The DNR created this map with a computer model that predicts locations of shallow-rapid-type landslides based on steepness and convergence.

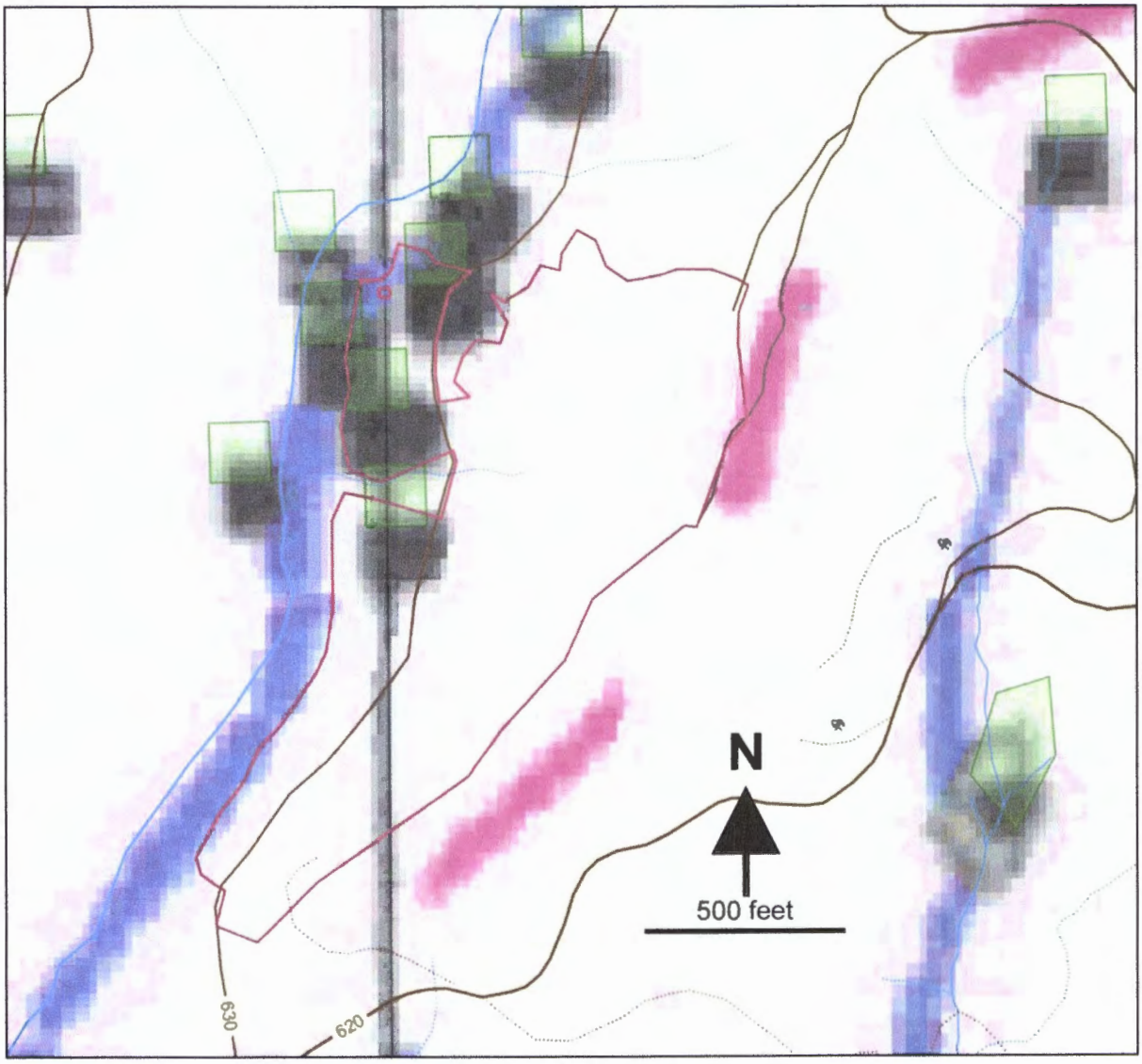


**Figure 5.** Mass wasting inventory map. This drawing combines Map A-1 in the mass wasting module of the West Fork Satsop Watershed Analysis with DNR's landslide inventory shapefile. Map A-1 landslides are mapped as black squares. The landslide inventory landslides are mapped as green squares. The PHU is delineated in red.

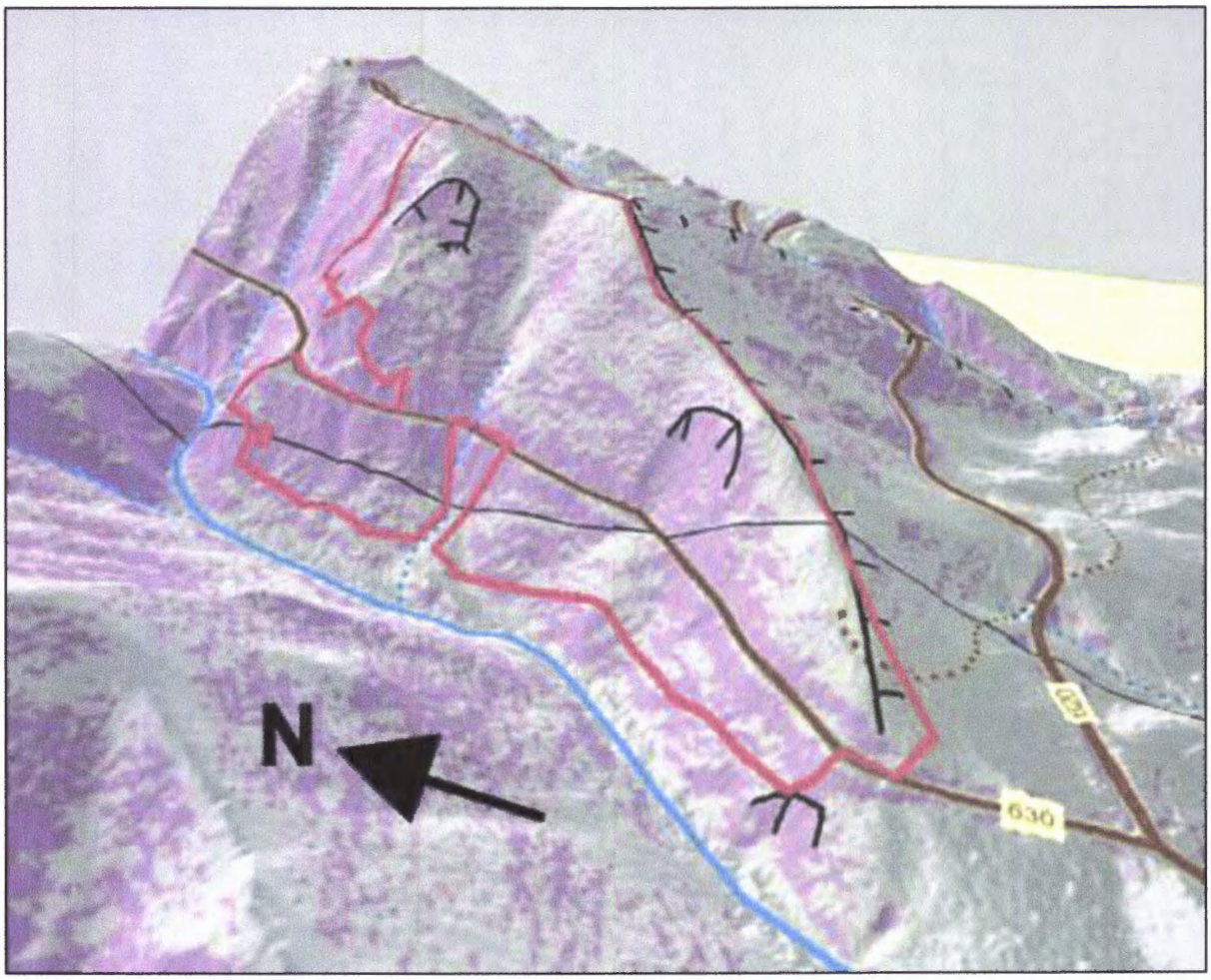


**Figure 6.** Oblique LiDAR image. This is a bare-earth image of the PHU facing northeast (no vertical exaggeration). The PHU is mostly situated on a west-facing valley wall. Hillslope gradients that exceed 70 percent are shaded magenta. Also shown are the approximate scarps of dormant deep-seated landslides (black comb lines), PHU boundary (red line), streams (solid and dotted blue lines), and existing roads (solid and dotted brown lines).

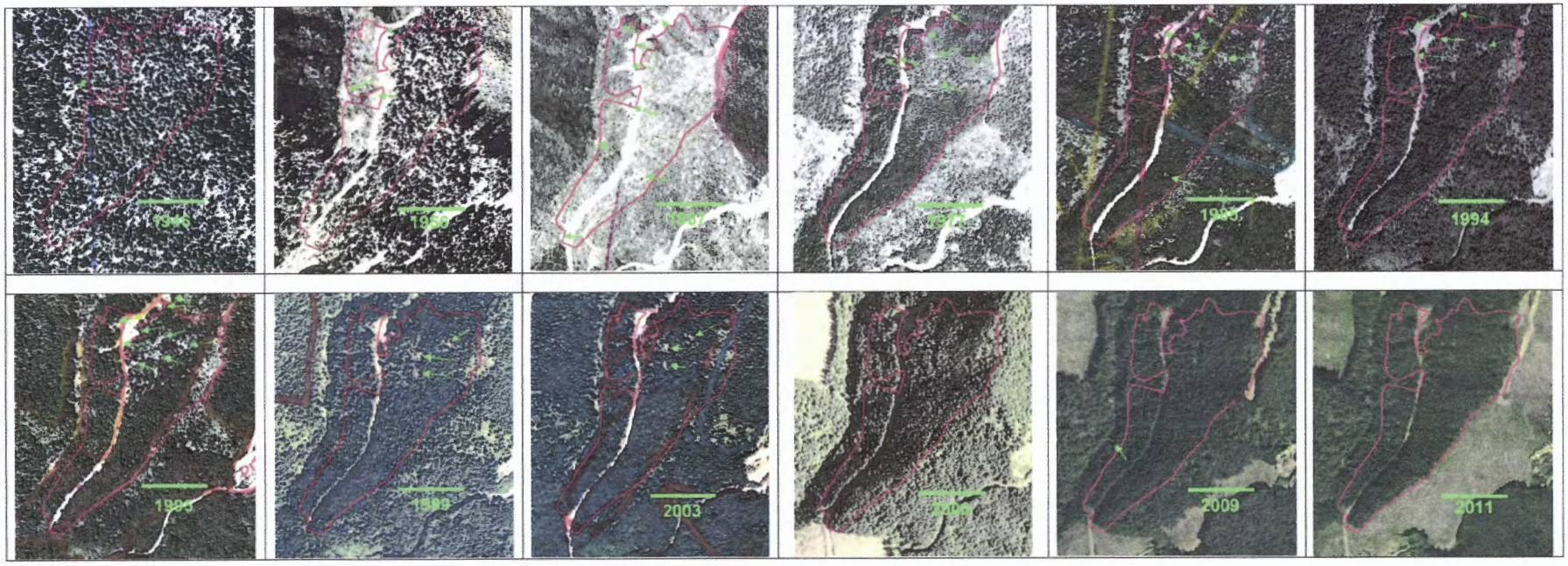


**Figure 7.** Historical aerial photographs. The PHU is outlined in red. Green arrows indicate bare soil associated with mass wasting, erosion, sedimentation, cuts, fills, and/or disturbance from heavy machinery. The heavy green line is 500 ft long. The photographs were taken in 1946, 1956, 1967, 1977, 1985, 1994, 1995, 1999, 2003, 2006, 2009, and 2011.



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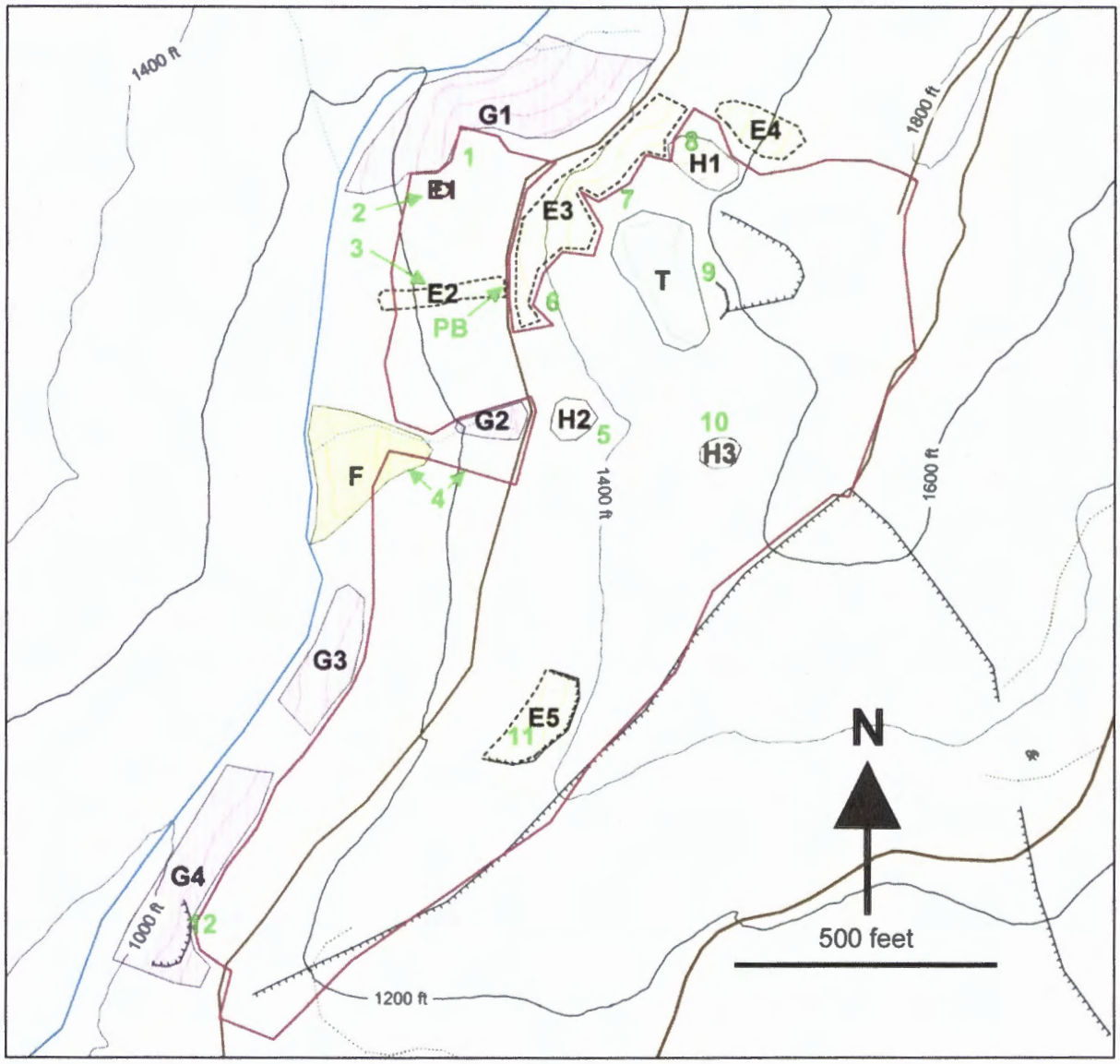


**Figure 8.** Observation location and landform map. The observation locations are numbered 1 through 12 (green numbers). Potentially unstable landforms are inner gorges (G1, G2, G3, and G4), bedrock hollows (H1, H2, and H3), the toe of a deep-seated landslide (T), and Category E landforms (E1, E2, E3, E4, and E5). Also shown are the scarps of dormant deep-seated landslides (black comb lines), a debris fan landform (F), and the location where side-cast pull back is recommended (PB). The contour interval is 40 ft.