2614391

LaManna Geosciences Inc.

2611 40th Avenue West
Seattle, WA 98199
206-352-8534
johnl@lamannageosciences.com

GEOTECHNICAL REVIEW
PROPOSED HARVEST UNIT WC-209,
T21N-R07W-SEC 11 AND 14,
GRAYS HARBOR COUNTY, WASHINGTON

Final

Prepared for

Green Diamond Resource Company

Prepared by

LaManna Geosciences Inc.

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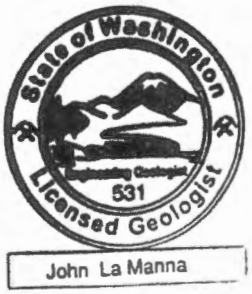
THIS REPORT HAS BEEN PREPARED UNDER THE RESPONSIBLE CHARGE OF A STATE OF WASHINGTON LICENSED ENGINEERING GEOLOGIST



JOHN LAMANNA

LAMANNA GEOSCIENCES INC.

2611 – 40TH AVENUE WEST

SEATTLE, WA 98199

PURPOSE AND SCOPE OF EVALUATION

This report presents the results of a geotechnical evaluation of proposed harvest unit (PHU) WC-209. The proposed forest practices will consist of constructing approximately 1,600 feet (ft) of new road and even-age harvesting approximately 44 acres of timber. The location of the PHU relative to nearby towns is shown on the vicinity map (Figure 1). (All figures are provided at the end of the report.)

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), Section 222-10-030(5). Green Diamond Resource Company (GDRCo) uses habitat conservation plan (HCP) prescriptions as alternatives to the Standard Forest Practices and Watershed Analysis (GDRCo, 2012; Mahan, 2013). The HCP prescription prohibits timber harvest on unstable slopes that have the potential to deliver sediment to public resources. The goal of the geotechnical evaluation was to determine whether the PHU boundary (i.e., the cutting line) appropriately excludes potentially unstable landforms and areas of instability (Figure 2). The conclusions are based on a review of available information and field reconnaissance of locations selected because they were judged to have the greatest potential for instability. In addition to the harvest boundary, Figure 2 also shows the topography, streams, existing roads, and proposed roads within and surrounding the PHU.

LaManna Geosciences, Inc. (LGI) performed the field reconnaissance on March 9, 2016, accompanied by GDRCo personnel. LGI's services were provided under a consulting agreement dated January 1, 2016.

This evaluation was performed to (1) 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; (2) determine whether potentially unstable landforms can be included in the PHU because they are likely to be stable or unlikely to deliver sediment to public resources; and (3) develop mitigation measures to reduce the likelihood that the proposed forest practices would cause or contribute to slope instability and to reduce 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 digital elevation model (DEM) of the PHU that was derived from light detection and ranging (LiDAR) data.
- Conduct field reconnaissance of specific areas within 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, 2015). LGI's method consisted of reviewing aerial photographs, LiDAR-derived topography, anecdotal information, and other available information, followed by field observations in selected areas to identify potentially unstable slopes and landforms. LGI's observations were focused on steep convergent areas and areas of concern identified by the GDRCo forest engineer. 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, or computer modeling of slope stability and delivery of sediment, debris, or runoff.

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).

Table 1. Information Reviewed by LGI

Description	Data Source
Topography and geography	LiDAR DEM 2013 data set provided by GDRCo. Topographic map (USGS, 1974; USGS, 1990a; USGS, 1990b). Google Earth.
PHU boundary	Geographic information system (GIS) digital files provided by GDRCo. Some boundaries were edited based on field observations.
Existing and proposed road locations	GIS digital files provided by GDRCo. Digital files were edited using information from aerial photographs and LiDAR data.
Streams (typed waters)	GIS digital files provided by GDRCo. Digital files were edited using information from aerial photographs and LiDAR data.
Rain-on-Snow shapefile (precipitation zones)	Department of Natural Resources. https://fortress.wa.gov/dnr/adminsa/DataWeb/dmmatrix.html
Geology (1:100,000-scale map), GIS shapefiles	Department of Natural Resources. https://fortress.wa.gov/dnr/protectiongis/geology/?Theme=wigm http://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases
Soil survey	Natural Resources Conservation Service. http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx
DNR Slope Stability Map	Department of Natural Resources. https://fortress.wa.gov/dnr/adminsa/DataWeb/dmmatrix.html#Geology
DNR Digital Landslide Inventory	Department of Natural Resources. February 2016 dataset. http://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases
West Fork Satsop Watershed Analysis	Department of Natural Resources. https://fortress.wa.gov/dnr/protectionsa/ApprovedWatershedAnalyses
1946 aerial photograph	10316 13-19; provided by GDRCo.
1956 aerial photograph	SL-10W-15; provided by GDRCo.
1967 aerial photograph	GH-67-43C-6; provided by GDRCo.
1977 aerial photograph	OL-77 60C-9; provided by GDRCo.
1985 aerial photograph	OL-85 18-060-100; provided by GDRCo.
1994 orthophotograph	University of Washington. http://rocky2.ess.washington.edu/data/raster/dogs/index.html
1995 aerial photograph	OLP-95 14-14-39; provided by GDRCo.
2003 aerial photograph	OL-C-03 37-60-61; provided by GDRCo.
2006 orthophotograph	National Agriculture Inventory Program (NAIP) 2006 imagery developed by the U.S.

Description	Data Source
	Department of Agriculture; available from various private and public sources.
2009 orthophotograph	NAIP 2009 imagery.
2013 orthophotograph	NAIP 2013 imagery.

Ownership, Surface Drainage, and Public Safety

LGI understands that GDRCo owns all the land within about one-half mile of the PHU and that GDRCo is not aware of any planned or proposed changes in land uses in this area.

The PHU is mostly situated on west- and east-facing slopes that drain to the Little River and the East Fork Little River. From its confluence with the East Fork Little River near the south end of the PHU, the Little River flows east-southeast approximately 3.6 miles and discharges into the West Fork Satsop River.

The downstream improvements closest to the PHU are summarized in Table 2, which is based on the U.S. Geological Survey 7.5-minute series topographic maps (USGS, 1990a; USGS, 1990b), Google Earth, and information provided by GDRCo.

Table 2. Summary of Nearest Downstream Improvements

Improvement	Location	Owner	Comments
48-inch-diameter corrugated metal pipe culvert	Northeastern portion of Section 14, T21N, R07W (Figure 2)	GDRCo	LGI did not observe this culvert in the field.
600 Road bridge	Northeastern portion of Section 14, T21N, R07W (Figure 2)	GDRCo	The bridge deck and eastern abutment displayed no obvious signs of distress when observed by LGI on March 9, 2016. The western abutment was not observed.
Abandoned railroad bridge	Northeastern portion of Section 21, T20N, R07W 47°12'22.76"N 123°33'18.19"W	GDRCo	The trestle is visible on the 2013 Google Earth image.
Cougar-Smith Road bridge	Northeastern portion of Section 33, T20N, R07W 47°10'46.33"N 123°33'35.52"W	GDRCo	This bridge is located about 14.3 miles downstream of the PHU. The 2013 Google Earth image shows cultivated fields and buildings (probably including dwellings) located near the West Fork Satsop River, which has meanders in this area. Nearby private property is unlikely to be directly impacted by landslides at the PHU that reach typed water because of the relatively long distance from the PHU.

LGI identified no non-GDRCo-owned land or property that might be directly affected by landslides at the PHU that deliver sediment and debris to typed waters. The closest non-GDRCo-owned property downstream of the PHU is sufficiently far away that sediment and debris are most likely to affect these properties only during unusual storm or weather events, when there are likely to be more significant contributions of sediment and debris from other sources in the drainage basin.

Public resources could be affected by landslides, regardless of their cause. They consist of water quality and fish and wildlife located on and downslope of the PHU.

LGI did not verify whether water from the West Fork Satsop River or the Satsop River is diverted for municipal, domestic, commercial, irrigation, livestock, or hatchery water supplies. 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 organisms that receive the diverted water.

No threats to public safety are apparent. The PHU is located on private property, with limited access due to locked gates. Forest roads in this area are patrolled by security personnel.

Precipitation Zones, Geology, and Soils

The PHU varies in elevation between approximately 890 and 1,590 ft and is entirely located in the Rain-Dominated precipitation zone.

According to the Washington State Department of Natural Resources (DNR) 1:100,000-scale geologic map, the PHU is situated on lower to middle Eocene-age basalt flows and flow breccias of the Crescent Formation (Ev[cf] on Figure 3) and lower to middle Eocene-age marine sedimentary rocks of the Crescent Formation (Em[1c] on Figure 3).[1] Published measurements in the vicinity of the PHU indicate that the basalt flows dip approximately 35 degrees to the south and east.

The Natural Resources Conservation Service soil map indicates that the PHU area is underlain by extremely gravelly sandy loam, extremely cobbly sandy loam, silt loam, and silty clay loam soils. The former two soil types are derived from the basalt bedrock, and the latter two types are derived from the marine sedimentary rocks.

LANDSLIDES AND SLOPE STABILITY

LGI identified four sources on the DNR website that might have landslide data relevant to this project: (a) the DNR 1:100,000-scale geology map, (b) the DNR slope instability model, (c) a mass wasting inventory map in the West Fork Satsop Watershed Analysis, and (d) the DNR digital landslide inventory.

DNR 1:100,000-Scale Geologic Map

The DNR 1:100,000-scale geologic map shows no landslides at or near the PHU (Figure 3). Relatively large landslides may be displayed at this map scale. Small landslides, typically the kind related to timberland management, are usually not displayed at this mapping scale.

DNR Slope Stability Model

The DNR slope stability map (Figure 4) was generated by a computer model developed for use as a screening tool. This map shows predicted locations of shallow earth slides determined primarily on the basis of slope steepness and convergence. The model does not predict delivery. As shown on the slope instability map, portions of the PHU are situated on areas of

[1] A 1:24,000-scale geologic map of the USGS Grisdale, Washington, 7.5-minute quadrangle map has not yet been published.

"medium slope instability" (yellow pixels) and "high slope instability" (blue pixels). In general, places where blue pixels coalesce into large blue areas may be of concern.

West Fork Satsop Watershed Analysis and DNR Digital Landslide Inventory

Map A-1 from the mass wasting module in the West Fork Satsop Watershed Analysis is a mass wasting inventory map that includes the location of the PHU. Map A-1, the DNR digital landslide inventory, and the location of the PHU are shown in Figure 5. According to these data, there are no landslides within the PHU and two landslides near the PHU that appear to be related to stream bank erosion.

The landslide polygons on the DNR digital landslide inventory are similar to the landslides on Map A-1 because the landslide inventory includes data from sources that include the mass wasting modules of the watershed analyses. The offset between the two data sets was caused by inaccurate rectification of Map A-1.

Oblique Terrain Image

Two obliquely oriented three-dimensional terrain images were prepared using GIS software and the bare-earth LiDAR DEM (Figure 6). The west-facing slope of the PHU is located on a steep valley wall. The south end of the PHU includes the scarp of a dormant deep-seated landslide and the scarps of two recently active deep-seated landslides. In addition, three recently active deep-seated landslides are located downslope from the cutting line. The toes of these deep-seated landslides all appear to be located adjacent to a stream, which suggests that the landslides were caused by stream down-cutting and bank erosion.

Historical Aerial Photography

The historical aerial photographs that were reviewed for this project begin in 1946 (Figures 7a, 7b, and 7c). LGI's observations from these photographs are summarized in Table 3. Inferred areas of bare soil and rock may represent earth slides, rock slides, ravel, erosion, sedimentation, or soil disturbance due to heavy equipment and log yarding. Aerial photographs are likely to underrepresent the extent of bare soil and rock because they can be hidden by tree canopy and shadow. Incomplete rectification of the photographs and errors in field mapping may inaccurately display the locations of some PHU boundaries relative to features visible on the photographs.

Table 3. Observations from Historical Aerial Photographs

Year	Description
1946	The resolution of this photograph is relatively poor because of graininess and high contrast. This photograph shows the PHU covered with old-growth forest. No roads are visible within or adjacent to the PHU. A white area located in the southwestern portion of the PHU (green arrow) is probably deciduous vegetation and/or bare soil associated with seepage and a deep-seated landslide that was observed in the field (Figure 9).
1956	The resolution of this photograph is mediocre. This photograph shows the PHU covered with old-growth forest. The 600, 620, and 630 Roads have been constructed. Even-age harvest has taken place adjacent to the southeastern and northeastern sides of the PHU. Bare soil and rock likely associated with landslides are not visible on this photograph.
1967	This photograph shows only the eastern portion of the PHU. The 633 Road has been constructed, and the PHU appears to have been even-age harvested. Most bare soil visible on this photograph is associated with road side-cast. Some areas of bare soil are associated with the inner gorge. One

Year	Description
	small midslope landslide that apparently did not deliver sediment to typed water is also visible.
1977	The west side of the PHU has older trees compared to the east side, suggesting that the trees on the west side were cut a few years before those on the east side. Bare soil likely associated with landslides is visible along the streams (inner gorges), as side-cast from the 633 Road, and associated with steep convergent slopes in the northwestern portion of the PHU.
1985	The trees appear relatively uniform across the PHU. In the northern portion of the PHU, the bare soil appears to be associated with steep convergent slopes and side-cast. Bare soil in the southeastern portion of the PHU is associated with the toe of a deep-seated landslide (Figure 9). Bare soil in the southwestern portion of the PHU is associated with the road cut into the body of a deep-seated landslide.
1994	Most bare soil appears to be associated with steep slopes and side-cast in the northern portion of the PHU.
1995	Most bare soil is primarily associated with streams, steep convergent slopes in the northern portion of the PHU, and side-cast. Bare soil in the southern portion of the PHU is associated with stream bank erosion at the toe of a deep-seated landslide (Figure 9).
2003	Most bare soil appears to be associated with streams and side-cast. Bare soil in the southern portion of the PHU is associated with stream bank erosion at the toe of a deep-seated landslide (Figure 9).
2006	Recent harvest has taken place near the northeast and southeast sides of the PHU. Bare soil in the southern portion of the PHU is associated with stream bank erosion at the toe of a deep-seated landslide (Figure 9).
2009	Small areas of bare soil are associated with stream bank erosion, toes of deep-seated landslides, and side-cast.
2013	In the southern portion of the PHU, the arrows point to shadows in a location with known deep-seated landslides. Presumably, tree canopy is missing because bare soil is exposed.

In summary, these historical photographs, which cover a 70-year period, display small areas of bare soil and rock that are likely to have been the result of small earth slides, ravel, or small rock slides associated with stream bank erosion, steep slopes, and side-cast. Some stream bank erosion is located at the toes of deep-seated landslides. The areas of bare soil and rock visible on these photographs were traced (using GIS software) and are summarized on a topographic map (Figure 8).[2]

FIELD OBSERVATIONS AND LANDFORMS

LGI's field observations are summarized in Table 4. Slope gradients were measured with a handheld clinometer, and distances were estimated. The field observation locations and landforms are shown on Figure 9.

Table 4. Field Observations, Opinions, and Recommended Mitigation

Location No.	Observations, Opinions, and Mitigation Measures
1	The PHU was situated on a planar slope with gradients in the 70 to 84 percent range. The slope had conifers, vine maple, ferns, salal, Oregon grape, and in situ old-growth stumps. Extending downhill about 50 ft horizontal distance (HD) from the 633 Road was a side-cast veneer of loose, angular,

[2] Incomplete rectification of the photographs and errors in field mapping may inaccurately display the locations of bare soil areas relative to features visible on the map.

Location No.	Observations, Opinions, and Mitigation Measures
	gravel- to cobble-size basalt that was 1 to 2 ft thick. The cutting line (PHU boundary) excluded bedrock hollows (i.e., landforms H1 and H2) from the PHU. Seepage was not observed. Observed at location 1 was an earth slide scar 10 to 15 ft in diameter and 2 to 3 ft deep in basaltic colluvium (landform E1). Sparse Oregon grape and salal were growing on the scar. The landslide deposit appeared to have spread out on the planar slope below the scar and did not deliver to typed water or scour the hillslope. The slope form was broadly divergent in this area. Landform E1 was not excluded from the PHU because delivery does not appear likely. The area surrounding E1 was not excluded because it appeared stable. Landform H2 is a bedrock hollow that hosted an earth slide about 25 to 30 ft wide (HD) and about 1 to 3 ft deep. Bedrock was exposed in the scarp of this earth slide. Slope gradients were 84 to 90 percent at the earth slide. The earth slide scoured a gouge into the colluvium in H2 and likely delivered sediment to typed water. Bedrock hollow H2 appeared to be the scarp of an earth or rock slide. Bare soil is visible in nearby leave areas on the 1977 photograph (Figure 7a). *Mitigation:* The mitigation measures are (a) to maintain root strength by excluding landforms H1 and H2 from the PHU, and (b) to control runoff from the 633 Road to prevent it from flowing onto steep, convergent west-facing slopes.
2	The slopes were planar and divergent, with gradients from 75 to 95 percent and conifers, salal, Oregon grape, ferns, vine maple, huckleberry, in situ old-growth stumps, and logging debris. Seepage was not observed. The cutting line excluded bedrock hollow landform H2 and the steep slopes that directly deliver to Landform H2. The cutting line also excluded what appeared to be a steep scarp of an earth slide, where a layer of soil about 1 to 2 ft deep slid (landform E2) in a location that was likely to deliver sediment to typed water. Also excluded were inner gorge landforms G1 and G2. Bare soil is visible in nearby leave areas on the 1977 photograph (Figure 7a). *Mitigation:* The mitigation measure is to maintain root strength by excluding landforms H1, H2, E2, G1, and G2 from the PHU.
3	Observed was a broad bedrock hollow (landform H3) with gradients between 65 and 75 percent and conifers, vine maple, salal, Oregon grape, ferns, in situ old-growth stumps (some on the hollow axis), and logging debris. Seepage was not observed. Sediment delivery to typed water was likely at this location. Landform H3 was not excluded from the PHU because it appeared to be stable. *Mitigation:* No mitigation measures are recommended at this location.
4	Observed was a rotational earth slide (slump) about 50 ft in diameter that appeared to predate management (landform E3). The scarp was about 20 ft high (slope distance). The slope had gradients between 70 and 80 percent, with conifers, salal, ferns, stumps, and logging debris. Seepage was not observed. Sediment delivery to typed water was likely at this location. Landform E3 was not excluded from the PHU because it appeared to be stable. *Mitigation:* No mitigation measures are recommended at this location.
5	A 40-ft-diameter earth slide scar (landform E4) was located on a broadly convergent slope. The deposit from this slide was located below the scarp and supported live second-growth conifers. The steep scarp had vine maple, conifers, and some logging debris. The PHU adjacent to the earth slide had slopes with gradients of 68 to 94 percent, conifers, vine maple, salmonberry, salal, ferns, in situ old-growth stumps, and logging debris. Sediment delivery to typed water is likely at this location. Conifers on and along the perimeter of the steep scarp were excluded from the PHU. Nine trees were paint-banded. The 1995, 2003, and 2013 photographs display lighter colored vegetation in this area (Figures 7b and 7c). This may have been caused by deciduous vegetation and could indicate soil disturbance. *Mitigation:* The mitigation measure is to maintain root strength by excluding the steep scarp in landform E4 from the PHU. The deposit below the scarp appeared stable and was not excluded.
6	Location 6 corresponds with what appeared to be the steepest slope in the PHU on which the proposed road construction will occur. This slope was planar to divergent, with conifers, vine maple,

Location No.	Observations, Opinions, and Mitigation Measures
	salal, ferns, and in situ old-growth stumps. Rule-identified potentially unstable landforms were not observed and the slope appeared stable. *Mitigation:* LGI understands that the proposed road construction will use full-bench, end-haul methods where slope gradients exceed 60 percent.
7	Excluded from the PHU was the scarp and body of a deep-seated landslide (landform E9). The scarp had an approximately 20-ft-high exposure of yellowish-brown siltstone or sandstone (possibly Lincoln Creek Formation) that had weathered to a soil composed of silty sand with about 5 to 10 percent gravel. The bedrock appeared to be marine sedimentary rock. Also observed was a marginal scarp about 4 ft high that exposed bare soil and overhanging roots. The slopes were vegetated with conifers, alder, vine maple, ferns, salmonberry, and *Oxalis*. The toe of the landslide body was located near the river and appeared to be undercut by the river. Hence, stream bank erosion and/or channel incision probably caused this landslide. The observed scarps appeared to be relatively recent. Observed in the PHU upslope from the cutting line was one vegetated sag (i.e., an unchanneled, closed depression), conifers (most stems straight and vertical), vine maple, ferns, huckleberry, local devil's club, in situ old-growth stumps, and logging debris. The slope above landform E9 appeared to be part of a much larger, dormant deep-seated landslide (Figure 9). Hence, landform E9 was a reactivated portion of the toe (landform T2) of this larger landslide. Bare soil is visible on landform E9 on the 1967, 1977, 1985, 1995, 2003, 2006, and 2009 photographs (Figures 7a and 7b). The shadow visible on the 2013 photograph is probably tree mortality related to soil disturbance on the landslide body (Figure 7c). *Mitigation:* The mitigation measure is to maintain root strength by excluding landforms E9 and T2 from the PHU.
8 to 9	Location 8 was the northwest end of an overgrown spur road off the 600 Road. At location 9, the spur road was severely damaged by a deep-seated landslide (landform E8). The road prism between locations 8 and 9 displayed no obvious distress or displacement (e.g., settlement, depressions, cracks, or benches) that might have indicated deep-seated landslide movement since the road was last graded. This observation suggests that this portion of the road is located on stable slopes. *Mitigation:* The mitigation measure is to maintain root strength by excluding landforms E8 and T2 from the PHU.
9	Location 9 was a relatively recent deep-seated landslide (landform E8) that severely damaged the spur road. The landslide body appeared to be about 60 to 70 ft wide (parallel to contour). The landslide had alder up to 8 inches in diameter, elderberry, and ferns. The top of the scarp approximately coincided with the cut slope of the spur road. The vegetation indicates this landslide is relatively recent. The cutting line is located well upslope of the inner gorge (landform G5). Bare soil appears to be associated with stream bank erosion on the 1977 photograph (Figure 7a). An increase in the size of the shadows between the 2009 and 2013 photographs suggests that this landslide occurred during this period (Figures 7b and 7c). The location of the East Fork Little River at the toe of this landslide suggests that stream bank erosion and/or incision was the cause of the landslide. *Mitigation:* The mitigation measure is to maintain root strength by excluding landforms E8 and G5 from the PHU.
10	The scarp of a relatively recent deep-seated landslide was exposed in the southwestern portion of the PHU and uphill from the 600 Road (the scarp and body of this landslide is landform E5). The scarp varied from about 2 to 10 ft high and exposed tree roots and bare soil. The soil typically consisted of yellowish-brown silty fine sand or sandy silt (possibly weathered Lincoln Creek Formation). Locally, the bare soil supported some moss and small shrubs, which suggested that the scarp had become dormant and was beginning to revegetate. The landslide body below the scarp had a swale, alder, some conifers (most straight and vertical), ferns, salmonberry, *Oxalis*, trace devil's club, and logging debris. Only two or three in situ old-growth stumps were observed on the body. In contrast, in situ old-growth stumps were more abundant and larger on the hillslope outside of the scarp. A split Douglas-fir stump, 2 ft in diameter, was observed at the base of the scarp.

Location No.	Observations, Opinions, and Mitigation Measures
	Observed in the cut slope of the 600 Road near the northern end of landform E5 were dark gray, fossiliferous, basaltic sandstone (probably marine sedimentary rocks of the Crescent Formation) and seepage into the ditch. GDRCo personnel reported that the 600 Road is graded every year and maintenance personnel have not reported any problems (e.g., cracking or settlement) where the road is located near landform E5. The road prism and running surface appeared flat and even when observed by LGI. GDRCo personnel reported that an active deep-seated landslide is located on the opposite side of the Little River from landform E5. This landslide damaged the 600 Road, which was being repaired at the time of LGI's field observations. The presence of these two deep-seated landslides adjacent to the Little River suggests that bank erosion and/or stream incision originally caused these landslides. Movement on one of these two landslides probably pushes the river toward the other landslide, causing erosion and contributing to its movement. The observations made at landform E5 suggest that movement was relatively recent, perhaps during the December 2007 storm event. The movement does not appear to be affecting the 600 Road and may be limited to the landslide body above the 600 Road. The slip surface may be located along a contact between the yellowish-brown, fine-grained sedimentary rock of the Lincoln Creek Formation and the underlying dark gray basalt and basaltic sedimentary rocks of the Crescent Formation. It seems likely that the road cut (of the 600 Road) intersected the slip surface of a preexisting deep-seated landslide and destabilized the landslide body above the road (i.e., landform E5). The toe of the preexisting landslide (landform T1), which is located downhill of the road, appears to be unstable because of stream erosion and movement of the landslide on the opposite side of Little River. White vegetation or bare soil is visible on the 1946 photograph at the approximately location of the seeps along the 600 Road (Figure 7a). On the 1977 and 1985 photographs, the cut bank in this same area appears to have eroded or slid. Bare soil is also visible in the southern portion of landform E5. LGI predicts that parts of the deep-seated landslide (i.e., landforms E6 and T1) will move because (a) the landslide body is being destabilized by erosion from the Little River and by a different landslide on the opposite side of the Little River that is pushing the river into the toe of the landslide, and (b) because the cut slope of the 600 Road intersected with the steep slip surface under the landslide body. Hence, the slope instability is primarily caused by weight removed from the bottom and midslope of the landslide body—not by an increase in groundwater recharge or a decrease in root strength due to timber harvest. Tree harvest, in LGI's opinion, is unlikely to cause or contribute to future movement. Hence, landform E5 was not excluded from the PHU. *Mitigation:* No mitigation measures are recommended at this location.
11	Relatively recent deep-seated movement resulted in a 5- to 10-foot-high scarp and exposed weathered reddish-brown, clayey siltstone (possibly Lincoln Creek Formation). A few tilted conifers about 2 ft in diameter were observed near the scarp. The hillslope was steep, brushy, and difficult to access. The deep-seated landslide movement appeared to be caused by the Little River undercutting the hillside. *Mitigation:* The mitigation measure is to maintain root strength by excluding the toe of the deep-seated landslide (landform T1) and the recently active landslide (landform E6) from the PHU.
12	Relatively recent movement resulted in an approximately 5-ft-high scarp and exposed fractured, dark gray basalt with calcite veins. Landform E7 consists of the scarp and body of this landslide. The cutting line is located upslope of the inner gorge (landform G5). *Mitigation:* The mitigation measure is to maintain root strength by excluding landform E7 and nearby landform G5 (inner gorge) from the PHU.
G3, G4, G6, G7	LGI did not observe these inner gorge landforms in the field. *Mitigation:* LGI understands that these inner gorge landforms were excluded from the PHU.
All locations	Errors and negligence by contractors and maintenance personnel can create conditions that trigger complaints, erosion, and landslides. *Mitigation:* LGI recommends that (a) a qualified person confirm that the contractors' work is properly performed; and (b) drainage structures (e.g., ditches, cross-drains, water bars, or road surfaces) be

Location No.	Observations, Opinions, and Mitigation Measures
	maintained to prevent uncontrolled discharge of runoff.
Cutting lines in vicinity of potentially unstable slopes	Identification marks on trees along the cutting line will be useful if it becomes necessary to verify that the logging contractor complied with the cutting line established for this project. *Mitigation:* LGI recommends painting or notching the butts of selected trees along the cutting line 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.

POTENTIALLY UNSTABLE LANDFORMS

Potentially unstable landforms relevant to the PHU are shown on Figure 9 and summarized in Table 5. LGI inferred the landform boundaries from field observations and LiDAR-derived maps.

Table 5. Summary of Potentially Unstable Landforms Identified in or near PHU

Landform	Map Symbol	Comments
Inner gorges	G1, G2, G3, G4, G5, G6, G7	Landforms G1 through G7 were excluded from the PHU.
Bedrock hollows	H1, H2, H3	Landforms H1 and H2 were excluded from the PHU. Landform H3 was not excluded from the PHU because it appeared to be stable.
Toe of deep-seated landslide	T1, T2	Landforms T1 and T2 were excluded from the PHU.
Category E	E1, E2, E3, E4, E5, E6, E7, E8, E9	Landform E1 was not excluded from the PHU because sediment delivery to typed water appeared unlikely. Landform E2 was excluded from the PHU. Landform E3 was not excluded from the PHU because it appeared to be stable. The potentially unstable steep scarp of landform E4 was excluded from the PHU. The body of landform E4 appeared stable and was not excluded. Landform E5 was not excluded from the PHU because timber harvest is unlikely to cause or contribute to movement. Landforms E6, E7, E8, and E9 were excluded from the PHU.

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, provided that the mitigation measures described in Table 4 are accomplished.

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, G4, G5, G6, and G7), the likelihood is LOW.
- For the bedrock hollow landforms (H1, H2), the likelihood is HIGH.
- For bedrock hollow landform H3, the likelihood is LOW.
- For the toe of deep-seated landslide landforms (T1 and T2), the likelihood is HIGH.
- For Category E landform E1, the likelihood is LOW.
- For Category E landform E2, the likelihood may be HIGH.
- For Category E landform E3, the likelihood is LOW.
- For Category E landform E4, the likelihood is HIGH for part of the landform that was excluded from the PHU. The likelihood is LOW for the part not excluded.
- For Category E landform E5, the likelihood is LOW.
- For Category E landforms E6, E7, E8, and E9, the likelihood is LOW.

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

Response:[4]

- For the inner gorge landforms (G1, G2, G3, G4, G5, G6, and G7), the likelihood is HIGH.
- For the bedrock hollow landforms (H1, H2), the likelihood is HIGH.
- For bedrock hollow landform H3, the likelihood is HIGH.
- For the toe of deep-seated landslide landforms (T1 and T2), the likelihood is HIGH.
- For Category E landform E1, the likelihood is LOW.
- For Category E landform E2, the likelihood may be 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.

[3] Movement responses assume that the proposed forest practices and the proposed mitigation will be implemented (i.e., the likelihood for movement is LOW *assuming the proposed forest practices and mitigation measures are implemented*).

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

- For Category E landforms E6, E7, E8, and E9, the likelihood is HIGH.

or in a manner that would threaten public safety;

Response:

- For the inner gorge landforms (G1, G2, G3, G4, G5, G6, and G7), the likelihood is LOW.
- For the bedrock hollow landforms (H1, H2), the likelihood is LOW.
- For bedrock hollow landform H3, the likelihood is LOW.
- For the toe of deep-seated landslide landforms (T1 and T2), the likelihood is LOW.
- For the Category E landforms (E1, E2, E3, E4, E5, E6, E7, E8, and E9), the likelihood is LOW.

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

Response:

- For the inner gorge landforms (G1, G2, G3, G4, G5, G6, and G7), the recommended mitigation is to exclude these landforms from the PHU and implement the measures described in Table 4.
- For bedrock hollow landforms H1 and H2, the recommended mitigation is to exclude these landforms from the PHU and implement the measures described in Table 4.
- For bedrock hollow landform H3, the recommended mitigation is to implement the measures described in Table 4. This landform was not excluded from the PHU.
- For the toe of deep-seated landslide landforms (T1 and T2), the mitigation is to exclude these landforms from the PHU and implement the measures described in Table 4.
- For Category E landform E1, the recommended mitigation is to implement the measures described in Table 4. This landform was not excluded from the PHU.
- For Category E landform E2, the recommended mitigation is to exclude this landform from the PHU and implement the measures described in Table 4.
- For Category E landform E3, the recommended mitigation is to implement the measures described in Table 4. This landform was not excluded from the PHU.
- For Category E landform E4, the recommended mitigation is to exclude the steep scarp of this landslide from the PHU and implement the measures described in Table 4. The stable landslide body was not excluded from the PHU.
- For Category E landform E5, the recommended mitigation is to implement the measures described in Table 4. This landform was not excluded from the PHU.
- For Category E landforms E6, E7, E8, and E9, the recommended mitigation is to exclude these landforms from the PHU and implement the measures described in Table 4.

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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 method that was used is based on provided information, observations of LiDAR-derived topography, aerial photographs, and surface expressions of slope movements; anecdotal information; and judgments about stability and sediment delivery. This method is limited by the accuracy and completeness of the provided information, resolution of the LiDAR, availability and clarity of photographs, conditions when field observations were made, and available time. 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 and run-out modeling. Because the method used does not predict slope stability and delivery with certainty, the opinions expressed herein cannot be used to guarantee that landslides and delivery will not occur or that the mitigation measures will perform as intended.

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

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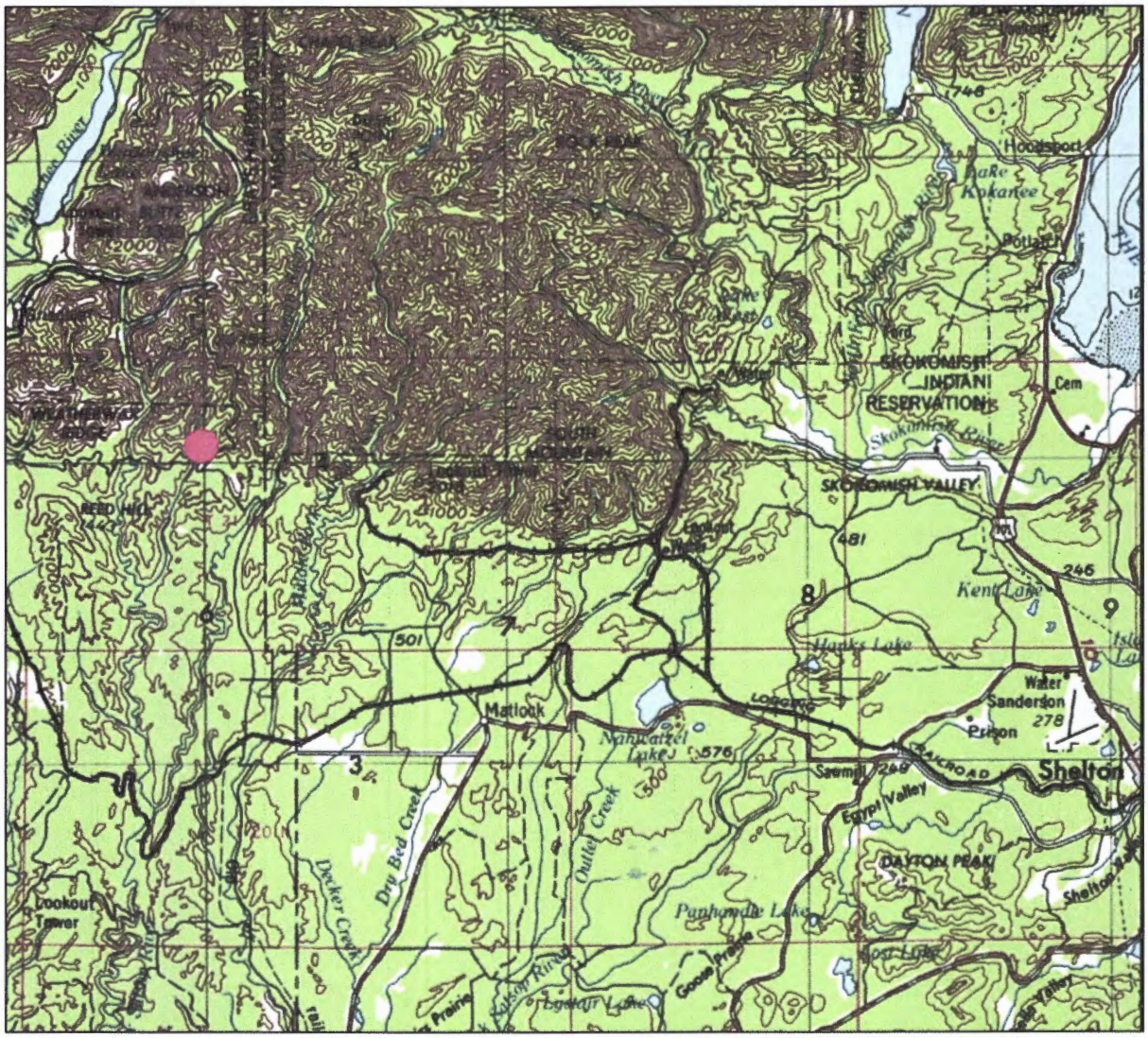

Figure 1. Vicinity map. Shown is the approximate location of the PHU (red circle) relative to Shelton, Washington. The PHU is located near the Little River in Grays Harbor County, Washington.

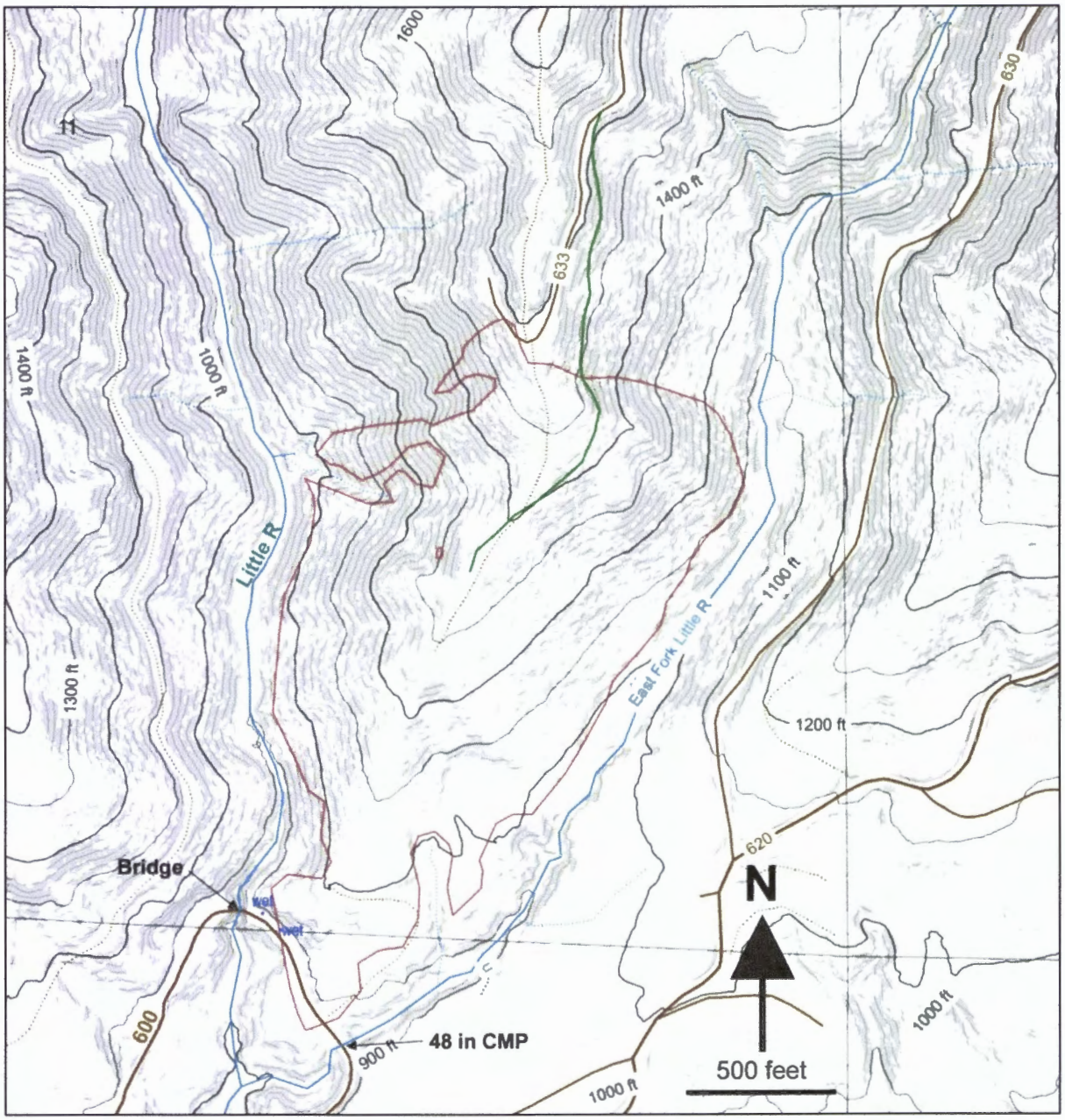

Figure 2. Topographic map. Displayed are the PHU boundary (red line), topography (20-ft contours, gradients greater than 70 percent shaded gray), existing roads (solid and dotted brown lines), proposed road construction (solid dark green line), and streams (solid and dotted blue lines). The locations of the 600 Road bridge and a 48-inch-diameter corrugated metal pipe (CMP) are also indicated.

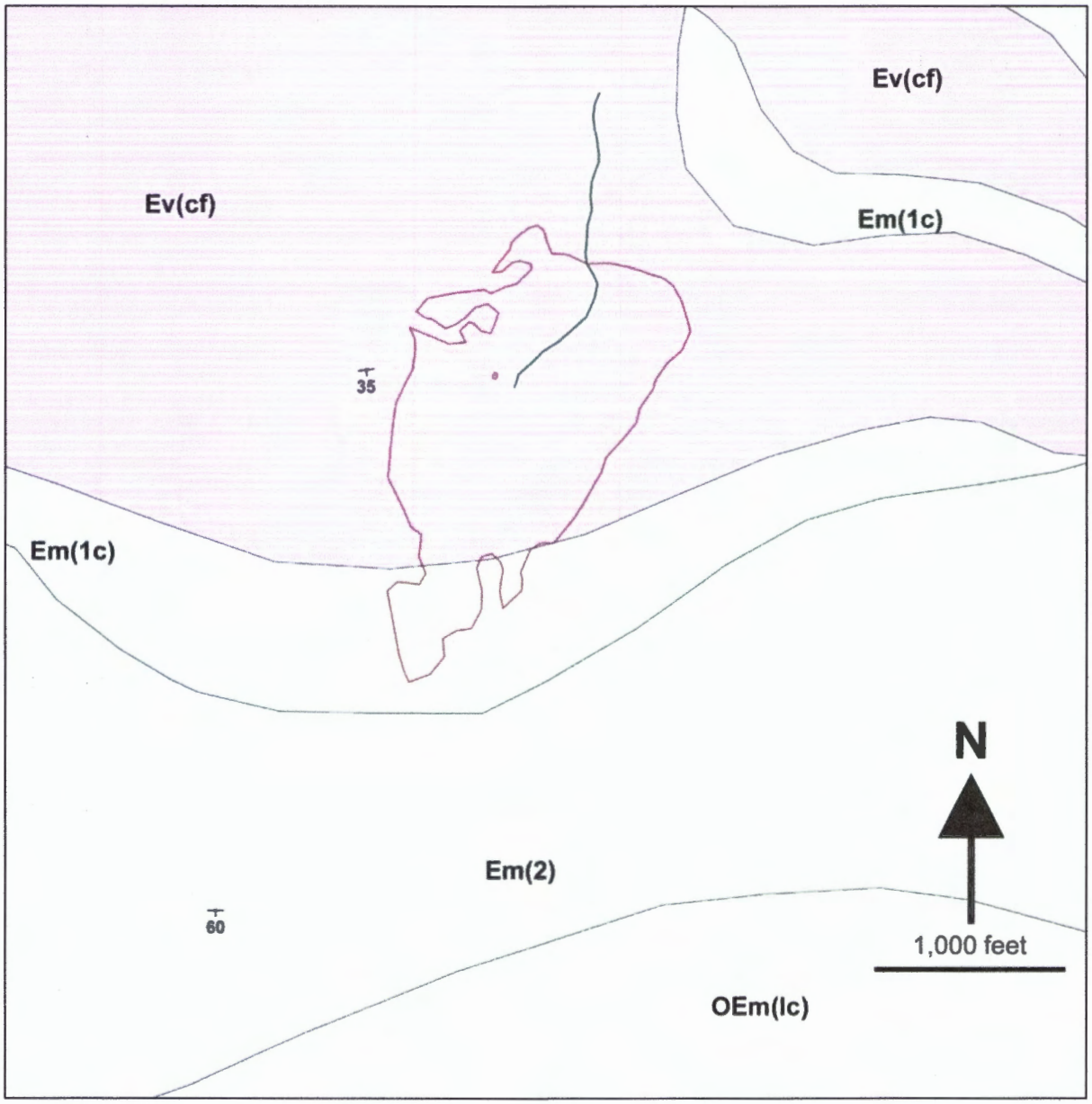

Figure 3. DNR geologic map. The PHU is situated on Eocene-age basalt flows and flow breccias of the Crescent Formation (Ev[cf]) and Eocene-age marine sedimentary rocks of the Crescent Formation (Em[1c]). Shown are the PHU (delineated in red) and proposed road construction (dark green line).

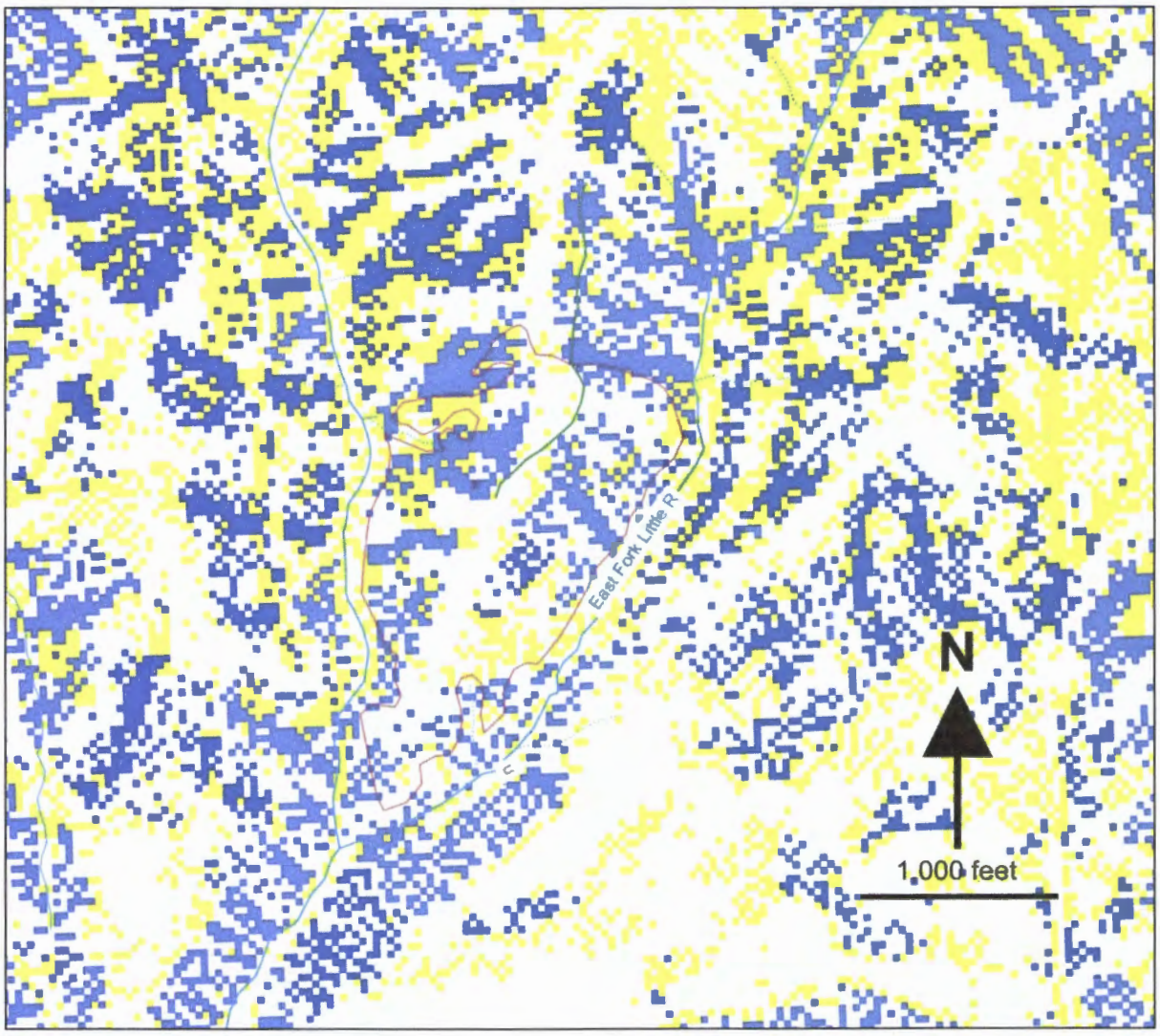

Figure 4. Slope stability map. Yellow pixels designate medium slope instability; blue pixels designate high slope instability.

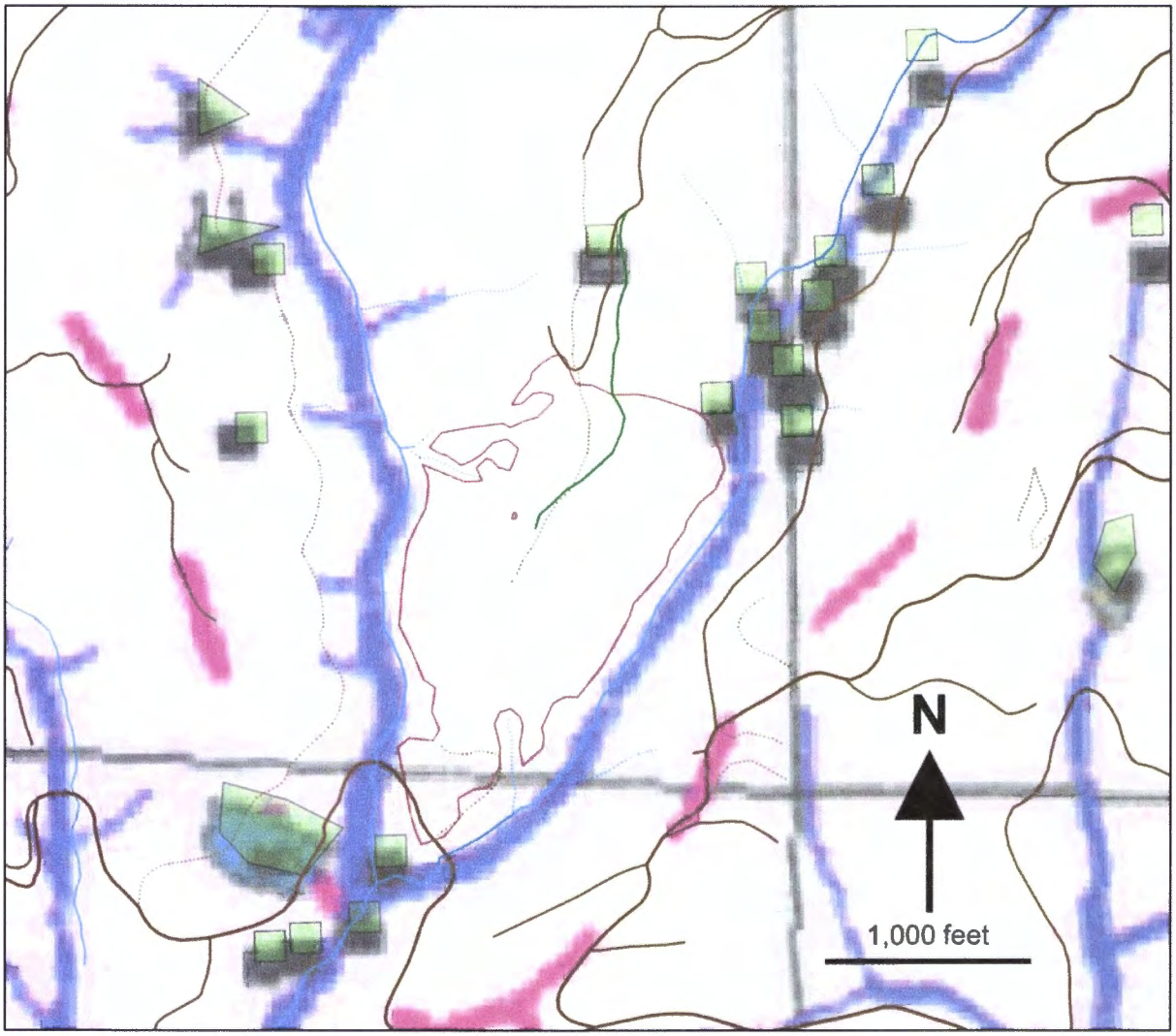

Figure 5. Map A-1 and DNR digital landslide inventory. This composite map displays Map A-1 from the West Fork Satsop watershed analysis (base map with dark gray and blue mass wasting polygons), the DNR digital landslide inventory (light green polygons), and the PHU (delineated in red). The green landslides on the digital landslide inventory coincide with the dark gray and blue polygons on Map A-1 because the digital landslide inventory includes the Map A-1 data set.

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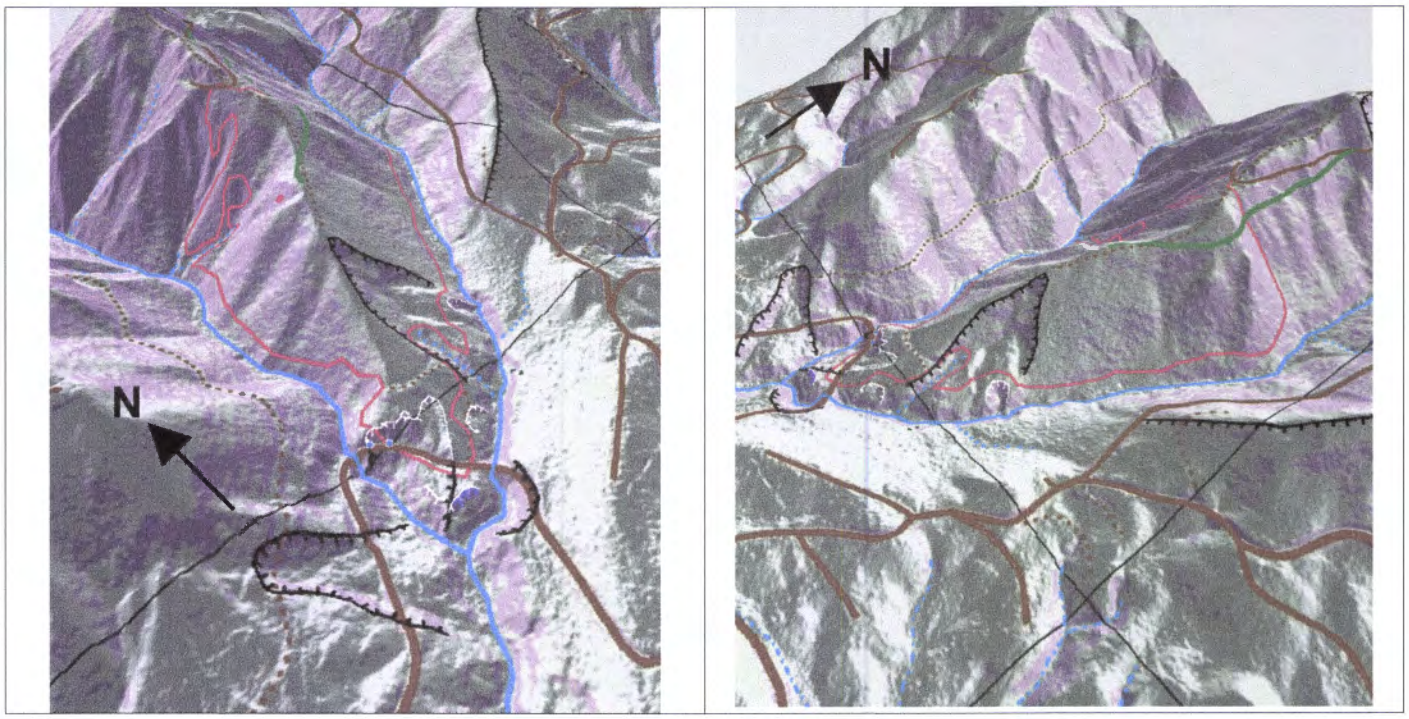

Figure 6. Oblique terrain images. These images were prepared using GIS software and the bare-earth LiDAR DEM (no vertical exaggeration, slope gradients greater than 70 percent shaded magenta). Displayed are the PHU (delineated in red), existing roads (solid and dotted brown lines), proposed road (solid dark green line), streams (solid and dotted blue lines), tops of scarps of dormant deep-seated landslides (black comb lines), and scarps of recently active deep-seated landslides (white comb lines).

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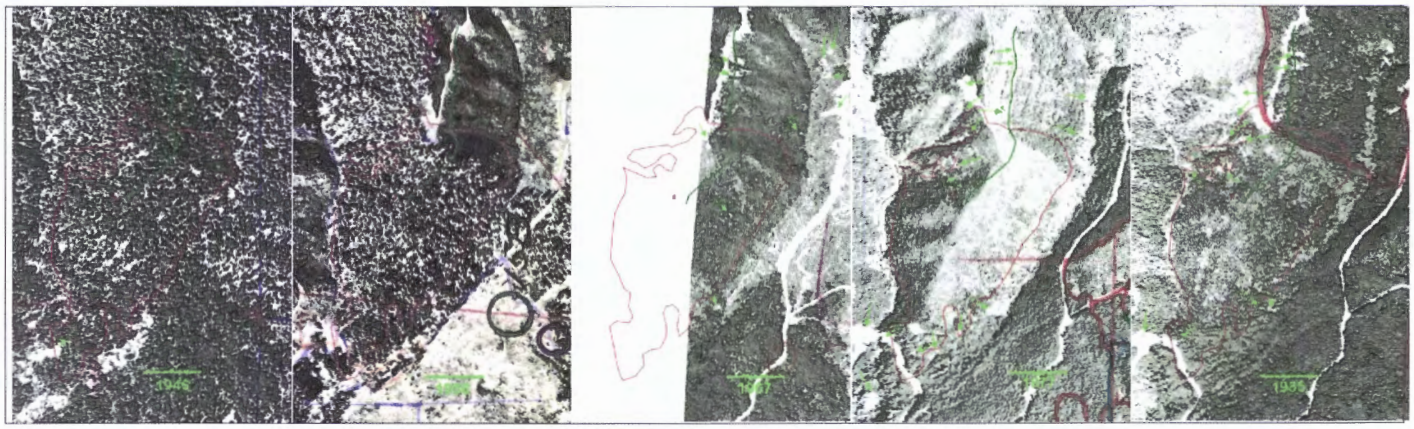

Figure 7a. Historical aerial photographs taken in 1946, 1956, 1967, 1977, and 1985. The light green arrows indicate areas likely affected by earth slides, rock slides, ravel, sedimentation, and/or mechanical disturbance due to heavy equipment. Also shown are the PHU boundary (red line) and the proposed road construction (dark green line). The light green line above the year is 500 ft long.

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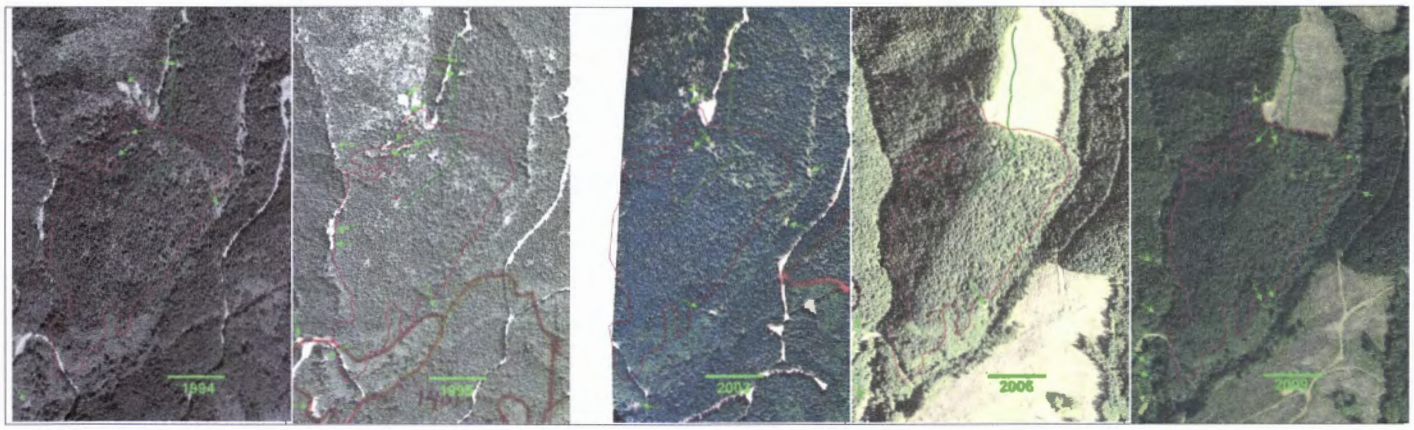

Figure 7b. Historical aerial photographs taken in 1994, 1995, 2003, 2006, and 2009. The light green arrows indicate areas likely affected by earth slides, rock slides, ravel, sedimentation, and/or mechanical disturbance due to heavy equipment. Also shown are the PHU boundary (red line) and the proposed road construction (dark green line). The light green line above the year is 500 ft long.

Figure 7c. Historical aerial photograph taken in 2013. The light green arrows indicate areas likely affected by earth slides, rock slides, ravel, sedimentation, and/or mechanical disturbance due to heavy equipment. Also shown are the PHU boundary (red line) and the proposed road construction (dark green line). The light green line above the year is 500 ft long.

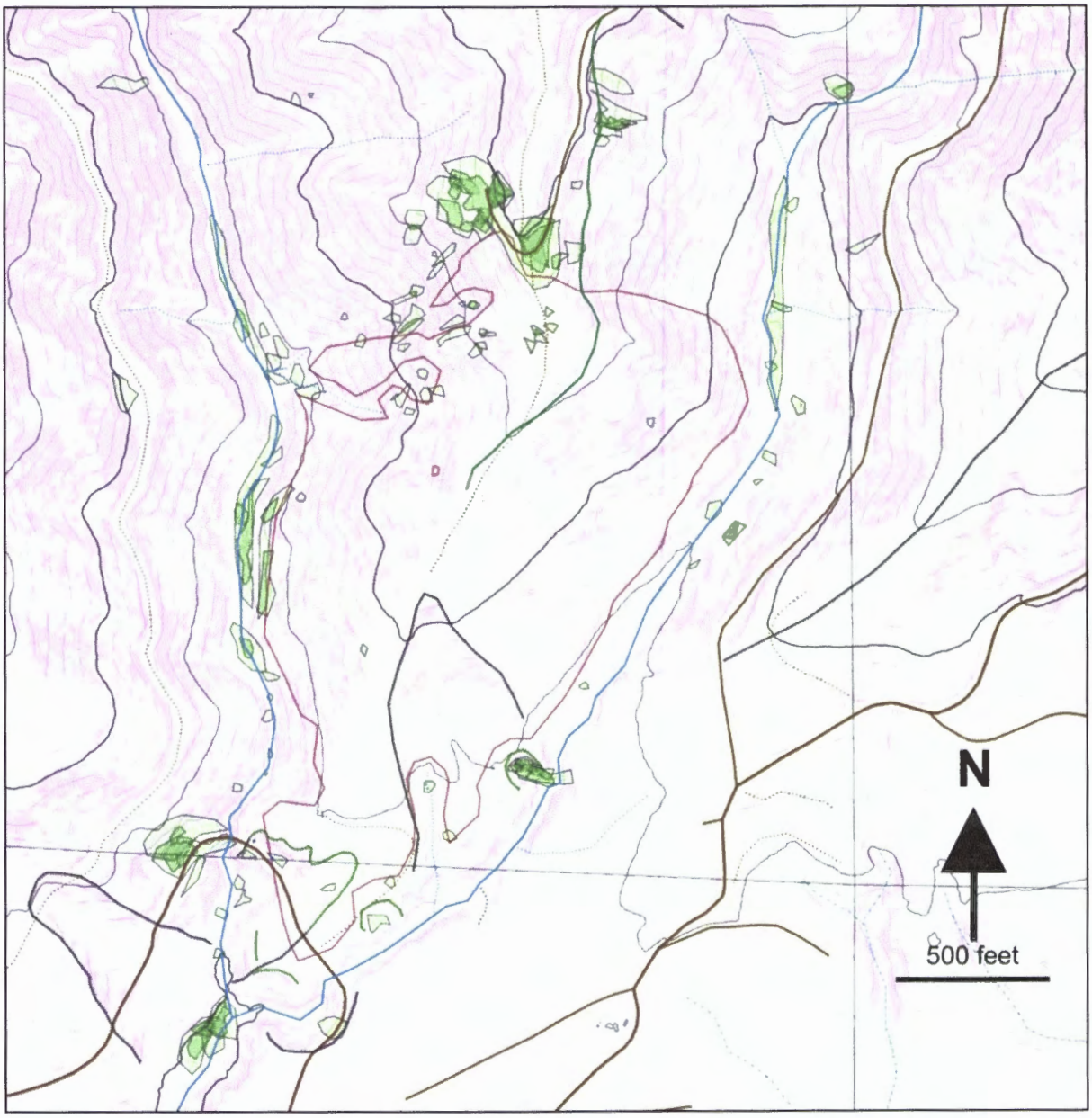

Figure 8. Bare soil and rock inventory map. Displayed are topography (40-ft contours, slope gradients steeper than 70 percent are shaded magenta) and areas of likely bare soil and/or rock observed on the aerial photographs (green polygons). Overlapping polygons appear as darker shades of green. Landslides are more likely to have occurred where the green polygons are located on steep slopes (which are shaded magenta).

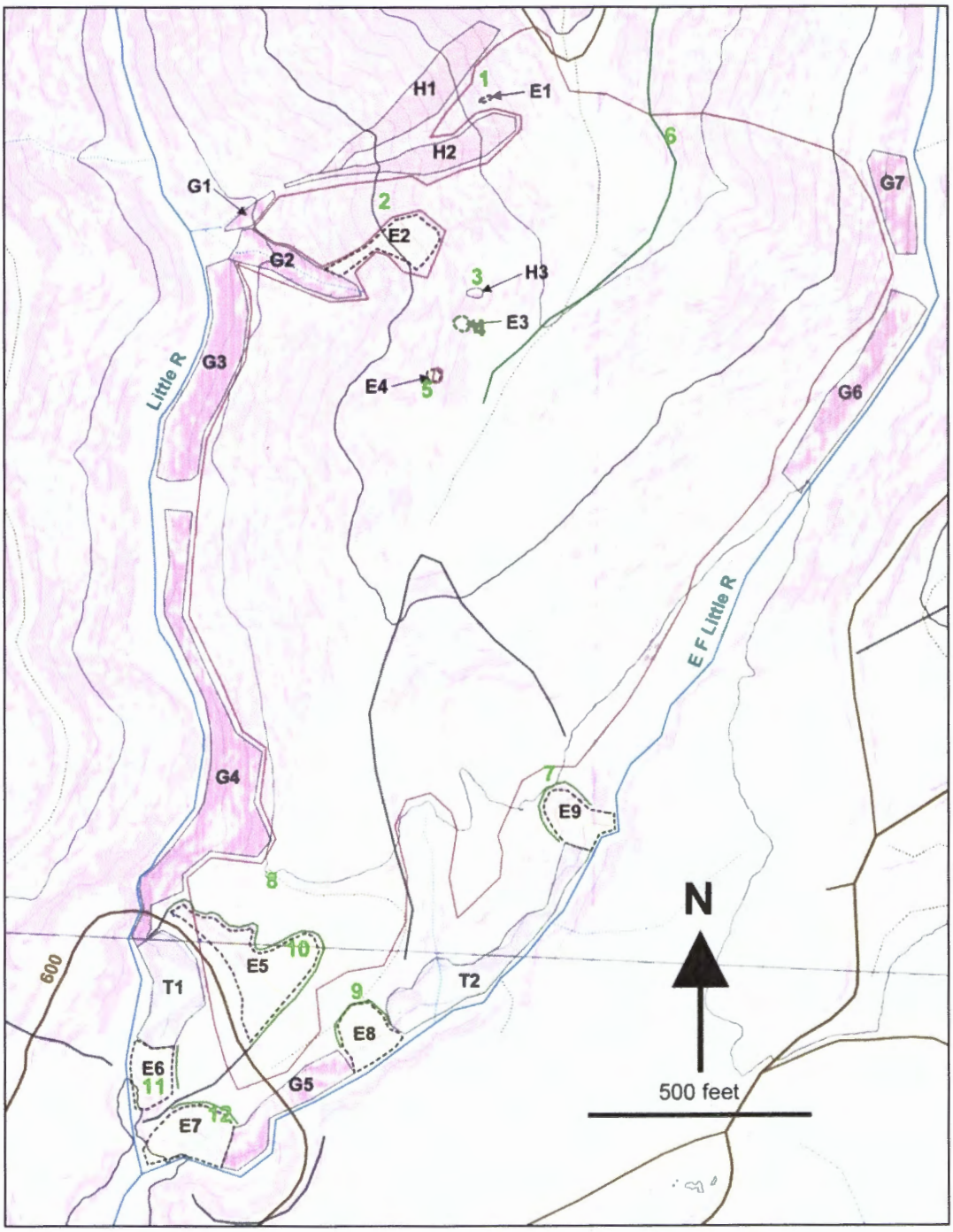

Figure 9. Observation location and landform map. Shown are topography (40-ft contours, gradients steeper than 70 percent shaded magenta), observation locations (green numbers 1 through 12), potentially unstable landforms (G1–G7, H1–H3, T1 and T2, and E1–E9), scarps of dormant landslides (heavy black lines), and scarps of recently active landslides (green lines).