2614101

Engineering Geologic Risk Assessment

Deer Timber Sale

Washington Department of Natural Resources

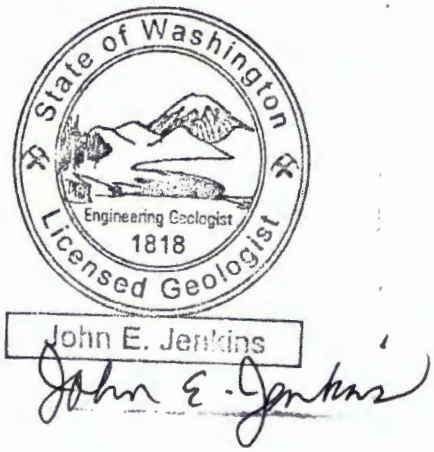
Prepared By:

John Jenkins, LEG #1818
Department of Natural Resources
Forest Resources Division
Earth Sciences Program

Prepared For:

Gary McLaughlin
Department of Natural Resources
Olympic Region
Straits District

February 1, 2016



John E. Jenkins, LEG #1818
State Lands Geologist
Forest Resources Division

Table of Contents

List of Tables iii

List of Figures iii

1.0 Introduction 1

1.1 Purpose and Scope 2

2.0 Physical Setting 2

2.1 Physiography 2

2.2 Climate 3

2.3 Geology 3

2.4 Soil Textures 4

3.0 Potentially Unstable Landforms and Geological Hazard Interpretations 4

3.1 Unit 3 5

3.1.1 Deep-Seated Landslide LS-1 5

3.1.2 Shallow Debris Slides DS-1, DS-2, and DS-3 6

3.1.3 Bedrock Hollow BH-1 7

3.2 Unit 4 7

3.2.1 Deep-Seated Landslide LS-2 7

3.2.2 Shallow Debris Slides DS-4 through DS-7 7

3.2.3 Inner Gorges IG-1, IG-2, IG-3 8

3.2.4 Bedrock Hollows BH-2 and BH-3 8

4.0 Harvest History 8

4.1 Landform Response to Past Harvest 9

5.0 Discussion 9

6.0 Forest Practice Rule Statements 11

7.0 Assessment Limitations 12

8.0 References 12

Appendix A – Qualifications of Analyst 15

Tables 16

Figures 81

List of Tables

Table 1 Historic stereographic aerial photographs reviewed 17

Table 2 Orthorectified aerial photographs reviewed 17

List of Figures

Figure 1 Location Map

Figure 2 Proposed Harvest Units (3 and 4) and Operations

Figure 3 GPS Tracks from Geologists Visits

Figure 4 Geologic Maps (from Schaase and Polenz, 2003)

Figure 5 Landform Map

Figure 6 Historic Logged Areas Map

1.0 Introduction

The proposed "Deer" timber sale by the Department of Natural Resources (DNR) is a four unit variable retention harvest. Deer is in eastern Clallam County approximately 10 miles southeast of Port Angeles and 10 miles southwest of Sequim, Washington in Sections10, 15 and 16 of T29N R05W, Willamette Meridian and Baseline (Figure 1). The harvest units total approximately150.2 acres. Unit 2 is accessed from Deer Park Road south from U.S. Highway 101. The other units are accessed by Deer Park Road the PA-F-2800 to PA-F 2870 for Unit 1 and PA-F-2600 for Units 3 and 4 (Figure 1).

Results of office and field reviews indicate that forest practices rule-identified groundwater recharge areas associated with glacial deep-seated landslides are present within or adjacent to Units 3 and 4. Other potentially unstable landforms such as inner gorges and bedrock hollows are adjacent to these units. This assessment focuses on evaluation potential impacts on slope stability from proposed variable retention harvest on portions of the glacial deep seated landslides and upslope groundwater recharge areas and also addresses potentially unstable landforms defined as adjacent to the harvest areas where no management activities will occur. I understand from the DNR sale forester that Units 1 and 2 of the Deer TS do not include potentially unstable landforms hence only Units 3 and 4 are discussed in this report.

DNR proposes using ground based logging methods over the bulk of the units' area and cable-based yarding from landings situated on the western terrace edges for Unit 3 and 4 (Figure 2). The cable yarding expected to access timber in Unit 3 will not extend past the harvest boundary thus does not go through any RILs identified as adjacent to the sale.

Approximately 3,200 feet of pre-haul maintenance for existing road PA-F-2600 and 1,425 feet of optional new road construction is planned to access Units 3 and 4 (Figure 2).

The physical setting of the proposed sale was reviewed in the office and with six field reviews by DNR State Lands Geologists in the company of the DNR sale forester (Figure 3). An additional track by the sale forester, trained in unstable slopes, was completed primarily along creeks adjacent to Unit 3. GPS tracks for the geological field reviews are shown on Figure 3 and occurred on the following dates:

- March 5, 2015
- July 30, 2015
- September 22, 2015
- November 30, 2015
- December 01, 2015, and
- December 02, 2015
- January 11, 2016 (DNR foresters only)

Weather on the field visits spanned a variety of conditions from sunny and clear to cloudy with rain.

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 a 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 "Deer". 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 orthophotographs
- Discussion with sale foresters and engineers
- Field review and reconnaissance including hand excavation of shallow soil test pits
- 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

2.1 Physiography

Siebert Creek and other north flowing creeks are is cut into a northerly sloping plateau located between the Strait of Juan de Fuca on the north and the mountainous uplands on the south. The plateau has been overridden multiple times during the Pleistocene by continental glaciers that advanced westerly through the Strait of Juan de Fuca. Units 3 and 4 overlie the plateau, but extend easterly onto the valley side slopes to the West Fork of Siebert Creek. The plateau slopes northerly and northeasterly towards the West Fork Siebert Creek at about 8 percent. Gradients along the creek (measured from Lidar topography) range from 9 percent opposite (east) of Unit 4 on the south decreasing to 5 percent opposite Unit 3 on the north. The upper reach of the

watershed for West Fork Siebert Creek occurs in the mountains to the south located within Olympic National Park.

A slope break occurs along the edge of the plateau at the transition to the valley side slopes. The elevation difference from the top to the edge of the flood plain ranges between approximately 240 feet on the south and 190 feet on the north. Slopes are variable with the average slope between the terrace edge and the creek flood plain being approximately 30 percent. The valley side slopes have been modified by stream incision, mass wasting, and deep seated landslides. Potentially unstable slopes are present within the valley slopes and are discussed in Section 3.0.

Land in the plateau region including the Deer TS is forested with land use being primarily for timber production. A homestead on private land is located just west of Unit 4.

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. According to the Western Region Climate Center[1] annual precipitation averages 25.6 inches at the Port Angeles COOP (Cooperative Observer Network) station, elevation 90 feet and about 10.5 miles northwest of the proposal, 16.5 inches at the Sequim 2E COOP station, elevation 50 feet and about 11.5 miles northeast of the proposal, and 27.0 inches at the Buck Knoll RAWS (remote automated weather station), elevation 1,631 feet and approximately 1.5 miles southwest of the proposal. Most precipitation falls as rain and generally occurs between November and April with any snowfall likely to persist for only a few days.

2.3 Geology

The DNR Division of Geology and Earth Resources published a 1:24,000 scale geologic map of the Morse Creek quadrangle (Schaase and Polenz, 2002) (Figure 4). Marine sedimentary bedrock is mapped along West Fork of Siebert Creek and locally on the plateau in proximity to the Site. Two rock units are mapped in the vicinity of the Site that are separated by an east-west trending fault mapped across the creek valley bottom east of the northern portion of Unit 4. North of the fault is middle to upper Eocene-age rocks of the Aldwell Formation (map unit Em(2a)). South of the fault is Eocene to Paleocene-age rocks (map unit EPAm). Bedrock was locally observed during site reconnaissance in proximity to West Fork Siebert creek and primarily consists of steeply north dipping, dark green Siltstone.

Schaase and Polenz (2002) mapped extensive Fraser aged continental glacial till (Qgt) that covers the plateau region locally. Underlying the till unit along the valley side slopes Pleistocene-age undifferentiated glacial and nonglacial deposits (Qguc) are mapped (Figure 4).

During reconnaissance local exposures were observed or shallow test pits were dug to identify the unconsolidated sediments on the slopes that overly bedrock. Soils interpreted to be glacial till were observed at upper to mid-level elevations. This material generally consists of hard silty clay with variable sand, gravel and cobbles. The coarse fraction is mainly granitic and metamorphic rocks. Occasional boulders of granitic rocks were observed on the forest floor. A prominent natural outcrop, approximately 20 feet vertical, is present adjacent to West Fork Siebert Creek

[1] Western Region Climate Center: http://www.wrcc.dri.edu/ (accessed May, 2015)

between Units 3 and 4. In this exposure the lower 12 feet (approximate) consists of very stiff to hard, thin bedded to laminated silty clay to clayey silt (with occasional lenses or thin layers of fine sand or sandy silt) that is overlain by dense silty sand, and sand with some gravel. The rounded gravel and coarse sand includes granitic and metamorphic rocks (thus not a local provenance) and is interpreted to be advance glacial outwash. The underlying fine-grained sediments are interpreted to be glacio-lacustrine sediments. The fine grained sediments were also observed at similar elevations to the north (east of Unit 3) as well as further north opposite harvest units for the Siebert Splits TS (DNR, 2015). At those locations cobbles and boulders of granitic rocks interpreted to be dropstones are present. Soils observed elsewhere on the slopes along the West Fork Siebert Creek in the vicinity of Deer TS mainly consist of silty sand to sand with variable amounts of rounded granitic gravel and occasionally clayey fine sand. Bedrock was only observed proximal to West Fork Siebert Creek opposite (east of) Unit 3 and further downstream.

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). Neilton soils are mapped on the slopes along West Fork Siebert Creek and the parent material is described as glacial outwash. Elwha soils are mapped on the plateau and descending locally to lower elevations on the valley side slopes with the parent material described as glacial till. A summary of the soils mapped is as follows:

- 67% of the units covered by Elwha gravelly sandy loam
- 33% of the units covered by Neilton very gravelly loamy sand

The 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 is mapped as high potential for erosion and medium potential for mass wasting.

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.

3.0 Potentially Unstable Landforms and Geological Hazard Interpretations

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 four dominant landform types observed within or adjacent to Units 3 and 4: two glacial deep-seated landslides (DSLS) with associated groundwater recharge areas (GWRA), seven shallow debris slides, three inner gorges, and three bedrock hollows. Most of these

[2] United States Department of Agriculture, Natural Resources Conservation Service, 2015, Web Soil Survey: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx (accessed May, 2015).

landforms are on the valley side slopes below the plateau edge and above West Fork Siebert Creek. For logistical ease landforms are numbered sequentially from north to south by landform type (Figure 5). Naming terminology for the DSLSs and debris slides 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).

Except for portions of DSLS's LS-1 and LS-2 and the associated upslope GWRAs no harvest or management activities are proposed on any of the identified landforms and are thus classified as "adjacent". Further discussion of potential slope instability risks is presented within Section 5.0.

3.1 Unit 3

3.1.1 Deep-Seated Landslide LS-1

Unit 3 overlies a portion of glacial DSLS LS-1 and the associated upslope recharge area (Figure 5). This relatively large apparently composite landslide descends from the slope break at the plateau edge down to near West Fork Siebert Creek. The landslide involves glacial and possibly non-glacial sediments of undetermined thickness that overly bedrock. A single continuous head scarp is not apparent rather the head scarp appears to be a series of broadly convergent steeper slopes (average of 60 percent) with moderately sloped bench like areas below. A secondary lower head scarp with an associated bench was mapped along the southern margin of LS-1 (Figure 5). As described below, two localized shallow debris slides (DS-1 and DS-2) occur within the mapped extent of LS-1, but are not related to movement on the LS-1.

Based on geomorphology and other indicators LS-1 is best described as relict. The limits of the landslide and component features (body, foot, and toe) are indistinct and uncertain. Establishment of a network of creeks that extend up into the interpreted head scarp areas has occurred over geologic time.

Below the upper head scarps and benches the downslope limit of the landslide complex is not well defined or obvious and the feature may not extend all the way to West Fork Siebert Creek as indicated on Figure 5. Exposures in creeks developed in the lower mapped area of the landslide appeared intact and not disturbed as would be expected in the foot of a deep seated landslide. The largest creek extends up the southern portion of LS-1 with a perennial initiation point (PIP)observed at elevation of 1,485 feet or about 70 feet below the plateau edge. Dense glacial till was observed below this PIP at two locations along the creek (elevations 1,475 and 1,450). Below the till sandy well drained soils were observed.

The area of LS-1 is densely forested with a mix of conifer and hardwood species. Trees in the landslide area were previously harvested in the 1920's and 1950's with further discussion of past forest practices in Section 4.0. Evidence of debris slides, debris flows or other landslide activity was not clearly indicated from review of historic aerial photographs (see Section 4.0). Recent appearing scarps or cracks were not observed on LS-1 during reconnaissance by DNR geologists. Slopes within the landslide area are predominantly smooth with slope breaks being subdued and gradual. Conifer trees and old growth stumps across the landslide area are predominantly straight

with stumps appearing in place. Locally some sweep in conifers or a more pronounced pistol butt is present. This may indicate some slow downslope movement or creep is occurring locally.

Some steeper areas show evidence of erosion or mass wasting. These areas are not related to movement of the deep seated landslide. Examples include DS-1 (on the head scarp area in the southern portion) and DS-2 (associated with a creek on the general toe area in the northeast portion).

The mapped limit of LS-1 (Figure 5) is approximately 15 acres with the adjacent upslope GWRA at 35 acres for a combined total GWRA of 50 acres. Approximately 4.9 acres of the harvest area of Unit 3 is within LS-1 whereas approximately 3.4 acres of the unit is within the upslope recharge area of the landslide, as such, a total of 8.3 acres of the recharge area is proposed for harvest.

LS-1 and the upslope GWRA was previously evaluated by DNR for the Deer Town TS as summarized in a Landslide Risk Analysis report (Grizzel and Hanell, 2010). Their mapped limits of the landslide and the upslope GWRA are very close to the same area as this study for the Deer TS. Unit 3 of the Deer Town TS is located immediately west of Unit 3 of the Deer TS; the limits of that harvest unit, logged in 2011, are shown on Figure 6: Historic Logged Areas Map. That 2011 harvest comprised approximately 12.8 acres or 36 percent of the upslope portion of the GWRA. Nearly all of the remaining upslope recharge area had been previously logged in the 1980's (see Figure 6). The analysis by Grizzel and Hanell (2010) provided an opinion that there is a low likelihood that the proposed Deer Town timber harvest (subsequently cut in 2011) will initiate or reactivate deep-seated slope movement. Their aerial photograph analysis revealed no evidence of deep-seated slope movement from 1981 through 2009.

Our opinion is that the proposed harvest on a portion of LS-1 and the GWRA will not increase the risk of slope instability or sediment delivery to a public resource. The activity level of LS-1 is classified as relict. If renewed movement of LS-1 occurred the risk of impacts to public safety or infrastructure is judged to be low.

3.1.2 Shallow Debris Slides DS-1, DS-2, and DS-3

Shallow debris slide DS-1 is a localized debris slide within steeper slopes associated with the southern head scarp portion of LS-1. In this area swales and type 5 creeks have eroded into the old head scarp. The limit of DS-1 was approximated based on low amplitude general hummocky appearance of the ground while an obvious head scarp was not observed. Few trees are present on the slide that is interpreted to be shallow (less than 10 feet thick) and translational.

Shallow debris slide DS-2 occurs in the northern downslope extent of LS-1 where stream incision has occurred. The slide is associated with a swale and type 5 creek that flows into the larger type 4 creek that extends up to the vicinity of DS-1. It appears the material deposited near the confluence. Large straight firs are present in the head area and area of accumulation suggesting the event occurred over 50 years ago. Soil pit data showed fine to medium Sand with some coarse sand and fine, rounded gravel.

Shallow debris slide DS-3 appears to have initiated on a 70 percent slope that is convex in profile and gradual decreasing to 40 percent and depositing on a benchy area. The area is characterized by mature even-age alder and is estimated to be approximately 20 feet wide. No water was evident however shallow groundwater is suspected based on abundant devils club and alder.

3.1.3 Bedrock Hollow BH-1

Bedrock hollow BH-1 is a localized convergent slope measured 68 percent at the head of a swale that is directed into a Type 4 creek below. In the lower portion groundwater seepage was observed and shallow groundwater is suspected. Tilted old growth stumps were noted on the body of the feature, but live trees appeared undisturbed. Soil within the feature was observed to be silty fine to medium Sand, some coarse sand and fine sub-round gravel.

3.2 Unit 4

A rotational DSLS identified as LS-2 occurs in the southern portion of Unit 4. The deep-seated landslide appears to be sourced in glacial sediments and a GWRA has thus been delineated. Other landform in the vicinity of Unit 4 includes inner gorges, shallow debris slides, and bedrock hollows as described below. The proposed landings, roads, cable yarding corridors and tail holds are all located within the unit (Figure 2) thus no management activities will occur on these latter landforms.

3.2.1 Deep-Seated Landslide LS-2

Deep-seated landslide LS-2 is approximately 1.1 acres in size and occurs along the edge of the plateau on the southern extent of Unit 4. As the slide appears to be sourced in glacial sediments an associated upslope GWRA area was delineated. Based on topography the upslope recharge area is limited in extent and estimated at 0.3 acres. The downslope extent of the LS-2 is outside the harvest limit. Based on FRIS (Forest Resources Inventory System) data from DNR the stand age of the southern-most portion of Unit 4 (that includes LS-2) and further south (including the slopes on both sides of a tributary creek to West Fork Siebert Creek), is 1922.

The activity level of LS-2 is best described as relict. The head scarp slope was measured at 65 percent and is forested with conifers and smooth. Drainage has been established within the body and toe of the feature. The trees were observed to be straight within the steep head scarp and elsewhere on the slide body and toe.

3.2.2 Shallow Debris Slides DS-4 through DS-7

Debris slide DS-4 is characterized by a low head scarp that is approximately 40 feet wide. The surface is hummocky and includes some down trees. Delivery to a creek was not evident. There are several areas on the western valley side slopes, primarily east of Unit 4 where down trees are common. These are believed to be related to past high wind storm events that, based on aerial photo review, occurred between 2006 and 2009. Root rot pockets are also suspected and infected trees are at higher risk of blow down.

Debris slide DS-5 occurs at mid-elevations below the northern extent of Unit 4. The feature may have originated as a debris avalanche from steep slopes at the head of the feature. Few standing trees are present on the feature with down trees being common. The lower extent appears to have shallow groundwater indicated by vegetation that includes devils club and salmon berry.

The head of shallow debris slide DS-6 occurs at the slope break to the plateau and near the harvest boundary. The slope in the slide area is between 55 and 60 percent and appears to terminate in a large area with gentler slopes below. Ground within the slide area is slightly irregular or hummocky with common swept trees indicating slope creep processes may be occurring. Fresh scarps or ground cracks were not observed. Evidence of surface water ponding or shallow groundwater was not observed.

Debris slide DS-7 appears to be a recent shallow debris slide estimated to be approximately 30 by 50 feet in area. It occurs in a broadly convergent area above at the head of the creek that is incised at lower elevations where inner gorge IG-3 occurs. Slopes in the slide area are 50 to 60 percent.

3.2.3 Inner Gorges IG-1, IG-2, IG-3

Inner gorge IG-1 occurs on a tributary creek to West Fork Siebert Creek between Units 3 and 4. I understand the creek that extends up on to the plateau, is a classed as type 3 in the lower reach. Steeper slopes (up to 78 percent) characterized as inner gorge occur in the central portion of creek. Evidence of recent localized debris slides with no trees or even age young trees were observed. Based on topography, this creek is not hydrologically connected to the harvest areas of Unit 3 and 4.

Inner gorge IG-2 occurs upstream on the same creek as IG-1. In this reach it a classified as a Type 4 creek. The southeastern slopes delineated as inner gorge are steeper being between 70 and 75 percent. Some localized segments appear to be hummocky in part with mature alder common. No recent debris slides were observed.

Inner gorge IG-3 occurs on a type 4 creek where erosion by the creek resulted in steep side slopes up to approximately 75 percent slope. Evidence of localized older debris slides with hummocky ground surface was observed with alder common.

3.2.4 Bedrock Hollows BH-2 and BH-3

These features are in proximity to the creek including inner gorges IG-1 and IG-2 thus they are not hydrologically connected to harvest units 3 and 4. BH-2 occurs on a first order creek to the larger creek where slopes were measured at 75 to 80 percent. Sweeping and leaning conifer trees are common and evidence of localized shallow debris slides is present.

BH-3 is at the head of a first order creek that flows into the larger creek. The slopes were measured to be between 65 and 75 percent; a slight sweep in a few conifer trees was observed.

4.0 Harvest History

Historic aerial photo analysis was used to estimate past harvest history. This was supplemented with data available from the DNR Forest Resources Inventory System (FRIS) where stand age has been estimated for delineated polygons. Table 1 lists historic stereographic aerial photographs reviewed. Table 2 lists digital aerial orthophotos reviewed. Figure 6 shows the

estimated extent of recent clear cuts revealed in the aerial photos with the photo year shown. Figure 6 also shows the stand origin year polygons from the FRIS data.

Portions of Unit 3 and 4 along with a large area between these units as well as north and east of Unit 3 were observed to have been recently logged in the 1939 orthophoto. The stand age for the remainder of Unit 3 including most of landslide LS-1 according to FRIS is 1956. FRIS data shows the stand age for most of Unit 4 and the lower east-facing slopes to West Fork Siebert Creek as 1935. The southern portion of Unit 4 that includes landslide LS-2 and further south has a stand age of 1922 according to FRIS. As can be seen on Figure 6 FRIS data indicates the valley slopes to West Fork Seibert Creek and apparently the riparian zones were logged previously with stand ages ranging from 1919 and 1939. The 35-acre upslope GWRA to LS-1 has been harvested in the past including portions in 1917 and later in 1956, 1985, 1986, and 2011.

4.1 Landform Response to Past Harvest

In addition to field reconnaissance, aerial photographs were reviewed to evaluate 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. Many of the potentially unstable features were clear cut in 1939 however evidence of canopy disturbances or failures for those features was not clearly evident from the 1939 and subsequent aerial photos. Canopy disturbances observed in the 2009 and subsequent photos correlate to blow down areas observed in the field. Field evidence supported that these pockets were blow down areas from storm events.

5.0 Discussion

This report has described the proposed forest practices within a portion of two glacial deep seated landslides and portions of their upslope recharge areas. Additional potentially unstable landforms, classified as adjacent, and where no management activities are proposed, were also described. In this section we review and evaluate the likelihood that the proposed forest practices will reactivate or increase movement on the glacial deep seated landslides.

The activity level of both the larger composite deep seated landslide LS-1 and the smaller LS-2 are interpreted to be relict. Rapid post glacial stream incision is thought to be a main driver of past deep-seated slope instability in the proposal area. The geology and terrain of the proposal area has been markedly impacted and sculpted by past glacial activity. It is thought that a paleo-West Fork Siebert Creek valley was in place before continental glaciation. The continental glaciation is thought to have largely filled the paleo-valley with sediment and that erosion since that last glaciation has incised completely through the outwash, till, and underlying lacustrine

deposits exposing basement bedrock. This rapid incision is thought to be a main driver of past landsliding in the proposal area, with the greatest rate of erosion happening soon after the last glaciation and coinciding with the time of greatest slope instability.

Both DSLS LS-1 and LS-2 have been modified by extensive creek incision extending from the toe of the features up into former scarp areas. Evidence of deep-seated movement on these features was not observed during field reconnaissance or through review of historic aerial photographs. There is evidence of more recent shallow failures along a steeper head scarp in the southern portion of LS-1 (DS-1) and a creek incised in the apparent toe area of LS-1 (DS-2).

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; Grant, et. al., 2008). 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 harvests on and adjacent to landslides LS-1 and LS-2. As noted above evidence of movement on the deep seated landslides was not found based on historic aerial photo review and field reconnaissance observations.

Proposed harvest areas on LS-1 and LS-2 encompasses portions of the head scarps and bodies of these features. The slopes in those areas appear generally stable as they are smooth, the existing conifer trees and old growth stumps are dominantly straight, and no water features are present. The harvest boundaries exclude all type creeks that occur and lower elevations.

Based on this analysis it is my 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. Review of other similar studies on the Olympic Peninsula (landslide risk analyses conducted to satisfy forest practices rules) also do not indicate a clear 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).

6.0 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.

- Field observed geomorphology indicates seep-seated landslides LS-1 and LS-2 are relict.
- No deep-seated slope instability has been observed due to past clear-cut logging as observed from historic aerial photographs, 1939 – 2013.
- Bedrock hollows, the inner gorges, and shallow debris slides are classified as adjacent to the timber sale where management activities are not planned and the majority are not hydrologically downgradient of proposed harvest areas.

(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 is 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 West Fork Siebert Creek are two US Highway 101 bridges, which span Siebert Creek more than 7 miles downstream from the proposed harvest. Siebert Creek's gradient below the confluence with West Fork Seibert Creek averages less than 3 percent, which is conducive to debris flow deposition rather than transmission (Benda and Cundy, 1990). It is possible that members of the public could be on the slopes or within West Fork Siebert Creek directly 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 have proposed the removal of any bedrock hollows, inner gorges, and shallow debris slides deemed of moderate or higher risk of slope failure 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. The proposed harvest areas avoid all typed creeks.

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 Deer 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.

8.0 References

Benda, L.E. and B. Collins, 1992, Slope stability investigation of the Crown-Pacific property in the South Fork of the Stillaguamish River Basin (t. 30 N, R. 8 E, E ½ of SW ¼ of S 14), unpublished report dated May 6, 1992, prepared for: Washington Department of Natural Resources, Forest Practices Division, Olympia, Washington, 37 p.

Benda, L.E. and T.W. Cundy, 1990, Predicting deposition of debris flows in mountain channels, Canadian Geotechnical Journal, Vol. 27, pp. 409-417.

Benson, L.A., and J.D. Grizzel, 2007, Geotechnical assessment – "Happe Max" timber sale Unit 2, unpublished report dated April, 2007, prepared for the Washington Department of Natural Resources – Olympic Region, 11 p.

Benson, L.A., and J.D. Grizzel, 2008, Landslide risk analysis – "Pleasantine" timber sale, unpublished report dated September 15, 2008, prepared for the Washington Department of Natural Resources – Olympic Region, 11 p.

Benson, L.A., and J.D. Grizzel, 2009, Landslide risk analysis – "Highark" timber sale, unpublished report dated June 19, 2009, prepared for the Washington Department of Natural Resources – South Puget Sound Region, 7 p.

Benson, L.A., S.L. Slaughter, and J.D. Grizzel, 2007, Geotechnical assessment – "Mad Max" timber sale Units 2 and 4, unpublished report dated January, 2007, prepared for the Washington Department of Natural Resources – Olympic Region, 15 p.

Cruden D.M. and D.J Varnes, 1996, Landslide types and processes, *in* Landslides Investigation and Mitigation Special Report 247, Transportation and Research Board, National Research Council, p. 36-75.

George, O. and C.R. Hanell, 2012, Engineering geologic landslide risk assessment: H-1000 Again timber sale, prepared for the Washington Department of Natural Resources – Olympic Region, 17 p.

George, O. and C.R. Hanell, 2015, Engineering geologic landslide risk assessment: Tacoma Select VDT timber sale, prepared for the Washington Department of Natural Resources – Olympic Region, 32 p.

George, O., Jenkins, J., and R. Skov, 2015, Engineering geologic landslide risk assessment: Siebert Splits Sorts timber sale, prepared for the Washington Department of Natural Resources – Olympic Region.

Grant, Gordon E.; Lewis, Sarah L.; Swanson, Frederick J.; Cissel, John H.; McDonnell, Jeffrey J. 2008. Effects of forest practices on peak flows and consequent channel response: a state-of- science report for western Oregon and Washington. Gen. Tech. Rep. PNW-GTR-760. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 76p.

Grizzel, J.D. and C.R. Hanell, 2010, Landslide risk assessment: "Deer Town" timber sale – Unit 3, unpublished report dated January 22, 2010, prepared for the Washington Department of Natural Resources – Olympic Region, 12 p.

Grizzel, J.D., 2006a, Final report – geotechnical assessment: "Q It Up" timber sale Unit 2, unpublished report dated June 20, 2006, prepared for the Washington Department of Natural Resources – Olympic Region, 23 p.

Grizzel, J.D., 2006b, Geotechnical assessment: "East Fork Tarboo" timber sale, unpublished report dated December, 2006, prepared for the Washington Department of Natural Resources – Olympic Region, 22 p.

Grizzel, J.D., 2008, Landslide risk assessment: "Ten Step" timber sale Units 2 and 3, unpublished report dated January 29, 2006, prepared for the Washington Department of Natural Resources – Olympic Region, 21 p.

Grizzel, J.D., L.A. Benson, and C.R. Hanell, 2008, Landslide risk assessment: "Dry Elwha" timber sale – Unit 3, unpublished report dated January 14, 2008, prepared for the Washington Department of Natural Resources – Olympic Region, 27 p.

Hanell, C.R. and O. George, 2013, Landslide risk assessment: F-1000 Remains timber sale, prepared for the Washington Department of Natural Resources – Olympic Region, 13 p.

Hanell, C.R. and O. George, 2014, Landslide risk assessment: Good Spread timber sale, prepared for the Washington Department of Natural Resources – Olympic Region, 25 p.

Hanell, C.R. and J.D. Grizzel, 2010a, Landslide risk analysis – "Deer Town" timber sale, unpublished report dated January 22, 2010, prepared for the Washington Department of Natural Resources – Olympic Region, 12 p.

Hanell, C.R. and J.D. Grizzel, 2010b, Landslide risk analysis – "More Stain" timber sale, unpublished report dated April 30, 2010, prepared for the Washington Department of Natural Resources – Olympic Region, 20 p.

Hanell, C.R. and A.P. Shafer, 2010, Landslide risk analysis – "Boundary Creek Mix" timber sale, unpublished report dated August 12, 2010, prepared for the Washington Department of Natural Resources – Olympic Region, 16 p.

Iverson, R.M. and J.J. Major, 1987, Rainfall, groundwater flow, and seasonal movement at Minor Creek landslide, northwestern California: physical interpretation of empirical relations, Geological Society of America Bulletin, v. 99, pp. 579-594.

Keaton, J. and J. DeGraff, 1996, Chapter 9 – Surface observation and geologic mapping, *in* Landslides: Investigations and Mitigation, Turner, A. and L.R. Schuster, *eds.*, Transportation Research Board Special Report 247, pp. 178 – 230.

Moore, R.D. and S.M. Wondzell, 2005, Physical hydrology and the effects of forest harvesting in the Pacific Northwest: a review, Journal of the American Water Resources Association, v. 41 (4): pp. 763-784.

Pyles, M.R., K. Mills, and G. Saunders, 1987, Mechanics and stability of the Lookout Creek earth flow, Bulletin of the Association of Engineering Geologists v. XXIV, no. 2, pp. 267-280.

Schaase, H.W. and M. Polenz, 2002, Geologic map of the Morse Creek 7.5 minute quadrangle, Clallam County, Washington, Open File Report 2002-8, Washington Department of Natural Resources, Division of Geology and Earth Resources, Olympia, WA.

Washington Forest Practices Board, August 8, 2015, Section 16 Guidelines for Evaluating Potentially Unstable Slopes and Landforms.

Appendix A – Qualifications of Analyst

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)).

John Jenkins has a Bachelor of Science degree (1980) and a Master of Science degree (1985), both in geology, from University of Illinois, Champaign-Urbana, and the New Mexico Institute of Mining and Technology, Socorro, NM. He has been employed by the Washington Department of Natural Resources (DNR) since April 2012. His duties include providing technical and scientific support to the agency's Forest Resources Division. A majority of his work with DNR has focused on landslide risk assessment related to forest practices activities. Mr. Jenkins has over 30 years of experience in slope stability risk assessment ranging from site-scale to regional-scale projects for public agencies and private parties. Additional professional experience was gained during employment with the Oregon Department of Transportation, the U.S. Bureau of Reclamation and geologic mapping for the U.S. Geological Survey. Mr. Jenkins is a Licensed Engineering Geologist (LEG #1818) and Licensed Hydrogeologist (LH #1818) in Washington. He has been recognized as a qualified expert pursuant to Washington's forest practice rules.

Tables

Table 1 Historic stereographic aerial photographs reviewed

Symbol	Year	Flight Line	Film Roll Number	Photograph Numbers
OLY-71	1971	355	44	27 – 28
OL-77	1977	106	---	27 – 30
OL-81	1981	24	106	232, 233-235
OL-85	1985	37	099	178 - 181
OL-90	1990	18	91	43 – 44
OL-97	1997	32	122	132 - 134
OL-C-03	2003	15	122	194 – 196

Table 2 Ortho-rectified aerial photographs reviewed

Year	Resolution	Source
1939	1:30,000	USGS[1]
1942	1:20,000	War Dept.[2]
1954	1:37,400	USGS
1956	1:60,000	USGS
1990 - 2000	3 feet	WA – DNR[3]
2005	18 inch	WA - DNR
2006	1 meter	NAIP[4]
2009	3 feet	NAIP
2011	1 meter	NAIP
2013	1 meter	NAIP

1 US Geological Survey, Earth Explorer
2 US War Department Army Corps of Engineers
3 Washington Department of Natural Resources
4 National Agriculture Imagery Program

Figures

2614101

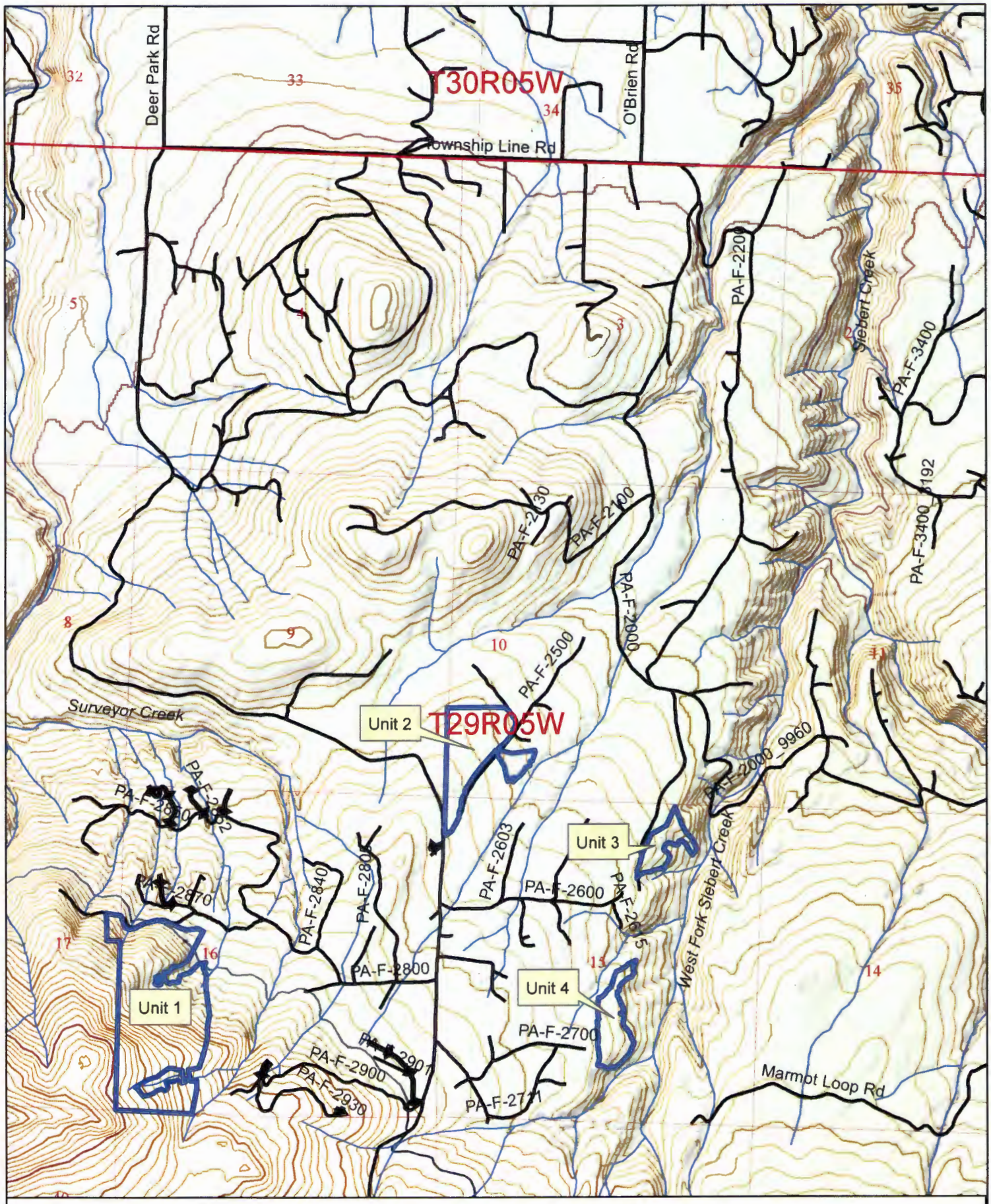


Figure 1: Location Map
Deer Timber Sale (Units 1, 2, 3, and 4)

N

1:24,000

2,000 Feet

2614101

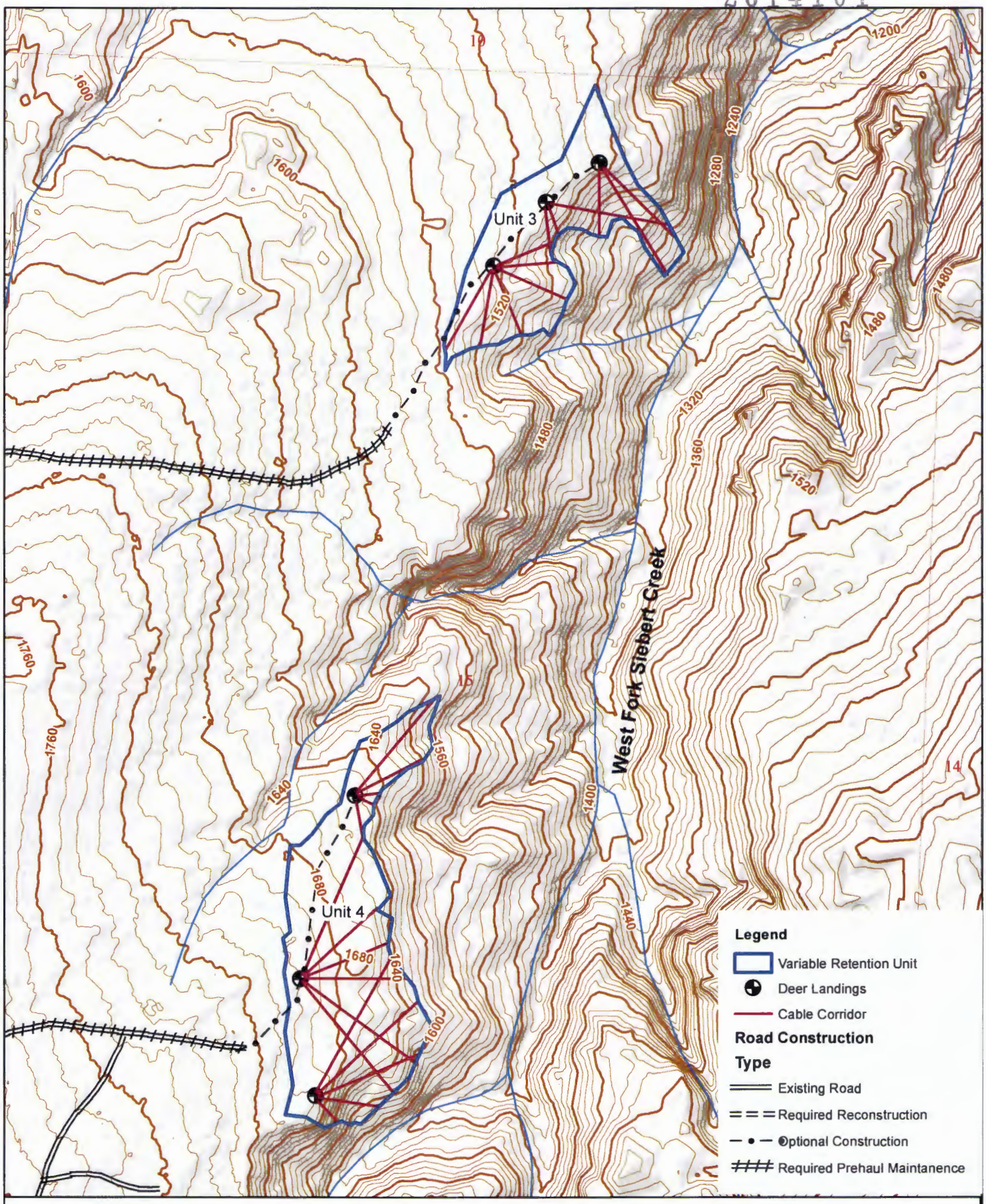


Figure 2: Proposed Harvest Units (3 and 4) and Operations
Deer Timber Sale

N

1:6,000

500 Feet

2614101

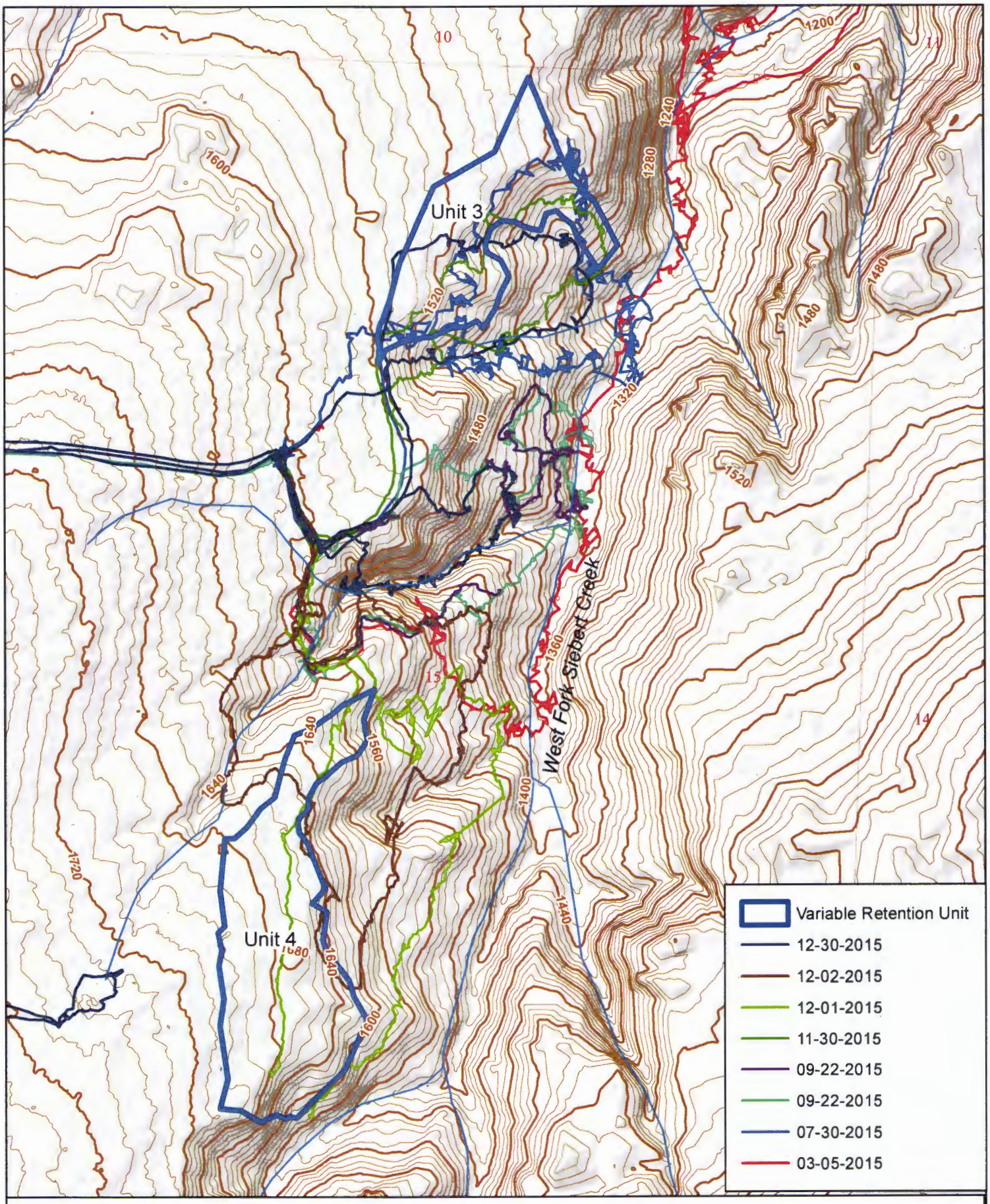


Figure 3: GPS Tracks from Geologists Visits
Deer TS - Units 3 and 4

N

1:6,000

500 Feet

2614101

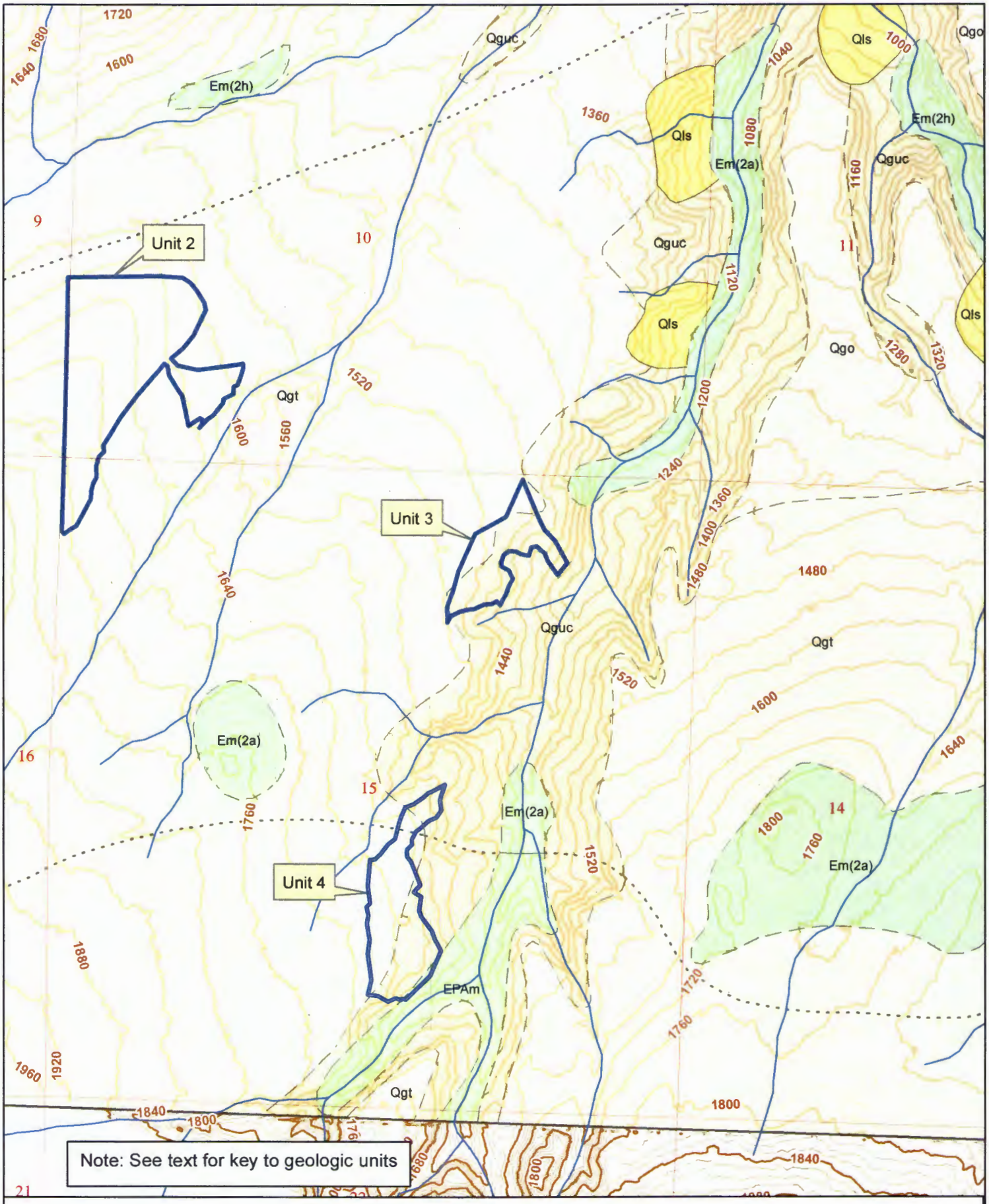


Figure 4: Geologic Map (from Schaase and Polenz, 2002)
Deer TS - Units 3 and 4

N

1:12,000

1,000 Feet

2614101

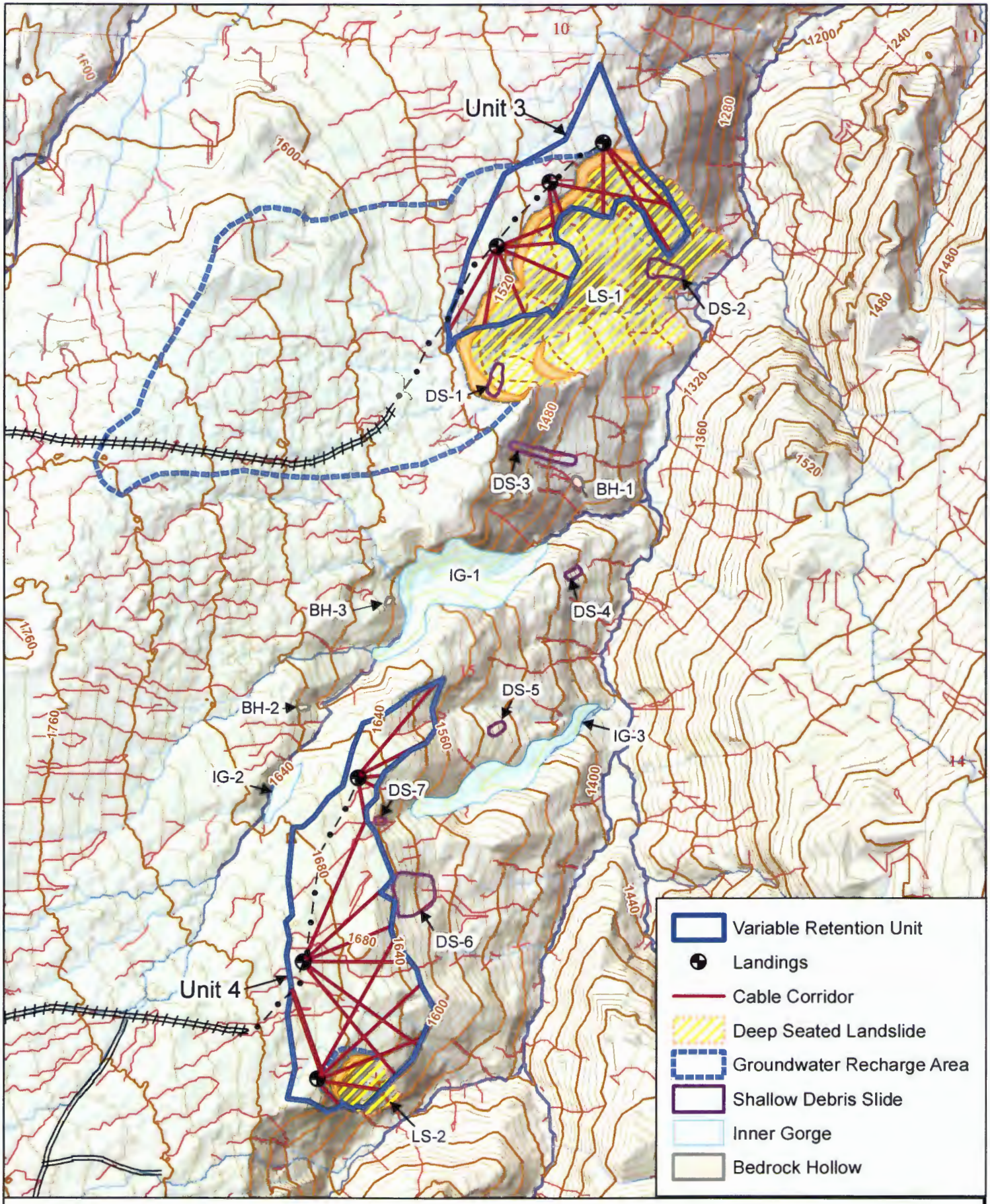


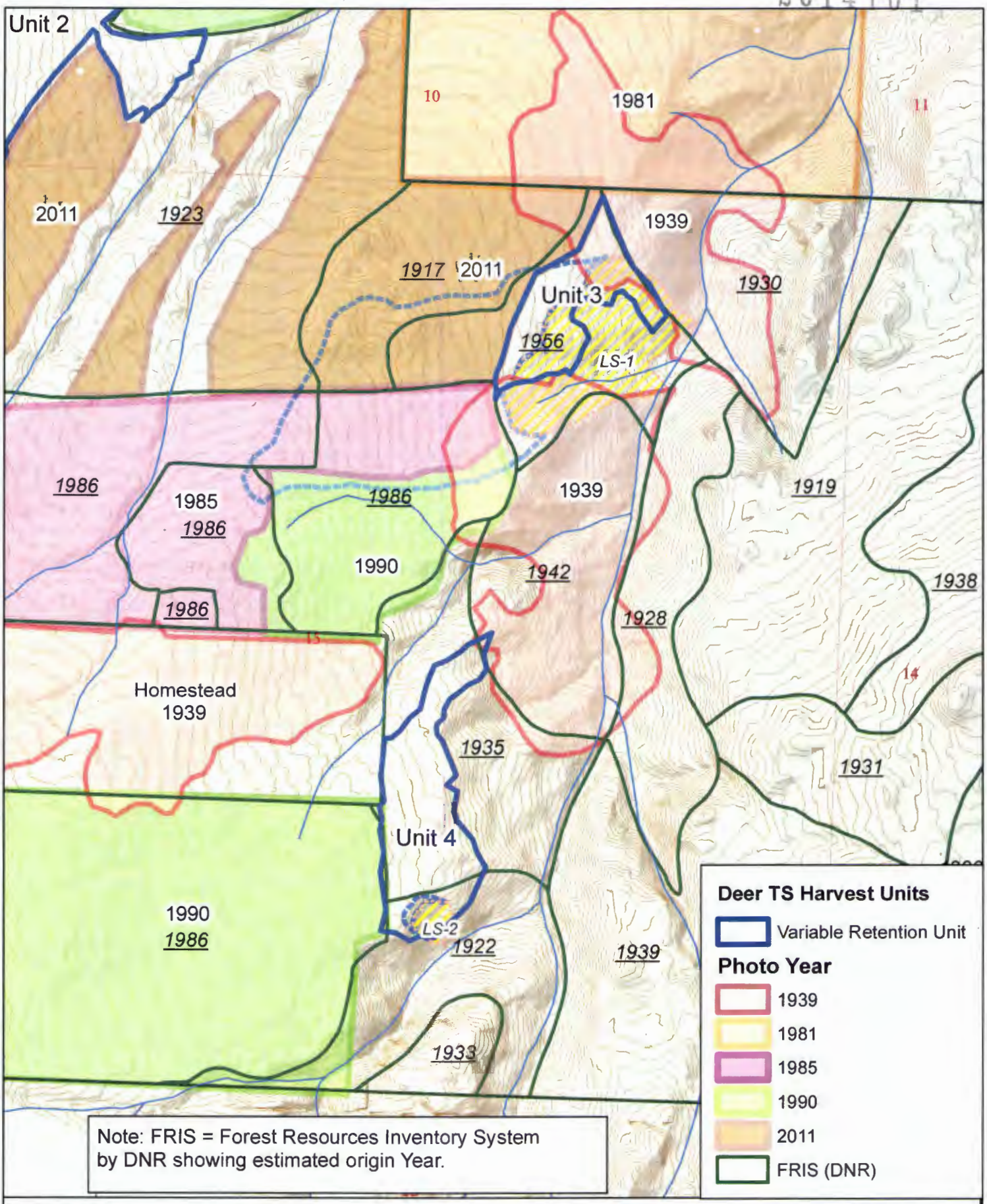
Figure 5: Landform Map
Deer Timber Sale

N

1:6,000

500 Feet

2614101



Note: FRIS = Forest Resources Inventory System by DNR showing estimated origin Year.

Figure 6: Historic Logged Areas Map
(clear cut; areas from aerial photos)
Deer Timber Sale

N

1:8,400

700 Feet