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Engineering Geologic Risk Assessment

Kari Makwa Sorts Timber Sale

Washington Department of Natural Resources

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1.0 Introduction

The proposed "Kari Makwa Sorts" timber sale is a two unit variable retention harvest. Kari Makwa Sorts is in eastern Clallam County approximately 10 miles west of Port Angeles, Washington in Sections 10, 11, 14, and 15 Township 30 north Range 08 west, Willamette Meridian and Baseline (Figure 1). The harvest units total approximately 77.5 acres. The units are accessed from the PA-J-4000 forest road via Wasankari Road and Highway 112 (Figure 1).

The Department of Natural Resources (DNR) proposes using ground based logging methods over the bulk of the area and potentially cable-based yarding of a smaller area from a landing situated in the middle-western part of Unit 1 (Figure 2). Approximately 2,250 feet of new road construction is proposed within Unit 1 to access the landing (Figure 2).

The physical setting of the proposed sale was reviewed in the office and with two separate field reviews (Figure 2). Areas requiring field reconnaissance were identified and communicated by foresters and from office review by us. The geological field reviews of the proposed timber sale were conducted on February 18 and March 22, 2016 (Figure 2). A Licensed Engineering Geologist (LEG) was present on the March 22, 2016 site visit. Weather during the field visits ranged from sunny and clear to cloudy with rain.

Results of office and field reviews indicate that forest practices rule-identified glacial deep-seated landslides and associated groundwater recharge areas are internal to proposed harvest Unit 1. This assessment is limited to addressing potential impacts on slope stability from proposed variable retention harvest activities on portions of groundwater recharge areas associated with two glacial deep-seated landslides and on the body of one of the glacial deep-seated landslides. Activities anticipated during harvest operations that could impact rule identified features include:

- potential skyline cables associated with cable yarding operations over or through rule identified landforms outside of Unit 1,
- road construction within a groundwater recharge area to a glacial deep-seated landslide inside of Unit 1,
- and ground based harvest equipment operation on groundwater recharge areas to glacial deep-seated landslides inside of Unit 1 of the DNR proposed Kari Makwa Sorts timber sale.

1.1 Purpose and Scope

Washington's Forest Practices Rules (Title 222 WAC) include an outcome-based decision making process for regulating forest practices activities on potentially unstable slopes and landforms. Where construction or harvest operations are proposed on potentially unstable landforms, landowners are required to provide the DNR with information that assists the agency in determining if the activities will cause a "probable significant adverse impact" (WAC 222-10-030). Part of the required information is an engineering geologic landslide risk assessment. Specifically, the assessment must include: 1) a description of the potentially unstable landforms on and around the site, 2) an analysis of the likelihood for the proposed forest practices to cause or accelerate slope movement, 3) an analysis of the likelihood that sediment or debris will be delivered to a public resource or will threaten public safety, and 4) a description of measures to

mitigate identified hazards and risks (WAC 222-10-030 (1)). A "qualified-expert" must prepare the assessment (WAC 222-10-030 (5)). See Appendix A for analysts' qualifications.

This report serves as the required engineering geologic landslide risk assessment for the forest practices proposal submitted by the Washington DNR's – Olympic Region known as "Kari Makwa Sorts". The scope of work for this assessment included:

- Review of pertinent published geologic maps and reports
- Review of past geologic assessments
- Review of relevant maps and harvest information provided by the sale forester and engineer
- Review of applicable maps and information within the DNR corporate database
- Review of pertinent historic stereoscopic aerial photographs and digital orthophotographs
- Review of historical data compiled from area weather stations, available from the Washington State Climatologist's website (http://www.climate.washington.edu/)
- Discussion with sale foresters and engineers
- Field review and reconnaissance
- Analysis of field and office generated data
- Preparation of this report

This work, combined with our collective experience addressing slope stability issues in forested environments, forms the basis of our opinions regarding potential for the proposed timber sale to affect slope stability and threaten public resources and public safety.

2.0 Physical Setting

The physical setting for Unit 1 includes the physiography, climate, geology, and soils.

2.1 Physiography

The proposed Kari Makwa Sorts timber harvest is located on the northern edge of the Olympic Peninsula physiographic province, a part of western Washington. The area of the proposed Kari Makwa Sorts timber harvest is on a broad gentle east-west trending ridge. A north-facing slope, that averages approximately 19 percent gradient, is incised by northward flowing creeks to the Strait of Juan de Fuca (Figures 1, 2 and 3). This area was overrun by the Juan de Fuca lobe of the most recent continental Cordilleran glaciation and affected by its subsequent erosion and sediment deposition (Bretz, 1920).

The local area of Unit 1 is on the southern side of a tributary to Salt Creek, which is flowing at an average 7 percent gradient and has incised about 100 feet in the sale area exposing the basement bedrock in the channel and the overlying glacial stratigraphy (Figures 3 and 4).The elevation range of the Unit is approximately 1,060 feet from the southern boundary to approximately 780 feet at the northern boundary (Figure 2). The surface of the unit is generally flat, but relief is observed over the terrace edge along the northwestern boundary of the unit.

2.2 Climate

The Olympic Peninsula has a maritime climate with moderate temperatures, dry summers and wet winters. Precipitation patterns are influenced by the rain shadow effect of the Olympic Mountains. Annual precipitation averages 25.6 inches at the Port Angeles COOP (Cooperative Observer Network) station[1], elevation 90 feet and about 7.5 miles northeast of the proposal and 56.3 inches at the Elwha Ranger Station COOP station[1], elevation 360 feet and approximately 6.5 miles southeast of the proposal (Figure 1). Most precipitation falls as rain and generally occurs between October and April with any snowfall likely to persist for only a few days.

2.3 Geology

The DNR Division of Geology and Earth Resources has done 1:100,000 scale geologic mapping for the Washington portion of the Port Angeles quadrangle (Schasse, 2003; Figure 3). The Hoko River Formation (Em_{2h}) is mapped around Unit 1 with a package of continental glacial till (Qgt) partially covering Unit 1 (Figure 3) The underlying Hoko River Formation is described as interbedded and well-bedded siltstone and sandstone; with the sandstone thin to medium bedded and medium to very fine sand. Locally interbeds of pebble-cobble conglomerate were described as well. The bedrock is mapped dipping north (Figure 3). Schasse (2003) described the till as mostly compact lodgement till made up of clay to cobble and boulder sized material. The till is stratigraphically between underlying advance outwash and overlying recessional outwash (Schasse, 2003).

Field observations substantiate the areal coverage as mapped in the vicinity of Unit 1, but advance outwash sediments underlying the till and overlying bedrock were also detected (Figure 4). Stratigraphy is more complex than mapped, but a basic stratigraphy was observed and interpreted after traverses over the area. A recessional outwash, comprised mainly of sand with gravel and some cobble appears to overlie sandstone and siltstone bedrock and the section is capped with the dense-hard till comprised of a diamict of clay to cobble sized material (Figures 4 and 5). The till appears to have a low hydraulic conductivity as the outcrops of the clay rich till were not saturated internally, but rather multiple outcrops had surface water seeping over them (Figure 5).

2.4 Soil Textures

Soil pits dug during field reviews throughout the area of interest are generally consistent with soil mapping obtained from the Web Soil Survey[2] (United States Department of Agriculture, 2014). Elwha soils are derived from glacial till and cover most of the surface of Unit 1. Neilton soils are derived from glacial outwash and mapped on the slopes below the Unit. Terbies soils cover a small portion of Unit 1 and are derived from sandstone-siltstone bedrock. Colluvium locally cover portions of the area, but was not indicated in acquired soils mapping. Colluvial deposits are considered to be soils thicker than approximately 40 inches and are accumulations of earth materials transported down slope by gravity driven processes from local uphill material.

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[1] Washington State Climatologist's website http://www.climate.washington.edu/ (accessed April, 2016)

[2] United States Department of Agriculture, Natural Resources Conservation Service, 2016, Web Soil Survey: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx (accessed March, 2016).

Soils mapped within the units:

- 94% of the units covered by Elwha gravelly sandy loam
- 5% of the units covered by Neilton very gravelly loamy sand
- 1% of units covered by Terbies very gravelly sandy loam

Elwha soils are characterized as being moderately well-drained with a low water capacity and a very low to moderately low capacity of transmitting water. Elwha gravelly sandy loam has an insignificant potential for mass wasting and low potential for erosion.

Neilton soils are characterized as being excessively drained with a very low water capacity and a high to very high capacity of transmitting water. Neilton very gravelly loamy sand has high potential for erosion and medium potential for mass wasting.

Terbies soils are characterized as being well drained with a very low water capacity and a moderately high to high capacity of transmitting water. Terbies very gravelly sandy loam has low potential for mass wasting and high potential for erosion.

3.0 Potentially Unstable Landforms

Washington's Forest Practices Rules define potentially unstable landforms for purposes of classifying and reviewing forest practice applications and regulating in those areas (WAC 222-16-050 (1)(d)(i)). Under the Forest Practices Rules, one component of a required landslide risk assessment is a description of the potentially unstable landforms on and around the site. This section describes three dominant landform types observed in, adjacent, and near Unit 1: two glacial deep-seated landslides (DSLS) with associated groundwater recharge areas (GWRA), five earth-flows, and two bedrock hollows (Figure 4). Portions of one DSLS and both GWRAs are proposed for harvest (Figure 4).

For logistical ease landforms are numbered sequentially from east to west by landform (Figure 4). Landform descriptions will be grouped by proximity to the identified deep-seated landslides, LS1 and LS2. Naming terminology for the DSLSs and earthflows was decided by using the definitions of Cruden and Varnes (1996) and activity levels were determined by following the guidance of Keaton and DeGraff (1996) as modified by the Washington Forest Practices Board Manual (2015). The primary method to estimate the limits of the groundwater recharge areas was based on topography as described in the Forest Practices Board Manual (Washington Forest Practices Board, 2015). Further discussion of potential slope instability risks is presented within Section 5.0.

3.1 Landslide LS1 and Earthflows EF1 and EF2

Glacial DSLS LS1, its associated GWRA, and two earthflows, EF1 and EF2, are discussed in this section (Figure 4).

The DNR intends ground-based harvesting over the bulk of Unit 1 and on a portion of the GWRA of LS1. Approximately 2,250 feet of gravel road construction is proposed with about 244 feet in LS1's GWRA; a landing is planned at the western end of the road (Figure 4).

Deep-seated landslide LS1 is sourced in glacial sediments and approximately 1.4 acres in size with an additional GWRA estimated at 9.0 acres, yielding a total GWRA of 10.4 acres (recharge areas calculated for this report had the area of the accompanying landslide area included) (Figure 4). An area of approximately 7.4 acres (71 percent) of LS1's GWRA is proposed for harvest (Figure 4).

The headscarp of LS1 is vegetated and smooth as are the lateral margins, which are not easily identified with available lidar data. A skid road was identified along the headscarp, the left lateral scarp, and over the body of LS1, but no displacement was observed along the road (Figure 4). The body of the feature is smooth and vegetated with predominantly straight coniferous trees that are of similar age and species as the surrounding forest. In situ old growth stumps were also observed. The toe of LS1 has been eroded by the stream below and has areas of saturation. Deep-seated landslide LS1 is best described as a relict rotational debris slide.

Earthflow EF1 is located just northeast of LS1 and EF2 and is approximately 0.4 acres (Figure 4). Earthflow EF1 has an old skid road across its head that does not appear to be disturbed. Below the road the broadly convergent area is saturated with vegetation consisting of heavy salmon berry and approximately 20 year old alder and straight coniferous trees are growing. Larger straight coniferous trees are located outside of EF1 along the dryer edges of the landform. In situ old growth stumps were observed on the body.

Earthflow EF2 is located in the northeast corner of LS1's toe and is approximately 0.03 acres (Figure 4). This feature is particularly saturated with hydrophytic plant species growing. The area of EF2 is mostly devoid of trees except for one large big leaf maple. An old growth stump located on the body of the feature appears to have been rotated. The bottom of EF2 is actively being eroded by the stream below.

3.2 Landslide LS2 and Earthflows EF3, EF4, and EF5

Deep-seated landslide LS2 is sourced in glacial sediments and approximately 6.7 acres in size with an additional GWRA estimated at 12.2 acres, yielding a total GWRA of 18.9 acres (recharge areas calculated for this report had the area of the accompanying landslide area included) (Figure 4). An area of approximately 0.3 acres of LS2's body and 3.8 acres of LS2's GWRA is proposed for harvest; about 4 percent of the landslide body and 22 percent of the total GWRA (Figure 4).

The headscarp of LS2 has steep slopes, up to 90 percent, with a sharp edge, and is vegetated with mostly straight coniferous trees, but more so in the eastern portion than the western portion. The lateral margins are similar to the headscarp because they are more heavily vegetated in the east than the west, but overall the lateral scarps are more subdued than the headscarp. A skid road that the Discovery Adventure Trail partially overlaps was identified above the headscarp and did not show any signs of displacement (Figure 4). Another skid road branches and extends down to the west over the headscarp of LS2 and on to the body where it switchbacks to the east (Figure

4). No disturbance along the skid road was observed. The body of LS2 has scarp-bench topography with two distinct benches along the western half of LS2. The benches are saturated and have fewer, smaller coniferous trees and more brush than the surrounding forest. In situ old growth stumps were observed on the body of LS2, including the western benches. An internal scarp in the western half of LS2 was actively raveling and exposed glacial till lower in elevation than glacial outwash sediments observed outside of the mapped landslide to the southwest. The toe of LS2 has been eroded by the stream below and has areas of saturation. Deep-seated landslide LS2 is best described as a dormant-distinct rotational debris slide.

Two hollows were also identified along the western portion of the headscarp (Figure 4). The hollows had surface water seeping over exposed hard glacial till during our field traverse. The convergent slopes are approximately 90 percent, but no channel was observed exiting either feature. Both features are located directly above the upper bench described inside of LS2.

Earthflow EF3 is located northeast of LS2's toe and is approximately 0.1 acres (Figure 4). This feature is saturated with wetland plant species growing. The area of EF3 has fewer trees than the surrounding forest, but some are large, straight conifers. Few in situ old growth cedar stumps were observed.

Earthflow EF4 is internal to LS2 and is approximately 0.6 acres (Figure 4). Earthflow EF4 is broadly convergent with low slopes. The body of EF4 has an open canopy with three large big leaf maples, devil's club, and salmon berry growing. The big leaf maples all had a downslope sweep of similar magnitude and character. A few old growth stumps observed also had a slight lean. The edge of EF4 has large, straight coniferous trees growing. The toe of EF4 is being eroded by the stream below.

Earthflow EF5 is also internal to LS2 and is approximately 0.1 acres (Figure 4). Earthflow EF5 is broadly convergent and saturated with heavy brush and approximately 20 – 30 year old alders growing on the body of the feature. The canopy is open with few trees, but large, straight coniferous trees are growing along the edge of EF5. In situ old growth stumps were few in this area.

3.3 Potential Cable Yarding

Cable yarding to the landing is an option to access timber to the west and northwest of the landing (Figure 6). This may include anchoring and hanging cables to the opposite side of the creek and over landforms LS1, LS2, EF3, EF4, and EF5. It is our understanding that no logs would be yarded over the creek or other rule identified landforms discussed, other than LS2. As such no yarding corridors would be cut and established in those areas. Two areas on the north side of the creek also meet rule identified criteria for inner gorges and fall in the area of potential cable hanging (Figure 6). However, it is our opinion that stringing and hanging cable without yarding logs over the landforms will have very minimal risk to increases of slope instability or delivery to a public resource. It is our understanding that no anchor trees would be located within the inner gorge sections located outside of the proposed harvest unit if cable yarding is used.

4.0 Aerial Photographic Review

Past harvest was observed during review of multiple years of historic aerial photographs (Tables 1 and 2). The area of, and adjacent to, the proposed Kari Makwa Sorts timber sale was observed to have been mostly clear cut logged approximately 10 years previous to the 1939 aerial photographs[3] (Figure 7). These areas showed no riparian or other leave tree areas on the slopes directly adjacent and entirely encompassing Unit 1. This logging is also corroborated in the DNR Forest Resource Inventory System data. Clear cut logging was observed near Unit 1 in the 1971, 1994, and 2011 aerial photograph data sets.

The skid roads identified in the field are first observable in the 1971 aerial photographs, however it is uncertain if their construction could be attributed to the pre-1939 harvest. In the 1971 aerial photographs the skid roads access areas located on LS2 that appear to have been harvested. This created open canopies that persist to the most recent 2015 aerial photographs.

A small area is noticeable in the 1994 aerial photographs with a new canopy opening that likely correlates to the bedrock hollows (Figure 4). This open canopy persists to at least the 1997 aerial photographs.

4.1 Landform Response to Past Harvest

In addition to field reconnaissance, aerial photographs were reviewed to analyze slope conditions and response to past timber harvest activities. The use of field observations along with historic aerial and orthorectified photographs to evaluate the stability of slopes is an approach that has been used elsewhere in western Washington (Benda and Collins, 1992; Grizzel et al., 2008). This approach is based on the assumption that slope response (or lack thereof) to past management activities, such as timber harvesting, can be used to reasonably predict landslide response to similar perturbations in the future.

No clear evidence of slope instability response to past harvest activities was observed in our field reconnaissance or review of historical imagery. However, a slope disturbance was observed in photographic imagery and others during field traverses. A tree canopy disturbance was observed in the 1990 historical aerial photographs where hollows were recorded during field traverses (Figure 4). This canopy disturbance occurred many years after logging occurred, pre-1939 and 1971, so a direct cause and effect relationship between harvest activities and the canopy disturbance was indeterminate.

5.0 Discussion and Interpretations

In this section we further discuss specific areas of potential slope instability associated within and adjacent to Unit 1. In particular glacial DSLSs LS1 and LS2 and their associated GWRAs described in Section 3.0.

All DSLSs and earthflows addressed in this report exhibited similar morphology and stratigraphy. The DSLSs documented in this report appear to have failed with a rotational mode. The DSLSs initiated off of the terrace edge and a general scarp-bench topography along with the

[3] United States Geological Survey, Earth Resources Observation and Sciences (EROS) Center, 2016, Earth Explorer: http://earthexplorer.usgs.gov/ (accessed March, 2016).

occurrence of glacial till below observed glacial outwash within LS2 supports this mode of failure (Figure 4). The lower earthflows however appear to be moving in a much different fashion as exhibited by their groundwater saturation levels, timber stand quality, and tree straightness. In multiple locations large coniferous and big leaf maple trees, estimated to be as old as the last harvest in the early 1930s, had a similar amount of sweep that suggested long term, slow creep movement over the past 80 to 90 years. This variation in failure mode suggests to us that the DSLSs and earthflows do not share a failure plane, but rather are only connected spatially.

Although a clear cause-and-effect relationship between timber harvesting and large-scale deep-seated landslide movement has not been established through the scientific literature, removal of canopy cover is known to reduce evapotranspiration, increase throughfall, and alter groundwater recharge (Moore and Wondzell, 2005). These hydrologic changes could elevate water table levels and increase soil pore water pressures, potentially initiating movement in dormant deep-seated landslides or accelerating movement of active landslides. Deep-seated slope movement can occur rapidly, displacing hundreds or even thousands of cubic yards of soil and rock in a matter of a few seconds. Such catastrophic movement is typically triggered by large-magnitude storms, seismic events, or chronic erosion of the landslide toe. More often however, deep-seated slope movement occurs at a much slower rate, typically on the order of inches to feet per year in response to seasonal or inter-annual fluctuations in precipitation or toe erosion (Iverson and Major, 1987; Pyles et al., 1987). Slower deep-seated movement commonly results in disrupted drainage patterns, deformed overstory vegetation, chronic erosion of the over-steepened toe, and sediment delivery to streams. Historic aerial photographic analysis described in the preceding section was a means we used to evaluate the correlation between deep-seated slope movement and previous timber harvest on and adjacent to debris slides and GWRAs currently proposed for harvest. Areas of canopy disturbance were identified near the proposal area, all of which are outside of the proposed harvest boundaries (Figure 4).

Observations also suggest transmission of water to the subsurface will be restricted. The bulk of Unit 1 is located on a glacial terrace that is capped by a dense-hard, clay rich glacial till (Figure 4). The till is composed of clay to cobble sized material and has a low hydraulic conductivity (Figure 5). It is expected that removal of trees over this area will create hydrologic changes that could theoretically elevate groundwater levels and increase soil pore pressures, but we consider the fine-grained till cover to be a cap that restricts groundwater recharge, and subsequent pore water pressure increases, to features below.

Harvest operations will likely disturb the ground and expose soils locally in areas proposed for harvest. No clear evidence of past failures due to previous clear cutting observed in 1939 aerial photographs, which impacted larger expanses and with no protected areas (associated with drainages and rule identified landforms described herein), suggests that a smaller area proposed for harvest will be impacted similarly. Further, areas below the proposed operational area are protected. There is also a lack of channelized connection to surface water from the area of operations to the stream below. As such, in areas outside of the harvest unit, trees and understory will remain largely intact and will act as barriers if shallow soil failures were to initiate within the proposed harvest area (Guthrie et al., 2010).

Road construction proposed within Unit 1 and the GWRA for LS1 is not expected to impact the groundwater recharge to LS1. The road will be largely impervious, but the glacial till capped terrace is thought to have a low hydraulic conductivity already. Drainage appears to be a minimal issue for this proposed road as it is along a fairly level road alignment that crosses a slope average of approximately 21 percent. The last 440 feet of the 2,250 foot road, including the approximately 244 feet inside the GWRA of LS1, is planned to be abandoned. Part of this planned abandonment will be tearing up the alignment and returning slope drainage to as natural a condition as is feasible.

It is possible that operators of the proposed Kari Makwa Sorts timber harvest may want to hang wire cable over LS1, LS2, EF3, EF4, EF5, and the stream corridor below, including inner gorge slopes, to provide good deflection for yarding logs off of the lower slopes of Unit 1 (Figure 6). No logs are proposed to be yarded outside of the boundaries of Unit 1 and as such no corridors would need to be cut outside of the proposed harvest boundaries. One expected impact we anticipate would be from wire cable scraping bark and breaking occasional branches on trees in close proximity to the skyline cable during raising and lowering of the skyline. Another potential impact could be from a tail hold tree being pulled over. However, we anticipate these to be minimal impacts with minimal risk of increasing slope instability if they were to occur.

Our remote review and field observations of the deep-seated landslide response to past forest practices is the basis of our opinion that the proposed harvest, with the identified mitigation measures, has a low risk of influencing slope stability or posing a risk of sediment delivery to public resources or a threat to public safety. Our review of other similar studies on the Olympic Peninsula (landslide risk analyses conducted to satisfy forest practices rules) also do not indicate a cause and effect relationship between timber harvesting and accelerated or reinitiated deep-seated landslide movement (Grizzel, 2006a; Grizzel 2006b; Benson et al., 2007; Benson and Grizzel, 2007; Grizzel 2008; Grizzel et al., 2008; Benson and Grizzel, 2008; Benson and Grizzel, 2009; Hanell and Grizzel, 2010a; Hanell and Grizzel, 2010b; Hanell and Shafer, 2010; George and Hanell, 2012; Hanell and George, 2013; Hanell and George, 2014; George and Hanell, 2015; George et al., 2015; Skov et al., 2015; George and Hanell, 2016).

6.0 Conclusions and Forest Practice Rule Statements

The following are the required Forest Practice Rule statements addressing WAC 222-10-030 (1) (a,b,c). These responses are based on the data and discussion presented above.

(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 is, in our opinion, low.

Below is a brief synopsis of our interpretations leading to our opinion. For a complete review of our reasoning please see Sections 1.0, 2.0, 3.0, 4.0 and 5.0.

- No deep-seated slope instability has been observed due to past clear-cut logging as observed from historic aerial photographs, 1939 – 2015.

- Fewer trees are proposed for removal than witnessed from past clear-cut harvests.
- The area of Unit 1 is capped by glacial till with low hydraulic conductivity. This will restrict groundwater recharge to LS1 and LS2.

(b) The likelihood of delivery of sediment or debris to a public resource, or in a manner that would threaten public safety, is in our opinion low.

This conclusion is based on our opinion that there is low likelihood the proposed forest practices will cause movement on the potentially unstable slopes or landforms. However, if there are any shallow failures, there may be some likelihood that sediment and debris will be delivered to a public resource. Again, it is our opinion that there is an overall low risk of such an outcome, but the location of potentially unstable slopes is such that if failures do occur it may deliver sediment and debris indirectly to waters draining DNR lands.

We believe there is minimal threat to public safety from this proposal. The nearest public resource, other than the stream below Unit 1 is a stretch of the Discovery Adventure Trail that goes through Unit 1. The trail will be closed during harvest operations. It is possible that members of the public could be on the slopes or within the stream below the proposed harvest, but it is our opinion that there is low likelihood the proposed forest practices will cause movement on the potentially unstable slopes or landforms. Further, the road systems are gated reducing easy public access to the area.

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

The following mitigation measures apply and are recommended to be included as contractual requirements in the Forest Practices Application (FPA).

1. We recommend the removal of any bedrock hollows from the proposed timber sale area. These areas have been identified in the field by a licensed geologist with the forester prior to the timber sale.
2. We recommend returning slope drainage to as natural a condition as is feasible during abandonment of the road within the GWRA of LS1.
3. If cable yarding is used by the harvest operators, no trees or stumps located on a rule identified landform outside the harvest area should be used as an anchor or tail hold without review from a licensed Washington State Department of Natural Resources engineering geologist.

7.0 Assessment Limitations

This landslide risk assessment is based on the scope of work outlined in Section 1.0, the proposed Forest Practices Application (FPA) as we understand it at this time, and our professional experience. Site conditions can change with time or other geologic information could be revealed that is not available, or obvious, at the time of our reconnaissance. If this were

to occur, our geologic interpretations of site conditions and thus our conclusions and recommendations could require modification. Our conclusions and recommendations are predicated on the Kari Makwa Sorts FPA going forward as proposed at the time of preparation of this assessment. If any changes in the proposed FPA are formulated or carried out differently in the field than currently proposed, our conclusions and recommendations shall not be considered valid unless those changes are reviewed in writing by the authors or authors' representative.

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Appendix A – Qualifications of Analysts

Washington's forest practices rules (Title 222 WAC) define a "qualified expert" as a person licensed under chapter 18.220 RCW as an engineering geologist with three years of experience in the evaluation of relevant problems on forested lands (WAC 222-10-030(5)).

Orion George has a Bachelor of Science degree, summa cum laude, (2006) from Humboldt State University, Arcata, California in Geology and a Master of Science degree (2012) from Western Washington University, with an emphasis on structural geology and geomorphology. His academic research involved mapping landslides and associated features using remote and field based techniques on Washington Department of Natural Resources-managed land. Previous work experience includes working as an exploration geologist for Barrick Gold Exploration, Corp. (2006 – 2008, 2011 – 2012) and for the National Park Service as a Physical Science Technician mapping landforms in Olympic and North Cascades National Parks (2010). He has been employed by the Forest Resources Division of the Washington Department of Natural Resources since May, 2012. Most of his work with the agency has been related to slope stability assessments of proposed land management activities. Mr. George is a licensed Engineering Geologist (LEG #3021) in the state of Washington and is considered a qualified expert for work on forested lands.

Casey Hanell has a Bachelor of Science degree from Western Washington University (2001) in Geology with an emphasis in Environmental Geology and a Master of Science degree in Geology from Western Washington University (2011). He has been employed by the Land Management, Forest Resources and Conservation, Forest Resources Divisions, and Olympic Region of the Washington Department of Natural Resources since July 2002. A majority of his work has been related to slope stability assessments of proposed land management activities such as timber harvest and forest road construction. In addition, he has worked on landscape-scale mass wasting assessments and review of state lands potentially unstable slopes procedures. Mr. Hanell is a Licensed Engineering Geologist (LEG #2771) in the state of Washington and meets the definition of a "qualified expert" as outlined in WAC 222-10-030(5).

Tables

Table 1 Historic stereographic aerial photographs reviewed[1]

Year	Flight Line	Film Roll Number	Photograph Numbers	Citation
1939	---	5	65 - 67	(1)
1956	---	9	23, 24	(1)
1971	381	50B	8 - 10	(2)
1976	---	1	30, 31	(1)
1977	---	112B	7 - 9	(2)
1977	---	113B	8 - 10	(2)
1981	23	112	314 - 317	(2)
1981	23	113	256, 258	(2)
1985	3	105	58 - 60	(2)
1985	2	106	278 - 280	(2)
1990	5	84	108 - 110	(2)
1990	14	85	93, 94	(2)
1997	23	116	87 - 89	(2)
1997	23	115	128 - 130	(2)
2003	14	116	183 - 185	(2)

(1) Photographs obtained from Earth Explorer[4].
(2) Photographs obtained from WADNR aerial photographic library.

Table 2 Orthorectified aerial photographs reviewed

Year	Resolution	Source
1994	3 feet	WA - DNR*
2005	18 inch	WA - DNR
2006	1 meter	NAIP†
2009	3 feet	NAIP
2011	1 meter	NAIP
2013	1 meter	NAIP
2015	1 meter	NAIP

* = Washington Department of Natural Resources
† = National Agriculture Imagery Program

[4] United States Geological Survey, Earth Resources Observation and Sciences (EROS) Center, 2016, Earth Explorer: http://earthexplorer.usgs.gov/ (accessed March, 2016).

Figures

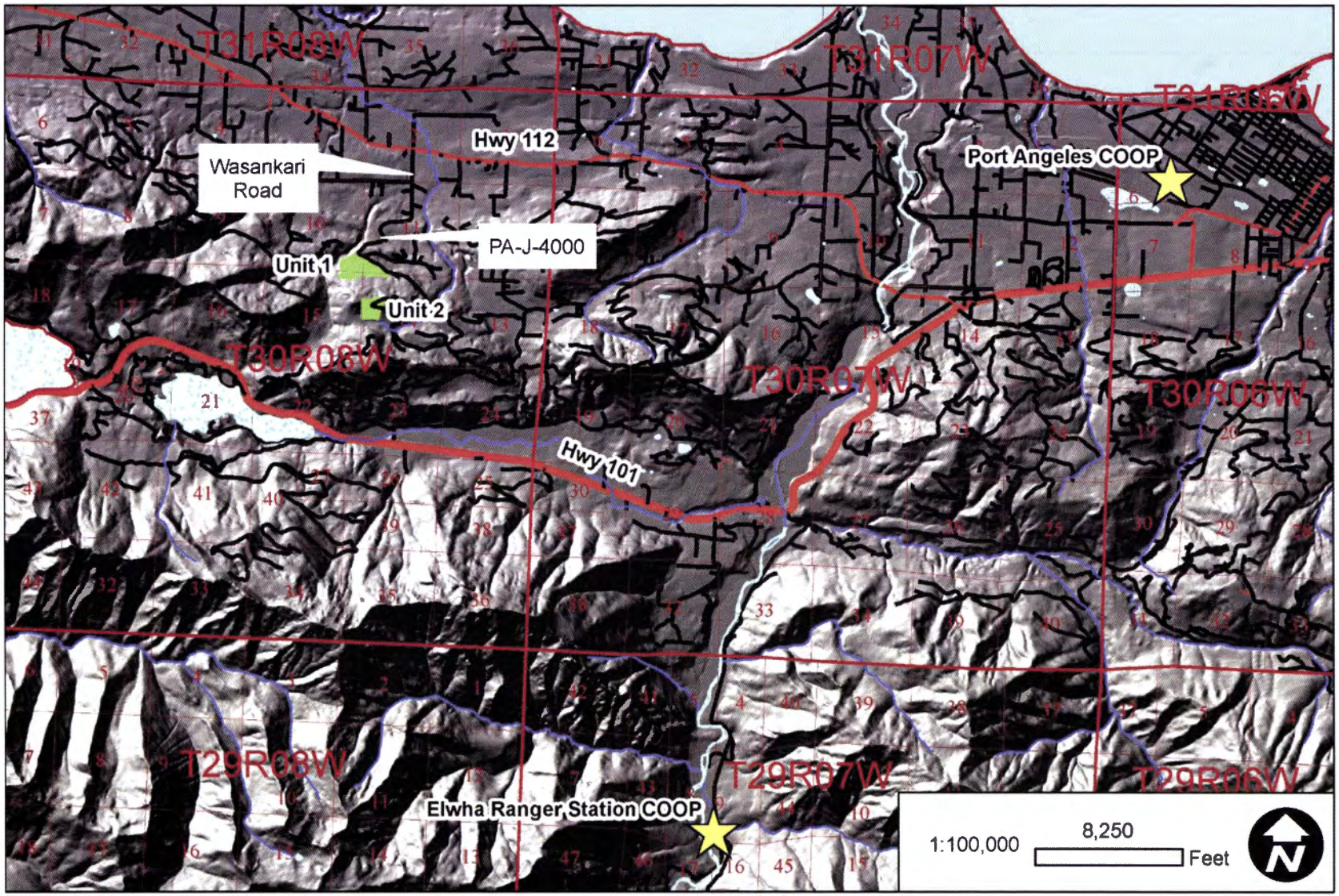

Figure 1 Regional overview map of the proposed Kari Makwa Sorts timber harvest. The units are in green west of Port Angeles. Two weather stations are located with yellow stars and labeled.

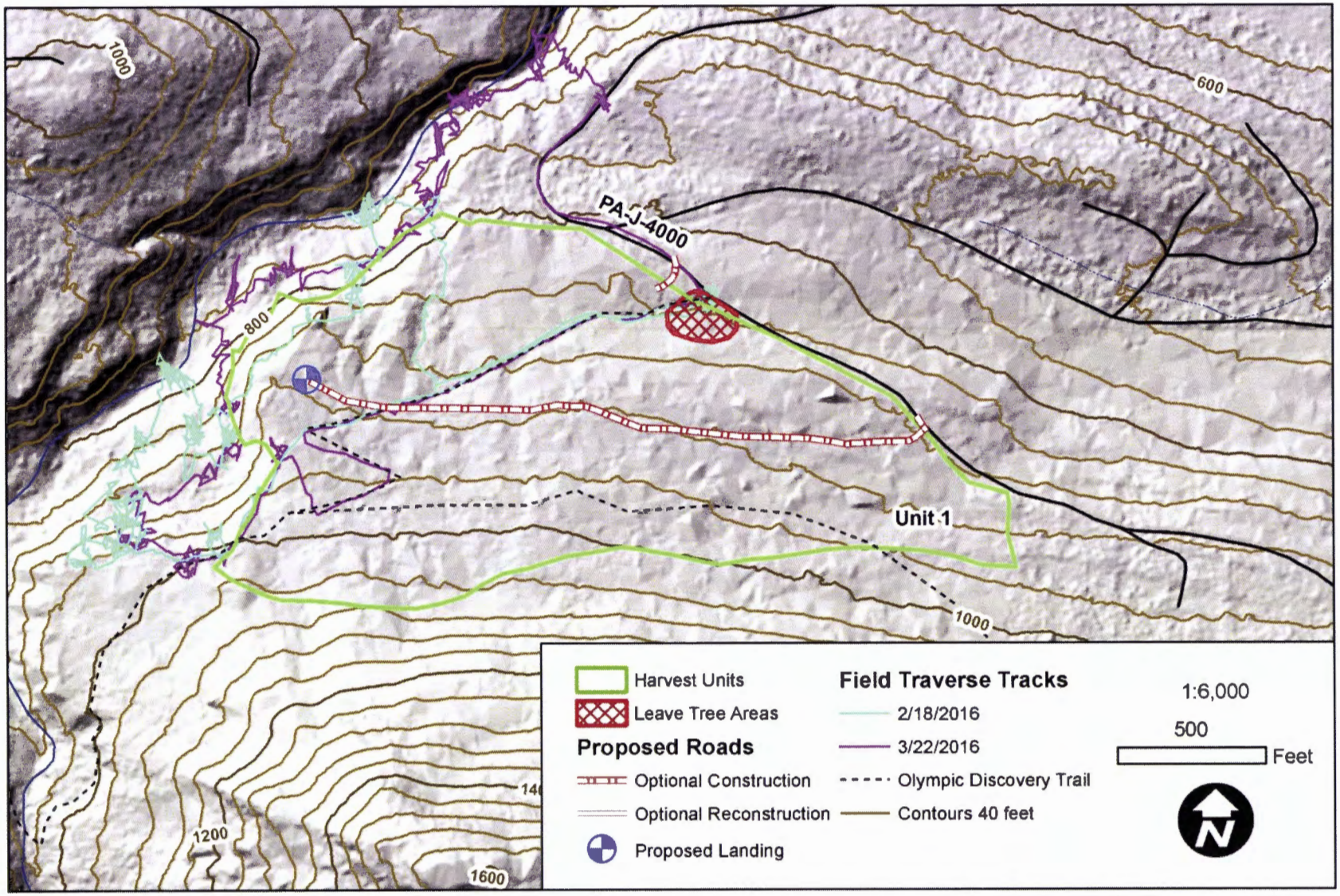

Figure 2 Map of Unit 1 of the proposed Kari Makwa Sorts timber harvest. Field traverses completed by geologists on February 18 and March 22, 2016 are shown with GPS tracks. The Discovery Adventure Trail goes through the southern portion of the trail. The northern section of the trail is no longer maintained. Proposed road construction with a landing are denoted.

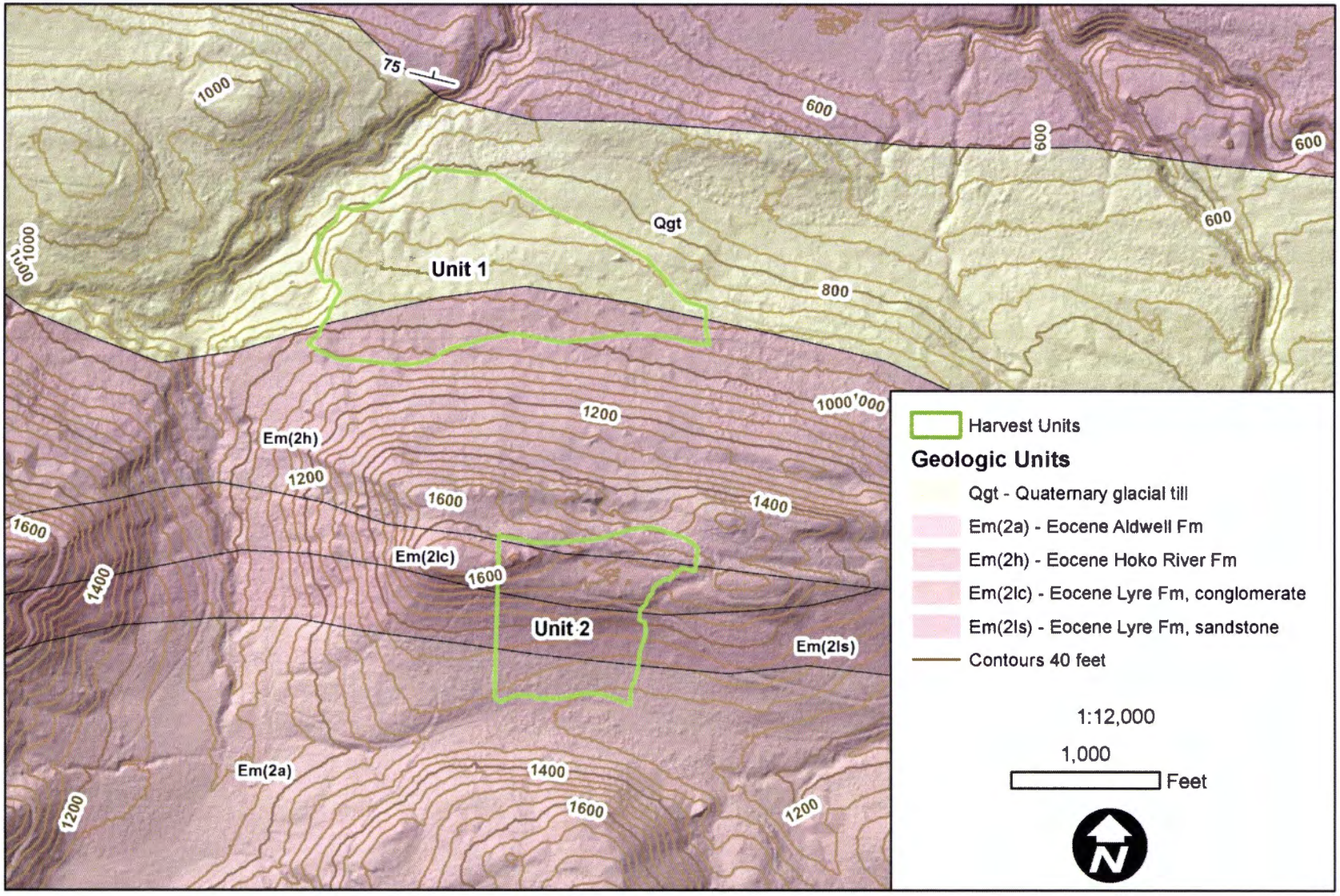

Figure 3 Geology, 1:100,000 scale, mapping completed by Schasse (2003) around the proposed Kari Makwa Sorts timber harvest.

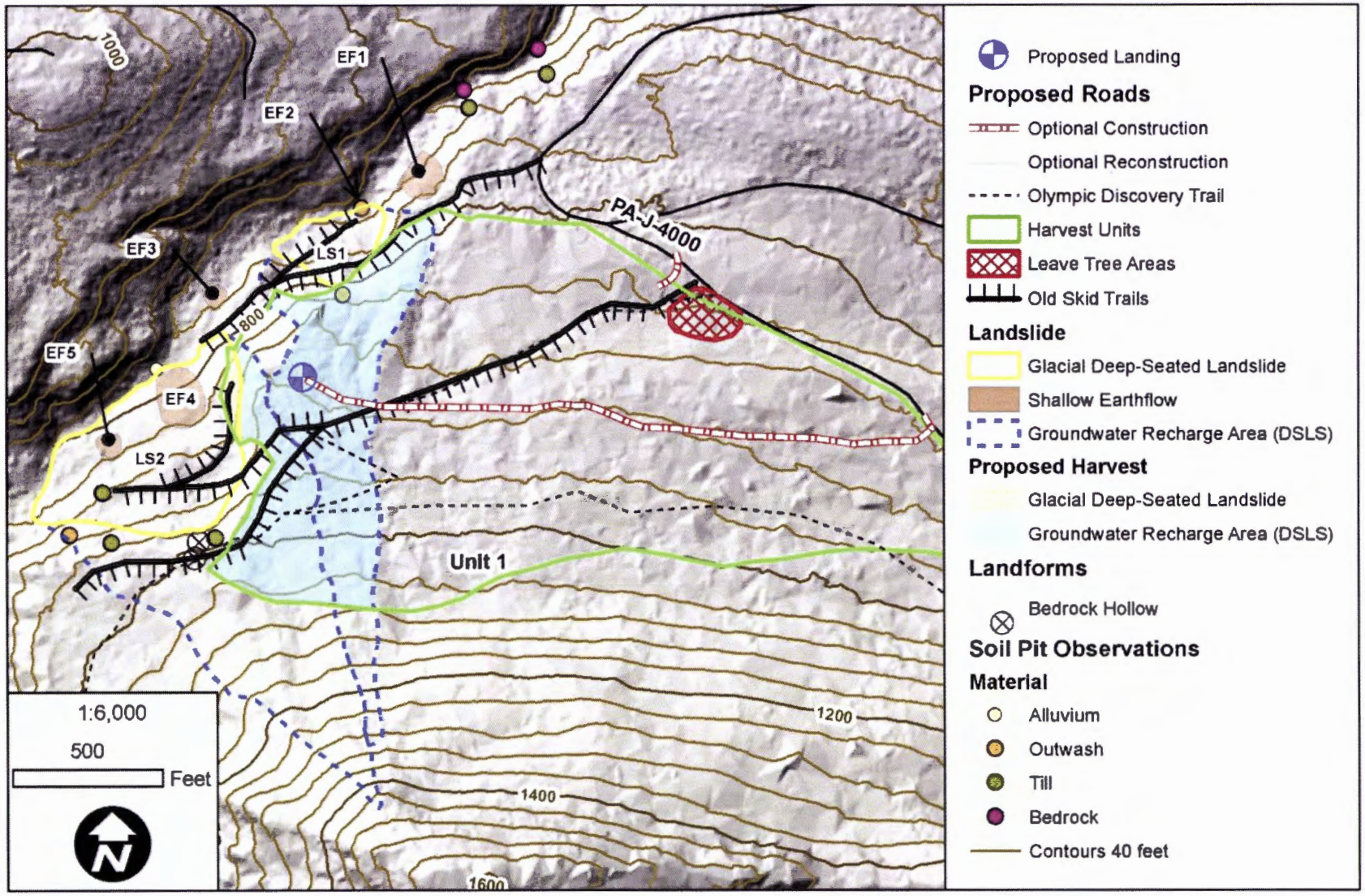

Figure 4 Geomorphology map of proposed Unit 1 and geologic material field observations. Old skid roads observed with lidar data, aerial photographs, and field observations are located on the map along with the location of the Discovery Adventure Trail and proposed road construction and landings. Note the occurrence of glacial till below outwash in the western portion of LS2.

Figure 5 Photographs of glacial till sediments, dense-hard, brownish gray to gray, clay to cobble sized material. The till caps the upper terrace and has a low hydraulic conductivity. Water is actively seeping over the outcrops, which are not internally saturated. Pulaski handle for scale is three feet long.

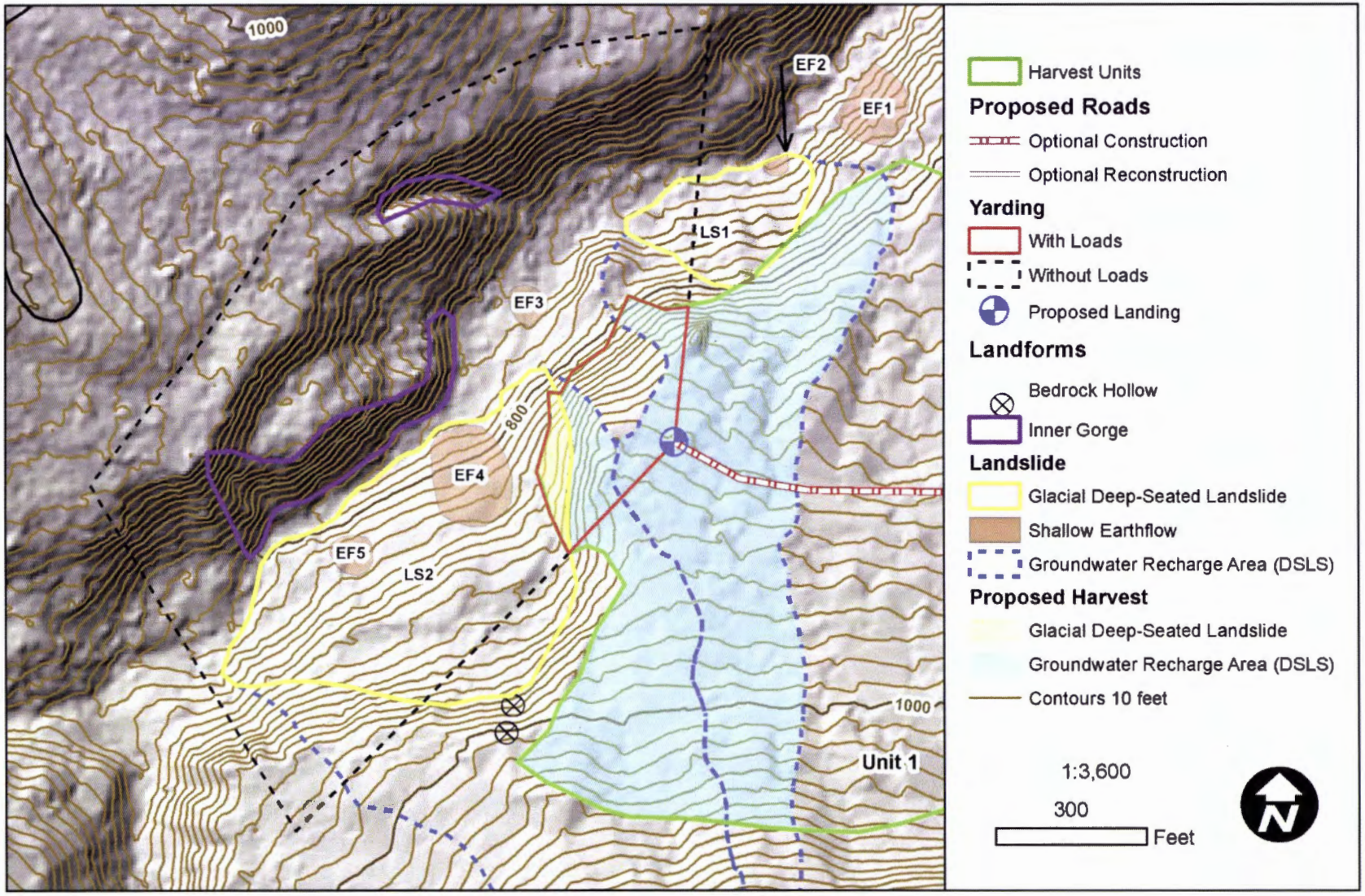

Figure 6 Map of the area possibly impacted by potential yarding operations for timber in Unit 1. The red highlighted area is the area timber may be removed from using skyline cable yarding and the area that would have cable strung and hung if cable yarding is completed is enclosed in the black dashed polygon. Inner gorges identified for this report are outlined in purple. Anchor trees are not recommended on rule identified features.

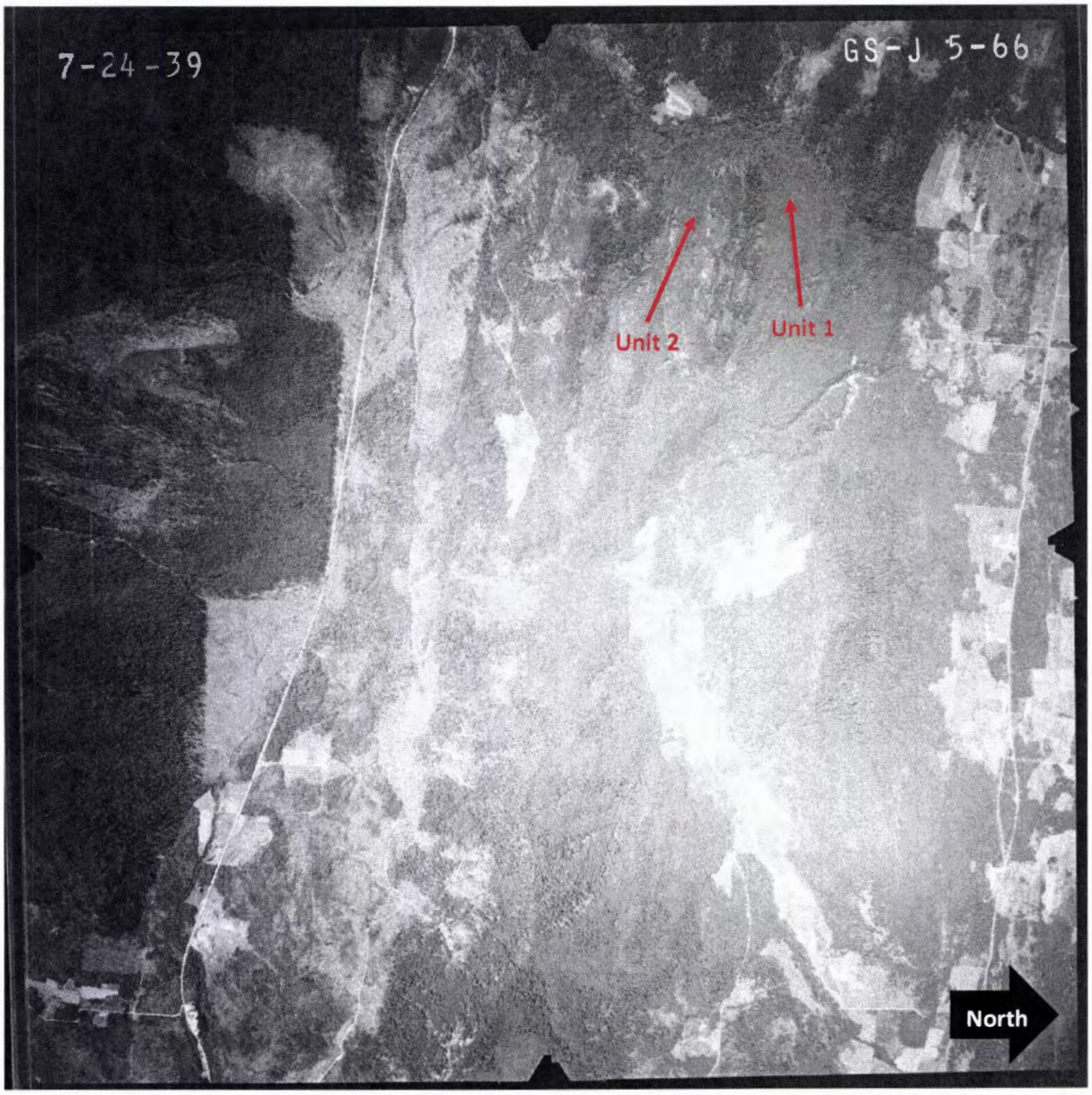

Figure 7 Historic aerial photograph taken in July of 1939 and obtained from the USGS[3]. North is to the right in this photograph and scale is 1:30,000. The red arrows point to the units of the proposed Kari Makwa Sorts timber harvest. The area around the proposed harvest is interpreted to have been clear cut logged approximately 10 years previous to the photograph being taken.