North Fork Calawah Watershed Analysis

Module K - 2015 Mass Wasting Prescription Reanalysis Level 2

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Overview

The North Fork Calawah Watershed Analysis (WA) was originally completed in 1997, one of the few that was a joint analysis incorporating both the Washington State Forest Practices methods and the Federal methods used by the United States Forest Service. Unique to the Federal methods were a Cultural Resources Module, a Vegetation Module that included all known information about natural disturbance regimes such as fire history, and the combination of the Mass Wasting Module and Surface Erosion Module into a Sedimentation Module. Particularly unique to Federal WA on the Olympic Peninsula was the development of geomorphic map units (GMU) that broadly delineated the watershed into hillslope and valley categories that were helpful in understanding mass wasting and surface erosion processes and relative hazards therein.

This report is Module K – 2015 Mass Wasting Prescriptions Reanalysis Level 2. It is an update of the mass wasting portion of the original Sedimentation Module, and it is specifically focused at state and private lands within the North Fork Calawah Watershed. Reanalyses are a required process of watershed analysis and occur every five years, or more often if a natural disaster occurs or watershed conditions appear to be declining. This reanalysis follows the administrative process described in WAC 222-22-090. The scientific evaluation and reporting of the reanalysis follow the specific protocols set out in Appendix K – Mass Wasting Prescription Reanalysis Module (WFPB, 2011).To this end, this reanalysis differs from the original Sedimentation Module in the following ways: 1) Only mass wasting processes are addressed – surface erosion either from roads or within harvest units has not been reanalyzed; 2) Surface erosion events and all events on Federal lands have been deleted from the original landslide and surface erosion inventory displayed on Map A-1 such that Map K-1 displays only landslides on state and private lands in the watershed; 3) Only GMU 71, relict deep-seated landslides, has been carried forward into the reanalysis (Map K-2 – now called MWMU #6): and 4) mass wasting map units (MWMU) typical of the Washington State Forest Practices methods have been delineated for state and private lands (Map K-2).

The evaluation of forest practices applications (FPA) and landslides that have occurred since the original WA was completed in 1997 is the direct and simple way to understand the efficacy of the North Fork Calawah Watershed Analysis Prescriptions that have been practiced for the past 17 years of road construction and timber harvest in the watershed. However, it must be noted that the Prescriptions as written in 1997 allowed for some flexibility under the recommendations of geotechnical personnel and this flexibility caused the Prescriptions to be deemed "non-specific" in 2008 when the WADNR re-interpreted WAC 222-16-050(1)(d)(iii)(C) which reads "*An application would not be classified as Class IV-Special for potentially unstable slopes or landforms under this subsection if: The applicable prescription is specific to the site or situation, as opposed to a prescription that calls for additional analysis. The need for an expert to determine whether the site contains specific landforms will not be considered 'additional analysis,' as long as specific prescriptions are established for such landforms.*" This means that some basic prescriptions such as no new sidecast and no timber harvest except for yarding corridors within the unstable landforms have been consistently followed and can be tested. Other prescriptions such as avoiding the placement of cross-drain culverts within the unstable landforms have been inconsistently followed because geotechnical review may have allowed for an alternate choice such as placing the cross-drain culvert on the unstable slope and then limiting the ditch length feeding to this

pipe. More information about the prescriptions, how they were followed or modified, and what we can infer from an evaluation of FPA and from the updated landslide inventory in light of this "non-specific" issue are discussed below in the section titled Testing the Prescriptions.

For this reanalysis, the landslide inventory has been extended by analyzing three years of aerial photos, 2003, 2009 and 2013, and these additional landslides have been individually evaluated to identify triggering mechanisms. Identification of the landforms where the recent landslides occurred provides reassurance that the unstable slopes described in the original WA are still valid (see below in the section titled Landslide Inventory). Delineation of MWMU then provides the opportunity to calculate landslides rates for the MWMU and systematic hazard ratings from the Landslide Hazard Zonation Protocol can be established (Table K-6). Hazard ratings in the original Sedimentation Module (Dieu and Shelmerdine, 1997) were unique to the North Fork Calawah WAU and could not be compared with other mass wasting assessments.

This report contains a discussion of the updated landslide inventory with emphasis on the landslides that have occurred since the original WA was completed in 1997 and since forest practices in the watershed were generally done in accordance with the prescriptions or by geotechnical recommendation. The recent landslides are summarized in Table K-1, data pertaining to all landslides is available in Appendix K-1 and all landslides are displayed on Map K-1. Landslide counts by landslide type, by land use and by geomorphic setting are summarized in Tables K-2, K-3 and K-4, respectively.

There is a short summary of the 6 MWMU present in the watershed. These are: bedrock hollows, inner gorges, convergent headwalls, outer edges of meander bends, small, sporadic deep-seated landslides and relict deep-seated landslides. Detailed descriptions are provided in Appendix K-2.

The critical questions of the reanalysis are answered in the section titled Critical Questions and Summary. These questions are:

1) Are there any newly identified areas of the landscape that are susceptible to high landslide frequencies?;

2) What is the distribution of new landslides throughout the landscape and are they found in existing MWMU, the rule-identified landforms or in new locations within the watershed?;

3) Are forest management activities associated with landslide activity?;

4) Can a determination be provided to analyze those slopes for which prescriptions were followed but the slopes failed compared with those slopes that were covered under the same prescriptions but did not fail?;

5) Have the prescriptions been properly implemented?;

6) How does the distribution of new landslides compare to the distribution of landslides at the time the WA was approved and are the new landslides on existing MWMU or not?;

7) What, if any, new types of landslides have been discovered since the time the current approved mass wasting analysis was completed? What land uses are associated with these landslides?;

8) Have the newly inventoried landslides delivered sediment to public resources?;

9) How does the rate of new landslides compare to the initial rate of landslides present when the WA was first approved and, in particular, how do the percentages of new landslides by land use compare to those inventoried in the original WA?

Landslide Inventory

The original landslide inventory was conducted across the entire watershed and also included areas of significant surface erosion such as large cutslopes and fillslopes along roads cut into steep hillslopes and areas of natural hillslopes where gully erosion was occurring. The inventory used stereo aerial photography from 1951 to 1995 and Map A-1 displayed events color-coded by the decade of aerial photography when the event was first observed. Map K-1 displays the landslides originally inventoried on state and private lands, color-coded the same as Map A-1. Surface erosion events and those landslides that occurred entirely on Federal land have been deleted from the current data set. Twenty-eight landslides straddled Federal property lines – these were individually scrutinized to determine the ownership at the initiation point. Those initiating on Federal land were deleted, those initiating on state or private lands were retained in the dataset and the portion of each on Federal land is displayed on Map K-1. No landslides were clipped except for two wide debris slides in inner gorges where the property lines transected the initiation zones.

Eighteen additional landslides were added to the layer. These were located using 2003 color, stereo aerial photography flown by the State of Washington (1:12,000 to 1:13,200, marked on each photo), and NAIP ortho photography of 2009 and 2013. Data for the additional landslides are presented below in Table K-1 (Form K-1).

- The *Event Numbers* are sequential from the original watershed analysis.
- *Landslide Types* are noted as debris flows, debris slides, rock slides and "SSDS" which are small, sporadic deep-seated landslides.
- The *Certainty*, given in "Definite," "Probable" and "Questionable" refers to the certainty that the observed feature is a landslide. All in Table K-1 are "Definite" because most were field reviewed and the two that were not are very clear on the aerial photography.
- Many of the eighteen landslides were field observed shortly after they occurred. For the sake of approximately dating the event and so others can locate the event on the aerial photography, the column titled *First Year Observed* contains the photo year upon which the landslide can first be observed. Several were first observed on the 2003 aerial photography, the last set of stereo aerial photography that Rayonier owns. Another several landslides occurred after 2003 and are noted as first observed on the 2009 or 2013 ortho photography. One SSDS was field located during the engineering of a harvest unit; the area remains canopied by mature forest, and cannot be discerned as a landslide on aerial photography so it is noted as "field."
- *Size* is presented in square yards. Six landslides are of medium size (501-2000 square yards), 4 are large (2001-5000 square yards), and seven are very large (>5001 square yards) as defined in Appendix K (WFPB, 2011).
- The *Slope Shape* is noted as "Convergent," "Planar" or "Divergent."

- The *Gradient at Initiation Site (Field)* is a field-measured gradient, available for sixteen of the landslides; these are not measurements of the scarps, but rather an estimate of the hillslope gradient before failure, usually measured adjacent to the scarp.
- *Gradient at Initiation Site (10-m DEM)* is the gradient measured on a 10-m digital elevation model right at the initiation site; many of these values are much lower than the field-measured values and in many cases may be complicated by the adjacent road prism.
- *Land Use* categories in Appendix K (WFPB, 2011) are gravel pit or quarry, clear cut, mature timber, road, orphaned road, abandoned road, landing, agricultural road, agricultural and unstable slope buffer. Only four of these are used in Table K-1; others were not observed among the 18 landslides. The four are noted as "Mature Timber," "Orphaned Road," "Landing" or "Forest Road" which is equivalent to "Road" in Appendix K. The timber age is noted as 50+ (all mature timber is post-1951 Forks Fire era or older). If timber was recently harvested adjacent to the slide, then "Unstable Slopes Buffer" is noted in the same column.
- The *Type of Landform*, if a rule-identified potentially unstable slope, is noted; NA means not applicable because the failure did not initiate in a rule-identified landform.
- Where *Delivery* to a public resource or infrastructure occurred, the answer is "Yes" and the water type is noted. Delivery to a private forest road or the forest floor is "No" and the location of delivery is noted. One landslide had indeterminate delivery, even with field review.
- The *Comment* field is where possible triggers for the landslides are noted – the failures that occurred in mature timber appear to be triggered by natural conditions while road failures are attributed to sidecast or cutslope origins.

Some additional data such as latitude and longitude are provided in Appendix K-1. The eighteen additional landslides are presented on Map K-1 in dark blue and their event numbers are provided.

Table 1: Landslides Observed on 2003 Aerial Photos or 2009 or 2013 Ortho Photos (see Appendix K-1 for complete data including Lat-Long for these landslides).

Event No.	**Landslide Type**	**Certainty**	**Year First Observed**	**Size** (square yards)	**Slope Shape**	**Gradient at Initiation** (Field)	**Gradient at Initiation** (GIS – 10 m DEM)	**Land Use**	**Type of Landform**	**Delivered? Water Type or Location?**	**Comment** (Possible Trigger)
1532	Debris Slide	Definite	2003	828	Convergent		29%	Mature Timber; 50+	Outer Meander Bend	Yes; Type F	Natural
1533	Debris Flow	Definite	2003	14988	Convergent		38%	Orphaned Road (verified by Rayonier's East Clallam RMAP 2610100)	Inner Gorge	Yes; Type F	Stream Crossing or Sidecast Failure
1534	Debris Flow	Definite	2003	4022	Convergent	85%	66%	Mature Timber; 50+	Inner Gorge	Yes; Type F	Natural
1535	Debris Slide	Definite	2003	1035	Convergent	106%	53%	Mature Timber; 50+	Bedrock Hollow	No; Forest Floor	Natural
1536	Debris Flow	Definite	2003	6465	Convergent	90%	58%	Mature Timber; 50+	Bedrock Hollow	Yes; Type Np	Natural
1537	Rock Slide	Definite	2003	3270	Planar to Divergent	68%	49%	Mature Timber; 50+	NA	Yes; Type F	Natural
1538	Debris Slide	Definite	2003	824	Convergent	80%	73%	Mature Timber; 50+	Inner Gorge	Indeterminate; Type Ns	Natural
1539	Debris Flow	Definite	2009	5984	Convergent	84%	89%	Forest Road	Bedrock Hollow	Yes; Type F	Sidecast Failure

1540	Debris Flow	Definite	2009	25562	Convergent	95%	81%	Mature Timber; 50+	Bedrock Hollow	Yes; Type F	Natural
1541	Debris Flow	Definite	2009	4420	Convergent	90%	39%	Mature Timber; Unstable Slopes Buffer; 50+	Bedrock Hollow	Yes; Type Np	Natural
1542	Rock Slide	Definite	2013	1507	Convergent	83%	115%	Forest Road	Bedrock Hollow	Yes; Type Ns	Sidecast Failure
1543	Debris Slide	Definite	2003	574	Convergent	50% above; cutslope 100+%	39%	Forest Road	Inner Gorge	No; Private Forest Road	Cutslope Failure
1544	Debris Slide	Definite	2009	4169	Planar	70% top; 85% just below	62%	Forest Road	NA	No; Private Forest Road	Cutslope Failure
1545	SSDS	Definite	2013	8516	Convergent	100%	85%	Forest Road	Inner Gorge	Yes; Type Ns	Cutslope Failure
1546	Debris Flow	Definite	2013	5590	Planar to Divergent	100%	27%	Forest Road	NA	Yes; Type Np	Sidecast Failure
1547	Debris Flow	Definite	2009	1682	Convergent	70%	49%	Landing	NA	Yes; Type F	Logging Debris Failure
1548	Debris Flow	Definite	2009	5503	Convergent	80%	44%	Mature Timber; Unstable Slopes Buffer; 50+	Bedrock Hollow	Yes; Type F	Natural
1549	SSDS	Definite	Field	26732	Planar	65%	44%	Mature Timber; Unstable Slopes Buffer; 50+	NA	Yes; Type Np	Natural

Nine recent landslides initiated in mature timber of 50+ years-of-age without orphaned road or other forest practices influences (Event Nos. 1532, 1534-6, 1538, 1540-1, and 1548-9). Two of these occurred within unstable slopes buffers where adjacent timber harvest had occurred (Event Nos. 1541 and 1548). One small, sporadic deep-seated landslide pre-dates the adjacent harvest in approximately 2003 and was removed from the harvest unit (Event No. 1549). All nine occurred within MWMU.

One rock slide initiated in mature timber on a 60% convex hillslope that does not meet any of the MWMU descriptions (Event No. 1537). Several very large rocks dropped onto the C8000 Mainline in Township 29 North, Range 12 West, Section 15 and had to be removed. It was hypothesized by Rayonier personnel on site in the days following the event that adjacent timber harvest caused 60-year-old conifer trees to whip about during a windstorm, loosening the large rocks above the cutslope; this hypothesis cannot be substantiated, but no other obvious cause for the rock fall was noticed. Delivery of a few rocks to Devil's Creek may have occurred. This single occurrence does not mean that an additional MWMU is needed.

Seven landslides initiated from roads or landings. One debris flow initiated when an orphaned road stream crossing failed (Event No. 1533 – the landslide is correctly scaled onto the stream and does not appear on Map K-1 to have initiated from the stream crossing because the road is very poorly mapped). Two landslides are cutslope failures with limited or no delivery (Event No. 1543-4). Four landslides are recent fillslope failures that could have been avoided. The first is a rock slide which occurred because road construction across a steep ridge nose, where sidecast construction was allowed, produced much greater volumes than anticipated and caused a dry rock slide down the adjacent bedrock hollow with limited delivery to the lower channel (Event No. 1542). The second, a debris flow, occurred where sidecast was allowed on an 80-90% planar slope above an inner gorge because the presence of a full road prism appeared to mean that no sidecast would be necessary (Event No. 1546); this particular road contractor builds road to the full 18-feet wide specifications, an effort not actually expected at this site. The third fillslope failure is a debris flow that initiated in the fillslope where new sidecast construction across a bedrock hollow was allowed because delivery appeared to be precluded by the lower C8000 Mainline and by the approximately 100-feet wide terrace between the mainline and the mainstem (1539)."Delivery" consisted of a 1-2 feet wide stream of turbid water that reached the mainstem during the storm AFTER the one that initiated the failure, and then a settling pond was dug into the terrace to prevent further delivery. The fourth avoidable fillslope failure was a debris flow that initiated in perched landing debris (Event No. 1547) – it traveled down a swale that was not an inner gorge (i.e., <70%), but was capable of transporting a debris flow, and delivered into Devil's Creek.

Two landslides (Event Nos. 1545 and 1549) are small, sporadic deep-seated landslides. One, Event No. 1545, is coincident with a cutslope and an inner gorge. It is not known if the deep-seated landslide pre-dates the original road construction in the 1940's or if it was triggered by the recent construction. It is clear that the recent construction of the orphaned road re-initiated motion. The other, Event No. 1549, is a re-activated portion of a much larger relict deep-seated landslide; current activity pre-dates the most recent eras of harvest and road construction (approximately 2003). This landslide was previously discussed in the paragraph about failures that occurred in mature timber.

Table K-2: Landslide counts by Landslide Type

Landslide Type	Landslide Count
Debris Slide	83
Debris Flow	21
Shallow-Rapid	45
Rock Slide	6
SSDS	2
Other	3

Table K-2 presents landslide type by landslide count for all landslides initiating on non-federal lands in the North Fork Calawah WAU (i.e., the entire 60-year air photo inventory). Mass wasting processes are dominated by debris slides, debris flows and generically identified shallow-rapid landslides. Rock slides and small, sporadic deep-seated landslides are rare.

Table K-3 Landslide Counts by Land Use

Land Use	Landslide Count	Percentage
Clear Cut	58	37%
Mature Timber	28	17%
Inner Gorge Failure	5	3%
Cutslope Failure	7	4%
Fillslope Failure	55	34%
Stream Crossing	1	1%
Landing Failure	1	1%
Other	5	3%
Total	**160**	

Table K-3 presents landslide type by landslide count. Many landslides occurred in the barren landscape that existed for up to 30 years after the 1951 Forks Fire – these were identified as "wildfire" in the original landslide inventory (see Appendix K-1 where a column labeled "Original Land Use Designation" retains the 1997 data), but have been lumped into "clear cut" because they represent a landscape denuded of vegetation. The clear cut land use category is 37% of the landslides. "Storm disturbance" was used equivalently to "Mature Timber" in the original analysis and has been lumped into that category. The mature timber land use category is 17% of the landslides. Cutslope failures, fillslope failures, landing failures and stream crossing failures are 40% of the landslides (these values do not add up to 100% because of a couple of miscellaneous categories in Table K-3). It is well established that landslides occurring under mature canopy are underrepresented in landslide inventories conducted by aerial photography (e.g., Turner et al. 2008). That having been said, it appears that loss of rooting strength when entire unstable landforms are denuded of vegetation, such as occurred by clear cut harvest and/or wildfire in the 1950's, leads to increased rates of landslides. And as many other landslide inventories have demonstrated, poor road practices trigger a disproportionate number of landslides, including failures outside of the naturally occurring unstable landforms.

Table K-4: Landslide Counts by Landform or Slope Shape

Geomorphic	Landslide Count	Percentage
Bedrock Hollow	84	53%
Inner Gorge	7	4%
Outer Meander Bend	1	1%
Concave	16	10%
Convex	10	6%
Planar	37	23%
Other	5	3%
Total	**160**	

Table K-4 presents landslide counts by landform or slope shape. This is discussed further, below Table K-5 (Form K-4), and the MWMU descriptions are presented in an analysis of the relationship between landslide location and the MWMU (see below).

Table K-5: Form K-4 – Mass Wasting Reanalysis Summary Table

Activity or Land Use	**Process** Shallow/Rapid	Debris Slide	Debris Flow	SSDS	Rock Slide	Totals
Clear Cut	8	43	4	0	2	57
Partial Cut	0	0	0	0	0	0
Yarding Corridor	0	0	0	0	0	0
Mature Timber	11	3	9	1	2	26
Road	21	31	7	1	2	62
Unstable Slope Buffer	0	0	2	0	0	2
Stream Crossing	0	0	1	0	0	1
Orphaned Road	0	0	1	0	0	1
Abandoned Road	0	0	0	0	0	0
Landing	0	0	1	0	0	1
Gravel Pit or Quarry	0	0	0	0	0	0

Table K-5 is called Form K-4 in Module K. Slight modifications have been made to the example provided in Module K, including that deep-seated landslides are noted as "SSDS" for small, sporadic deep-seated landslides and the columns for debris avalanche and snow avalanche have been removed because none were observed on state and private lands in the North Fork Calawah WAU. All activity or land use classes related to forest practices and provided in Module K are included. "Yarding Corridors" which is of special concern in the WAU has been added. "Agricultural Road" and "Agriculture" have been removed because there is no agriculture except the 16-acre, privately owned, ranch in Twn 29 N, Rng 11 W, Section 7; it is not near any potentially unstable slopes and has not experienced any landslide initiations.

Table K-5 (Form K-4) highlights: 1) that shallow/rapid failures, debris slides and debris flows are the dominant failure mechanisms; 2) that clear cuts are a common forest practices trigger; 3) that yarding corridors, which represent minor and temporary loss of rooting strength, are not a trigger (this is discussed

in further detail in the Section titled "Testing the Prescriptions"); 4) that roads, like clear cuts, are a common forest practices trigger; and 5) that natural failures are a part of the landscape.

Mass Wasting Map Units

Mass wasting map units #1, #2, #3 and #4 are landforms identified in the forest practices rules as potentially unstable; it has become common practice among Forest & Fish stakeholders at both the CMER and TFW Policy levels to call these "rule-identified landforms," and although that expression is not actually used in the WAC it will used interchangeably with "potentially unstable slopes" in this report. The potentially unstable landforms are briefly defined in the forest practices rules in WAC 222-16, Definitions, and are more fully described in Section 16 of the Forest Practices Board Manual. Each MWMU is a naturally unstable landform, developed by a history of mass wasting, and each is sensitive to the forest practices of past decades such as loss of rooting strength due to clear cut harvest and the addition of excess soil and focused drainage from poor road building techniques. In addition to four rule-identified landforms (see Map K-2), small sporadic deep-seated landslides have been mapped as MWMU #5 and relict deep-seated landslides, originally mapped as GMU 71, have been labeled MWMU #6. As is discussed below in the Section titled Statement of Confidence, Map K-2 was developed from actual engineered harvest units where those have occurred and from detailed mapping from the post-fire 1953 black and white, stereo aerial photography (approximately 1:12,000) in conjunction with Rayonier's LiDAR data. (Note: The relict deep-seated landslides are not inventoried in Appendix K-1 because they are ancient features that are a landform today. They have been mapped as MWMU #6 for the sake of completeness, although they have not been observed to be sensitive to forest practices.)

<u>MWMU #1 – Rule-Identified Inner Gorges</u>

Inner gorges in the North Fork Calawah WAU are formed by two distinctly different erosional processes. Along low gradient, fish-bearing channels, such as Devil's Creek, the inner gorge edges are formed by fluvial undercutting and downcutting. The inner gorge surface is >70% and can exceed 100% in places. Where the bedrock is particularly competent, such as it is in the tributaries north of the lower mainstem North Fork Calawah River, these inner gorges may have lower sidewalls of exposed and nearly vertical bedrock. The larger of these inner gorges, such as Devil's Creek, were delineated as GMU 90 in the original watershed analysis; smaller ones such as the unnamed tributaries north of the lower mainstem and west of Devil's Creek were included in the planar hillslope GMU (Map A-2).

The second type of inner gorge is incised into the steep hillslopes in the watershed and carries high gradient streams, >20%, to the valley floor. These are formed by repeated debris flows and were called "debris flow tracks" in the original watershed analysis; the larger ones were delineated as GMU 78 and the rest were included in the planar hillslope GMU. Where channels within the debris flow tracks are larger, near the valley floor, or flow across debris fans and glacial terraces on the valley floor, fluvial processes play more of a role and there is a transitional zone between the two types of inner gorge. With rare exception, hillslope inner gorges have one to many bedrock hollows within their headwater drainage.

Side slopes of the inner gorge landform are experiencing active erosion. The side slopes of the inner gorges formed by fluvial undercutting experience debris slides and slumps. The side slopes of the inner

gorges formed by debris flows traveling down the channel are scoured, and then the oversteepened colluvium above the scoured edge may experience debris slides and slumps (which can evolve into debris flows). Both situations lead to the side slopes of the inner gorge landform being oversteepened and displaying historic failure scars. The top edge of the inner gorge is demarked by a break-in-slope created by the erosional activity on the side slopes of the inner gorge.

MWMU # 2 – Rule-Identified Bedrock Hollows

Bedrock hollows are steep (>70% along one or more of the axes), spoon-shaped or elongate areas of convergent topography, typically with concave profiles. Bedrock hollows are also called colluvium-filled bedrock hollows, zero-order basins, swales, bedrock depressions, or simply hollows (Crozier et al., 1990; Dietrich et al., 1987). These features can exist on any moderate to steep hillslope and may have developed within a larger landform such as a deep-seated landslide or a convergent headwall. Hollows seldom have a stream channel within the feature, although if a failure has occurred in the past few decades surficial water may be present. Hollows commonly drain directly into a channel head or laterally into a channel that started higher on the hillslope. In many locations, the channel the bedrock hollow drains towards lies within an inner gorge; these hillslope inner gorges were called debris flow tracks in the original watershed analysis. Colluvial debris accumulates in bedrock hollows, primarily by soil creep processes and weathering. The colluvium is prone to saturation during extreme rainfall events because shallow groundwater is also preferentially accumulating in the concave landform.

MWMU #3 – Rule-Identified Convergent Headwalls

Rule-identified convergent headwalls are steep (>70% and often much greater than 70%) teardrop-shaped landforms that are concave in both the vertical and horizontal planes. A convergent headwall is comprised of many bedrock hollow and hillslope inner gorges that converge into a single channel in a midslope position. Knife-edged ridges and broader convex surfaces may extend from the ridgetop above the convergent headwall, but are likely to be pinched out downslope by convergence. Some lower elevation headwalls, such as the large one delineated in Township 29 North, Range 11 West, Section 17, contain some broad, <70% ridges between the hollows and <70% swales between a hollow and its hillslope inner gorge. Higher elevation headwalls may have little slope area <90%. It is specifically the bedrock hollows and inner gorges that are unstable slopes and the convex, planar and lower gradient surfaces are stable, but where ridges are so narrow that both edges fall side hill into an adjacent hollow at 90+%, there may not be any stable areas.

MWMU #4 – Rule-Identified Outer Meander Bends

Rule-identified outer edges of meander bends occur where the North Fork Calawah River is experiencing channel migration that causes a meander bend to erode into a glacial terrace or the base of the hillslope for a period of years or decades (e.g., in the middle valley downstream of the confluence of the North Fork Calawah Headwaters and Pistol Creek) or where the North Fork Calawah River is somewhat entrenched and has relatively permanent outer meander bends with a slow rate of erosion (e.g., in the lower valley). These slopes are concave in the horizontal plane, often extend for several hundred feet along the river and then may re-develop of the other side of the river where the next meander occurs. They are rarely >30 feet high except for those rare locations where the CMZ is against the hillslope. These were not directly identified or discussed in the original watershed analysis because most are

protected within riparian buffers and the large ones also reasonably meet inner gorge definitions; they have been added here because they are now a rule-identified landform.

MWMU #5 – Small, Sporadic Deep-Seated Landslides

Two small, sporadic deep-seated landslides have been mapped as a MWMU. Both are active features and both failure planes appear to be planar (i.e., both are translational failures). They are 1-5 acres in size and are moving slowly downhill as one or more simple slump blocks. Both exist in fault gouge/breccia associated with the Calawah Thrust Fault (Tabor and Cady, 1978). One is a re-activated portion of a much larger relict deep-seated landslide; current activity pre-dates the most recent era of harvest and road construction. One was re-activated when road construction of a previously orphaned grade cut into the feature. Other, similar but smaller features that did not deliver and re-stabilized within 2 years are mapped as landslides on Map K-1 and were not added to the MWMU.

MWMU #6 – Relict Deep-Seated Landslides

These features vary from approximately 15 acres to approximately 200 acres in size. Typically, there is a distinct head scarp which may be a bedrock cliff but is more commonly a 50-70% slope that supports living trees, and has old growth stumps and soil including a humus layer. The latter indicate significant age. The side scarps are often less obvious, but where deep-seated landslides are adjacent to one another as they are on Bigler Mountain, discrete ridges may exist between features. In the broad perspective, these features are horizontally planar or concave and vertically convex, planar or concave. Locally, surfaces can be hummocky. Some features are formed of a few large blocks, creating benched topography. Marginal streams are often cut deeply into the hillslope (20-100 feet) and usually qualify as inner gorges as defined in MWMU #1; they may delineate the side scarps of the deep-seated landslides. Bedrock hollows (MWMU #2) are not common on the deep-seated landslides, but can occur.

MWMU Hazard Analysis

Following the Landslide Hazard Zonation Protocol, Table K-6 provides landform area and landslide count, then calculates a landslide frequency rate. Because the landslide frequency rate includes the total number of years covered by aerial photography (60 years, 1953-2013), these values are then comparable to results from other reanalyses and from Landslide Hazard Zonation projects. The values are calculated as landslide count divided by landform area divided by years and then multiplied by one million to produce a whole number. Values less than 100 are considered low; values between 100 and 199 are considered moderate; values between 200 and 999 are considered high (these designations were established from pre-existing results by the committee that wrote the Landslide Hazard Zonation Protocol).

The basic results of Table K-6 show us that MWMU #1, #2, #3 and #4, subject to shallow-rapid landslides, have high or very high hazard ratings. This is an unremarkable result from two perspectives: 1) All four MWMU are rule-identified landforms; and 2) The North Fork Calawah Watershed is known for having high landslide rates which prompted the USFS to fund detailed studies of sediment production and transport (e.g., O'Connor and Cundy, 1993). In fact, the watershed as a whole rates "moderate," a testimony to the prevalence of the MWMU and to their high landslide rates. MWMU #5 is not in Table

K-6 because the 2 landforms are landslides, causing the Landslide Frequency Rate to be a meaningless number. MWMU #6 has an overall low hazard rating; the five landslides used in the calculation also occurred within MWMU #1 and no delivering shallow-rapid landslides have been observed in MWMU #6 and not within MWMU #1.

Table K-6 provides two values for MWMU #1 and #2, one for those inner gorges and bedrock hollows outside of convergent headwalls and one for those features located inside convergent headwalls. This produces a particularly interesting result. Convergent headwalls as its own MWMU has a high hazard rating (730); this was noted in the original watershed analysis where a simplified hazard was calculated as landslides/area. However, the striking difference between the two bedrock hollow hazard ratings (370 outside of convergent headwalls and 1606 inside convergent headwalls) means that the high hazard rating of convergent headwalls does not just predicate on the high density of unstable landforms within them, but that the bedrock hollows within convergent headwalls are preferentially unstable, and to a lesser extent so are the inner gorges (220 outside versus 415 inside). A recent field traverse across 11 bedrock hollows in an un-roaded convergent headwall, performed to capture descriptions of bedrock hollows that are adjacent to proposed road construction, found that 8 had failed in the past several decades as evidenced by distinct scarp margins and a lack of old growth stumps in the center axes (Township 29 N, Range 12 W, Section 26 on the north-aspect). This is not a typical failure rate within bedrock hollows in other parts of the watershed not mapped as convergent headwalls where maybe none or only one of 11 bedrock hollows would show evidence of non-road-related historic failure (e.g., Township 29 N, Range 12 W, Section 28 on the south-aspect).

Table K-6: Landslide Area Rates for 60 years

Landforms	MWMU #1	MWMU #2	MWMU #3	MWMU #4	MWMU #6	WAU
Total Landform Area (acres)	1716.84	955.70	662.29	95.36	898.36	11,327 (non-federal)
Mapped within MWMU #3 (acres)	200.59	145.29	(the same)	NA	NA	
Landslide Count (initiation sites)	20 outside MWMU #3 5 inside MWMU #3	18 outside MWMU #3 14 inside MWMU #3	29	3	5	70
Landslide Frequency Rate (Landslide Count/landform area/years) x 10^6	Overall: 243; High Outside MWMU #3: 220; High Inside MWMU #3: 415; High	Overall: 558; High Outside MWMU #3: 370; High Inside MWMU #3: 1606; Very High	730; High	524; High	93; Low	124; Moderate

Testing the Prescriptions

Effects of Forest Practices on Slope Stability

The following paragraphs are italicized because they are quoted directly from Stewart et al. (2013); the author of this report is a co-author of Stewart et al. This material provides a brief overview of the effects forest practices are known to have on slope stability.

Landslides are a natural occurrence in western Washington but forest practices may alter both physical and biological factors that influence slope stability. The following is a brief summary of the most common forest management effects.

Hydrologic effects: The removal of forest canopy results in increased soil moisture because of reductions in both canopy interception and evapotranspiration (Lewis et al., 2001; Johnson et al., 2007). During storm events, evapotranspiration is generally small compared to the rate of precipitation and canopy saturation can occur, but forest cover can still affect landslide occurrence by smoothing the transfer of water to the soil which in turn modulates peak pore pressures (Keim and Skaugset, 2003). The removal of canopy simultaneously enhances snow accumulation and melt which can increase peak soil moisture (Coffin and Harr, 1992; Marks et al., 1998) and result in greater landslide occurrence.

Loss of root strength: Tree roots are believed to contribute significantly to slope stability. When soils are at or near the angle of repose, root systems serve to reinforce soil strength and provide resistance to gravitational forces that tend to pull soil masses downhill (Riestenberg and Sovonick-Dunford,1983; Schmidt et al., 2001). Timber harvest reduces root reinforcement during the period when harvested timber root systems are decaying and new root systems are expanding (Ziemer, 1981; Sidle and Ochiai, 2006). Total root strength is believed to be at a minimum between approximately 4 and 10 years after timber harvest (Sidle, 1991; Sidle 1992; Schmidt et al., 2001). Simulation studies illustrate that vegetation leave areas can significantly reduce landslide volumes by retaining available root strength in areas prone to failure (Sidle and Ochiai, 2006).

Road construction: Landslide inventories in the Pacific Northwest have established that roads in steep terrain have historically been responsible for a high proportion of landslides in managed forests (Robison et al., 1999). Poor construction techniques and inadequate drainage are believed to be the main causes (Furniss et al., 1991). Landslides associated with forest roads often initiate from sidecast road fill material perched on steep slopes. Road failures can occur when stream crossing or drainage culverts become plugged and excessive runoff is concentrated on unstable slopes. The use of uncompacted fill and the inclusion of organic material (logs) in road fill have also been found to contribute to slope failures (Sidle and Ochiai, 2006). Modern road building techniques include 1) the construction of steeper grades which reduces road mileage and 2) the complete removal of excavated material to lower gradient waste areas. These techniques have significantly reduced road landslide frequency (Sessions et al., 1987), but hydrologic alteration remains difficult to avoid (Montgomery, 1994; Borga et al., 2004).

General Prescriptions

Mass Wasting prescriptions written for watershed analyses were designed to minimize or prevent and avoid the effects of forest practices on landslide rates. Some prescriptions addressed situations directly observed during the watershed assessment and others addressed triggering mechanisms more broadly understood from the literature. At the simplistic level, mass wasting prescriptions have meant NOT doing activities that are known or thought to trigger landslides. For example, sidecast construction has led to

high landslide rates from road fillslopes, so building full-bench roads and endhauling the excess fill to stable locations should limit landslide initiations from new road construction.

Testing the efficacy of modern measures intended to reduce mass wasting triggered by forest practices, including watershed analysis prescriptions and Washington Forest Practices Rules, against an earlier era of forest practices which were conducted without concern of triggering landslides has proven to be confounded by numerous influences. Known influences include differences in stand age as it influences both rooting strength and aerial photo detectability of landslides, storm history which varies decade to decade, storm intensity across the geographic extent of a single storm, and land use history.

Two major field-based studies have been conducted immediately post-storm. Robinson et al. (1999) studied areas of intense precipitation in the Oregon Cascades following a major storm in 1996. They saw significant differences in landslide rates between different stand age categories – not a surprising result, but the first large-scale result not influenced by issues of air photo detectability. And they saw fewer and smaller landslide initiations from midslope roads that had been remediated for mass wasting potential (i.e., sidecast had been removed). However, Robinson et al. (1999) did not control for any of the factors except aerial photo detectability of landslides. Stewart et al. (2013) specifically studied the effectiveness of leaving buffers on unstable slopes – their results suggest that buffers are effective at limiting landslides, but the statistical power of the results were confounded by the influence of stand age as it related to rule-implementation age. They also documented a positive response from mass wasting remediation on roads (Stewart et al. 2013).

North Fork Calawah Watershed Analysis Mass Wasting Prescriptions

Four mass wasting hazard prescriptions were written for the North Fork Calawah Watershed Analysis (1997). Mass Wasting Hazard #1 Prescription for GMU 77, convergent headwalls now identified as MWMU #3, were vague and largely relied on field-review and recommendations from geotechnical personnel. Actual implementation within the convergent headwalls has closely mimicked the prescriptions written for the GMU on more planar hillslopes with individual bedrock hollows and inner gorges because those were more specific (discussed below). Mass Wasting Hazard #2 Prescription for GMU 90, large inner gorges, had some harvest prescriptions (e.g., no harvest for smaller features and no harvest on the lower 200 feet with geotechnical recommendations above there for larger features) and very specifically stated that no road construction was allowed but an inner gorge could be spanned by a bridge.

Mass Wasting Hazard #3 and #4 Prescription and Mass Wasting Hazard #4 Prescription covered the broadly planar GMU and GMU 71 – relict deep-seated landslides – where bedrock hollows and inner gorges are present. Many of the individual elements of the prescriptions applied only to bedrock hollows and inner gorges within the broader GMU, and there was no specific prescription written for GMU 71 because no sensitivity to forest practices was noted except as it applied to the smaller landforms within the relict deep-seated landslides. The two prescriptions, which applied to the majority of the North Fork Calawah WAU on state and private lands, were nearly identical but applied individually to those areas of *Prevent & Avoid* versus those areas of *Minimize* for the Rule Calls developed by the WA. These prescriptions are the ones that have been, to a greater or lesser degree as described below, applied to unstable slopes in the North Fork Calawah WAU. (Note: "Reconstruction" is no longer an activity

recognized by Forest Practices, but the activity was recognized as a distinct activity at the time the prescriptions described below were written.)

The Mass Wasting Hazard #3 and #4 (and just #4) Prescriptions for road construction and reconstruction had several elements - these are quoted below:

> *Road construction across GMU 78 and bedrock hollows (Mass Wasting Hazard # 3 and #4) should be avoided where reasonable alternatives exist (e.g., building on ridgetop). If the construction of a ridgetop road is not possible, the next best alternative is to place the road above the heads of bedrock hollows.* (Note: This prescription was not included in Mass Wasting Hazard #4 Prescription.)
>
> *Culverts in channels within Mass Wasting Hazard #3 and #4 shall be no smaller than 36-inch metal or 24-inch smooth plastic. All culverts within Mass Wasting Hazard #3 and #4 shall be placed on no less than 5 percent gradient.*
>
> *All roads in GMU 36, 52, 53, 54, and 71 where the hazard is moderate shall be full-bench roads wherever slopes are greater than 55 percent.*
>
> *Landings must be constructed in GMU 36, 52, 53, 54, and 71 where the hazard is moderate to avoid placement in Mass Wasting Hazard #3 and #4.* (This means avoiding the bedrock hollows and debris flow tracks.)
>
> *Excess rock and soil shall be end-hauled out of GMU 36, 52, 53, 54, and 71 where the hazard is moderate or, upon geotechnical advice, may be deposited on a large convex surface within these GMU if delivery to fish-bearing waters by mass wasting or surface erosion processes is unlikely to occur.*
>
> *If blasting is required for landings or construction of roads and landings, blast materials which roll or fall over the hillslope should not be left in Mass Wasting Hazard #3 and #4 if they can be safely removed.*
>
> *As much ditchline as possible should be cross-drained onto convex landforms within GMU 36, 52, 53, 54, and 71 where the hazard is moderate, and frequent cross-drains (300 to 400 ft) to disperse the water should be used. In places, outsloped roads may aid water control.*

Although not explicit in the prescriptions, the watershed analysis synthesis team emphasized the reconstruction of old roads as an alternative preferable to the construction of new road prisms.

The Mass Wasting Hazard #3 and #4 (and just #4) Prescriptions for harvest had several elements - these are quoted below:

> *Wherever roads cross Mass Wasting Hazard #3 and #4, no harvest of these mass wasting hazard units shall be done if a landslide triggered in the bedrock hollow or debris track is likely to deliver to a fish-bearing stream. In these cases, sufficient root strength (i.e., one to two tree widths) shall be left to protect the slope breakout of debris track portions of the Mass Wasting Hazard Units.*(Note: This prescription was not included in Mass Wasting Hazard #4.)

Where practicable, pre-existing downed wood should be left in place in Mass Wasting Hazard #3 and #4. In the event of salvage operations after a major blowdown event, some fresh downed wood should be left in place (25 percent or value recommended by geotechnical personnel).

Selective harvest, not to exceed 50 percent of the total stems, within Mass Wasting Hazard #3 and #4 may be possible if sufficient root strength is maintained. The geotechnical report must mathematically substantiate that the factor of safety will not fall below 1 as a result of this selective harvest. (Note: Mass Wasting Hazard Prescription #4 for *Minimize* allowed 50% removal without mathematical efforts.)

Additional harvest or alternative harvest plans considered experimental may be possible in Mass Wasting Hazard #3 and #4 under review and total consensus of a team consisting of representatives from the Landowner, DNR, WDFW, DOE, and affected tribes. The team will determine the nature of harvest, the nature and acceptability of risk (i.e., delivery and routing) and a monitoring plan.

Actual Implementation of North Fork Calawah Prescriptions

The North Fork Calawah Watershed Analysis was approved in 1997. Between the approval and the 9 October 2014 draft of this report, 83 forest practices permits have been approved in the WAU. Eight were submitted by Green Crow; 75 were submitted by Rayonier. A data summary pertinent to the implementation of the North Fork Calawah Prescriptions is provided in Appendix K-3, and information derived from that data is provided in this section.

Since 1997, most FPA within the North Fork Calawah have had geotechnical review by both a landowner geologist and a WADNR geologist to confirm that the unstable landforms were identified and appropriately buffered or protected from inappropriate road building techniques. FPA that did not receive geotechnical review were those few that proposed to harvest terrace surfaces. The author has field reviewed most of Rayonier's FPA across all seventeen years; since 2005, some harvest unit FPA have been reviewed by geotechnical consultants to the author. And almost all FPA were subsequently field reviewed by the WADNR Forest Practices Forester and the WADNR Geologist. Fifty-five FPA were approved as Class III applications following the North Fork Calawah Prescriptions. In later years, where significant deviations from the Prescriptions were necessary and then starting in 2008 when the Prescriptions were deemed "non-specific," 27 FPA have been approved as Class IV-S applications. Specific FPA with geotechnical letters or reports are referenced below to provide evidence that prescriptions have been followed or modified as described.

Road Prescriptions

With three frequent deviations, the road prescriptions in Mass Wasting Hazard #3 and #4 Prescription have been consistently followed.

- Midslope construction has been limited to those locations where it is necessary to reach ridgetop or to access timber that cannot be yarded to a high ridgetop. In some areas, multiple road locations have been designed to best limit the crossing of unstable slopes and road gradients have been adjusted to place a road higher, above one or more bedrock hollows (e.g., FPA 2609930).

- During the analysis of multiple road location alternatives, it has been common to identify both environmental and financial advantages to constructing the orphaned road prisms where they exist rather than constructing new roads (e.g., FPA 2609256, 2610681). This practice, with sidecast pullback of unstable fill and careful water management, reduces existing mass wasting potential of these old roads.

- Culverts in channels are always 24-inch double-wall plastic or 36-inch metal pipes (or bigger). It has become usual practice to require a minimum of a 10% gradient and many culverts are installed on stream gradient (often much steeper than 10%) without a flume (e.g., FPA 2609256 and 2610681).

- Roads are full-benched by requiring no sidecast or by requiring sidecast pullback for reconstructions wherever the roads cross bedrock hollows and inner gorges (e.g., FPA 2609256, 2610681, 2611196 and 2612023). In fact, lengths of road where sidecast was not permitted have been identified in 39 FPA (see Appendix K-3); another 19 FPA that proposed road construction did not require lengths of no sidecast because road construction occurred on terraces or ridges. Fifteen of the 39 FPA included construction on existing orphaned roads and also had lengths designated for sidecast pullback. When not in an unstable landform, hillslope shape, gradient and distance to an unstable slope are considered when deciding where full-benched construction is necessary outside of the unstable landforms. This means that sidecast has occurred within the hillslope GMU on slopes greater than 55%, but these locations have been carefully selected as appropriate (e.g., 2612023). This is the first consistent deviation from the prescriptions.

- Landings are, as a matter of practicality, always placed on ridgetops or ridge noses and are never built within the unstable landforms (e.g., FPA 2610614, 2611690, 2612345 and 2613018). Landing maintenance after logging has become common practice in the WAU, in recognition of the landslide potential of perched landing debris. The maintenance indirectly stems from WAC 222-24-035 Landing location and construction which requires that landings be located to prevent potential or actual damage to public resources and that excess filling be avoided.

- Excess sidecast has been hauled to the valley floor or placed within the GMU but outside of the unstable landforms upon geotechnical advice (e.g., FPA 2609256 and 2611981). In one particular deviation from this prescription, the WADNR disapproved the placement of a designed waste area within a bedrock hollow (the approved FPA without the waste area was 2611981).

- Blast materials that leave the road prism and roll or fall down the hill cannot be reached, so this particular prescription lacks practical reality (e.g., FPA 2611981). However, smaller, more controlled blasting efforts could better limit this occurrence and avoid the problem of not being able to reach the material. This is the second consistent deviation.

- Cross-drain culverts are drained onto convex surfaces wherever possible, and have been spaced so that each only receives 200-300 feet of ditch water. Where deviations to this prescription occur, it is because there are low grade breaks on orphaned roads where new construction is occurring (e.g., FPA 2611228). Many geotechnical reports have explained that a few cross-drain

culverts must be placed in an unstable landform and that the best mitigation is to place another cross-drain nearby so that the water reaching the unstable landform is very limited (e.g., FPA 2612023). It has also become general practice to add either flumes or energy dissipaters to all cross-drain culverts draining onto hillslope that exceeds 40%. Forty-two of the FPA listed in Appendix K-3 had careful placement of cross-drain culverts to avoid focusing excessive water towards an unstable slope; the other FPA proposed road construction on ridgetop or on terrace surfaces where cross-drain culverts were not needed or were harvest-only FPA. (Note: The number of FPA with carefully placed cross-drains is higher than the number of FPA with no sidecast lengths because of the reconstruction of railroad grades on terraces but near the outer meander bend landform.) Outslope road construction has not been used more than once (e.g., FPA 2605903) and has generally been deemed to be unsafe in steep ground.

To provide a specific example of the efforts made to meet the aforementioned road prescriptions, here is summary of the construction of the previously orphaned 8500 Road within the Fahnestock Sub-basin. The first phase of road construction up the Fahnestock Valley (FPA 2609256) began at Station 19+00 and ended at Station 96+50 (Fahnestock Bridge). The road was broken into 29 segments. Thirteen segments, 2255 feet, received sidecast pullback. Nine segments, 4140 feet, were designated no sidecast. Seven segments, 1355 feet, were designated as okay to sidecast. Twenty-one cross-drain culverts were required, and thirteen stream-crossing culverts ranging from 24-inch to 72-inch were installed. The larger stream-crossing culverts were necessary to accommodate heavy sediment transport from midslope debris fans. The second phase of road construction (FPA 2610681) saw the installation of the Fahnestock Bridge and road construction from Station 96+50 to Station 178+75 (intersection with the 8530 Road). The road was broken into forty-five segments. Thirteen segments, 2650 feet, received sidecast pullback. Eighteen segments, 3350 feet, were designated no sidecast. Fourteen segments, 2175 feet, were designated as okay to sidecast. (There is a 50-feet discrepancy in the total feet versus total stations because of the length of the bridge itself.) Sixteen cross-drain culverts were designed, and 15 stream-crossing culverts ranging from 24-inch to 72-inch were installed. In summary, for 2.74 miles of road construction of the previously orphaned road, pullback was done on 34%, no sidecast was required on an additional 52% of the length and sidecast was only allowed on 14% of the total length. A total of 65 pipes were installed, with an average drainage length of 246 feet.

Harvest Prescriptions

The basic harvest prescription in Mass Wasting Hazard #3 and #4 Prescription, to identify and avoid all bedrock hollows and inner gorges has been consistently applied across the North Fork Calawah with limited deviation (see black outlined unstable slopes in Map K-2 to understand the extent of buffering). 1) A few landforms have been accidently missed – see the southeast corner of Section 14 of Township 29 N, Range 12 Won Map K-2 for a bedrock hollow outlined in red but attached to landforms outlined in black. 2) Just to the west, there is an isolated bedrock hollow outlined in red – this feature and several others on Map K-2 are unstable landforms that do not deliver to the channel network (this deviation has always been allowed under the prescriptions and under standard Forest Practices). 3) Where necessary, trees have been cut for yarding corridors (27 FPA are listed in Appendix K-3) and occasionally guyline circles on otherwise buffered unstable slopes (5 FPA are listed in Appendix K-3). Where this occurred, felled trees in the yarding corridors are left as downed wood (e.g., FPA 2610614, 2612861) and a row of felled trees are left at the bottom of the guyline circles (e.g., FPA 2610614). In addition to meeting the downed wood

requirements in the prescription, these felled trees have been mitigation by the argument that they may limit surface erosion and landslide initiation. 4) Where the uppermost portion of a bedrock hollow lies above a road, the 2-3 lines of trees in the bedrock hollow have been harvested on the argument that they are likely to blow over, bury the road and may create a hazard (6 FPA are listed in Appendix K-3). The thinning prescription and the opportunity for alternative plans have not been utilized.

Prescription Performance

Approximately one-half of the state and private land in the North Fork Calawah WAU has been roaded and harvested since the 1997 watershed analysis. Except for specific deviations, described above, the Mass Wasting Hazard #3 and #4 (or just #4) Prescription was applied to the hillslopes in the WAU, including within the convergent headwalls where Mass Wasting Hazard #1 Prescription was applicable but was too vague to be useful. Using 3 additional photo years (2003 stereo and 2009 and 2013 ortho photos), plus field observations by both Rayonier personnel and WADNR staff, eighteen landslides have been added to the original landslide inventory developed from several photo years between 1951 and 1997. Compared with the number of landslides observed in response to the first era of harvest and road construction, and the 1951 Forks Fire (143), these eighteen new landslides represent a limited landscape response to this era of harvest and road building in comparison to the occurrence of landslides during and after the previous history of forest practices and fire, and particularly from the viewpoint that nine of the eighteen landslides occurred in mature timber.

As detailed above, nine of the landslides occurred in mature timber and within MWMU. Two were cutslope failures with limited or no delivery. Four were fillslope failures that could have been avoided by not placing sidecast and/or logging debris in or near an unstable landform; three of these were a compliance problem not a design deficiency. The remaining four landslides were the orphaned road stream-crossing failure, the rock slide on a convex surface, the SSDS landslide that pre-dates the 2003 harvest (Event No. 1549) and the SSDS landslide affiliated with the road cutslope.

Approximately ½ of the private and state ownership in the North Fork Calawah WAU has been harvested in the past 17 years and 2 of the 9 landslides in mature timber occurred within unstable slopes buffers where adjacent harvest had occurred. IF buffers were not effective at preventing effects from adjacent harvest, then the proportion of "in buffer" landslides should be >50% of the total failures in mature timber. From this, we can infer that the avoidance of unstable slopes during harvest unit design is an effective prescription.

None of the 9 mature timber failures are associated with yarding corridors, suggesting that limited tree cutting that retains downed wood is not affecting the overall stability of the buffered areas. The geotechnical reports attached to numerous FPA have stated that the cutting of individual tress within the proposed yarding corridors is unlikely to have any significant effect on overall slope stability because only a small proportion of trees are being felled in each landform. These reports further state that the stands of remaining trees around the yarding corridors will provide significant lateral root reinforcement across the potentially unstable slope (e.g., 2613018, 2613057). Gray and Megahan (1981), Schmidt et al. (2001) and Roering et al. (2003) are referenced to support these statements. In addition, the yarding corridors have been consistently limited to 30-feet or less, only those trees that need to be cut for logger safety or equipment operation are cut, these are felled sideslope with the landform to limit landslide initiation and surface erosion, and techniques such as mid-span supports and elevated tail holds are

required as necessary to achieve full suspension. These measures are included in the new Prescriptions. Several FPA that are greater than or equal to 10 years of age included yarding corridors; these very limited harvests have been tested through the lowest point of rooting strength and have not caused landslides.

None of the eighteen landslides are associated with harvested MWMU within guyline circles or with the uppermost portions of bedrock hollows that have been harvested above cutslopes. The harvest within guyline circles has occurred below rock knobs in the uppermost portions of bedrock hollows that remain quite rocky with thin (<1 foot deep) soils (e.g., FPA 2611207). The harvest within bedrock hollows above cutslopes has only occurred when the buffer would be 2-3 tree widths in the uppermost part of a bedrock hollow and when it seems likely that IF the hollow failed, that the road could capture the material. It may be that both of these deviations from complete buffering of bedrock hollows is not causing landslides because the uppermost portion of a bedrock hollow has lower failure potential than the lower center where water and soil are preferentially concentrated and where initiations are observed. However, it must be noted that these harvests of guyline circles and the uppermost portions of bedrock hollows did not occur before 2004 and were rare before 2009, so these harvests have not yet been tested through the lowest point of rooting strength loss. Justification for the harvest of 2-3 tree widths of a bedrock hollow above a cutslope is supported by the scientific literature on the grounds that roads do stop as many as one-half of the upslope debris flows that reach them and limit the volume of some of the debris flows that cross them (Guthrie et al., 2010). It stands to reason that roads are most likely to stop small volume events, such as a failure that has initiated a short distance up the slope, although Guthrie et al. did not make this observation.

Many of the relict deep-seated landslides, now mapped as MWMU #6, have been field reviewed and harvested. Field review verifies that they are truly relict, and responses to forest practices have not been observed (e.g., FPA 2605306, 2605322, 2605460, 2606353, 2608023, 2609015, 2609018 and 2611237).

No stream crossings have failed, suggesting that larger culverts on 10% gradient or greater, or on stream gradient, are working properly and not plugging. However, it is no longer necessary to increase pipe sizes above those required by current forest practices rules because modern pipe sizing in Washington State has been tested by a large storm in the eastern Willapa Hills and found to work well (Stewart et al., 2013).

None of the fillslope failures that have occurred have had a visually obvious water trigger such as a plugged cross-drain culvert that led to water flowing down the road and onto a fillslope that then failed, suggesting that the close spacing of cross-drain culverts is effectively dispersing ditch water. The necessity in road construction spatially coincident to orphaned roads to place cross-drain culverts within the MWMU, coupled with a close cross-drain culvert that limits drainage to that first pipe, has not triggered water-related fillslope failures. A consistent cross-drain spacing such that no cross-drain receives greater than 300 feet of ditch water has proven effective in the North Fork Calawah WAU.

Where sidecast pullback has been done or no sidecast allowed during initial construction, no failures have occurred. Where sidecast has been inappropriately placed because the volume was not correctly understood, because delivery was believed to be impossible or because logging debris was excessive and was not subsequently cleared, fillslope failures have occurred. This re-enforces the importance of not sidecasting within the MWMU.

The new prescriptions should reflect the original prescriptions as they have been practically applied, with some limited but specific deviations and additions, for the past 17 years.

Prescription Comparison with Standard Forest Practices

The prescriptions being proposed are prescriptions from the original watershed analysis or are deviations that have been commonly to occasionally practiced in the North Fork Calawah WAU. Some are identical to today's standard forest practices, but they were developed four years earlier than the current standards and, in fact, helped inform the development of current rules. Some allow limited harvest on unstable landforms, an activity not permitted by standard forest practices without going through state environmental policy act (SEPA) review. However, this reanalysis will be submitted for SEPA review as a non-project and the mitigations for limited harvest which are specifically crafted into the prescriptions and are not standardized in current forest practices rules or within the SEPA review will be considered in the process. Other prescriptions remain above and beyond standard forest practices. These comparisons are described below.

Identical to current forest practices rules and associated best management practices (e.g., WFPB, 2013) are the prescriptions calling for no harvest on MWMU #1-#4 (WAC 222-10-030 which causes identification of the same landforms and encourages avoidance), the prescription that forbids sidecast to be placed within MWMU #1-#4 (WAC 222-24-020 (8)), the prescription that uses current rules to size stream-crossing pipes (WAC 222-24-042) and the best management practices that require the stream-crossing fills to be built of clean soil and rock in compacted lifts or of keyed rock.

Limited harvest of MWMU #1-#4 for yarding corridors and road construction is only permitted under current forest practices rules when a geotechnical report is written and the FPA is submitted as a Class IV-S for SEPA review (WAC 222-10-030). Thus, it appears that the prescriptions are providing less protection than current forest practices rules. However, specific mitigations for these activities have been developed for the North Fork Calawah WAU -these are more specific then current forest practices and appear to be successful at limiting or preventing landslides. This is particularly true of harvest within the yarding corridors and for basic road construction which have be utilized for 15 years and do not display a signature of landslide occurrence related to loss of rooting strength. Portions of MWMU #2 harvested above cutslopes have not failed, but the test of these limited harvests spans fewer years and fewer sites and cannot be considered as solid of a result.

The emphasis placed on construction of existing orphaned road prisms as the preferred alternative over construction of entirely new roads leads to mitigation of a road category not addressed by current forest practices. Cross-drain spacing of 300 feet or less in a well-drained soil is closer than the spacing that would be calculated by the formula in Section 3 of the Board Manual (WFPB, 2013). Stream-crossing culverts placed on 20% gradient or stream gradient is more specific than standard forest practices. These prescriptions provide more protection than standard forest practices.

Collectively, the prescriptions practiced in the North Fork Calawah WAU have proven effective at preventing landslides related to forest practices activities. The prescriptions are nuanced to the watershed conditions and to the logging conditions, and mitigations are built into the prescriptions. The original prescriptions were deemed "non-specific" in 2008 because they required further geotechnical review to implement them. The proposed prescriptions are primarily based on the original prescriptions with

additional mitigations that have been commonly practiced and that the reanalysis process has found to be effective.

The new prescriptions for MWMU #5 and #6 default to standard forest practices because specific prescriptions for deep-seated landslides were not written for the original watershed analysis.

Critical Questions and Summary

1) Are there any newly identified areas of the landscape that are susceptible to high landslide frequencies?

No, all areas of the landscape susceptible to high landslide frequencies were displayed in appropriate GMU on Map A-2 in the original WA.

However, MWMU have now been established for this watershed. Geomorphic map units, a Federal system of mapping broad hillslope and valley areas into categories that reflected both mass wasting and surface erosion hazards, were originally mapped for this WA. Within the steep hillslope GMU, the mass wasting hazard was identified as bedrock hollows and inner gorges and not the convex and planar portions of the hillslope. These two unstable landforms were clearly described in the original WA; now they are individually mapped on Map K-2. Convergent headwalls were mapped as a distinct GMU and are now a MWMU. Outer edges of meander bends is a new MWMU not described as an unstable landform in the original WA, but they are largely contained within Type F riparian buffers so they were not missed by the WA but rather purposely ignored because of adequate protection through another forest practices rule. Small, sporadic deep-seated landslides are a newly identified MWMU – the two that are mapped have been found in the field, they are very small and delivery to the channels within them has occurred at a slow rate across decades of time – likely comparable to the delivery of soil creep along the margins of channels. Relict deep-seated landslides were a delineated GMU in the original WA, but they were not considered an unstable slope except as they may contain bedrock hollows and inner gorges, and extensive FPA review in the years since has not detected issues of instability within the bodies of these features. Nevertheless, they have been identified as MWMU #6 as a precautionary measure.

2) What is the distribution of new landslides throughout the landscape and are they found in existing MWMU, the rule-identified landforms or in new locations within the watershed?

Eighteen new landslides have been identified from the 2003 aerial photography and the 2009 and 2013 ortho photography and from field observations. Sixteen occurred in the newly delineated MWMU, four of which are also rule-identified landforms, and the unstable slopes were described as occurring within the GMU by the original watershed analysis. One occurred on a 60% convex hillslope – a rock slide that may have been triggered by wind stress on mature timber after an adjacent hillslope was clear cut harvested. One was a fillslope failure on an 80% planar to divergent slope above an inner gorge, not a naturally unstable slope, and another was a landing fillslope failure in a swale that did not meet inner gorge definition (i.e., >70%); both were poor locations to place sidecast.

3) Are forest management activities associated with landslide activity?

Nine landslides occurred in mature timber, two of those in unstable slope buffers with recent, adjacent timber harvest. One of the nine is a SSDS landslide that pre-dates the adjacent harvest in approximately 2003 and was removed from the harvest unit. A tenth one occurred above a cutslope and near a recent harvest. Only the last one appears to have been associated with a forest practice, and that not a direct association. One landslide is a stream-crossing failure from an orphaned road. Three landslides are fillslope failures from the placement of sidecast during construction. And one landslide is a fillslope landing failure caused by the placement of logging debris at the top of a concave headwater area. Three landslides are cutslope failures, one associated with a pre-existing SSDS that was re-activated; these had limited or no delivery. The four fillslope failures caused by the placement of sidecast or logging debris on or above unstable slopes are the "associated" landslides that could have been prevented by better compliance of road construction and logging operations.

4) Can a determination be provided to analyze those slopes for which prescriptions were followed but the slopes failed compared with those slopes that were covered under the same prescriptions but did not fail?

No. There are too few new landslides and, where prescriptions were applied, landslides did not happen except for two failures that occurred within unstable slopes buffers and a pre-existing SSDS landslide that was protected in an unstable slopes buffer (an expected and unexceptional result in a watershed with naturally high landslide rates).

5) Have the prescriptions been properly implemented?

A. Review a random subset of at least ten-year-old FPA using aerial photos and, if possible, field review to evaluate and verify the efficacy of potentially unstable landform buffers. A complete landslide inventory from 2003 aerial photography, 2009 and 2013 ortho photography and field-observed events has been done. For the entire portion of the WAU harvested in the past 15 years, only two non-SSDS landslides have occurred in unstable slopes buffers after numerous harvest units have been logged over the last 15 years. Thirty-six FPA are at least 10 years old – these are listed in Appendix K-3 as those FPA approved in 1999-2004 inclusive. Twenty-nine of the 36 FPA were harvest unit or harvest unit plus road construction FPA; seven were exclusively road construction FPA. All these have been periodically field reviewed in the years since harvest as other, adjacent FPA have been engineered. A final review of all 36 was conducted by doing a second examination of the NAIP 2013 ortho photography to confirm that additional landslides were not missed during the field reviews and the landslide inventory completed for this reanalysis. (Note: All FPA of at least 10-years-old or greater were reviewed rather than a random subset.) It was confirmed that only previously identified landslides were present – these are Event Nos. 1537, 1539, 1541, 1543, 1547, 1548 and 1549. Of these, three were road- or landing-related failures (Event Nos. 1537, 1539 and 1547), one is a SSDS that pre-dates FPA 2604676 and was protected when Block 29.466 was engineered (Event No. 1549), and two occurred within unstable slope buffers (Event No. 1541 and 1548). The small number of failures within unstable slope buffers in the context of the extensive harvest that has occurred on state and private ownership in the WAU suggests that buffers are effective at preventing landslides on the naturally unstable slopes within the watershed.

B. Conduct an aerial photo, LiDAR, and if necessary, field review to determine if potentially unstable slopes in MWMU were identified. In 1997 when the WA was completed, the non-federal land in the WAU was in post-fire timber of 40+ years of age. Since 1997, FPA within the North Fork Calawah WAU except those on terrace surfaces have had geotechnical review to confirm that the unstable landforms

were identified and appropriately avoided or protected from inappropriate road building techniques. The author has field reviewed most FPA across all seventeen years; since 2005, some harvest unit FPA have been reviewed by geotechnical consultants to the author. And almost all FPA were subsequently field reviewed by the WADNR Forest Practices Forester and the WADNR Geologist. With rare accidental omission, all potentially unstable slopes have been identified. This conclusion is confirmed by the aerial photo and LiDAR review conducted to map individual MWMU on Map K-2.

C. Compare landslide locations to areas of buffered MWMU.

A total of 88 delivering landslides were investigated for their relationship to the MWMU layer. Seventy-two percent, 70 landslides, initiated within a MWMU. Of the remaining 18 delivering landslides, 16 were fillslope or cutslope failures which do not always occur within a MWMU, and two were rock slides. None of these occurrences suggest that an additional MWMU is needed.

D. Determine land use associations for landslides that occurred outside of MWMU.

Only three new landslides occurred outside of MWMU. The rock slide above the cutslope of the C8000, which is hypothesized as being triggered by wind stress from the mature trees after adjacent areas were clear cut harvested, is a unique event on a convex hillslope where slope failure is not likely. A fillslope failure occurred on a steep planar slope above an inner gorge. A fillslope landing failure occurred in a concave headwater area that was <70% - this site needed to have been burned or pulled back after logging. The latter two landslides are representative of the predictable, road-related failures that occur outside of naturally unstable landforms. None of these failures warrants an additional MWMU.

6) How does the distribution of new landslides compare to the distribution of landslides at the time the WA was approved and are the new landslides on existing MWMU or not?

The spatial distribution of new landslides is similar to the distribution observed in the original watershed analysis.

Eighteen new landslides have been identified. Fifteen occurred in the newly delineated MWMU, four of which are also rule-identified landforms, and the unstable slopes were described as occurring within the GMU by the original watershed analysis. One occurred on a 60% convex hillslope – a rock slide that may have been triggered by wind stress on mature timber after an adjacent hillslope was clear cut harvested. One was a fillslope failure on an 80% planar to divergent slope above an inner gorge, not a naturally unstable slope, and another was a landing fillslope failure in a swale that did not meet inner gorge definition (i.e., >70%); both were poor locations to place sidecast.

7) What, if any, new types of landslides have been discovered since the time the current approved mass wasting analysis was completed? What land uses are associated with these landslides?

Small, sporadic deep-seated landslides have been field-identified. One was triggered or re-activated by road construction. It is not known whether the second one was triggered by the previous era of harvest; it did pre-exist this era of harvest. All other new landslides are types observed during the original watershed analysis. Land uses include Mature Timber, Landings, Forest Roads and Orphaned Roads.

8) Have the newly inventoried landslides delivered sediment to public resources?

Fourteen of the eighteen new landslides delivered sediment to typed water (see Table K-1). Seven of the nine landslides that occurred within MWMU and within mature timber delivered; one debris slide in a bedrock hollow appears to have not delivered and delivery of a debris slide near the top edge of an inner gorge is uncertain. The orphaned road stream crossing failure obviously delivered. All four fillslope failures delivered, although delivery was very limited in three cases (details are provided in the section titled Landslide Inventory). Only one of the cutslope failures delivered – this small, sporadic deep-seated landslide is crossed by an inner gorge so delivery was inevitable, but of limited volume because the SSDS landslide settled several feet and very little of the material appears to have transported downstream.

9) How does the rate of new landslides compare to the initial rate of landslides present when the WA was first approved and, in particular, how do the percentages of new landslides by land use compare to those inventoried in the original WA?

From the original inventory, 86 landslides were not related to roads, and 18 of those were attributed to storm disturbance rather than clear cut harvest or wildfire which probably means they occurred in mature timber. Fifty-six landslides were associated with roads. This means a 60/40 split between non-road and road-related landslides overall and a 24/76 split between mature timber and road-related landslides. For the newly inventoried landslides, there are 10 non-road and 8 road-related landslides, a 56/44 split which is quite similar to the 60/40 split observed in the original dataset. Given the small number of newly inventoried landslides, this result is problematic to interpret, but it may be that applying basic prescriptions such as no harvest and no new sidecast within the unstable landforms has reduced landslides from both loss of rooting strength when unstable landforms are denuded and road triggers by similar rates. The mature timber versus road-related landslide split is approximately a 50/50 split, which is quite different from that of the original database, but given the extreme disturbance history of this watershed (i.e., the 1951 Forks Fire and crude salvage logging that followed), we cannot expect a comparable result because the distribution of stand ages has been very different from the 1950's-1980's to present.

Statement of Confidence

Original Landslide Inventory: The original landslide inventory was done in 1996 and it has not been updated during this reanalysis except to remove the surface events and the landslides that initiated on Federal lands. Subsequent field review during harvest unit layout has demonstrated that the original landslide inventory missed some landslides that are visible on the aerial photography. In general, events mapped as landslides are, in fact, landslides (I mention this because this is not true of some landslide inventories from watershed analyses and landslide hazard zonation projects). And landslides are mapped in the correct locations. This means that there is only a moderate confidence in the quality of the original landslide inventory itself, but a high confidence in its value as a tool to validate the MWMU.

New Landslide Inventory: The 2003 color, stereo aerial photography (1:12,000 to 1:13,200 as marked on each photo) is high quality; field-observed landslides were clearly evident and other landslides not previously located in the field were also obvious, even in the areas of mature timber. All landslides were inventoried with a certainty of "Definite." However, after 2003, only ortho photography exists and it does

not appear to be a good tool for locating landslides. Fortunately, recent landslides occurring near new harvest units or driveable roads where modern forest practices may have influenced the events were first identified in the field and it is expected that few if any landslides influenced by modern forest practices are missed in the new inventory. This means that it is unlikely that an important trigger from modern forest practices has been missed. It is likely that un-inventoried, very small and small landslides (<500 square yards) have occurred within the inaccessible areas of mature timber where modern forest practices have not exerted influence – this is a well-understood limitation of inventory by aerial photography (e.g., Turner, et al. 2008) and is likely even more significant when utilizing ortho photography. This means that comparisons between naturally occurring landslides and those influenced by modern forest practices have an inherent bias that likely over-emphasizes the impacts of forest practices, but does not preclude believing that forest practices do increase landslide rates as evidenced by 50 years of scientific literature.

MWMU Map: There is a high level of confidence in the accuracy and completeness of the MWMU mapping based on extensive field work including a high proportion of actual field-verified and delineated unstable slopes from engineered harvest units and based on remote unstable slope delineation that utilized 1953 black and white, stereo aerial photography (approximately 1:12,000) (post-Forks Fire with clear ground) and early LiDAR DEM. The author has used many other unstable slope maps from watershed analyses and landslide hazard zonation projects as remote tools to assist with field engineering and geotechnical analysis. Several recently engineered harvest units in the North Fork Calawah WAU very closely resemble the distribution of unstable slopes on Map K-2; only a few other maps from watershed analyses and landslide hazard zonation projects closely resemble field delineation of unstable slopes.

MWMU Validation and Hazard Analysis: Years of air photo review and field work have empirically validated that landslides are occurring in the rule-identified landforms. Very few landslides, mostly road-related, have been observed outside of rule-identified landforms. For these reasons, there is a high level of confidence that MWMU #1, #2, #3 and #4 do represent the potentially unstable slopes in the watershed (MWMU #5 is a trivial part of the sediment story and has been recorded more because of the safety issues than because of its watershed impacts and MWMU #6 is a low hazard MWMU recognized as a precautionary measure). Field observations support the relative hazard ratings among the MWMU: 1) convergent headwalls have high landslide rates, particularly because the bedrock hollows within convergent headwalls have very high landslide rates; 2) bedrock hollows outside of convergent headwalls have high landslide rates; and 3) landslide initiations within inner gorges are occurring at a lower rate. It should be noted that these conclusions and the actual hazard ratings are semi-quantitative, particularly because the landslide inventory is missing some photo-observable landslides and because there may be observational bias between the landforms (e.g., it may be harder to see landslide initiations within inner gorges). It shall be noted here that if indicators of a potentially unstable slope with delivery potential which do not meet the MWMU #1-#4 descriptions are identified by the landowner or WADNR personnel, that a forest practice on that potentially unstable slope would trigger IV-Special/SEPA pursuant to WAC 222-22-010 (6).

Testing the Prescriptions: Since 1997, FPA within the North Fork Calawah have consistently had high levels of geotechnical review to confirm that the unstable landforms were identified and appropriately buffered or protected from inappropriate road building techniques. The author has field reviewed most FPA across all seventeen years; since 2005, some harvest unit FPA have been reviewed by geotechnical consultants to the author. And almost all FPA were subsequently field reviewed by the WADNR Forest

Practices Forester and the WADNR Geologist. FPA with geotechnical letters or reports are referenced in the section titled Testing the Prescriptions to provide evidence that prescriptions have been followed or modified as described. Deviations from the prescriptions are described in section titled Testing the Prescriptions; additional deviations will have only occasionally occurred because frequent occurrence would have become apparent to the author and the WADNR personnel. Appendix K-3, a table summarizing all FPA in WAU between the approval of the original watershed analysis and the 2015 reananalysis, provides proof that the prescriptions, with limited and consistent deviation, have been followed. The table was developed with help from WADNR and Green Crow personnel; maps and geotechnical letters and reports were reviewed to fill in the prescription-related data in the table. The table may be lacking a small number of road construction FPA, but all harvest unit FPA have been found. There is a high degree of confidence in the data, and a high degree of confidence in the interpretation of these data.

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North Fork Calawah WAU

Appendix K-2

Form K-3 Mass Wasting Map Unit Descriptions for the North Fork Calawah WAU

MWMU #1 – Inner Gorges (>70%) – High Hazard

Description of Mass Wasting Unit: Inner gorges in the North Fork Calawah WAU are formed by two distinctly different erosional processes. Along low gradient, fish-bearing channels, such as Devil's Creek, the inner gorge edges are formed by fluvial undercutting and downcutting. The inner gorge surface is >70% and can exceed 100% in places. Where the bedrock is particularly competent, such as it is in the tributaries north of the lower mainstem North Fork Calawah River, these inner gorges may have lower sidewalls of exposed and nearly vertical bedrock. The larger of these inner gorges, such as Devil's Creek, were delineated as GMU 90 in the original watershed analysis; smaller ones such as the unnamed tributaries north of the lower mainstem and west of Devil's Creek were included in the planar hillslope GMU (Map A-2).

The second type of inner gorge is incised into the steep hillslopes in the watershed and carries high gradient streams, >20%, to the valley floor. These are formed by repeated debris flows and were called "debris flow tracks" in the original watershed analysis; the larger ones were delineated as GMU 78 and the rest were included in the planar hillslope GMU. Where channels within the debris flow tracks are larger, near the valley floor, or flow across debris fans and glacial terraces on the valley floor, fluvial processes play more of a role and there is a transitional zone between the two types of inner gorge. With rare exception, hillslope inner gorges have one to many bedrock hollows within their headwater drainage.

Side slopes of the inner gorge landform are experiencing active erosion. The side slopes of the inner gorges formed by fluvial undercutting experience debris slides and slumps. The side slopes of the inner gorges formed by debris flows traveling down the channel are scoured, and then the oversteepened colluvium above the scoured edge may experience debris slides and slumps (which can evolve into debris flows). Both situations lead to the side slopes of the inner gorge landform being oversteepened and displaying historic failure scars. The top edge of the inner gorge is demarked by a break-in-slope created by the erosional activity on the side slopes of the inner gorge.

Delineation of hillslope inner gorges that are incised a few to approximately 20 feet into the extended hillslope is often as simple as delineating between the fall line of trees into the inner gorge and the fall line of trees on the extended hillslope. But if there has not been a historic debris flow within a hillslope inner gorge, delineation can be difficult because of the smooth and stable appearance of the side slopes and because of the convex nature of the upper break-in-slope; where this occurs, delineation can follow the subtle, convex break-in-slope which may be more distinct where historic failure scars occur. Where a historic debris flow has occurred, there may be two breaks-in-slope, one on the edge of the scoured portion of the side slope and a second one higher on the hillslope; where this occurs, the higher break-in-slope should be used for delineation. The larger inner gorges with low gradient channels may have a broad expanse of >70% hillslope above them, all within the fall line of the feature. Where this occurs,

look for a break-in-slope, which can be either convex or concave in nature, between the upper planar or convex hillslope which does not have evidence of historic landslide processes and the side slopes of the inner gorge that do display evidence of historic landslide processes; where this occurs, the break-in-slope may be used to delineate the inner gorge.

Slopes: Generally >80%, always >70%
Slope Shape: Convergent to planar
Material: Marine sedimentary sandstones and lesser siltstones of Eocene age (OEm Formation as mapped by Gerstel and Lingley, 2000 and Schasse, 2003) and continental glacial outwash (Qgo).
Total Area: 1716.84 acres; 200.59 acres within MWMU #3

Mass Wasting Process: The inner gorges formed by fluvial processes along low gradient streams experience failure along the side slopes, typically debris slides and slumps that reach the channel but do not evolve into channelized events such as debris flows. Where these inner gorges have lower sidewalls of sheer bedrock, debris flows initiating higher on the hillslope may dam these channels and then breach as a dam-break flood event. The hillslope inner gorges are formed by repeated debris flows, usually initiating in the bedrock hollows although initiations within the inner gorges themselves are possible and road stream crossing or sidecast failures can cause a debris flow to initiate on steep slopes either within or near the unstable landforms.

Forest Practice Sensitivity and Trigger Mechanisms: High – Significant loss of rooting strength by clear cut harvest or wildfire elevates landslide rates above levels observed in mature forests. Road-related triggers including focused water, undersized stream-crossing culverts and sidecast construction. These triggers cause twice as many landslides as loss of rooting strength.

Mass Wasting Potential: High – Inner gorges are naturally unstable landforms whose propensity for failure is increased by both poor road construction and maintenance techniques and the loss of rooting strength through timber harvest of entire unstable landforms.

Delivery Potential/Criteria: Very High – Immediate adjacency to channels means that delivery potential directly by landslide or indirectly through fluvial transport into the extended channel network is likely except where specifically noted as "No Delivery" on Map K-2.

Overall Hazard Potential Rating: High – Hazard Potential is based on the LHZ Protocol, Table 5.

Confidence: High level of confidence based on extensive field work including a high proportion of actual field-verified and delineated unstable slopes from engineered harvest units and based on remote unstable slope delineation that utilized 1953 aerial photography (post-Forks Fire with clear ground) and early LiDAR DEM.

Comments: As noted during field observation and frequently documented in geotechnical reports, between many bedrock hollows and their debris flow tracks (hillslope inner gorges), there is a short distance of unchanneled swale that is <70%. Many of these swales are 30-100 feet in length; an occasional one is hundreds of feet long. As a matter of convenience and

because these areas of unchanneled swale should be field verified, most of the short swales are mapped as the bedrock hollow or inner gorge landform without showing a small separation on Map K-2.

North Fork Calawah WAU
Appendix K-2

Form K-3 Mass Wasting Map Unit Descriptions for the North Fork Calawah WAU

MWMU #2 – Bedrock Hollows (>70%) – High to Very High Hazard

Description of Mass Wasting Unit: Bedrock hollows are steep (>70% along one or more of the axes), spoon-shaped or elongate areas of convergent topography, typically with concave profiles. Bedrock hollows are also called colluvium-filled bedrock hollows, zero-order basins, swales, bedrock depressions, or simply hollows. These features can exist on any moderate to steep hillslope and may have developed within a larger landform such as a deep-seated landslide or a convergent headwall. Hollows seldom have a stream channel within the feature, although if a failure has occurred in the past few decades surficial water may be present. Hollows commonly drain directly into a channel head or laterally into a channel that started higher on the hillslope. In many locations, the channel the bedrock hollow drains towards lies within an inner gorge; these hillslope inner gorges were called debris flow tracks in the original watershed analysis. Colluvial debris accumulates in bedrock hollows, primarily by soil creep processes. The colluvium is prone to saturation during extreme rainfall events because shallow groundwater is also preferentially accumulating in the concave landform.

Delineation can be difficult on steep hillslopes. If a hillslope exceeds 70% above the bedrock hollow, the upper edge of the hollow should be delineated where the landform ceases to be concave in the horizontal plane, often just below a rocky ridge where the hillslope becomes planar or rolls out convex. If the hollow is deeply cut into the hillslope and strongly teardrop-shaped such that there are strong, broad ridges on either side of the lower hollow, the fall line of the trees remains towards the hollow well onto what is clearly the ridge landform. Where this occurs, the lower center of the hollow and the ridge landform must be delineated along a line that separates the concave and the convex slope forms.

Slopes: 70% or greater
Slope Shape: Concave (always in the horizontal plane and usually in the vertical plane)
Material: Marine sedimentary sandstones and lesser siltstones of Eocene age (OEm Formation as mapped by Gerstel and Lingley, 2000 and Schasse, 2003).
Total Area: 955.70 acres; 145.29 within MWMU #3

Mass Wasting Process: This landform is fundamentally formed by the repeated occurrence of landslides. It is a self-perpetuating process, known as a positive feedback mechanism in the vernacular of geomorphologists, and it appears that hollows become wider and deeper and head cut towards ridgeline as millennia pass. Many landslide initiations within well-developed hollows are several feet deep and appear to have initiated as a debris flow. Some initiations, particularly in small, shallow bedrock hollows, initiate as a debris slide that may evolve into a debris flow downslope. Rarely, a slump block rotates into the base of the bedrock hollow, creating a perched feature within the hollow.

Forest Practice Sensitivity and Trigger Mechanisms: High – Loss of rooting strength by clear cut harvest or wildfire elevates landslide rates above levels observed in mature forests. Road-related triggers including focused water, undersized stream-crossing culverts and sidecast construction. These triggers cause twice as many landslides as loss of rooting strength.

Mass Wasting Potential: High – Bedrock hollows are naturally unstable landforms whose propensity for failure is increased by both poor road construction and maintenance techniques and the loss of rooting strength through clear cut harvest or wildfire.

Delivery Potential/Criteria: High – Proximity to channels means that delivery potential directly by debris flow or indirectly through fluvial transport into the extended channel network is likely except where specifically noted as "No Delivery" on Map K-2.

Overall Hazard Potential Rating: High outside of MWMU #3; Very High within MWMU #3 – Hazard Potential is based on the LHZ Protocol, Table 5.

Confidence: High level of confidence based on extensive field work including a high proportion of actual field-verified and delineated unstable slopes from engineered harvest units and based on remote unstable slope delineation that utilized 1953 aerial photography (post-Forks Fire with clear ground) and early LiDAR DEM.

Comments: As noted during field observation and frequently documented in geotechnical reports, between many bedrock hollows and their debris flow tracks (hillslope inner gorges), there is a short distance of unchanneled swale that is <70%. Many of these swales are 30-100 feet in length; an occasional one is hundreds of feet long. As a matter of convenience and because these areas of unchanneled swale should be field verified, most of the short swales are mapped as the bedrock hollow or inner gorge landform without showing a small separation on Map K-2.

North Fork Calawah WAU
Appendix K-2

Form K-3 Mass Wasting Map Unit Descriptions for the North Fork Calawah WAU

MWMU #3 – Convergent Headwalls (>70%) – High Hazard

Description of Mass Wasting Unit: Rule-identified convergent headwalls are steep (>70% and often much greater than 70%) teardrop-shaped landforms that are concave in both the vertical and horizontal planes. A convergent headwall is comprised of many bedrock hollow and hillslope inner gorges that converge into a single channel in a midslope position. Knife-edged ridges and broader convex surfaces may extend from the ridgetop above the convergent headwall, but are likely to be pinched out downslope by convergence. Some lower elevation headwalls, such as the large one delineated in Township 29 North, Range 11 West, Section 17, contain some broad, <70% ridges between the hollows and <70% swales between a hollow and its hillslope inner gorge. Higher elevation headwalls may have little slope area <90%. It is specifically the bedrock hollows and inner gorges that are unstable slopes and the convex, planar and lower gradient surfaces are stable, but where ridges are so narrow that both edges fall side hill into an adjacent hollow at 90+%, there may not be any stable areas.

Slopes: >70%; often many slopes are 90+%
Slope Shape: Convergent
Material: Marine sedimentary sandstones and lesser siltstones of Eocene age (OEm Formation as mapped by Gerstel and Lingley, 2000 and Schasse, 2003).
Total Area: 662.29 acres

Mass Wasting Process: Debris flows, often of large volume and long runout, are the primary landslide type. Debris slides may also occur, but either evolve into debris flows or stop where they reach a bedrock surface or a feature, such as a downed log, that can stop them.

Forest Practice Sensitivity and Trigger Mechanisms: High – Loss of rooting strength by clear cut harvest or wildfire elevates landslide rates above levels observed in mature forests. Road-related triggers including focused water, undersized stream-crossing culverts and sidecast construction. These triggers cause twice as many landslides as loss of rooting strength.

Mass Wasting Potential: High – the extreme density of MWMU #1 and #2 within this broader landform, formed by landslide processes, and the dramatic size and concave nature of this landform mean that erosion rates are higher than adjacent, broadly planar hillslopes.

Delivery Potential/Criteria: Very High – the development of these features by repeated debris flow particularly means that the single inner gorge into which all the bedrock hollows and smaller inner gorges feed is a highly effective debris flow track with direct delivery to the mainstem valley floor.

Overall Hazard Potential Rating: High – Hazard Potential is based on the LHZ Protocol, Table K-5.

Confidence: High level of confidence based on extensive field work including a high proportion of actual field-verified and delineated unstable slopes from engineered harvest units and based on remote unstable slope delineation that utilized 1953 aerial photography (post-Forks Fire with clear ground) and early LiDAR DEM. These features were originally delineated as GMU 77 in the original watershed analysis – subsequent field review of many of the features has validated the original mapping effort. Two additional have been added to Map K-2. However, mapping bedrock hollows within the north-aspect convergent headwalls is difficult because of photo shadows – it is likely that there are unmapped bedrock hollows within these convergent headwalls and care should be taken to find them during field engineering.

Comments: Although the principal unstable slopes concerns within the convergent headwalls are the bedrock hollows and small inner gorges, this landform is delineated separately because the original watershed analysis found that landslide rates (reported as per square mile for a 4-decade air photo history) were a little more than double in this landform as compared with steep planar hillslope with moderate to high dissection by bedrock hollows and small hillslope inner gorges that were not converging. Of particular concern is the construction of midslope roads across those features that lack stable ridges onto which to drain ditch water.

North Fork Calawah WAU
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Form K-3 Mass Wasting Map Unit Descriptions for the North Fork Calawah WAU

MWMU #4 – Outer Edges of Meander Bends (>70%) – High Hazard

Description of Mass Wasting Unit: Rule-identified outer edges of meander bends occur where the North Fork Calawah River is experiencing channel migration that causes a meander bend to erode into a glacial terrace or the base of the hillslope for a period of years or decades (e.g., in the middle valley downstream of the confluence of the North Fork Calawah Headwaters and Pistol Creek) or where the North Fork Calawah River is somewhat entrenched and has relatively permanent outer meander bends with a slow rate of erosion (e.g., in the lower valley). These slopes are concave in the horizontal plane, often extend for several hundred feet along the river and then may re-develop of the other side of the river where the next meander occurs. They are rarely >30 feet high except for those rare locations where the CMZ is against the hillslope. These were not directly identified or discussed in the original watershed analysis because most are protected within riparian buffers and the large ones also reasonably meet inner gorge definitions; they have been added here because they are now a rule-identified landform.

Slopes: Generally >70%
Slope Shape: Convergent to planar
Material: Marine sedimentary sandstones and lesser siltstones of Eocene age (OEm Formation as mapped by Gerstel and Lingley, 2000 and Schasse, 2003) and continental glacial outwash (Qgo).
Total Area: 95.36 acres

Mass Wasting Process: This landform is undercut by the lateral movement of the North Fork Calawah River. It fails by a combination of debris slides and small slump blocks.

Forest Practice Sensitivity and Trigger Mechanisms: High – Loss of rooting strength by clear cut harvest or wildfire elevates landslide rates above levels observed in mature forests. Road-related triggers including focused water, undersized stream-crossing culverts and sidecast construction. These triggers cause twice as many landslides as loss of rooting strength. Because modern forest practices avoid the near-river corridor, except where an activity such as alder conversion is proposed and this does not occur on MWMU #4, responses to forest practices are not expected to be observed today but the existing road network is still contributing sidecast failures.

Mass Wasting Potential: High – for those features being actively eroded by channel migration; Moderate – for those features along the lower reaches of the North Fork Calawah where the mainstem is entrenched and stable.

Delivery Potential/Criteria: Very High – delivery is usually directly into the mainstem, although delivery can be indirect where the river has migrated away from the edge and established a floodplain terrace.

Overall Hazard Potential Rating: High – Hazard Potential Rating based on the LHZ Protocol, Table K-5.

Confidence: High level of confidence based on extensive field work including a high proportion of actual field-verified and delineated unstable slopes from engineered harvest units and based on remote unstable slope delineation that utilized 1953 aerial photography (post-Forks Fire with clear ground) and early LiDAR DEM.

Comments: Modern road design and riparian buffers have greatly reduced impacts to outer meander bends where they occur at the scale observed in the North Fork Calawah Watershed (e.g., <30 vertical feet above the river).

North Fork Calawah WAU
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Form K-3 Mass Wasting Map Unit Descriptions for the North Fork Calawah WAU

MWMU #5 – Small Sporadic Deep-Seated Landslides – Moderate Hazard

Description of Mass Wasting Unit: Two small, sporadic deep-seated landslides have been mapped as a MWMU. Both exist in fault gouge/breccia associated with the Calawah Thrust Fault. They are 1-5 acres in size and are moving slowly downhill as one or more simple slump blocks. One is a re-activated portion of a much larger relict deep-seated landslide; current activity pre-dates the most recent era of harvest and road construction. One was re-activated when road construction of a previously orphaned grade cut into the feature. Other, similar but smaller features that did not deliver and re-stabilized within 2 years are mapped as landslides on Map K-1 and were not added to the MWMU.

Slopes: Generally >50%
Slope Shape: Planar to convex
Material: Marine sedimentary sandstones and lesser siltstones of Eocene age (OEm Formation as mapped by Gerstel and Lingley, 2000 and Schasse, 2003) and continental glacial outwash (Qgo).
Total Area: 7.77 acres

Mass Wasting Process: This landform is comprised of small areas within larger areas of unconsolidated materials (fault gouge/breccia or relict deep-seated landslides) within which motion is re-activated.

Forest Practice Sensitivity and Trigger Mechanisms: One of the mapped features, in Township 29 North, Range 11 West, Section 8, pre-existed the latest era of road construction and harvest (and, in fact, was protected from both). The other mapped feature, in Township 29 North, Range 12 West, Section 33, and the related, smaller features noted on Map K-1 are triggered when road construction undercuts a hillslope of unconsolidated fault gouge/breccia. Occurring as one or more simple blocks, these features usually stabilize after two winters. However, the eastern mapped feature has been active for a period of decades and the western mapped feature may be more persistent.

Mass Wasting Potential: Low to Moderate – Where the fault gouge/breccia exists, particularly where the bedrock has been strongly sheared into a flour-like matrix and a few angular clasts, road construction will continue to trigger these events. Empirical evidence suggests that these are unlikely to be triggered by natural disturbance or by timber harvest because active features are only associated with roads and have not been observed other places in the watershed.

Delivery Potential/Criteria: Low to Moderate – These small, slow-moving features rotate off the cutslope and deposit on the road tread. The western of the mapped features has delivery potential, being co-incidental with an inner gorge, but only if it catastrophically fails. The eastern of the mapped features lies high on Bigler Mountain and generally lacks delivery potential. The smaller cutslope failures have not delivered, or have only indirectly delivered as a trickle of turbid ditch water down to the next stream crossing.

Overall Hazard Potential Rating: The overall hazard rating from the prospective of public resources is quite low. The real hazard is to road contractors, two of whom have sustained equipment damage as shallow failure has occurred on the front face of a newly activated block. It is not mathematically possible to calculate the Landslide Frequency Rate for these features; the assigned hazard is Moderate in recognition of their response to forest practices but limited delivery.

Confidence: High level of confidence based on field work at both features and at the other, smaller cutslope failures; the materials, the process and the triggering mechanism are well understood. Very limited confidence that we can identify future locations, although the limited confidence is a little higher for road construction spatially coincident with orphaned grades where historic locations can be seen in the old cutslope and engineering measures can avoid re-activating this subset.

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Form K-3 Mass Wasting Map Unit Descriptions for the North Fork Calawah WAU

MWMU #6 – Relict Deep-Seated Landslides

Description of Mass Wasting Unit: These features vary from approximately 15 acres to approximately 200 acres in size. Typically, there is a distinct head scarp which may be a bedrock cliff but is more commonly a 50-70% slope that supports living trees, and has old growth stumps and soil including a humus layer. The latter indicate significant age. The side scarps are often less obvious, but where deep-seated landslides are adjacent to one another as they are on Bigler Mountain, discrete ridges may exist between features. In the broad perspective, these features are horizontally planar or concave and vertically convex, planar or concave. Locally, surfaces can be hummocky. Some features are formed of a few large blocks, creating benched topography. Marginal streams are often cut deeply into the hillslope (20-100 feet) and usually qualify as inner gorges as defined in MWMU #1; they may delineate the side scarps of the deep-seated landslides. Bedrock hollows (MWMU #2) are not common on the deep-seated landslides, but can occur.

Evidence of recent or active deep-seated movement is not present. Trees are not curved or jack-strawed (although pistol-butted trees growing on logs or stumps are common, as they are everywhere on this near-coastal landscape). Tension cracks and stretched tree roots are not present. Bare mineral soil can be associated with shallow, rapid failures such as debris flows and debris slides within the inner gorges and bedrock hollows that have developed on the deep-seated landslides and nowhere appears to be symptomatic of deep-seated movement. Small wet or seepy areas may occur. However, rainfall is 130+" per year and the bedrock is highly fractured with alternating units of massive sandstone and thin siltstone beds; such seeps are common across the geologic unit and do not appear to reflect continued activity of the deep-seated landslides.

Slopes: 20% or greater
Slope Shape: Variable; usually benched or hummocky topography
Material: Marine sedimentary sandstones and lesser siltstones of Eocene age (OEm Formation as mapped by Gerstel and Lingley, 2000 and Schasse, 2003).
Total Area: 898.36 acres

Mass Wasting Process: Most of the relict deep-seated landslides in the central and western areas of the North Fork Calawah WAU (e.g., adjacent to and west of the area known as Bonidu Flats which lies on Sections 3 and 9 in Township 29 North, Range 11 West) appear to have been triggered by the undercutting action of glacial ice or glacial melt waters during the last era of glaciation. Two small deep-seated landslides in Sections 20 and 29 in Township 29 North, Range 11 West in the Albion Creek Subbasin are unlikely to have been triggered by glacial processes, but lie on USFS ownership outside the scope of this reanalysis. The deep-seated landslides east of Bonidu Flats and also on USFS ownership

are of unknown origin; Dieu and Shelmerdine (1997) hypothesized that alpine glaciation occurred in the Mainstem Headwaters and Pistol Creek subbasins, but this has not been field verified and, if true, may not have triggered those deep-seated landslides which toe into the current inner gorge. There is some association between the Calawah Thrust Fault (Tabor and Cady, 1978) and the occurrence of these features, although a few are not adjacent to the fault.

Forest Practice Sensitivity and Trigger Mechanisms: Low – During the watershed analysis, the following was noted: "There is no evidence that forest practices reinitiated movement on a deep-seated landslide in the North Fork Calawah Watershed; confidence is low that this possibility is a real concern." Eighteen years later, many of these features have been field evaluated and then harvested again. Confidence that the relict deep-seated landslides are truly relict and do have a low sensitivity to forest practices is now high. However, the sensitivity of the inner gorges and bedrock hollows that have developed on the relict deep-seated landslides is High. Just like MWMU #1 and #2 outside of MWMU #6, loss of rooting strength by clear cut harvest or wildfire elevates landslide rates above levels observed in mature forests. Road-related triggers including focused water, undersized stream-crossing culverts and sidecast construction. These triggers cause twice as many landslides as loss of rooting strength.

Mass Wasting Potential: High where MWMU #1 and #2 lies within MWMU #6 – Inner gorges and bedrock hollows are naturally unstable landforms whose propensity for failure is increased by both poor road construction and maintenance techniques and the loss of rooting strength through clear cut harvest or wildfire. Low for the portions of MWMU #6 not coincident with MWMU #1 or #2.

Delivery Potential/Criteria: High where MWMU #1 and #2 lies with MWMU #6 – Proximity to channels means that delivery potential directly by debris flow or indirectly through fluvial transport into the extended channel network is likely except where specifically noted as "No Delivery" on Map K-2. Variable delivery potential for the relict deep-seated landslides as whole features – many toe onto outwash plains and terraces where even the marginal streams do not connect to the extended channel network, but two deep-seated landslides on state or private land toe against the mainstem North Fork Calawah and would have direct delivery if reactivated.

Overall Hazard Potential Rating: Low – Hazard Potential is based on the LHZ Protocol, Table 5.

Confidence: High level of confidence on remote unstable slope delineation that utilized 1953 aerial photography (post-Forks Fire with clear ground) and early LiDAR DEM. Many features have been field verified since the 1997 North Fork Calawah Watershed Analysis.

Comments: If one of these features should be determined to be active, standard forest practices should be followed. If a small portion of one should be identified as MWMU #5, those prescriptions should be followed.

Appendix K-3: North Fork Calawah Forest Practices Applications

This appendix provides summary data for all known FPA in the North Fork Calawah WAU submitted between the approval of the North Fork Calawah Watershed Analysis and the 2015 Reanalysis of the Mass Wasting Module. The table is ordered by FPA No., which provides chronology. Eight FPA are noted as "Green Crow" and all others are Rayonier applications. Rayonier's Block or Road number is provided; Green Crow has recently throw away older FPA files, so Stand Numbers for the recently planted trees are provided. The Year of approval, FPA Class and Twn/Rng/Sec are also provided.

Harvest means that the FPA was a harvest unit proposal – "No" means that the FPA was for construction of a road and that only road right-of-way was cut. A "Yes" in Yarding Corridors means that one or more yarding corridors over unstable slopes were required. A "Yes" in Bedrock Hollows means that one or more upper extents of bedrock hollows above a cutslope were harvested, and NOT just that bedrock hollows were present. A "Yes" in Guyline Circles means that one or more guyline circles around landings in the harvest unit required the cutting of unstable slopes.

Road Construction means that the FPA included road construction. A "Yes" in the No Sidecast column means that the road design included lengths where the placement of sidecast was not permitted. A "Yes" in the Sidecast Pullback column means that the road design was for the construction of an existing road prism and that the road design included lengths where pullback was required. A "Yes" in the Cross-Drains column means that cross-drain culverts were spaced at 300-feet or less and so that excess water was not concentrated into unstable slopes. Of particular note is that new construction without an existing road prism creates the common sequence of "Yes" to No Sidecast, "NA" to Sidecast Pullback and "Yes" to Cross-Drains. If road construction occurred and all three of No Sidecast, Sidecast Pullback and Cross-Drains are "NA," then a reason is provided in the Cross-Drains column (e.g., spurs on terraces).

FPA No.	Block/Road	Year	Class	Tn/Rg/Sec	Harvest	Yarding Corridors	Bedrock Hollows	Guyline Circles	Road Construction	No Sidecast	Sidecast Pullback	Cross-Drains
2602504	29.427	1999	III	29N12W Sec 11	Yes	No	No	No	No	NA	NA	NA
2602629	29.420	1999	III	29N12W Sec 12	Yes	No	No	No	Yes	NA	NA	Yes
2603355	29.434 Roads	2000	III	29N12W Sec 11	No	No	No	No	Yes	Yes	NA	Yes
2603631	29.461	2000	III	29N12W Sec 11	Yes	No	No	No	No	NA	NA	NA)
2603907	29.465 (8000 Road)	2001	III	29N12W Sec 21	No	No	No	No	Yes	Yes	No	Yes

2604273	29.434	2001	III	29N12W Sec 11	Yes	No	No	No	No	NA	NA	NA
2604290	29.477	2001	III	29N11W Sec 10	Yes	No	No	No	Yes	NA	NA	NA
2604494	29.445 Roads	2002	III	29N11W Sec 9	No	No	No	No	Yes	Yes	Yes	Yes
2604514 (Green Crow)	Stand 1599	2002	III	29N11W Sec 15	Yes	No	No	No	No	NA	NA	NA
2604637	29.465	2002	III	29N12W Sec 22	No	No	No	No	Yes	Yes	No	Yes
2604676	29.466	2002	III	29N11W Sec 8	Yes	No	No	No	No	NA	NA	NA
2604798 (Green Crow)	Stand 0805	2002	III	29N11W Sec 8	Yes	No	No	No	No	NA	NA	NA
2604846 (Green Crow)	Stands 1004, 1007 and 1508	2002	III	29N11W Sec 10	Yes	No	No	No	Yes	NA	NA	NA
2604854	29.425	2002	III	29N12W Sec 2	Yes	No	No	No	Yes	NA	NA	NA
2605033 (Green Crow)	Stand 1095	2003	III	29N11W Sec 10	Yes	No	No	No	Yes	Yes	NA	Yes
2905098 (Green Crow)	Stand 1904	2003	III	29N11W Sec 19	Yes	No	No	No	Yes	NA	NA	NA
2605123	29.435	2003	III	29N12W Sec 10	Yes	Yes	No	No	Yes	Yes	NA	NA (spur on ridge)
2605125/ 2605248 (Green Crow)	Stand 1580	2003	III	29N12W Sec 15	Yes	Yes (?)	No	No	No	NA	NA	NA
2605136	29.428	2003	III	29N12W Sec 14	Yes	Yes	No	No	Yes	Yes	NA	Yes
2605185	29.481 Roads	2003	III	29N11W Sec 8	No	No	No	No	Yes	NA	NA	Yes

2605306	29.445	2003	III	29N11W Sec 9	Yes	Yes	No	No	Yes	NA	NA	NA (spurs on terraces)
2605322	29.460	2003	III	29N11W Sec 10	Yes	No	No	No	Yes	Yes	NA	Yes
2605460	29.481	2003	III	29N11W Sec 9	Yes	No	No	No	Yes	NA	NA	Yes
2605623	29.476	2003	III	29N11W Sec 19	Yes	Yes	No	No	Yes	Yes	Yes	Yes
2605629	29.474	2003	III	29N12W Sec 21	Yes	No	No	No	Yes	NA	NA	Yes
2605647 (Green Crow)	Stands 1096 and 1099	2003	III	29N12W Sec 10	Yes	No	No	No	Yes	Yes	NA	Yes
2605772	29.471	2004	III	29N12W Sec 15	Yes	Yes	No	No	Yes	Yes	NA	Yes
2605793	29.511 Roads	2004	III	29N11W Sec 17	No	No	No	No	Yes	Yes	NA	Yes
2605844	29.502/29.505	2004	III	29N12W Sec 29	Yes	No	No	No	Yes	Yes	Yes	Yes
2605903	29.470 Roads	2004	III	29N12W Sec 21	No	No	No	No	Yes	Yes	NA	Yes
2605983 (Green Crow)	Stand 2004	2004	III	29N12W Sec 20	Yes	No	No	No	No	NA	NA	NA
2606143	29.342	2004	III	29N12W Sec 11	Yes	No	No	No	Yes	NA	NA	Yes
2606274	29.485	2004	IV-S	29N12W Sec 11	Yes	Yes	No	No	Yes	NA	NA	NA (short spur)
2606338	29.472	2004	III	29N12W Sec 15	Yes	No	No	No	Yes	Yes	NA	Yes
2606353	29.511	2004	III	29N11W Sec 17	Yes	Yes	No	No	No	NA	NA	NA
2606355	29.470	2004	IV-S	29N12W Sec 21	Yes	Yes	Yes	No	No	NA	NA	NA
2606492	29.513	2005	III	29N11W Sec 16	Yes	No	No	No	Yes	NA	NA	Yes
2606576	29.513C	2005	III	29N11W Sec 16	Yes	No	No	No	No	NA	NA	NA

2606763	29.532	2005	III	29N12W Sec 11	Yes	No	No	No	No	NA	NA	NA
2607045	29.436	2005	III	29N12W Sec 15	Yes	Yes	No	No	Yes	Yes	Yes	Yes
2607154	29.506/29.548	2005	III	29N12W Sec 32	Yes	No	No	No	Yes	NA	NA	Yes
2607841	29.531	2006	III	29N12W Sec 31	Yes	No	No	No	Yes	NA	NA	NA (terrace surface)
2607844	29.503/29.504	2006	III	29N12W Sec 29	Yes	No	No	No	Yes	NA	NA	NA (terrace surface)
2607860	29.429/29.501	2006	III	29N12W Sec 13	Yes	Yes	No	No	Yes	Yes	Yes	Yes
2608023	29.512	2006	III	29N11W Sec 9	Yes	No	No	No	Yes	Yes	NA (reconstruction part not unstable)	Yes
2608332	29.534 Roads	2007	III	29N12W Sec 31	No	No	No	No	Yes	Yes	No (yes, later after construction)	Yes
2608637	29.507	2007	III	29N12W Sec 32	Yes	No	No	No	Yes	Yes	No	Yes
2608842	29.551	2007	III	29N12W Sec 11	Yes	No	No	No	Yes	Yes	NA	No
2609015	29.433	2008	III	29N11W Sec 8	Yes	No	No	No	Yes	Yes	No	Yes
2609018	29.528	2008	III	29N11W Sec 9	Yes	No	No	No	Yes	NA	NA	Yes
2609035	29.533	2008	IV-S	29N12W Sec 20	Yes	Yes	No	No	Yes	Yes	NA	Yes
2609189	29N12W550	2008	III	29N12W Sec 10	Yes	No	No	No	Yes	Yes	NA	NA (spur on broad ridge)
2609256	29.553 Roads	2008	III	29N12W Sec 28	No	No	No	No	Yes	Yes	Yes	Yes
2609930	29.547 Road	2009	IV-S	29N12W Sec 24	No	No	Yes	No	Yes	Yes	Yes	Yes
2610602	29.514 Roads	2010	III	29N11W Sec 16	No	No	No	No	Yes	NA	NA	NA (terrace surface)

2610614	29.546	2010	IV-S	29N12W Sec 24	Yes	Yes	No	Yes	No	NA	NA	NA
2610681	29N12W510 Roads	2010	IV-S	29N12W Sec 28	No	No	No	No	Yes	Yes	Yes	Yes
2610890	29N12W574	2008	III	29N12W Sec 15	Yes	No	No	No	Yes	NA	NA	Yes
2611196	29.514	2011	IV-S	29N11W Sec 17	Yes	Yes	Yes	No	Yes	Yes	NA	Yes
2611205	29N11W595	2011	III	29N12W Sec 16	Yes	No	No	No	No	NA	NA	NA
2611207	29.547	2011	IV-S	29N12W Sec 24	Yes	Yes	No	Yes	No	NA	NA	NA
2611228	8500 Road (29N12W509)	2011	IV-S	29N12W Sec 33	No	No	No	No	Yes	Yes	Yes	Yes
2611237	29N11W596	2011	III	29N11W Sec 9	Yes	No	No	No	No	NA	NA	NA
2611455	29.468	2011	IV-S	29N12W Sec 14	Yes	Yes	No	No	Yes	Yes	NA	NA (small, ridgetop spurs)
2611672	29N12W668	2012	IV-S	29N12W Sec 32	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
2611690	29N12W510	2012	IV-S	29N12W Sec 28	Yes	No	No	No	No	NA	NA	NA
2611721	29.555	2012	IV-S	29N12W Sec 28	Yes	Yes	No	No	No	NA	NA	NA
2611863	29.475	2012	IV-S	29N11W Sec 20	Yes	No	No	No	No	NA	NA	NA
2611981	8510/8511 Roads	2012	IV-S	29N12W Sec 27	No	No	No	No	Yes	Yes	Yes	Yes
2612023	29.508/509 Roads	2012	IV-S	29N12W Sec 32	No	No	No	No	Yes	Yes	Yes	Yes
2612105	29.534	2012	IV-S	29N12W Sec 31	Yes	Yes	Yes (no delivery)	Yes	No	NA	NA	NA
2612345	29.508	2013	IV-S	29N12W Sec 32	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
2612367	29.521	2013	IV-S	29N12W Sec 24	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
2612368	Upper Grindstone Roads	2013	IV-S	29N12W Sec 18	No	No	No	No	Yes	Yes	NA	Yes
2612431	29.535 Roads	2013	III	29N12W Sec 31	No	No	No	No	Yes	Yes	No	Yes

2612678	29N12W563	2013	IV-S	29N12W Sec 28	Yes	Yes	No	No	No	NA	NA	NA
2612775	29N12W564 Roads	2014	III	29N12W Sec 21	No	No	No	No	Yes	NA	NA	NA (spurs on terrace)
2612861	29N12W588	2014	IV-S	29N12W Sec 15	Yes	Yes	No	No	Yes	Yes	Yes	Yes
2612931	8900 Road (west of 29.521)	2014	IV-S	29N12W Sec 24	No	No	No	No	Yes	Yes	Yes	Yes
2613018	29N12W555	2014	IV-S	29N12W Sec 27	Yes	Yes	No	No	No	NA	NA	NA
2613019	29N12W587	2014	IV-S	29N12W Sec 28	Yes	Yes	No	No	No	NA	NA	NA
2613039	29N12W565	2014	IV-S	29N12W Sec 28	Yes	Yes	No	No	No	NA	NA	NA
2613057	29N12W509	2014	IV-S	29N12W Sec 33	Yes	Yes	Yes	No	No	NA	NA	NA

North Fork Calawah Watershed Analysis

Module K - 2015 Mass Wasting Prescription Reanalysis Level 2

29 December 2016 Addendum

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The North Fork Calawah 2015 Mass Wasting Prescription Reanalysis Level 2 Report was finalized on August 12th. Subsequently, during the process of drafting and reviewing the Mass Wasting Prescriptions, two notable landslides occurred during December of 2015. This addendum documents their occurrence and describes specific road construction considerations that have been included in the final prescriptions. The two landslides are drawn on the attached Redlining Section Maps and are numbered in sequence with those in the primary report. Basic data are provided below in Table 1. The field-observed gradients are clinometer measurements recorded in the original geotechnical reports (FPA No. 2611981 and 2613853); these represent natural pre-roaded hillslope conditions, and may not be reproducible today after road construction and failure initiation.

Landslide 1550 initiated in Section 27 of Township 29 N, Range 12 W, W. M. The landslide initiated in a combination of native soil and woody debris from the recent road construction, and rock from an adjacent cutslope collapse. It initiated approximately 20 vertical feet below the edge of the 8511 Road, just below the sidecast removal that had been done during the summer of 2014. The debris flow traveled through one of multiple paths in the complex of bedrock hollows, buried and then continued across the 8510 Road below, and deposited a few hundred feet below the 8510 Road. This event validates conclusions in the original watershed analysis and the reanalysis – sidecast in steep, convergent topography is the most common, road-related landslide trigger in the North Fork Calawah Watershed (see Table K-3 on page 10).

Landslide 1551 initiated in Section 33 of Township 29N, Range 12 W, W. M. The landslide initiated in a temporary sidecast prism during active road construction of the 8540 Road during the night of December 3rd or 4th, 2015. It buried and then continued across the 8500 Road and deposited at a sharp bend in the Type Np channel several hundred feet below the 8500 Road. Turbid water from the deposit did reach Fahnestock Creek, a Type F stream.

It was apparent from site visits that the presence of a temporary sidecast prism in a bedrock hollow during a time of heavy rainfall created landslide-triggering conditions. The take-home message is that new construction across unstable slopes where a temporary sidecast prism is necessary to gain adequate construction width must be a seasonally restricted activity. The final mass wasting prescriptions include seasonal restrictions specifically where new construction crosses MWMU. The seasonal restrictions do not include the reconstruction of existing road prisms nor ridgetop construction that does not require a temporary sidecast prism as these activities have occurred without incidence through many winters.

Table 1: Landslides That Occurred in December, 2015. (These will be added to the next Reanalysis Report and will be included on Map K-1 and in Appendix K-1 at that time.)

Event No.	**Landslide Type**	**Certainty**	**Year First Observed**	**Size** (square yards)	**Slope Shape**	**Gradient at Initiation** (Field)	**Gradient at Initiation** (GIS – 10 m DEM)	**Land Use**	**Type of Landform**	**Delivered? Water Type or Location?**	**Comment** (Possible Trigger)
1550	Debris Flow	Definite	2015	6928	Convergent	90%	74%	Recent Road Construction	Bedrock Hollow	Yes; Type Np	Sidecast Failure
1551	Debris Flow	Definite	2015	11510	Convergent	85%	79%	Active Road Construction	Bedrock Hollow	Yes; Type Np	Sidecast Failure