Development of Preventative Streamside Landslide Buffers on Managed Timberlands[1]

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Abstract

Shallow streamside landslides are a principle source of sediment on managed timberlands in northern California. Using an adaptive management process, LiDAR, and a detailed field-based landslide inventory, Green Diamond Resource Company (GDRCo) has redefined the interim preventative landslide tree-retention buffers it applies to steep streamside slopes along fish bearing (Class I) and non-fish bearing (Class II) watercourses. The application of these buffers are dependent on slope gradients and when applied, enhance and in some cases, expand upon the customary riparian buffers associated with these watercourse types in our California Timber Harvesting Plans (THP). They are designed to significantly reduce the amount of management related sediment delivery associated with landsliding when compared to historical management practices.

Initially, the steep slope prescriptions were derived from a pilot field inventory of streamside landslides during the developmental stages of an Aquatic Habitat Conservation Plan (AHCP). The Steep Slope Delineation study was a long term research project associated with the AHCP monitoring program with an objective of redefining the initial prescriptions based on a comprehensive field-based landslide inventory. The first phase of the steep slope project was completed in 2011, and in 2015 we completed the final phase.

The final results of the Steep Slope Delineation project covered roughly 145,690 ha (360,000 ac) of privately owned timberlands in California. The work included a review of aerial photographs, detailed field survey of slopes adjacent to 357, 0.8 km (half-mile) long, watercourse segments, and analysis of the resulting data. These data, characterizing more than 2,000 landslides, are used to develop new maximum buffer widths and new slope gradient buffer triggers which are exclusive to the four geographic areas within the ownership. While the majority of the buffer widths decreased, nearly one third increased in width. As for the slope triggers, slightly more than half of the slope gradients decreased, nearly half had no change, and a few increased. The revised steep slope prescriptions were submitted to federal agencies in December of 2014 and were successfully incorporated into the AHCP in January of 2015.

Introduction

The Steep Streamside Slope (SSS) Delineation project is an analysis of streamside landslides on privately owned timberlands that are bound by an Aquatic Habitat Conservation Plan (AHCP). The results of this analysis determine the new SSS default protection measures for the ownership in northern California. These buffers are applied to specific areas that are known to have a high potential for streamside landsliding and enhance the standard Riparian Management Zones (RMZ) in those areas (A generalized example of a SSS is shown in fig. 1). This project is an expansion of a previous landslide study that produced the AHCP Steep Streamside Slope initial “default” protection measures during development of the AHCP.

The primary goal of the SSS prescription is to reduce the amount of sediment delivered to watercourses as a result of streamside landslides generated by forest management related operations. The objective of the SSS prescriptions, which will be assessed at a later date as part of the SSS Assessment project, is to achieve a 70 percent reduction of delivered streamside landslide volumes in comparison to historical management related streamside landslides. This paper presents the findings of the final phase of the SSS Delineation project which involved a review of streamside slopes in each

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of the Hydrographic Planning Areas (HPA) except the Coastal Klamath, which was the focus of the first phase of this project completed in March of 2011. A summary of the Coastal Klamath findings is also included in this report.

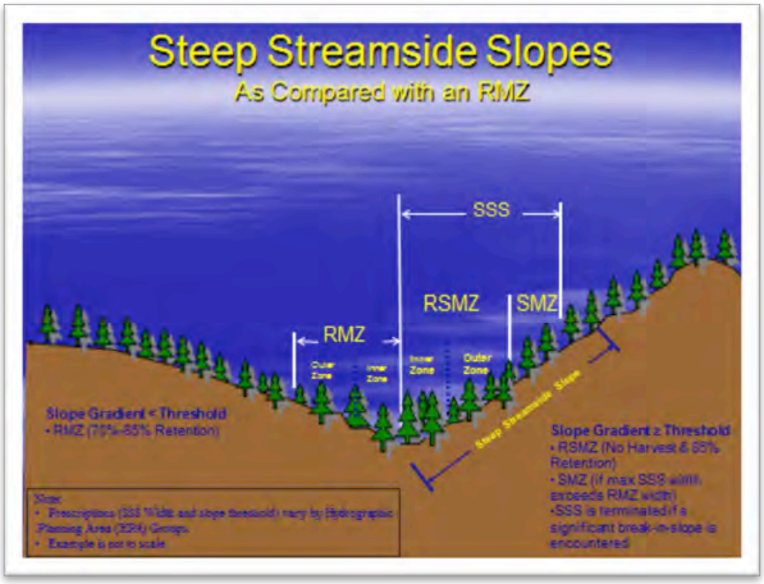

Figure 3—Generalized schematic diagram of a SSS buffer. The SSS Zone shown at right is compared with an RMZ to the left. When the SSS -gradient threshold is triggered the RMZ is enhanced by the application of SSS measures through an increase in overstory canopy retention in that area.

The initial default SSS prescriptions were established during the developmental stage of the AHCP. These default prescriptions were based on an initial study that evaluated streamside landslides. The purpose of the study was to develop an expanded protection zone adjacent to watercourses that would reduce the amount of streamside landslides related to timber harvesting. Furthermore, the initial study was small in scope and designed to produce conservative results. The study intentionally targeted areas that exhibited high concentrations of landslides due to the limited scope and compressed time frame to conduct the study. The SSS Delineation project expands upon the initial landslide evaluation effort with: a larger sample size, more thorough review of landslides, and a random sampling process applied to each of the HPA's outlined in the AHCP. This project will more accurately define the SSS protection measures and achieve the AHCP objectives directed at streamside landslides.

The 70 percent reduction in sediment delivery compared to historical sediment delivery was a goal developed between Green Diamond Resource Company (GDRCo), U.S. Fish and Wildlife Service, and National Marine Fisheries Service during the development of the AHCP. The actual performance of the SSS buffers will be evaluated over the next 15 years during the SSS Assessment Project and reviewed by an independent scientific review panel.

Our revised SSS slope gradient trigger was determined by reviewing streamside landslide data collected from our work and selecting the slope gradient that corresponds with landslides that account for 80 percent of the cumulative volume of sediment delivered to a watercourse. The maximum SSS buffer distance is determined by evaluating the distance from the main scarp to a watercourse that correspond with landslides that represent 60 percent of the cumulative volume of sediment delivered. This process was established and used during development of the AHCP. Both of the aforementioned cumulative volume assessment values were chosen with the assumption that the majority of the landslide data to be collected would have occurred under historical logging practices that are no longer used (i.e., reduced or no riparian protections, intensive ground-based operations, oversized harvest units, poor road building practices, etc.). Both the sediment reduction goal and cumulative volume based buffer criteria are thought to yield conservative values based on these assumptions.

The project focuses on shallow streamside landslides that were active to historically active, were not caused by roads or skid trails, and have observably delivered sediment to a watercourse based on field observations. The AHCP road management and harvest related prescriptions are designed to address road and skid trail related landslides; accordingly, they are excluded from this study.

Additionally, the SSS prescriptions are not designed to address deep-seated landslides as they are addressed separately and on a case by case basis at the THP level. Shallow landslides associated with an active or historically active deep-seated landslide were also excluded from this project because the primary causal mechanism of failure of these features is due to movement of the deep-seated landslide which results in weakening of earth materials and over steepened slopes. These types of slides are addressed as part of their corresponding deep-seated landslides at the THP level.

Project Area

The project area is located on the north coast of California in a tectonically active area just north of the Mendocino Triple Junction (MTJ) where the North American, Gorda, and Pacific plates collide. Green Diamond Resource Company ownership spans from the California/Oregon border on the northern end to the town of Rio Dell on the southern end and as far inland as the headwaters of Redwood Creek. The ownership is broken up into hydrographic planning areas (HPA) that are associated with local watershed boundaries. There are nine HPAs within the project area, each of which is shown in fig. 2. Those HPAs with similar physical characteristics are lumped together into HPA Groups in order to apply regional variations in management prescriptions.

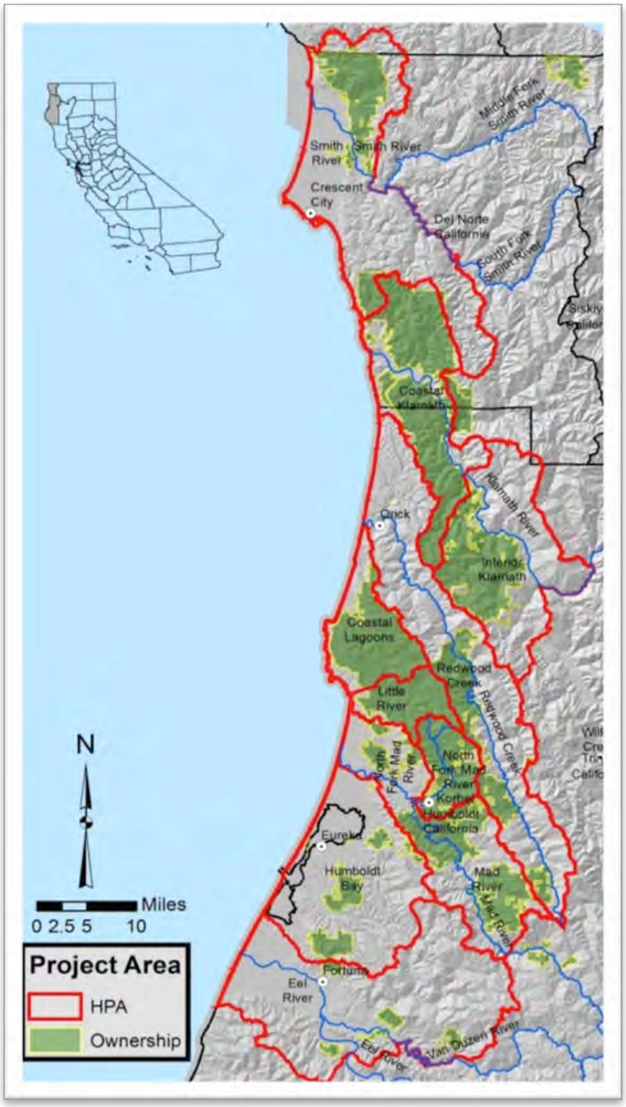

Figure 4—Project area; figure includes individual HPA, county and ownership boundaries.

Seismogenic fault systems in the area are part of the MTJ and include the north end of the San Andreas Fault zone to the southwest, the Mendocino fracture zone to the southwest, and the southern end of the Cascadia subduction zone to the west, just off the coastline. There are also numerous on-land upper plate thrust faults throughout the region that are thought to be considered as potential sources for seismic shaking (Cao et al. 2003, Kelsey 2001, Petersen et al. 1996), they include, but are not limited to: the Little Salmon fault, Mad River fault zone, Bald Mountain-Big Lagoon faults, Grogan, Surpur Creek fault, Saint George Fault and the Smith River Faults. The structural orientation of these faults is typically northwest-trending as a result of the compressional forces exerted on the region due to the converging North American, Pacific, and Gorda Plates.

Earth materials vary throughout the property due to the highly active tectonic regime in the region. At the southern extent of the ownership the bedrock is dominated by Miocene to late Pleistocene deposits of the Wildcat formation (Ogle 1953). The Wildcat formation is thought to be a coarsening upward regressional sequence of the ancestral Eel River basin. To the north the remainder of the property is dominated by deposits of the coastal and central belt of the Franciscan formation, which range in age from Pliocene to early Jurassic (McLaughlin et al. 2000). Bedrock within the Franciscan includes sedimentary, igneous, and metamorphic rock types; the most common earth materials encountered (generally speaking from north to south) are sandstone and metasandstone, mélange, schist, and the broken formation of the Franciscan. These units are typically characterized by broken to sheared moderately indurated sandstone and metasandstone (largely Korbel and Klamath HPAs), highly sheared siltstones and mudstones in an argillaceous matrix (largely found in Korbel and Klamath HPA Groups), quartz-mica schist (primarily found in the Redwood Creek HPA) and moderate to well indurated fractured greywake (primarily found in the Klamath and Smith River HPAs). Throughout the ownership bedrock may be capped by Pleistocene to Holocene alluvial sediments or marine terrace deposits (Irwin 1997). Surficial deposits are also found throughout the ownership in the form of alluvial deposits in the low lying areas along active streams and at the mouths of valleys. In addition, colluvium collects in the low lying zones such as swales and low lying slopes throughout the hillside. Due to rapid uplift, faulting, and subsequent down cutting through these young and poorly consolidated earth materials the general morphology of the region is typically characterized by immature topography. Steep valleys and landslide prone terrain are common throughout this region.

Methods

This project generally follows the same framework we established in our previous analysis of the Coastal Klamath HPA (Woodward et al. 2011). The results of that analysis are summarized in table 1. As part of that work we established protocols for aerial photo review, field methods, and calculations; each of which are briefly discussed below. In addition we developed distinct areas based on morphology which included using a topographic ruggedness model. We applied this same model to the remaining areas of the ownership and the results of that analysis are discussed below under “GIS Analysis”.

Table 1—Comparison of revised Coastal Klamath SSS prescriptions and initial default prescriptions

Coastal Klamath SSS maximum slope distances m (ft) and minimum slope gradient thresholds			
SSSMU	**Class I**	**Class II-2**	**Class II-1**
1	72 (240) @ 65%	34 (110) @ 70%	41 (135) @ 75%
2	130 (425) @ 75%	59 (195) @ 85%	
Initial Default Buffers	145 (475) @ 70%	61 (200) @ 70%	30 (100) @ 70%

Historical Context

We reviewed historical aerial photographs for landslides and past land management practices for all of our field sites. Aerial photographs dated back to as early as 1942 and we typically included one set from each decade thereafter, as available, in our review. The majority of the aerial photos in our collection are at a scale of 1:12,000. Only landslides visible at the scale of the photos were mapped, which included slides typically 148.6 square meters (1,600 square feet) and larger. These landslides were transferred into our GIS landslide layer with associated tabular data that included; photo year and label, land use and approximate stand age at the time of failure, road and/or skid trail association, landslide type, slope curvature, geomorphic association, watercourse association, feature certainty and delivery. Landslide types are based on definitions modified from Cruden and Varnes (1996).

In reviewing the historical aerial photos and conversations with staff foresters and local historical logging experts, we developed a brief summary of the logging history of the ownership. Beginning in the late 1800s and early 1900s up until the mid-1930s, the central and southern portions of the ownership saw railroad and steam donkey logging. By the late 1940s into the late 1960s much of these areas were thinned or clearcut using ground-based tractor yarding methods, which utilized networks of skid trails. During this same time period, cable-yarding harvest methods were used on steeper areas. Some areas were thinned or clearcut on a smaller scale in the 1970s and 1990s. Much of the northern half of the ownership did not see harvesting start until much later. Tractor logging of old-growth timber in Redwood Creek, Klamath and Smith River areas started in the early 1950s to late 1960s. The tractors would construct networks of skid trails often times using side-cast fills on steep slopes, which tend to trigger road-related landslides. Interior Klamath saw the highest concentration of road and skid trail related slides of all HPAs. Some steeper areas were logged using cable-yarding harvest methods starting in the late 1950s and continuing until the mid-1970s. Recent timber harvesting across the ownership, from the late 1990s up to the present day, have utilized cable- and tractor-yarding with shovel yarding beginning to replace tractors around the year 2002.

While we understand the importance of comparing historic landsliding to climactic events, this was beyond the scope of this particular project. We are currently evaluating climactic impacts and the relationship with landsliding as part of a more encompassing mass wasting assessment of the ownership which is currently under review.

Project Design

The project design and methods involve the development of sample reaches, field measurements, calculations, data entry, and the analysis of the resulting data. Most were derived from our previous work in the Coastal Klamath HPA.

Our sample area involves hillsides adjacent to watercourses that are classified on the ownership as Class I and Class II watercourses. Class I watercourses are fish bearing streams and Class II watercourses are perennial flowing streams that support other aquatic life. The Class II streams are further subdivided into 1st and 2nd order (II-1 and II-2) stream types. Using the same approach applied during our work in the Coastal Klamath HPA, we sampled random hillside areas adjacent to Class I and Class II watercourses by breaking up the mapped Class I, Class II-2 and Class II-1 watercourses into half-mile survey reaches throughout the property.

The geographically distributed systematic random sampling method used both random selection and spatial distribution of the 0.8 km (half-mile) segments within the study area. This method involved delineating whole streams, from the confluence to the upstream end of a Class II, breaking these streams into approximate 0.8 km (half-mile) sample reaches. In addition, we stratified the Class I watercourses to ensure an even distribution of sample reaches from the lower, middle, and upper portions of these streams. Both the current sample and the previous Coastal Klamath reaches are shown in fig. 3. The current sample set, which excludes the Coastal Klamath, covers approximately 74 percent of the ownership (111,690 ha, 276,000 ac).

Our target sample rate was five percent (by distance) for Class II-2 and Class II-1 watercourses and 10 percent for Class I watercourses. The final sample percentages vary slightly from our original sample draw due to a variety of factors. Field review of watercourses during operations typically results in fluctuations in the location of a watercourse transition which affected some of the selected reaches. Another is that we ran into logistical issues in the field that prevented access to certain areas. For the current sample we surveyed a total of 293 km (182 mi) of streams, 93 km (58 mi) (11 percent) of Class I, 123 km (76.5 mi) (6 percent) of Class II-2, and 76 km (47 mi) (5 percent) of Class II-1 watercourses. An additional 77 km (48 mi) were surveyed in the Coastal Klamath HPA. For the entire SSS Delineation project, there were a total of 357 sample reaches, of which 264 were part of the current study and 93 were part of the Coastal Klamath work.

Field Work, Measurements, and Calculations

All landslides were reviewed in the field. Field work involved surveying the hillsides adjacent to the sample reaches for shallow streamside landslides. Our study focused on those landslides that were: a) active to historically active, b) not associated with active or historically active deep-seated landslides, c) non road- and non skid trail-related, and d) had observably delivered sediment to a watercourse. Only landslides greater than 3 m by 6 m (10 ft by 20 ft) were included in the survey. Data collected for each landslide included a field-developed cross section using a tape measure and clinometer, causal factors, slope characteristics, dimensions of the source area and slide debris, a field estimate of the delivery volume, distance from the crown of the slide to the edge of the watercourse, and the average slope gradient of the hillside effected. Cross sections show the main scarp, projected failure surface, the estimated original surface, and the extent of slide debris relative to the associated watercourse. We utilized the cross sections to determine the length of the rupture area, length of debris, estimated thickness of the failure, and estimate the thickness of the remaining slide debris.

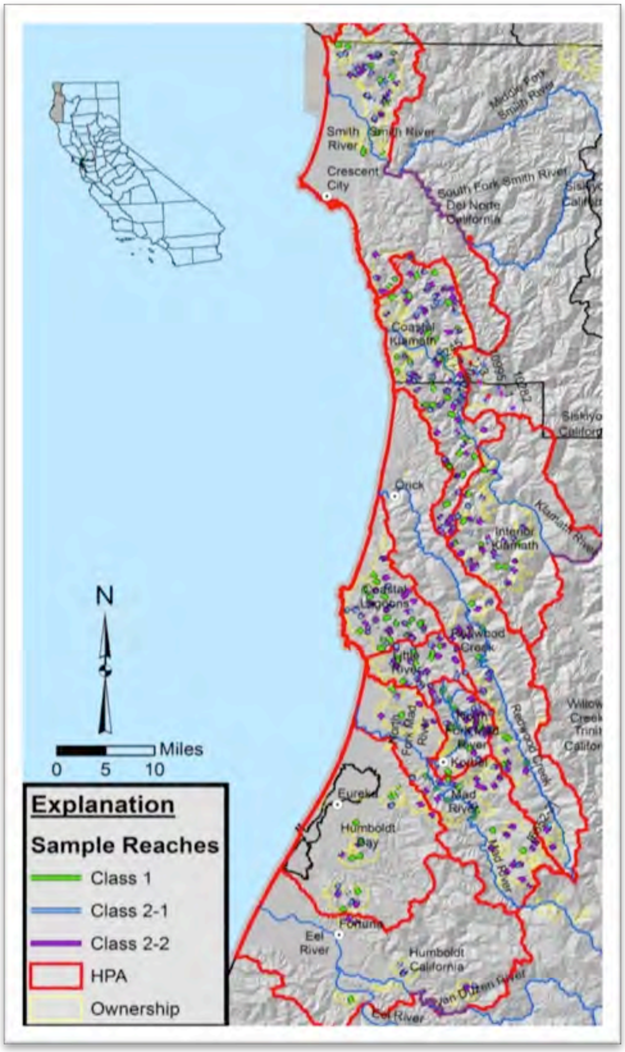

Figure 5—Project area and survey locations.

The average slope gradient of the hillside associated with the failure was obtained primarily by field estimates using a clinometer and the projected original surface gradient from the field-developed cross sections. In some cases, typically larger landslides or areas obstructed by thick shrubbery or excessively steep slopes, we utilized slope gradients derived from LiDAR. In each case we evaluated the average slope of the hillside associated with the failure defined as the area from the crown of the slide to the base of the hillside.

As mentioned above, we did not include landslides that were thought to have been caused by roads or skid trails in our analysis as road related landslides are addressed at the THP level and in our road management program. The purpose of the SSS prescription is to reduce the potential for streamside landslides typically associated with harvesting. Therefore our efforts focused on open slope streamside landslides not associated with roads. Determining whether or not a slide has been caused by a road or skid trail is a difficult task; especially if the failure is not a recent one. Often times, professional judgment is required in attributing a causal mechanism such as roads to the failure of a landslide. As a result we attempted to attribute road- or skid trail caused only to failures that appeared to have a reasonable or obvious negative association with a road or skid trail.

Volume estimates were derived from a calculation based on the length, width, and depth of both the rupture area and the remaining slide debris observed in the field. The calculation (Eq. 1) treats the slide rupture area and debris as a half of an ellipse and was obtained from published work by Cruden and Varnes (1996).

Eq. (1): $\text{Volume of delivered material} = (1/6\ \Pi\ Lr{*}Wr{*}Dr) - (1/6\ \Pi\ Ld{*}Wd{*}Dd)$

In this equation Lr, Wr, Dr, and Ld, Wd, Dd are defined as the length (L), width (W), and depth (D) of the rupture "r" and debris "d" of the landslide. In more complicated situations we found smaller slides nested within larger slides. In these instances, the slope distance and slope gradients of a smaller "nested slide" was not counted separately for the SSS analysis since it had failed as part of the larger slide. We did however calculate the volume of debris that had been delivered by a nested slide and added it to the volume of delivered material of the larger slide.

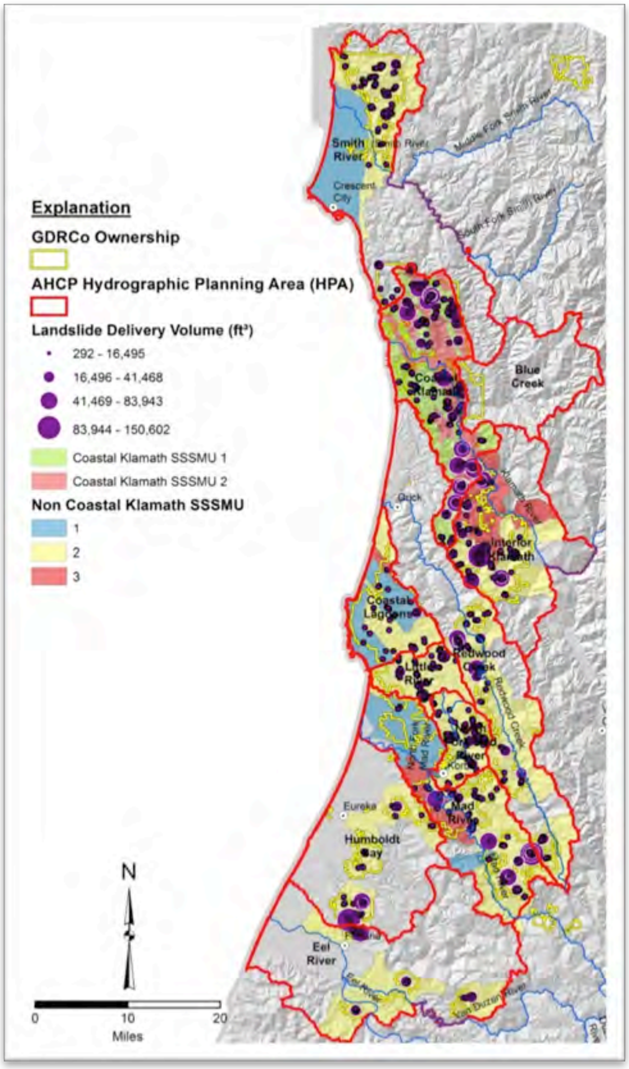

Figure 6—Landslide distribution by volume (includes previous work in Coastal Klamath HPA).

GIS Analysis

During our work in the Coastal Klamath we developed discrete areas based on morphologic complexity which we termed "Steep Streamside Slope Morphologic Units" (SSSMU). Looking at the shaded relief model from a 1-meter LiDAR DEM we determined that the morphologic complexity of this region could be separated into three discrete units (although two were combined due to lack of landslide data in those areas). Each of which showed a varying degree of landsliding. By doing so we could develop multiple SSS buffers within the HPA that would be more accurately applied to specific areas based on their morphology and landslide patterns. Using the same topographic ruggedness model from our work in the Coastal Klamath (Riley et al. 1999), we applied it to the rest of the ownership (fig. 4).

Although there were three discernable groupings within the Terrain Ruggedness Index (TRI) data, the groupings were not as strong as they had been in the Coastal Klamath. The majority of the ownership fell into the mid-range SSSMU group 2; roughly twenty five percent of the sample area fell within the SSSMU 1 or 3 groups. We evaluated these areas to see if they warranted specific SSS prescriptions but we did not find enough variation in the landslide data between these areas and the rest of the property to justify separate buffer criteria. This is illustrated in fig. 4 where we see a fairly even distribution of the number of landslides as well as an even distribution of the number of landslides by volume throughout the Non Coastal Klamath SSSMUs. If there were reason to identify prescriptions based on the SSSMUs, we would expect to see a larger portion of landslides, especially larger landslides, clustered within a specific SSSMU. This was evident and worked well for the Coastal Klamath HPA, but as we applied this methodology to the rest of the ownership we found that the topography and landslide patterns outside of the Coastal Klamath are not quite as variable. Based on this evaluation we did not apply SSSMUs to the remaining HPAs. Instead we analyzed the landslide data in relation to the HPA and HPA groups. A comparison of landslides to bedrock units was also made, however no observable correlations were found that would contribute to redefining the SSS zones.

Results

A total of 1,676 landslides were analyzed for our evaluation of the SSS prescriptions in the final phase of the SSS Delineation project. The SSSMUs were not applied in the final phase of the analysis. We did however analyze the landslide data in relation to the HPAs and found three relatively distinct groups that stood out. Our final HPA groupings include revised SSS prescriptions for the Coastal Klamath HPA (completed in 2011), Smith River HPA, Interior Klamath HPA, and together the Korbel and Humboldt Bay HPA groups (minus the Interior Klamath, which was originally part of the Korbel HPA Group). As a result the original HPA groups outlined in the AHCP have been revised and the new groupings are shown in table 2. The revised SSS prescriptions are specific to each of these groups.

Table 1—Revised HPA groups

	Revised HPA groups
HPA group	**HPAs**
Smith River	Smith River
Coastal Klamath	Coastal Klamath
Interior Klamath	Interior Klamath
Korbel	Coastal Lagoons, Little River, Redwood Creek, North Fork Mad River, Mad River, Humboldt Bay, Eel River

Slope Distances

The initial slope distance thresholds were determined by evaluating the maximum distance from the watercourse to the main scarp of all landslides reviewed with a total cumulative sediment delivery volume of 60 percent. The same cumulative volume value of 60 percent was used to determine the revised SSS slope distances. The cumulative volume of delivered sediment versus landslide distances from crown to watercourse is shown in fig. 5(a-c). The revised SSS slope distances have been calculated and a summary of the results are shown in table 3.

Table 2—Revised default SSS slope distances

	Revised SSS slope distances m (ft)		
HPA Group	**Class I**	**Class II-2**	**Class II-1**
Smith River	30 (100)	23 (75)	24 (80)
Interior Klamath	59 (195)	30 (100)	27 (90)
Korbel	41 (135)	34 (110)	32 (105)

Slope Gradient Thresholds

Slope gradient thresholds were based on the minimum slope gradient associated with all landslides within a cumulative volume of delivered sediment of 80 percent. In the initial study the slope thresholds were lumped together for all watercourse types. For the most part there was little variance of slope thresholds between watercourse types observed at that time. We found this to be true again as we assessed the remainder of the ownership. As a result we grouped the revised slope gradients for all watercourse classes by prescription area. The distribution of cumulative volume of sediment delivered versus landslide slope gradients are shown in fig. 5(d) and a summary of the slope gradient thresholds is shown in table 4.

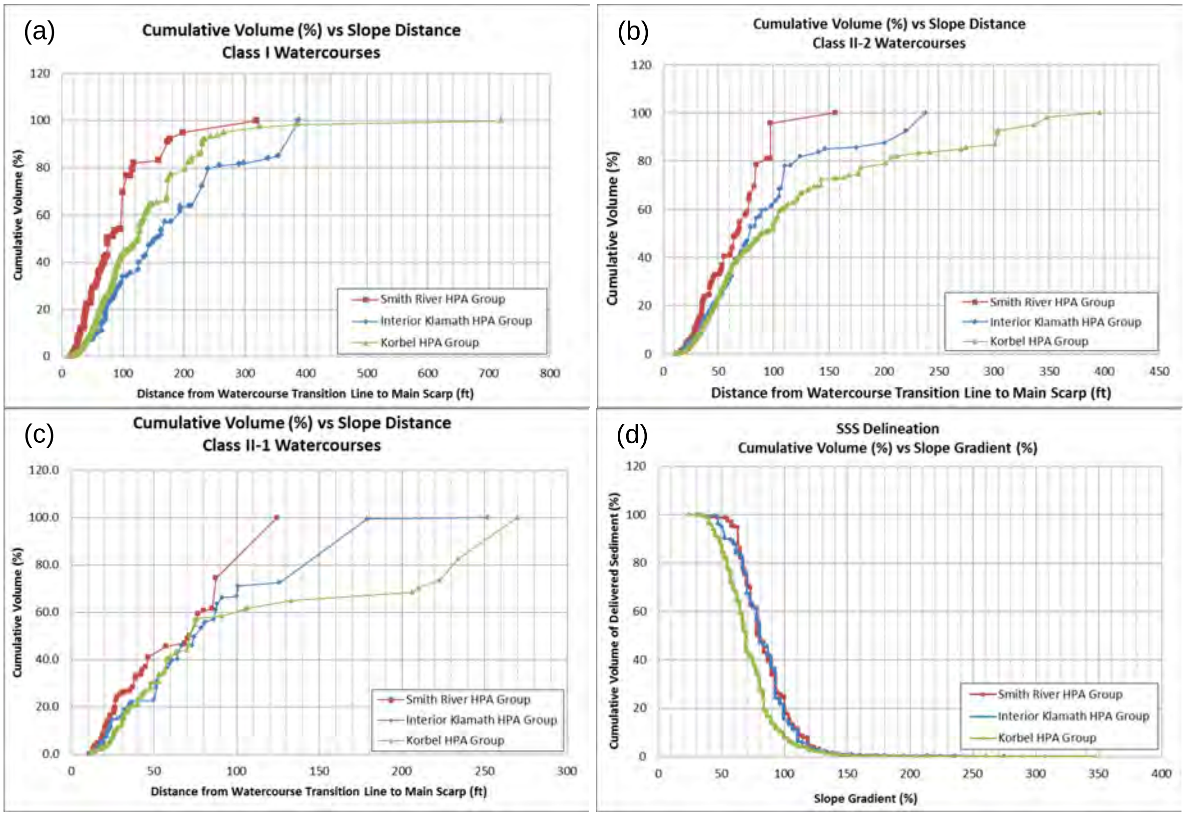

Figure 7—Cumulative volume vs slope distance; (a) Class I watercourses, (b) Class II-2 watercourses, (c) Class II-1 watercourses, (d) Cumulative volume vs slope gradient.

Table 3—New default SSS slope gradient thresholds for Smith River, Interior Klamath, and Korbel groups

Revised SSS slope gradient triggers (all watercourse classes)	
HPA group	**Slope gradient**
Smith River	65%
Interior Klamath	65%
Korbel	55%

Landslide Data

The distribution of landslides by HPA and watercourse type is shown in table 5. Taking into account the sampling rates, 10 percent of the lineal distance on the Class I's and 5 percent on each of the Class II's, the majority of the landslides observed occurred along the Class II-2 watercourses. As was the case in our work for the Coastal Klamath, fewer landslides were found along the Class I and II-1 watercourses throughout the remainder of the ownership. This is a logical observation as the Class II-2 streams are erosion and transport reaches that are characterized by higher flows than the Class II-1 streams. They are generally characterized as having much steeper stream gradients than the Class I streams which are often depositional reaches. As a result, these streams and adjacent hillside areas are subject to more erosion and down cutting, so we would expect there to be a higher occurrence of landsliding compared to the other watercourse types.

Table 4—Distribution of the number of landslides by watercourse class and HPA grouping

	Number of landslides by watercourse classification		
Watercourse class (% sampled)	Smith River HPA	Interior Klamath HPA	Korbel HPA group
Class I (10%)	100	123	380
Class II-2 (5%)	106	165	585
Class II-1 (5%)	54	63	100

When assessing the effectiveness of the preventative "SSS" prescriptions, GDRCo, U.S. Fish and Wildlife Service and National Marine Fisheries Service agreed on a value that would exceed the value identified under historical conditions and settled on 70 percent cumulative volume as an achievable goal. In general we saw that the number of landslides decreased over time. Based on our review of aerial photographs from 1941 to 2009 for the SSS Delineation study, 86 percent of the landslides observed on aerial photographs occurred between the 1941 and 1988 aerial photo sets resulting in 6.65 slides per year, 14 percent of the slides were observed in photographs after the 1988 photo set resulting in 2.57 slides per year, and only 2 percent occurred after the 1997 set resulting in 0.75 slides per year. Our preliminary estimates on landslide erosion rates show similar decreases over time. Current erosion rates are only a fraction of what they were in the 1960s and 1970s when they were at the peak historically (0.06 m^3/ha/yr (28 U.S. Tons/mi^2/yr) since the implementation of the AHCP in 2007 compared to 1.5 m^3/ha/yr (684 Tons/mi^2/yr) in the 1960's and 1.79 m^3/ha/yr (820 Tons/mi^2/yr) in the 1970's).

Discussion

This study did not include the data collected in the initial study. However each of the areas of the initial study had an opportunity to be resampled as part of the SSS Delineation based on the random selection process. In fact a few areas were resurveyed. Data from the initial study were significantly limited. The sample areas from the study were not random. Volume estimates for the initial study were based solely on ocular estimates. Additionally, slide locations were mapped onto transparent overlays of aerial photographs. Slide locations from these data would be difficult to determine and transfer to our GIS as the overlays used for mapping did not capture any sort of reference markers such as the photograph fiducials. As a result we did not include these data in this project.

Table 6 outlines a comparison of the initial maximum SSS buffer distance and slope gradient triggers with the revised SSS buffer criteria. The majority of the maximum buffer widths decreased compared with the preliminary prescriptions while nearly one third increased in width. As for the slope triggers, just over half of the slope gradients decreased, nearly half had no change, and a few, in the Coastal Klamath, resulted in increased slope gradient triggers. Modeling potential SSS areas across the ownership, we estimate the new prescriptions will reduce the amount of SSS applied to streamside slopes by roughly 20 percent compared with the initial default prescriptions. A decrease was anticipated as the initial default prescriptions were created from a dataset that was intended to produce conservative values in the interim, until a full evaluation of steep streamside slopes could be completed under the SSS Delineation project.

The resulting slope distances and slope inclinations presented in table 6 highlight a need for flexibility of the prescriptions across much of the landscape. However, geomorphic characteristics were fairly homogenous in the southern portion of the ownership. As discussed earlier we explored the use of the SSSMU's across these areas but found little to no variation in the TRI model data or the landslide data. Additionally we attempted to further subdivide the Korbel HPA Group even more but found no significant subdivision within the HPAs that would justify separate SSS prescriptions. Although the bedrock geology varies throughout the Korbel HPA Group, average slope inclinations are fairly consistent. In fact, we evaluated the average slope inclination for each of the HPAs within the Korbel HPA Group. For this evaluation we looked at all slopes over 20 percent in order to eliminate low lying slopes such as streams and prairies where landslides are rarely found. The lowest slope gradient we observed a landslide on was 24 percent. Reviewing these slope gradients we found that the average slope inclination varies by no more than four, between any given HPA. Additionally the standard deviation of the average slope between these HPAs is also similar and does not vary by more than 4 percent. This shows that slope inclinations are fairly consistent in these areas. Hence, we may expect landslide run out lengths also should be similar across these areas. Given that we are assessing shallow landslides that largely involve fine grain materials such as colluvium and regolith; we can expect that the physical characteristics such as length and failure inclination would be fairly consistent and thus result in similar SSS prescriptions.

Table 5—Comparison of initial default SSS prescriptions to the revised SSS prescriptions

SSS maximum slope distances [m (ft)] and minimum slope gradient thresholds

Results from previous work: coastal Klamath HPA group

SSSMU	Class I	Class 2-2	Class 2-1
1	72 (240) @ 65%	34 (110) @ 70%	41 (135) @ 75%
2	130 (425) @ 75%	59 (195) @ 85%	
Initial default buffers	145 (475) @ 70%	61 (200) @ 70%	30 (100) @ 70%

Results from current work

Smith River HPA group

Watercourse c	Initial distance (ft)	Revised distance (ft)	Initial slope (%)	Revised slope (%)
C-I	46 (150)	30 (100)	65	65
CII-2	30 (100)	23 (75)		
CII-1	23 (75)	24 (80)		

Interior Klamath HPA group

Watercourse class	Initial distance (ft)	Revised distance (ft)	Initial slope (%)	Revised slope (%)
C-I	61 (200)	59 (195)	65	65
CII-2	61 (200)	30 (100)		
CII-1	23 (75)	27 (90)		

Korbel HPA group[a]

Watercourse class	Initial distance (ft)	Revised distance (ft)	Initial slope (%)	Revised slope (%)
C-I	61 (200)	41 (135)	-	-
CII-2	61 (200)	34 (110)	-	-
CII-1	23 (75)	32 (105)	-	-
Korbel	-	-	65	55
Humboldt Bay	-	-	60	

[a] Korbel HPA group includes; Mad River, North Fork Mad River, Little River, Coastal Lagoons, Redwood Creek, Humboldt Bay and Eel River HPAs.

Conclusions

The revised steep slope prescriptions were submitted to federal agencies in December 2014 and were successfully incorporated into the AHCP in January 2015.

Our analysis of landslides in the Smith River HPA, Interior Klamath HPA, and the Korbel HPA Groups has resulted in changes to both the slope distance and slope gradient criteria associated with the initial default SSS prescriptions across these areas. These new criteria offer specific protections to each Hydrologic Planning Area. The new default SSS buffers present a reduced encumbrance across the GDRCo ownership in comparison with the initial default prescriptions. A result that was not unexpected, as the initial study was intended to provide a rapid assessment with interim results that were intentionally biased towards areas known to be steep and with high concentrations of recent landsliding. Our sampling methods significantly reduced bias and spatially distributed the samples across the HPAs such that we were able to produce a robust data set that more accurately characterizes the geomorphic conditions of the region as they pertain to streamside landsliding.

The goal of the SSS buffer prescriptions is to achieve a 70 percent reduction in management-related sediment delivery from landslides compared to delivery volumes from landslides in appropriate historical clearcut reference areas. The significant reduction in landslide occurrence observed in aerial photographs over the last 18 years suggests that this goal set forth in the AHCP is achievable. It is our judgment that these new default buffer prescriptions will help meet this goal. If we consider that the SSS landslide data set consists almost entirely of historical landslides that occurred under historical logging practices that no longer exist (i.e., historical tractor logging, steam donkey logging, reduced or no riparian management zones), we expect to see a natural decrease in landslide related sediment over time and our preliminary review of historical erosion rates supports this. Additionally, since the implementation of the AHCP in 2007, much has been done to improve management practices such as implementing our AHCP Riparian Management Zones and road management measures, as well as adopting less impactful logging methods such as shovel yarding. Therefore we expect that the revised prescriptions will achieve the SSS goal identified in the AHCP due to our site specific preventative landslide prescriptions in conjunction with the much improved forest practices currently applied to this property. It should be emphasized that the effectiveness of these new prescriptions will be tested through the SSS Assessment study, which will be reviewed by an independent scientific review panel and modified as necessary through the adaptive management process of the AHCP.

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