



WASHINGTON FOREST LAW CENTER

615 Second Avenue, Suite 360  
Seattle, WA 98104  
www.wflc.org

Tel: 206.223.4088  
Fax: 206.223.4280

October 1, 2009

Daniel S. Fulton, President and CEO  
Weyerhaeuser Company  
P.O. Box 9777  
Federal Way, WA 98063-9777

Guillaume Gignac, Manager, Strategic Products & Forestry  
QMI-SAI Global  
865 Ellingham Road  
Pointe Clarie, Quebec, CA H9R 5E8

**Re: Sustainable Forestry Initiative (SFI) Non-Conformance Complaint –  
Weyerhaeuser Forest Practices – Logging on Steep and Unstable Slopes  
In Lewis and Pacific Counties, Washington State**

Dear Messrs. Fulton and Gignac:

**Abstract**

We represent Sierra Club. The purpose of this letter is to initiate, on behalf of Sierra Club, a Sustainable Forestry Initiative (SFI) non-conformance complaint and inquiry to the Weyerhaeuser Company (Weyerhaeuser) under SFI's Audit Procedures and Qualifications (APQ) 8.2. This complaint presents science-based evidence that Weyerhaeuser's forest practices within the Upper Chehalis and Stillman watersheds in southwest Washington are not compliant with the SFI standards. We demonstrate that Weyerhaeuser's clearcutting and road-building on steep slopes in these watersheds was associated with a high concentration of landslides, which contributed to record flooding and damage of the

Chehalis River basin during the December 2007 storm. First, we identify the scientific information and methods available to Weyerhaeuser when it made its decisions to harvest unstable slopes, and then we assess the extent to which its forest practices reflect this information. In essence, Weyerhaeuser's forest practices were highly inconsistent with Best Available Science, and its failure to use Best Available Science contributed to major damage downstream. Despite Weyerhaeuser's acknowledgement that this area is "a landscape vulnerable to mass wasting," Weyerhaeuser harvested forests and built roads on thousands of acres of slopes that had a high hazard rating, probable stream delivery rating, a history of landsliding in the past, high slope instability, high soil erosion potential, and in peak rain-on-snow zones. Landslide densities inside Weyerhaeuser harvest and road-building units were consistently higher than landslide densities on neighboring private industrial forest lands with comparable precipitation, lithology, stand age, and slope instability. This relationship holds when all variables were included in a logistic regression model: the odds of sliding on Weyerhaeuser lands were 2.2-2.7 times the odds of sliding on other private industrial forest lands in the study area while holding all other variables constant. Further, we provide evidence that wood and sediment from these landslides exacerbated the flooding and associated damage downstream. The flood caused more than \$57 million in property damage to homes, farms and businesses. Finally, we describe how Weyerhaeuser's forest practices violated the SFI standards, and we request relief from SFI to prevent further soil loss, unnaturally high rates of landsliding, degradation of water quality, and economic, environmental, and social devastation associated with the flooding that resulted from these violations.

## **Introduction**

This SFI non-conformance complaint and inquiry is brought under SFI's APQ 8.2 and pertains to Weyerhaeuser's widespread logging and road-building on steep slopes known to be unstable in the Upper Chehalis and Stillman watersheds in southwest Washington. These forest practices led to a high concentration of landslides, and contributed to record flooding and damage of the Chehalis River basin during the December 2007 storm. In this complaint, we present science-based evidence of Weyerhaeuser's noncompliant forest practices within these two watersheds. The complaint is organized as follows:

- I. Best Available Science for Preventing Landslides on Steep and Unstable Forested Slopes.
- II. Consistency of Weyerhaeuser's Forest Practices with Best Available Science.
  - A. Mass Wasting Hazard and Delivery.
  - B. Slope Instability.
  - C. Soil Erosion Potential.
  - D. Rain On Snow Zones.
- III. Univariate Correlates of Landslide Density.
  - A. Landslide Density and Precipitation.
  - B. Landslide Density and Lithology.
  - C. Landslide Density and Stand Age.
  - D. Landslide Density and Slope Instability.
- IV. Multivariate Landslide Model.
- V. Failure to use Best Available Science Contributed to Major Damage Downstream.

VI. Weyerhaeuser's Noncompliance with the SFI Standards.

- A. Weyerhaeuser's forest practices fail to conserve soil or protect soil productivity.
- B. Weyerhaeuser does not appropriately identify or manage geologically important areas.
- C. Weyerhaeuser does not adequately plan for wet-weather events.
- D. Weyerhaeuser does not replant all of the forests it harvests.
- E. Weyerhaeuser does not adequately protect riparian zones.
- F. Weyerhaeuser does not comply with state water quality standards.
- G. Weyerhaeuser's forest practices are not economically, environmentally, or socially responsible.

VII. Request for Relief.

**I. Best Available Science for Preventing Landslides on Steep and Unstable Forested Slopes.**

It is well-established in the scientific literature that clearcut areas are more prone to slope failure than forested areas. Many studies have shown the number, density, and volume of landslides is significantly higher on clearcuts relative to unlogged areas (Gresswell *et al.* 1979, Pentec 1991, Benda *et al.* 1998, Robison *et al.* 1999, Montgomery *et al.* 2000, Guthrie 2002, May 2002). For example, the frequency of debris torrents in clearcuts increased 4-9 times relative to the frequency in forested areas (Swanson & Lienkaemper 1978). Relative to intact forests, debris flows in cleared forests are more frequent after a 20 percent increase in rainfall intensity (Franklin *et al.* 2000). Slumps and slump-earthflows can be reactivated or accelerated after being harvested (Swanston 1981, Ziemer 1984, Benda *et al.* 1988, Swanston *et al.* 1988).

Landslides in clearcuts are more likely to deliver to streams, and to impair water quality with episodic and chronic sedimentation, than landslides in forested areas. For instance, in Alaska, Johnson *et al.* (2000) showed that the proportion of landslides and debris flows that flowed into steep first order through third order channels was 9/9 (100 percent) in clearcuts, 4/9 (44 percent) in second growth forests, and 1/9 (11 percent) in old growth forests. Logging-related landslides in British Columbia reached 7-13 times more streams than natural landslides (Guthrie 2002). “Replacement of a mature forest along channels by a young alder forest following clearcutting increases the potential for migrating organic dams” (Benda *et al.* 1998). Debris flows in clearcuts travel farther than debris flows in forested environments (Ketcheson and Froelich 1978), which increases the likelihood of delivery to streams. Debris flows elevate turbidity downstream (FPB 2004) and negatively affect aquatic species. For example, Cederholm & Lestelle (1974, p. xiii) showed “populations of benthic organisms were significantly (1 percent level) lower in landslide-affected areas of Stequaleho Creek compared to landslide-unaffected areas.”

Fortunately, methods are available to identify unstable areas and minimize landslide rates in forested landscapes. Potentially unstable slopes can be identified using two general methods (Benda *et al.* 1998). The first group of methods includes informal field examination on a case-by-case basis. This process utilizes standard techniques for evaluating maps such as aerial orthophotos, topographic maps, and Digital Elevation Models (DEMs). The scientific literature also contains extensive guidance for the evaluation of slope instability in the field, some of which is specific to this region (Chatwin *et al.* 1994, Benda *et al.* 1998) and to Washington State (FPB 2004). The efficacy of field examinations depends on the level of training of those people responsible

for identifying unstable slopes. For example, Forest Practices Foresters (WDNR staff) are trained to classify Forest Practices Applications (FPAs) in part according to the presence of unstable landforms in the proposed harvest unit, so that further environmental (SEPA) review is triggered when appropriate. If road construction or timber harvest is proposed on potentially unstable slopes or landforms, the applicant must submit a report prepared by a qualified expert to determine whether the forest practices are likely to have a significant adverse impact (WAC 222-10-030(1)). A qualified expert is “a person licensed under chapter 18.220 RCW as either an engineering geologist or as a hydrogeologist (if the site warrants hydrologist expertise), with 3 years of field experience in the evaluation of relevant problems in forested lands” (WAC 222-10-030(5)). If the potentially unstable slopes or landforms have the potential to deliver sediment or debris to a public resource or to threaten public safety, the FPA is classified as Class IV – Special (WAC 222-16-050 (1)(d)) and an environmental impact statement (EIS) is required. If prior Watershed Analysis prescriptions are applied to a proposed harvest unit, then WDNR Foresters rely largely on the expertise of the people who wrote the Watershed Analysis prescriptions in the past. Unfortunately, these were not always the same people who wrote the Mass Wasting Assessment section of Watershed Analysis, who were typically either independent environmental consultants or on-staff geologists of the timber company that owns the watershed (C. Mendoza, pers. comm.). The FPA evaluation and approval system is designed to provide ample opportunity for qualified experts to assess slope stability in the field, but only a small proportion of FPAs are actually subjected to this level of scrutiny (C. Mendoza, pers. comm.).

The second group of methods available for identifying potentially unstable slopes consists of formal slope stability analyses conducted by specialized experts (Benda *et al.* 1998). These analyses yield screening tools and maps that indicate the locations of unstable areas across large spatial scales (as opposed to a case-by-case basis). At the most basic level are landslide inventory maps, which are valuable for identifying unstable slopes because areas that have slid in the past are likely to slide again (Swanston 1981, Ziemer 1984, Benda *et al.* 1988, Swanston *et al.* 1988). In Washington, the Landslide Inventory (LSI) GIS layer is a compilation of a variety of landslide data sets across the state (Boyd and Vaugeois 2003). The LSI has been available to the public since 2004 and is updated quarterly.

Slope stability across landscapes is also assessed formally in the Mass Wasting Assessment section of Watershed Analyses (WAC 222-22-030). This assessment typically includes an inventory of former mass wasting events, designation and mapping of Mass Wasting Map Units (MWMU), determination of the sensitivity of each MWMU to forestry activities, and rating of level of hazard associated with each MWMU. These MWMU are compiled with many other sources of landslide hazard data into the State's HAZONE GIS layer by the landslide hazard zonation project (WDNR 2003). This relatively comprehensive data set indicates the potential for instability, the ability to deliver debris to a resource or threaten public safety, and the sensitivity to forest practices of each mapped landform or polygon. HAZONE has been available to the public since 2003 (updated quarterly) and will eventually have state-wide coverage.

Another GIS-based screening tool is the SLPSTAB model, which predicts shallow-rapid landslide potential with 93 percent accuracy and covers all forested watersheds of western Washington (Shaw and Vaugeois 1999). It is intended to be used for pre-

classification screening of FPAs for slope stability concerns on managed timberlands and is a feature viewable to the public on the online Forest Practices Application Review System (FPARS) resource maps (WDNR 2007).

Also available is the Washington State Soil Survey GIS layer, which maps soil erosion potential and mass wasting potential across landscapes (WDNR 2000).

The final publicly available tool for predicting landslide potential is the Rain-On-Snow GIS layer (WDNR 1991). Because “hydrologically immature” areas (such as recently-harvested, open, and less dense forests) generally accumulate greater snowpack, generate more rapid snow melt, and create higher peak flows during rain-on-snow conditions, they are most susceptible to significant hillslope and stream channel erosion (Weyerhaeuser 1994b). The statewide Rain-On-Snow GIS layer defines five zones based on climate, elevation, latitude, and vegetation (WDNR 1991).

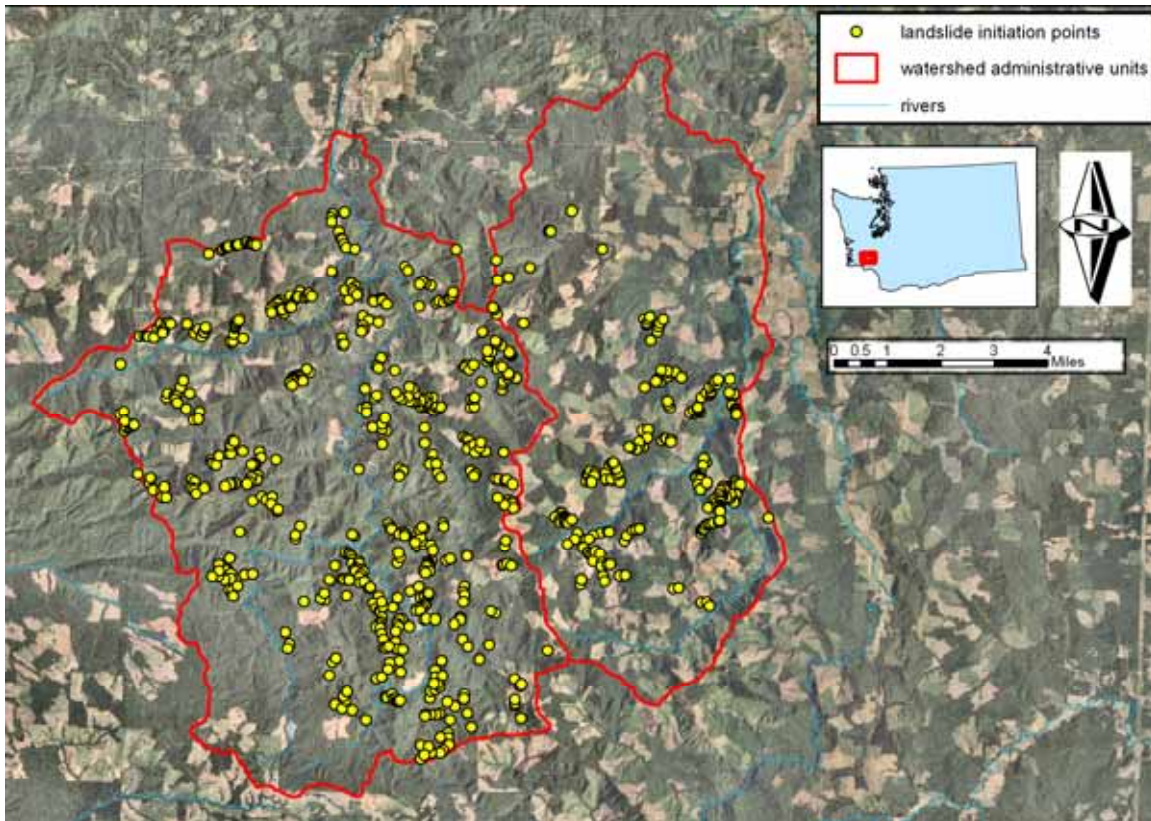
This wide variety of FPA screening tools can be especially useful in identifying unstable slopes that are not easily recognizable “rule-identified” landforms but should nonetheless be classified and evaluated as Class IV - Special, defined in WAC 222-16-050(1)(d)(E) as “Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes” (emphasis added).

## **II. Consistency of Weyerhaeuser’s Forest Practices with Best Available Science.**

Given the regulatory requirements and abundance of screening tools and maps available to the public for identifying unstable slopes outlined above, we now evaluate the extent to which Weyerhaeuser’s forest practices reflect the use of this information. This analysis is restricted to Weyerhaeuser ownership in a sampled area of two Watershed Administrative Units that showed a high concentration of landslides after the December 2007

storm: the Upper Chehalis watershed and the Stillman Creek watershed (Fig. 1). The majority of the landslides documented after the storm occurred in these two watersheds, and of these roughly three-quarters occurred in the Upper Chehalis watershed (Table 1). We used two GIS maps of landslides from WDNR's post-storm inventory (Sarikhani *et al.* 2008). Landslide initiation points are locations where landslides began (WDNR 2009a). Landslide processes (polygons) also include the remobilization of material and count debris avalanches (mostly soil, rock, and vegetation) and debris flows (more water added, usually upon entry to a stream) separately (WDNR 2009b). In other words, if a debris avalanche delivered into a stream, dammed a creek, and later remobilized as a debris flow before it finally came to rest, WDNR considered these to be two separate landslide processes.

We used several factors to delineate the study area for this analysis. WDNR conducted landslide reconnaissance flights that "were focused on the general storm track and areas that experienced the greatest precipitation" (Sarikhani *et al.* 2008). To determine the area subject to equal sample effort in detecting landslides after the storm, we created a 9000 ft. buffer around WDNR's flight paths. This distance was verified by I. Sarikhani (WDNR) as the extent visible on photos taken during the flight given the light conditions and topography. We also restricted the study area to only those land cover classes found in industrial forest lands, which included deciduous, evergreen, and mixed forest, barren land, shrub/scrub, herbaceous, woody wetlands, and developed open space (Homer *et al.* 2004). These combined methods captured all but one landslide in the study area and included a total area of 74,225 acres.



**Figure 1.** Upper Chehalis (left) and Stillman watersheds (right) and the initiation points of landslides that occurred after the December 2007 storm (WDNR 2009a).

**Table 1.** After the storm, WDNR inventoried landslide initiation points (WDNR 2009a) and landslide processes (WDNR 2009b) statewide, most of which occurred in two watersheds owned primarily by Weyerhaeuser.

	<b>Upper Chehalis</b>	<b>Stillman</b>	<b>Total Weyco.</b>	<b>Total (storm)</b>
landslide initiation points	554	217	756 (59%)	1273
landslide processes	954	331	1259 (64%)	1962

Landslides were not evenly distributed across the landscape, but rather varied with stand age and road association (Table 2). As expected, the greatest proportion of landslide processes occurred on units clearcut-harvested within the past five years (32 percent), and the lowest proportion of landslide processes occurred in mature stands (0 percent). Less expected were the higher rates of landslide processes in submature stands (23 percent) and at roads within submature stands (26 percent), but this may have been due to the inclusion of hydrologically immature stands (younger than 25 years) in these categories. The lack of young stands (5-15 years old) and mature timber (50+ years old) within these watersheds might explain the lower proportion of landslides in those categories (Sarikhani *et al.* 2008). According to our estimates, only 10 percent of the study area consists of young stands, and only 4 percent of the study area consists of mature stands (LEMMA 2009). In addition, the number of landslides may have been underestimated within the small area of mature timber because up to 85 percent of landslides in heavily forested areas may be omitted from inventories that are conducted primarily using aerial photos (Brardinoni *et al.* 2003). Overall, 749 (59 percent) landslide processes were harvest-related, one (0.1 percent) was road-related, 497 (39 percent) were harvest- and road-related, and 12 were of unknown origin (Table 2).

**Table 2.** Proportion of landslide processes (WDNR 2009b) by stand age and road association in the Upper Chehalis and Stillman Creek watersheds.

<b>Stand age/road association</b>	<b># landslides</b>	<b>% landslides</b>
0-5 years (clearcut)	402	32
5-15 years (young stands)	58	5
15-50 years (submature stands)	289	23
50+ years (mature stands)	0	0
clearcut and road associated	9	1
submature and road associated	25	2
road or yarding association	1	0
road within a clearcut	117	9
road within a young stand	13	1
road within a submature stand	333	26
unknown	12	1
<b>total</b>	<b>1259</b>	<b>100</b>

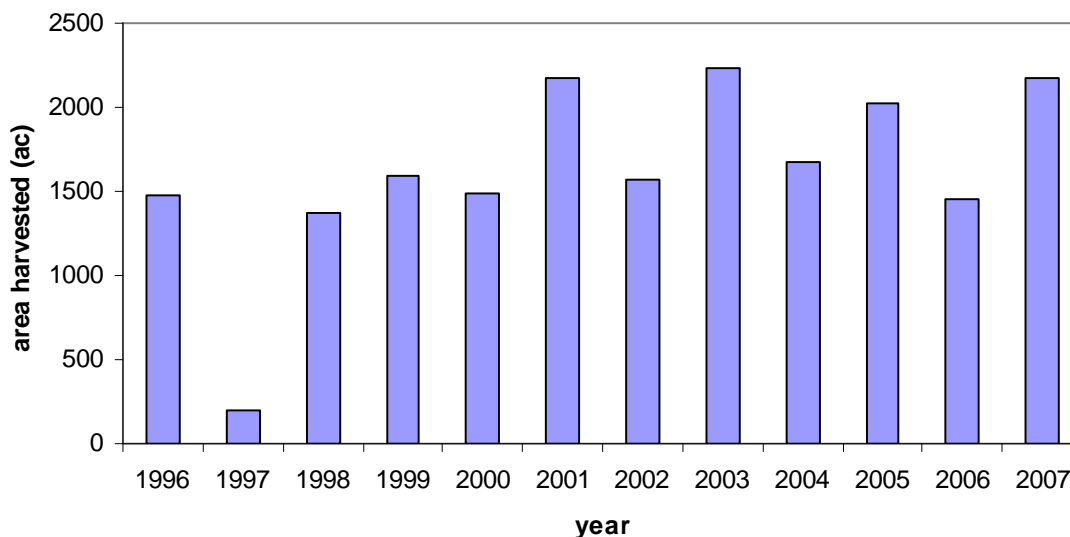
Weyerhaeuser conducted case-by-case field examination of potentially unstable slopes using a variety of methods. The first, most obvious source of information is the Watershed Analysis (WSA) Mass Wasting Assessment completed for each watershed in 1994 (Weyerhaeuser 1994a, 1994b). Each WSA was written by a “certified analyst” (a consulting firm scientist for the Stillman watershed, and a Weyerhaeuser geologist for the Upper Chehalis watershed). The mapped MWMU and prescriptions from the WSA should have been identified for each proposed harvest unit. In a sample of nine FPAs (2510567; 2500534 (unit 2); 2511805; 2510122; 2511943; 2508791; 2509024; 2510971; 2910347; WDNR 2006), the use of WSA prescriptions was indicated in some, but not all, cases. In all nine cases, FPAs were Class III (no SEPA review required), and Weyerhaeuser stated that “the harvest unit was field reviewed by a qualified geologist and no potentially unstable areas were found” (emphasis added). Four of these nine FPAs included formal geologist’s reports in which slope stability was assessed in the field and on aerial photos.

In some cases, unstable leave areas were designated. Despite the availability of this and other information on landslide potential, a total of 69 landslides initiated within these nine FPA harvest units.

Although we do not know the extent to which Weyerhaeuser used screening tools and maps to identify potentially unstable areas on its harvest units, we do know what screening tools and maps were available at the time Weyerhaeuser mapped its harvest units (Table 3). Here we use these tools to assess how consistent Weyerhaeuser's forest practices were with these sources of Best Available Science. Given the effects of forest practices on landslide rates, we evaluated landslide density both inside and outside of areas approved for forest practices (FPAs, include harvest units and roads). We defined these areas according to the publicly available FPA GIS layer (WDNR 2006) and areas mapped as harvested by Pierce et al. (2005) since 1996. The year 1996 is the earliest extent of FPA mapping by WDNR in GIS, fits the 4-year harvest categories defined by Pierce et al. (2005), and is well after Weyerhaeuser's watershed analyses were completed in the study area (1994). Restricting the analysis to the 11 years before the storm makes this a conservative estimate of the effects of logging on mass wasting, because forests are not typically considered hydrologically mature until they are 25 years old. Within this 11-year period, Weyerhaeuser harvested 1620 acres per year on average within the Upper Chehalis and Stillman watersheds (Fig. 2).

**Table 3.** Sources of Best Available Science with spatial information on landslide susceptibility.

<b>Data</b>	<b>Metric</b>	<b>Source</b>	<b>Year</b>
Rain on Snow	rain on snow zones	WDNR	1991
Watershed Analyses	hazard and delivery ratings	Weyerhaeuser	1994
SLPSTAB	slope instability model	Shaw and Vaugeois	1999
Washington State Soil Survey	soil erosion potential	WDNR	2000
Hazone	slope instability	WDNR	2003
Landslide Inventory (LSI)	landslide locations	Boyd and Vaugeois	2004



**Figure 2.** Annual area logged by Weyerhaeuser in the Upper Chehalis and Stillman watersheds during the 11 years preceding the storm (WDNR 2006).

**A. Mass Wasting Hazard and Delivery.**

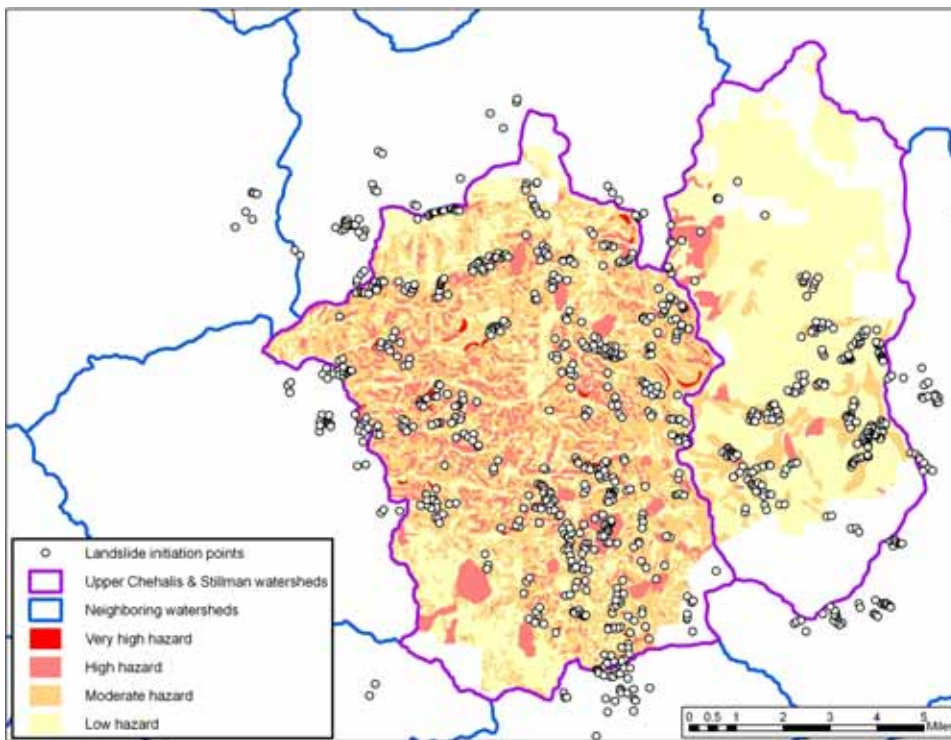
The first source of spatially explicit information on slope stability in these watersheds should have been the Mass Wasting Map Units (MWMU) from their Watershed Analyses (Weyerhaeuser 1994a, 1994b, WDNR 2003). Each MWMU is rated by the level of mass wasting hazard (low, moderate, high, or very high; Fig. 3) and the

probability of delivery of sediment to a public resource (possible, probable, or immediate and certain; Fig. 4). Despite having access to these hazard and delivery ratings maps, in the 11 years preceding the storm Weyerhaeuser has logged trees and/or built roads on 1771 acres with a high hazard rating (20 percent of the area rated as such) and 987 acres with an immediate and certain probability of delivery (14 percent of the area rated as such, Table 4). As expected, landslide density increased with hazard and delivery rating categories of increasing risk when all land was considered (Fig. 5, total). An exception to this pattern was in harvest and road-building units (FPAs) with a moderate hazard rating, where landslide density was the highest (Fig. 5). In all categories, landslide density was greatly elevated inside FPAs (with the exception of the very high hazard category, where no landslides occurred in FPAs in a 5-acre area). These results indicate that it should not be assumed that slopes rated with a moderate mass wasting hazard are stable after being harvested. After harvest, areas of moderate instability may become highly unstable until they reach hydrologic maturity. The intensity and extent of forest practices on these slopes should reflect this information.

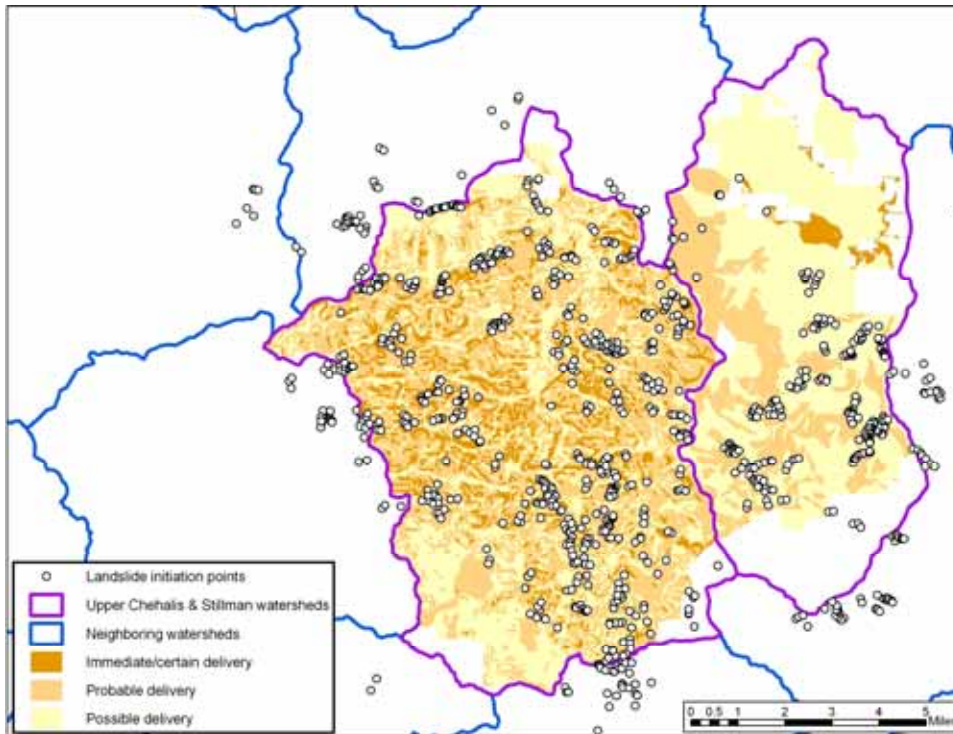
**Table 4.** Area with forest practices (FP) from 1996-2007 by MWMU hazard and delivery rating.

	<b>FPA acres</b>	<b>total acres</b>	<b>% area with FP</b>
hazard rating			
low	11504	30462	38%
moderate	5134	23544	22%
high	1771	8917	20%
very high	5	262	2%
delivery rating			
possible	9965	27148	37%
probable	7462	28969	26%
immediate and certain	987	7067	14%

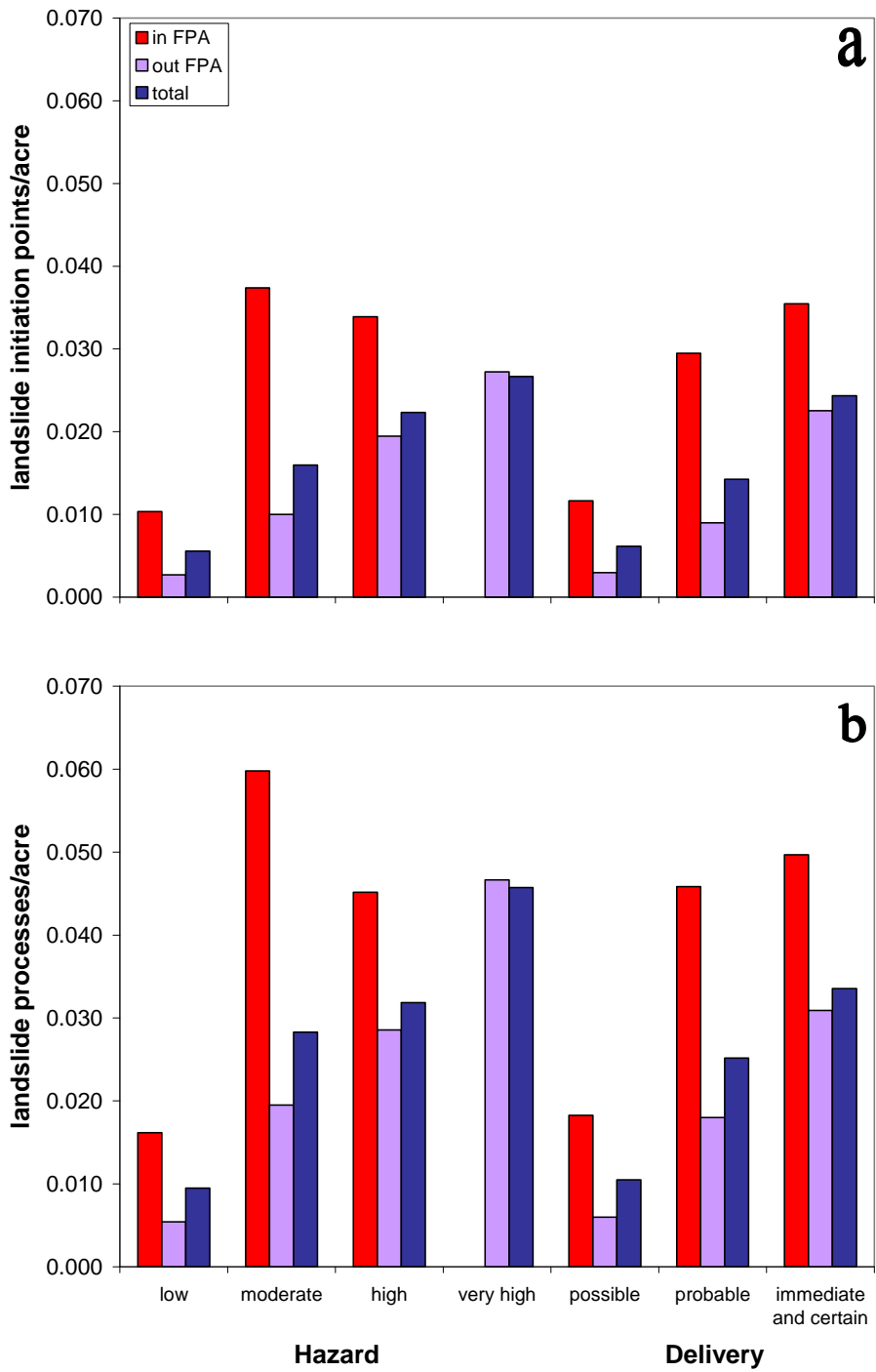
Previous slope failure is a good indicator of future susceptibility to failure. Fortunately, this is mapped in the Landslide Inventory GIS layer (Boyd and Vaugeois 2003, Fig. 6). Despite having access to this information, from 1996-2007 Weyerhaeuser conducted forest practices on 28 percent (841 of 2980 acres) of the area mapped as having failed before. In these areas 25 landslides initiated (LIP/ac = 0.03) and 33 landslide processes occurred (LP/ac = 0.04) during the December 2007 storm.



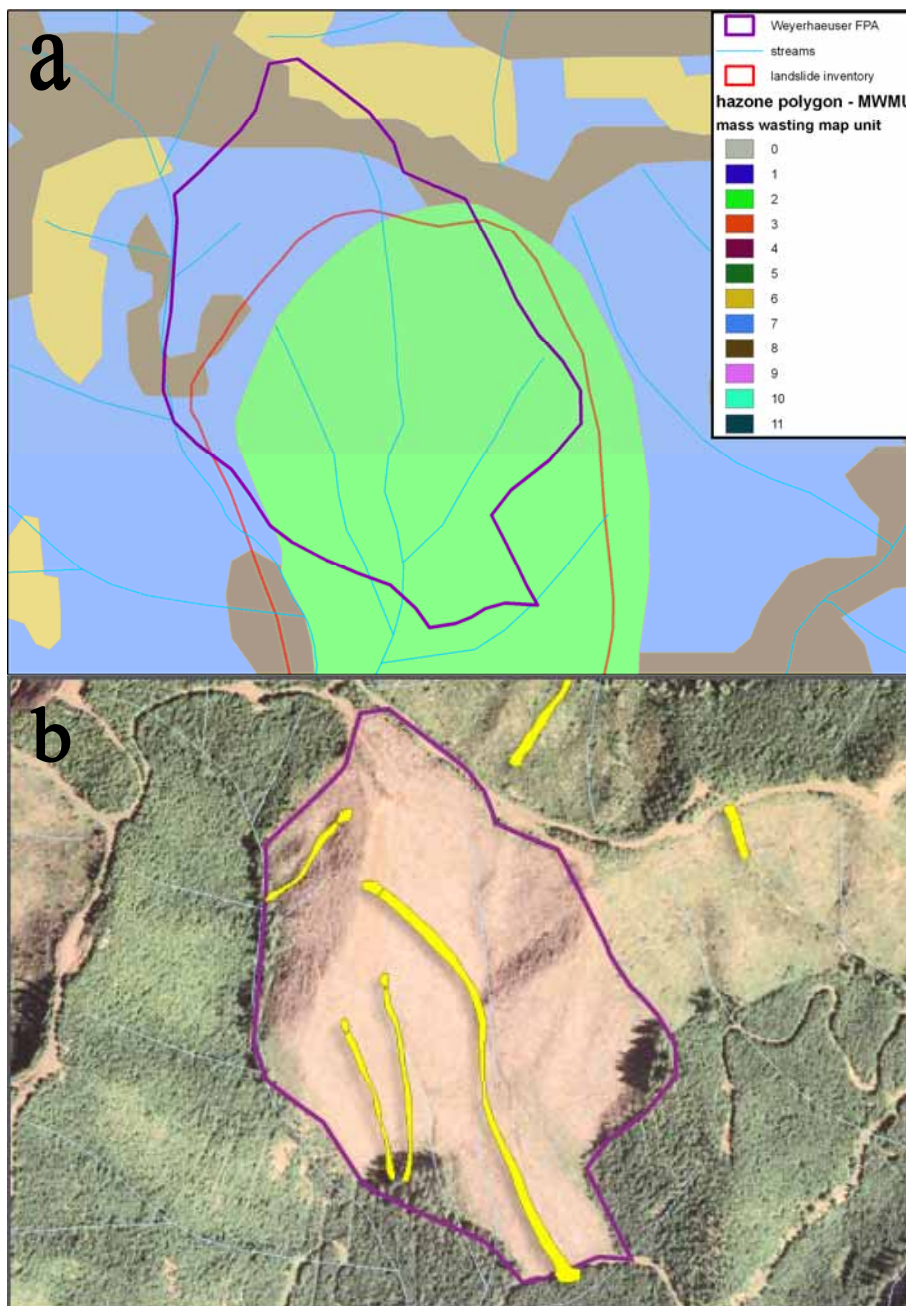
**Figure 3.** Mass Wasting Map Units (MWMU) by the level of mass wasting hazard (WDNR 2003).



**Figure 4.** Mass Wasting Map Units (MWMU) by the probability of delivery to a stream (WDNR 2003).



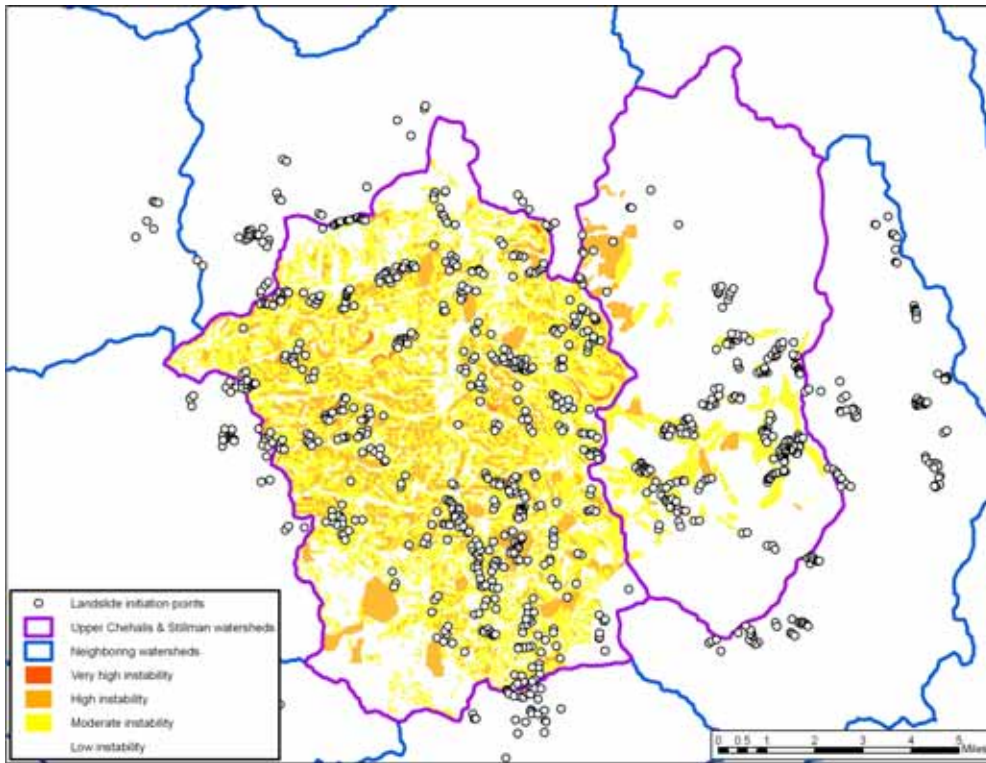
**Figure 5.** Relationship between MWMU hazard and delivery ratings and landslide density by forest practices derived from landslide initiation points (a) and landslide processes (b).



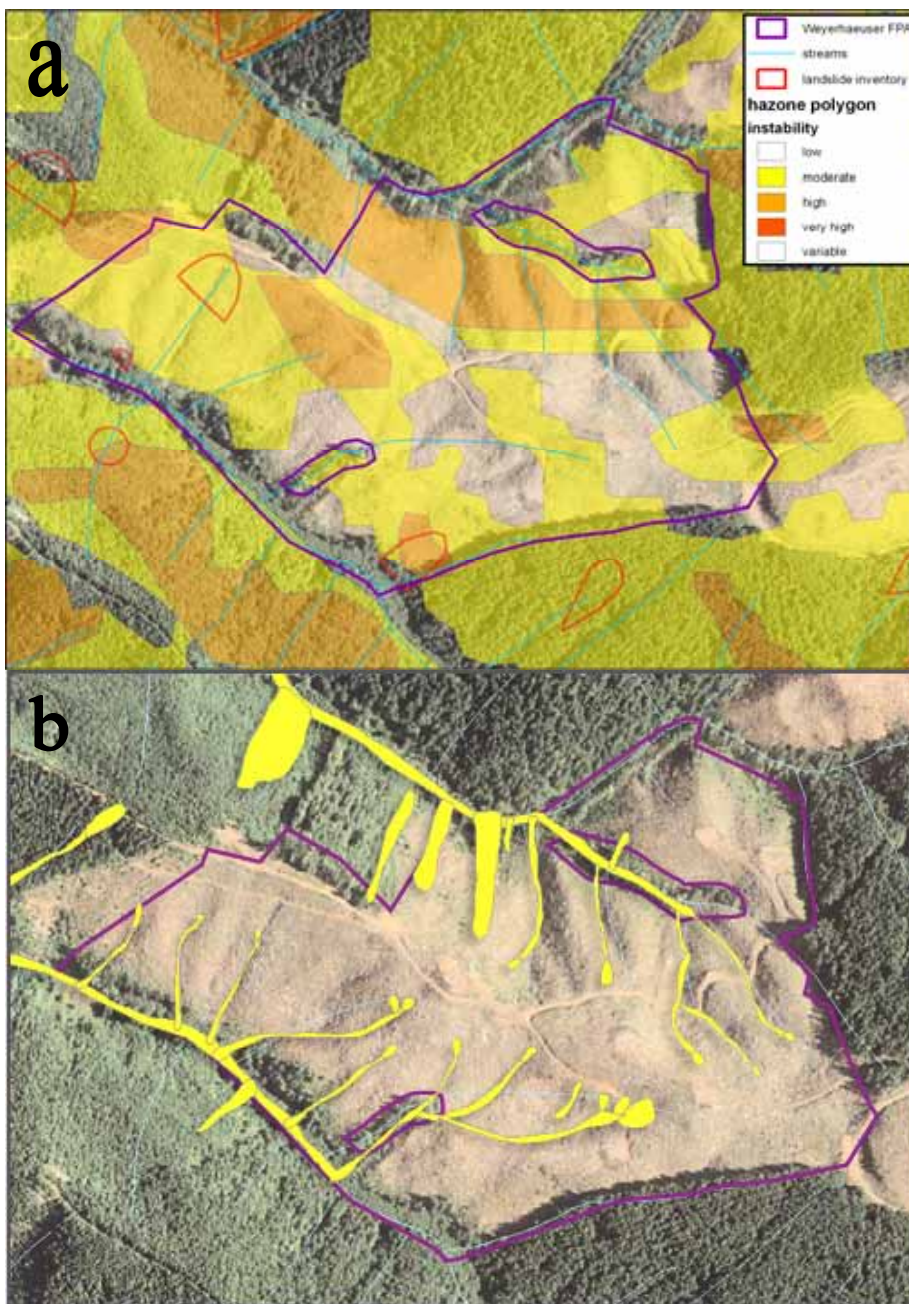
**Figure 6.** (a) 60-acre Weyerhaeuser clearcut (FPA 2511943, purple outline: WDNR 2006) of highly unstable, high hazard portions of an ancient landslide (MWMU 2 in green: WDNR 2003; red outline: Boyd and Vaugeois 2003) and (b) 8 landslide processes in harvest unit (yellow) polygons, WDNR 2009b) after the December 2007 storm.

## **B. Slope Instability.**

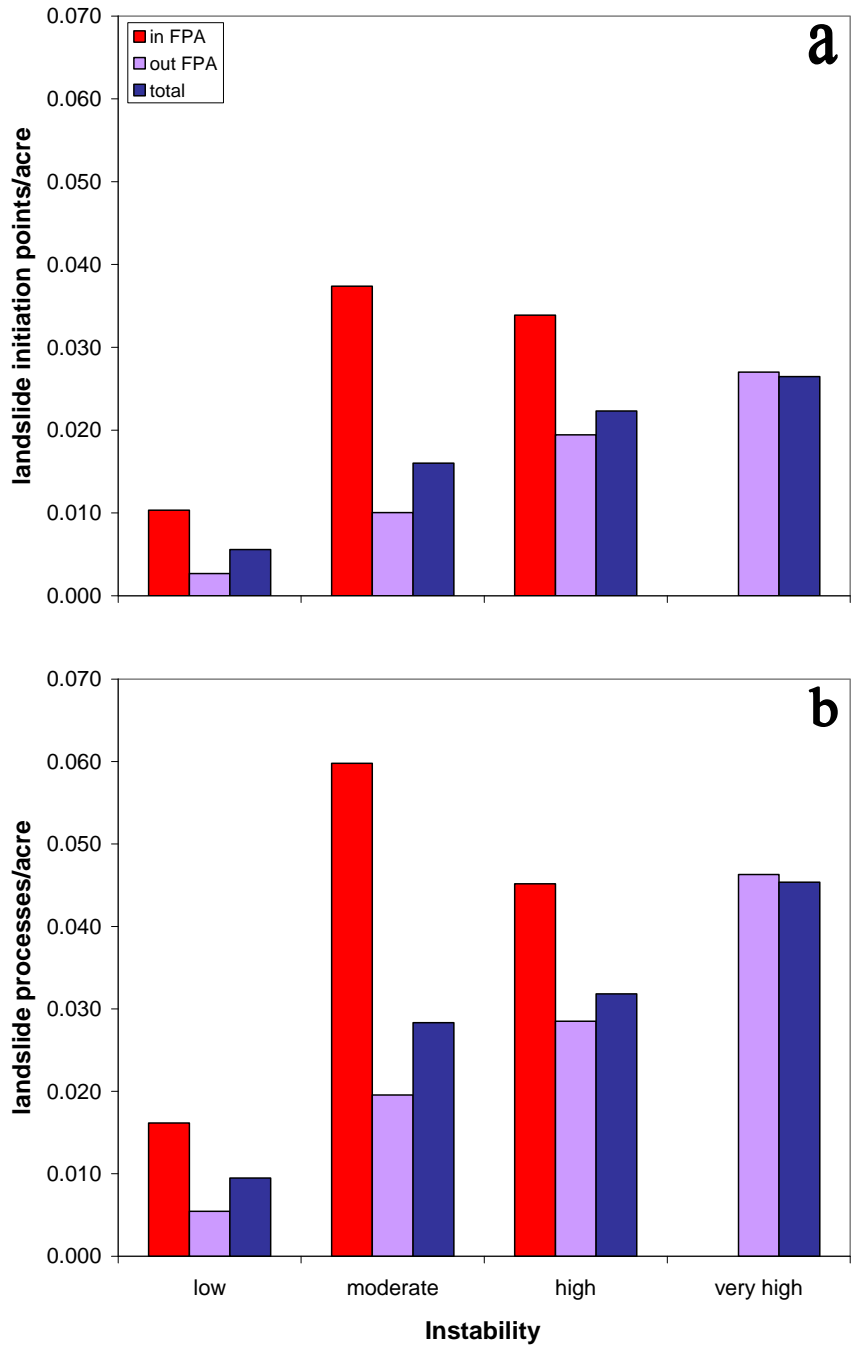
Another essential source of spatially explicit information on slope stability in these watersheds is the Hazzone GIS layer (WDNR 2003). The slope stability field in this dataset indicates areas of low, moderate, high, or very high instability, which can easily be mapped on proposed harvest unit areas (Fig. 7, 8). During the 11 years preceding the storm, Weyerhaeuser had clearcut and/or built roads on 1771 acres with high instability (20 percent of the area rated as such, Table 5). As predicted, landslide density increased with increasing instability ratings when all land was considered (Fig. 9, total). An exception to this pattern was in harvest and road-building units with moderate instability, where landslide density was the highest (Fig. 9). In all categories, landslide density was greatly elevated inside FPAs (with the exception of the very high hazard category, where no landslides occurred in FPAs in a 5-acre area). As above, slopes with moderate instability cannot be assumed to be stable in big storms, and harvest and road-building on slopes with moderate to high instability predictably resulted in higher landslide densities.



**Figure 7.** Slope instability ratings according to the Hazzone GIS layer (WDNR 2003).



**Figure 8.** (a) 108-acre Weyerhaeuser clearcut (FPA 2508791, purple outline: WDNR 2006) of areas of moderate and high slope instability (yellow and orange areas, respectively; WDNR 2003) and historic landslides (red outlines: Boyd and Vaugeois 2003) and (b) 37 landslide processes in harvest unit (yellow polygons, WDNR 2009b) after the December 2007 storm.



**Figure 9.** Relationship between slope instability and landslide density by forest practices derived from landslide initiation points (a) and landslide processes (b).

**Table 5.** Area with forest practices (FP) from 1996-2007 by Hazone slope instability categories.

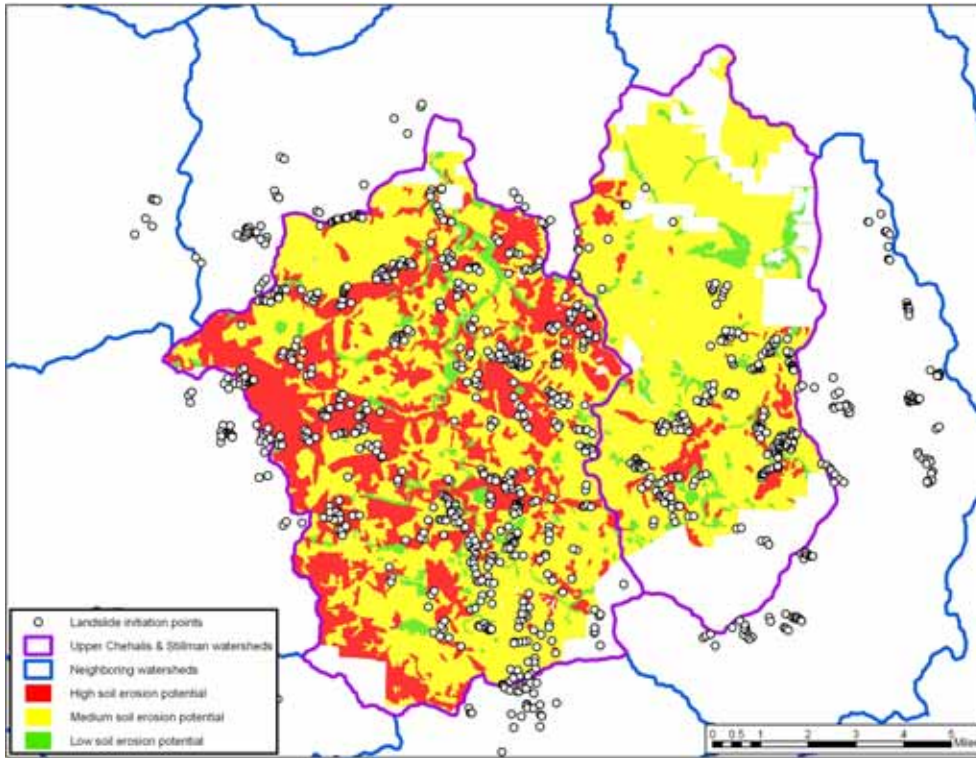
<b>slope instability</b>	<b>FPA acres</b>	<b>total acres</b>	<b>% area with FP</b>
low	11504	30466	38%
moderate	5135	23550	22%
high	1771	8924	20%
very high	5	264	2%

### **C. Soil Erosion Potential.**

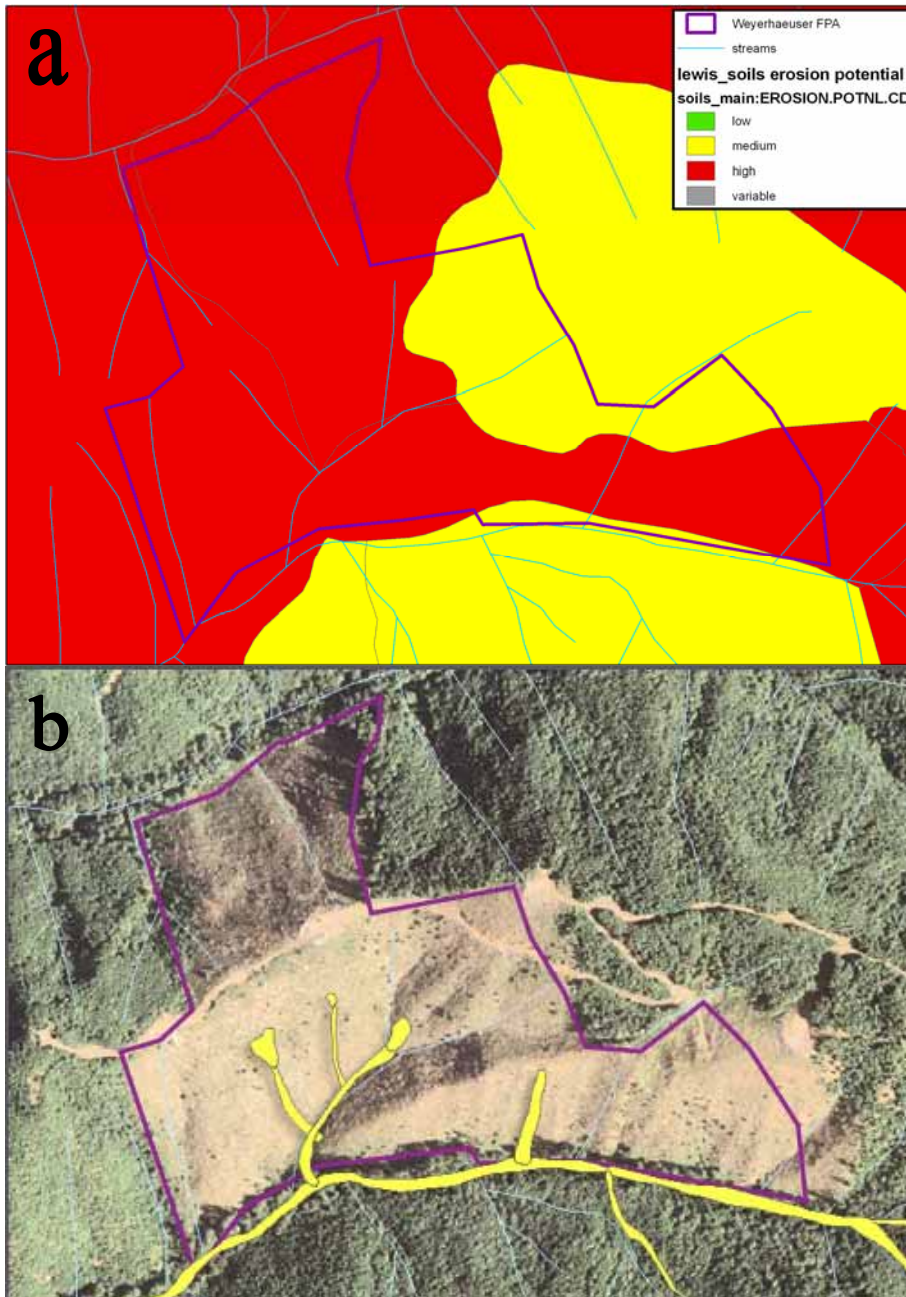
The state soil survey GIS layer also contains spatial data Weyerhaeuser could have used to assess the stability of slopes in proposed harvest units (WDNR 2000). For predicting landslide-prone areas, the erosion potential field can be mapped as low, moderate, or high (Fig. 10, 11). From 1996-2007, Weyerhaeuser had clearcut and/or built roads on 3461 acres with high soil erosion potential (19 percent of the area rated as such, Table 6). As expected, landslide density increased with increasing soil erosion potential regardless of forest practices (Fig. 12). In all soil erosion potential categories, landslide density was greatly elevated inside FPAs, and the highest densities were inside FPAs with high soil erosion potential. As with other tools examined thus far, harvest and road-building on slopes with high soil erosion potential predictably resulted in higher landslide densities.

**Table 6.** Area with forest practices (FP) from 1996-2007 by soil erosion potential categories.

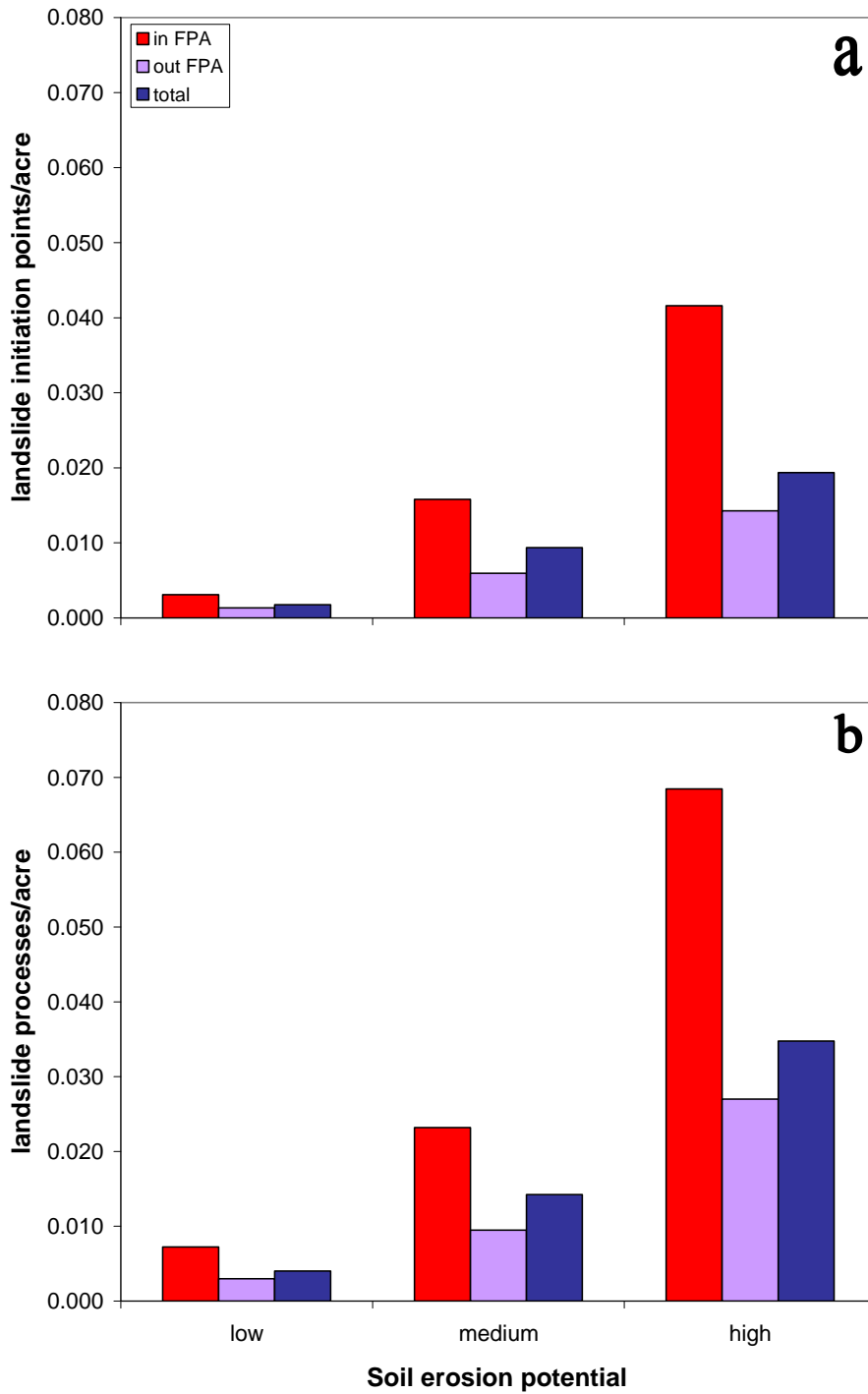
<b>slope instability</b>	<b>FPA acres</b>	<b>total acres</b>	<b>% area with FP</b>
low	967	3973	24%
moderate	14227	41111	35%
high	3461	18532	19%



**Figure 10.** Soil erosion potential (WDNR 2000).



**Figure 11.** (a) 67-acre Weyerhaeuser clearcut (FPA 2510122, purple outline: WDNR 2006) on slope with high soil erosion potential (red, WDNR 2000) and (b) 8 landslide processes within the harvest unit (yellow polygons, WDNR 2009b) after the December 2007 storm.



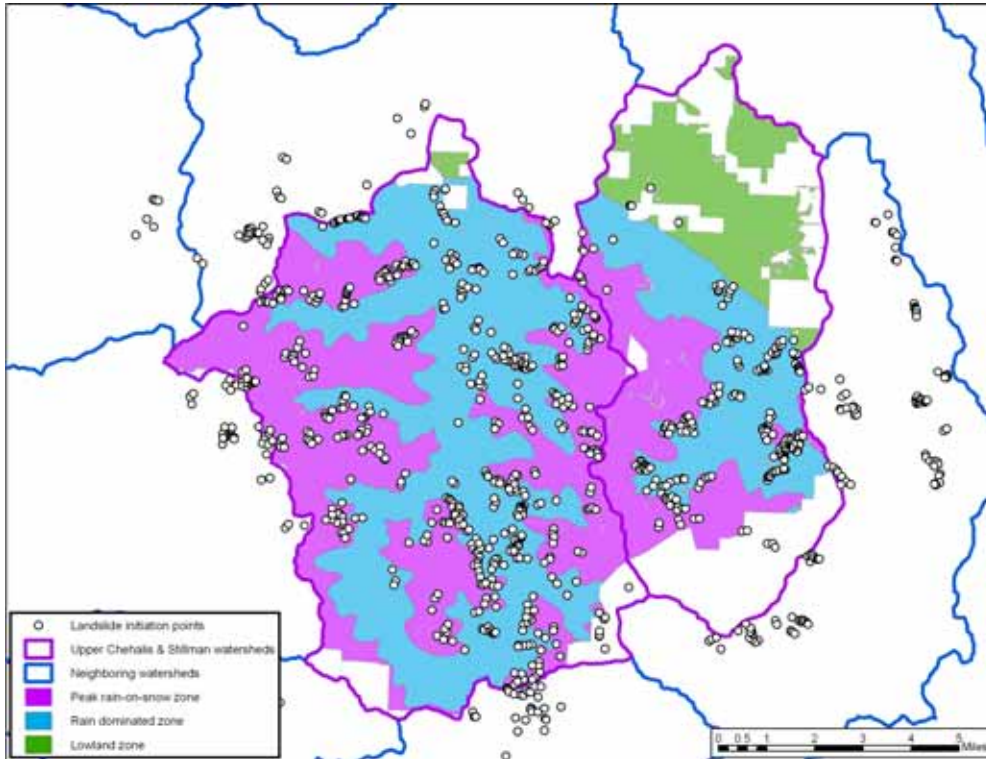
**Figure 12.** Relationship between soil erosion potential and landslide density by forest practices derived from landslide initiation points (a) and landslide processes (b).

#### **D. Rain On Snow Zones.**

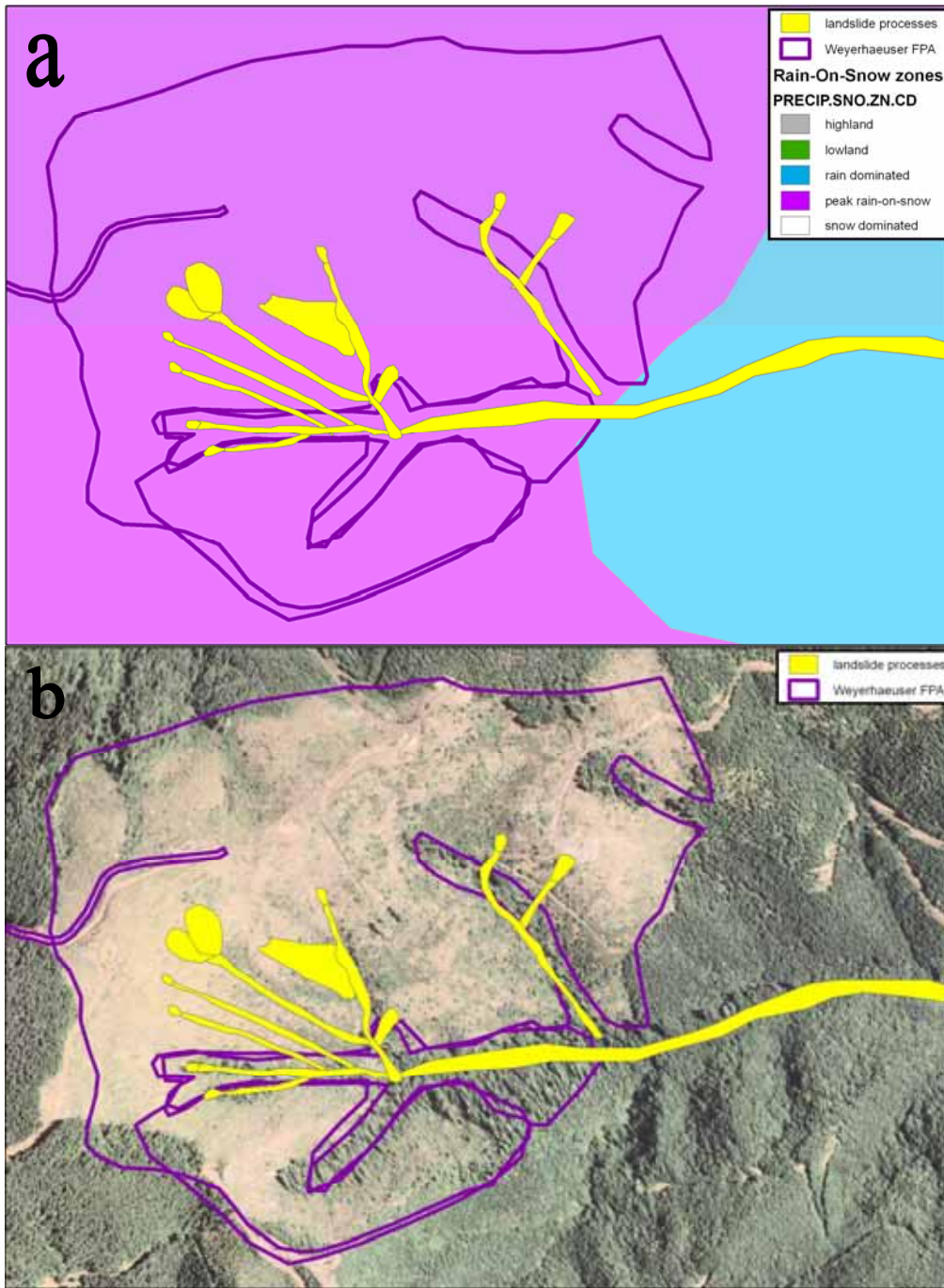
The final publicly available tool we assessed that Weyerhaeuser could have used to predict landslide potential is the Rain-On-Snow GIS layer (WDNR 1991). For predicting areas susceptible to high peak flows and hillslope erosion, the rain/snow accumulation field can be mapped as highland, lowland, rain dominated, peak rain-on-snow, and snow dominated zones (Fig. 13, 14). In the eleven years preceding the storm, Weyerhaeuser had clearcut and/or built roads on 7610 acres in peak rain-on-snow zones (28 percent of the area rated as such, Table 7). In December 2007, nearly all landslides occurred in the rain-dominated and peak rain-on-snow zones, and the highest landslide densities were inside FPAs in these two zones (Fig. 15).

**Table 7.** Area with forest practices (FP) from 1996-2007 by rain-on-snow zones.

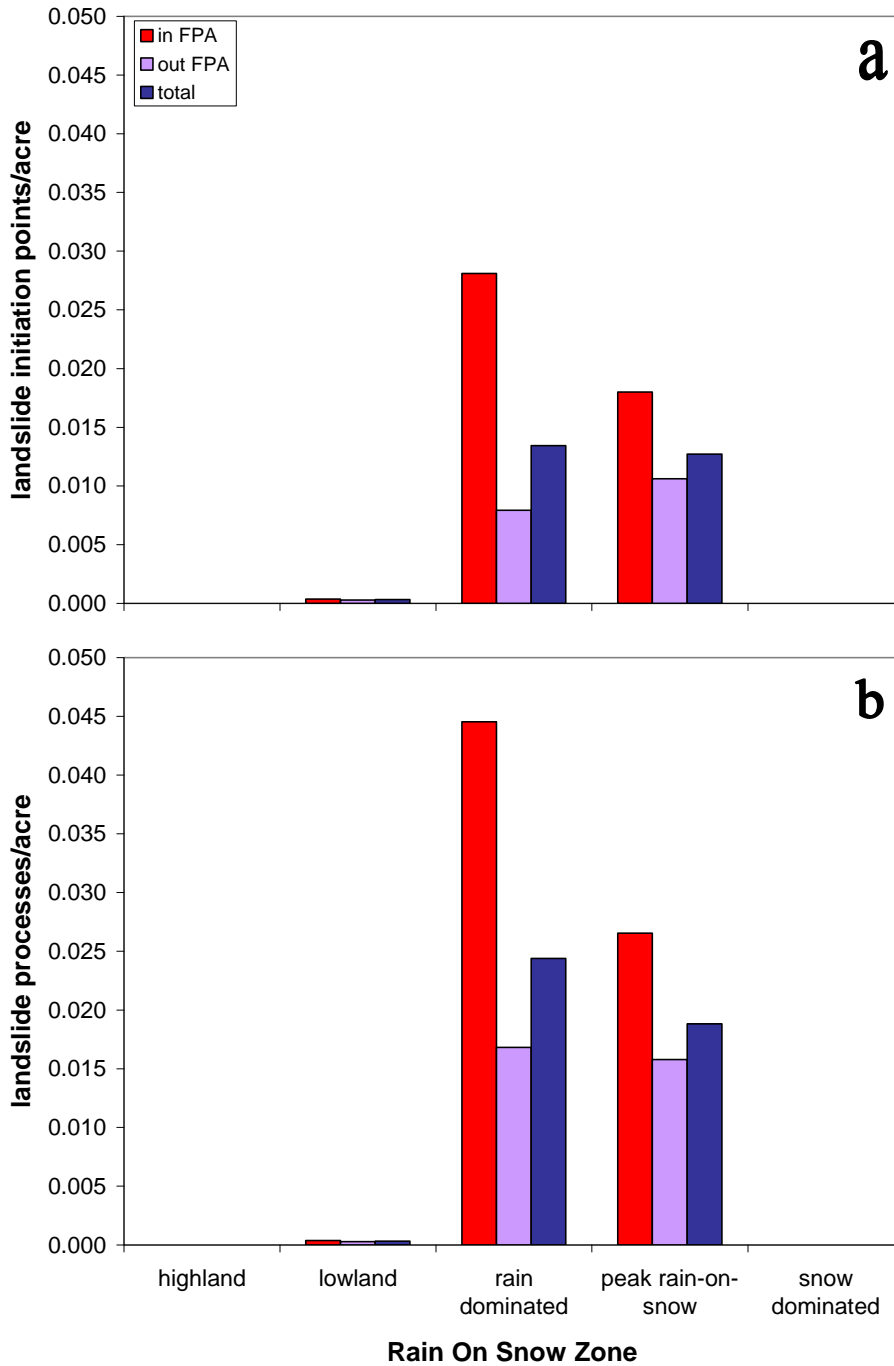
<b>zone</b>	<b>FPA acres</b>	<b>total acres</b>	<b>% total area with FP</b>
highland	0	0	0%
lowland	2738	6269	44%
rain dominated	8330	30510	27%
peak rain-on-snow	7610	27000	28%
snow dominated	0	0	0%



**Figure 13.** Rain-on-snow zones (WDNR 1991).



**Figure 14.** (a) 128-acre Weyerhaeuser clearcut (FPA 2505927, purple outline: WDNR 2006) in a peak rain-on-snow zone (purple, WDNR 1991) and (b) 19 landslide processes within the harvest unit (yellow polygons, WDNR 2009b) after the December 2007 storm.



**Figure 15.** Relationship between rain on snow zones and landslide density by forest practices derived from landslide initiation points (a) and landslide processes (b).

Weyerhaeuser's Watershed Analyses for the Stillman Creek and Upper Chehalis watersheds (1994a, b), discuss the interaction between climate, hydrology, and forest practices. These two watersheds are "exposed to frequent southwesterly frontal storms that dominate precipitation processes in the region" (Weyerhaeuser 1994b, App. C, p. 4). The Rain-On-Snow zone susceptible to high peak flows and hillslope erosion covers 49 percent of the Upper Chehalis watershed and 34 percent of the Stillman Creek watershed (Weyerhaeuser 1994a, b, App. C, Fig. 13). Potentially significant increases in water available for runoff are expected during Rain-On-Snow events where more forests are converted to a hydrologically immature "young forest" condition. Weyerhaeuser explains, "it is reasonable to assume that significant additional water input to soils could occur in harvested areas, particularly during extreme ROS events and in the peak ROS precipitation zone. Such additional input can increase the potential for soil mass wasting and hillslope failures on steeper slopes (Dyrness 1967, Swanston 1974, Harr 1981)" (Weyerhaeuser 1994b, App. C, p. 18).

Weyerhaeuser understood that Rain-On-Snow peak flow increases and landslide risk could be reduced by maintaining the proportion of the watersheds at "(1) about 40 percent or less immature cover, and (2) about 40 percent or more mature cover" (Weyerhaeuser 1994b, App. C, p. 16). We estimated the hydrologically immature forested area in these two watersheds at the time of the storm as that area harvested between 1984-2007 (stands 23 years old or younger) by combining the Pierce et al. (2005) harvest data between 1984-2004 and the record of FPAs between 2005-2007. Between 1994 and 2007, Weyerhaeuser had increased the hydrologically immature forested area in these two

watersheds combined from 17 percent (12765 acres) in 1994 (Weyerhaeuser 1994a, b, App. C), to 29 percent (21834 acres) in 2007 (Table 8).

**Table 8.** Increase in hydrologically immature (HI) area between 1994 (Weyerhaeuser 1994a, b, App. C) and the 2007 storm due to Weyerhaeuser’s forest practices (FP; Pierce et al. 2005, WDNR 2006).

<b>watershed</b>	<b>total ac</b>	<b>1994 HI ac</b>	<b>1994 HI %</b>	<b>1984-2007 FP ac</b>	<b>1984-2007 FP %</b>
Upper Chehalis	44922	7722	17%	11274	25%
Stillman	29375	5043	17%	10560	36%
total	74297	12765	17%	21834	29%

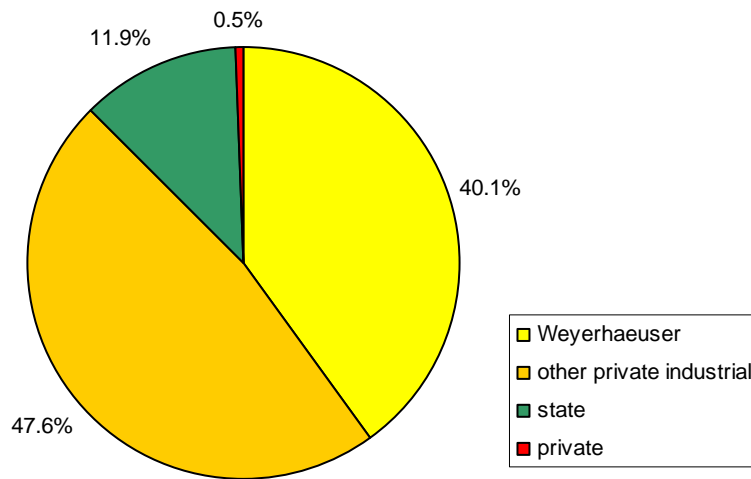
### **III. Univariate Correlates of Landslide Density.**

State geologists explain, “prolonged or intense precipitation is a major factor in slope instability, but during the December storm event, a combination of geology, thin soils, impermeable bedrock, age of timber stands, and topography probably controlled where landslides initiated, especially in the Chehalis headwaters” (Sarikhani *et al.* 2008). Most of these factors are out of Weyerhaeuser’s control, except for the location and extent of logging and road building. To identify factors that correlated with rates of landsliding in this storm, we investigated the relationships between landslide density and precipitation, lithology, stand age, and slope instability. Because forest practices are constrained by rules that vary with land ownership (private vs. public), we also analyzed landslide density by ownership category.

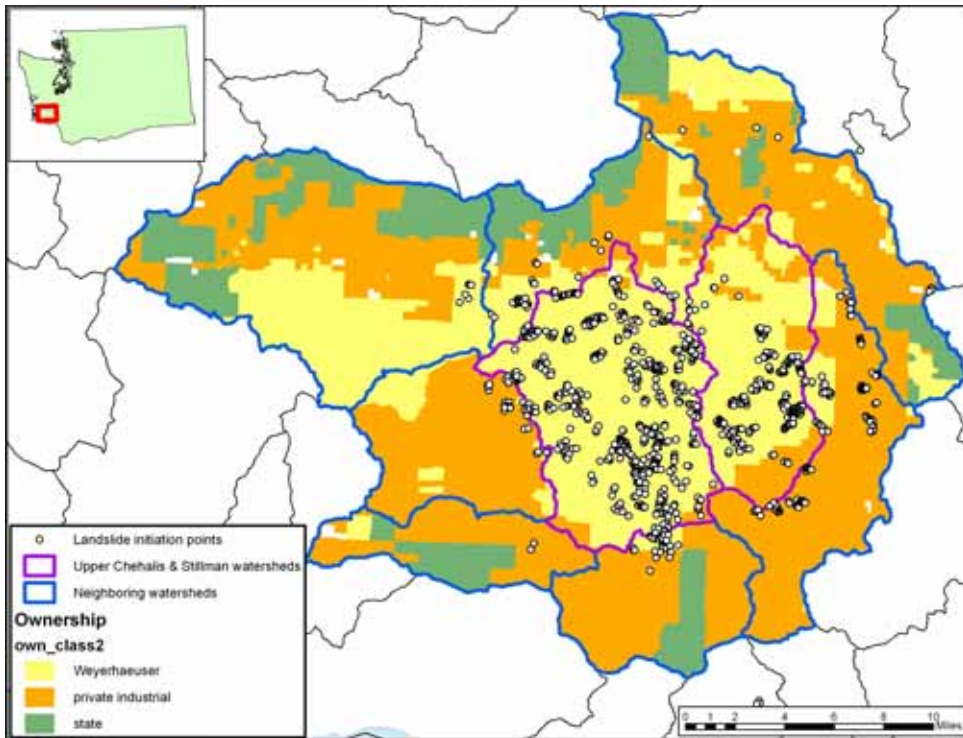
To enable these univariate analyses, we expanded the study area to include the seven watersheds adjacent to the Upper Chehalis and Stillman Creek watersheds (Fig. 14, 15). The adjacent watersheds were selected to be comparable in lithology, topography,

land-use, and precipitation intensity during the storm. We separated privately owned lands by Weyerhaeuser ownership and other private industrial ownership, and we found that the overall landslide density on Weyerhaeuser lands (0.013 landslides/acre) was seven times that on other private industrial forest lands (0.002 landslides/acre) in the study area. From 1996-2007, 22 percent of the area on State lands was harvested, compared with 34 percent of the area on all private industrial forest lands in the study area. Zero landslides were documented on State lands within the study area, so this area was excluded from further analysis.

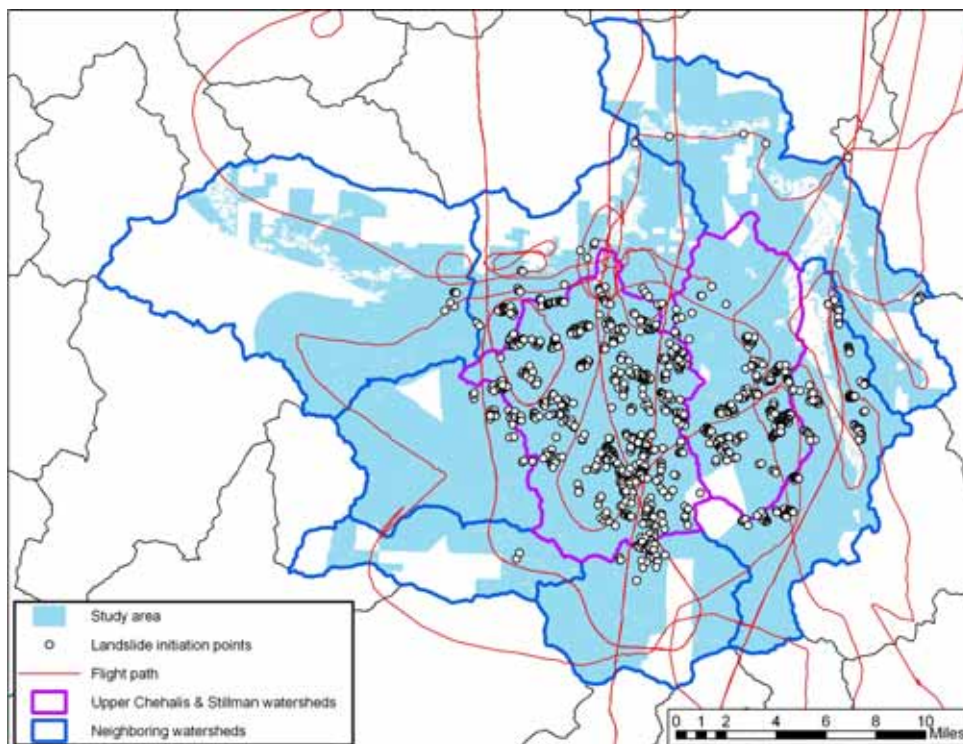
The following analyses illustrate the relative effects of various biophysical factors and ownership patterns on landslide density associated with this storm event. As described above, we limited the area of analysis to that subject to equal sample effort in detecting landslides after the storm, within a 9000-foot buffer around the flight path taken by WDNR staff during their landslide reconnaissance (Sarikhani *et al.* 2008) and to only those land cover classes found on industrial forest lands (Figure 18). These methods combined captured all but one landslide in the study area and included a total area of 262994 ac.



**Figure 16.** Proportion of each ownership category represented in the study area.



**Figure 17.** Pattern of ownership within the study area.



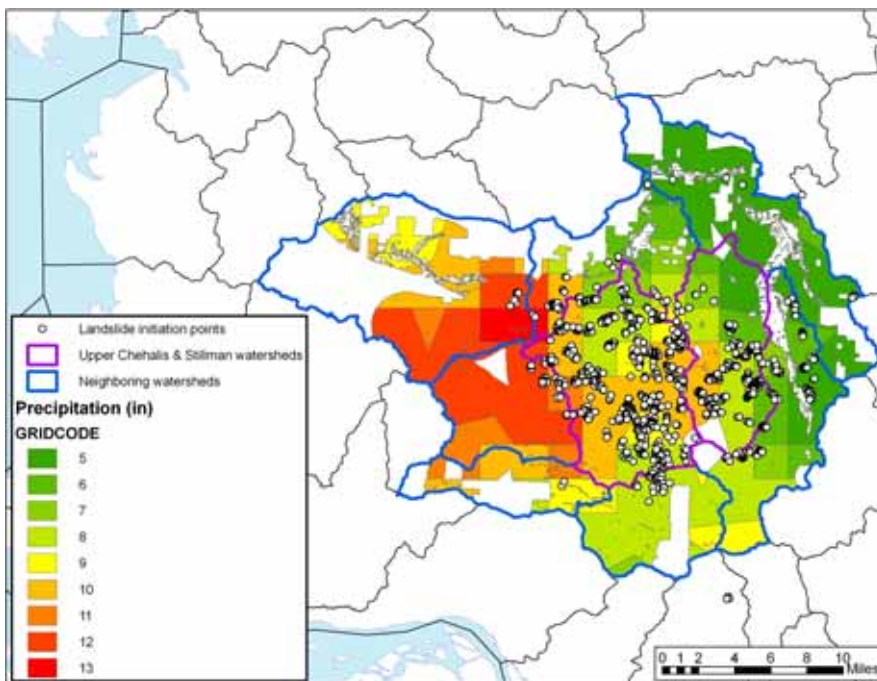
**Figure 18.** Lands in the study area of industrial forest land cover classes within 9000 feet of WDNR landslide reconnaissance flight path.

### **A. Landslide Density and Precipitation.**

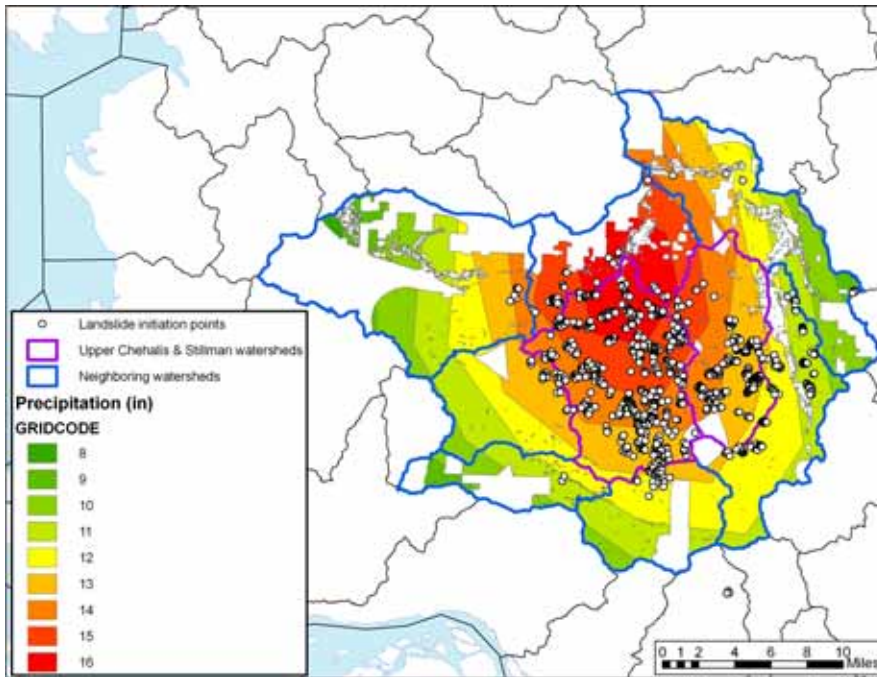
To investigate the effects of precipitation and forest practices on landsliding, we compared landslide densities between the two private industrial forest ownership categories in and outside of harvest units among areas with similar amounts of rainfall. Isohyetal maps created during the ENTRIX hydrology analysis (2009, Attachment 1) were used in this analysis (Fig. 19-21). Each contour of the isohyetal map represents areas with the same amount of rainfall during the seven-day period from November 28 to December 4, 2007. These maps are based on data from several sources: the NWS Cooperative Observer Program (COOP), US Forest Service RAWs, Natural Resource Conservation Service Snow Telemetry (SNOTEL), USGS, Weyerhaeuser, and two local volunteer observers.

Because the stations are spread throughout the region, the information had to be interpolated for those areas without weather stations. The first interpolation was created by NWS (Fig. 19). The second map was created by ENTRIX using the data reported by Weyerhaeuser (Reiter 2008, Fig. 21). Because the interpolation process was different for the latter map, we re-interpolated the NWS data so the Reiter (2008) data could be compared to the NWS under the same algorithms (Fig. 20).

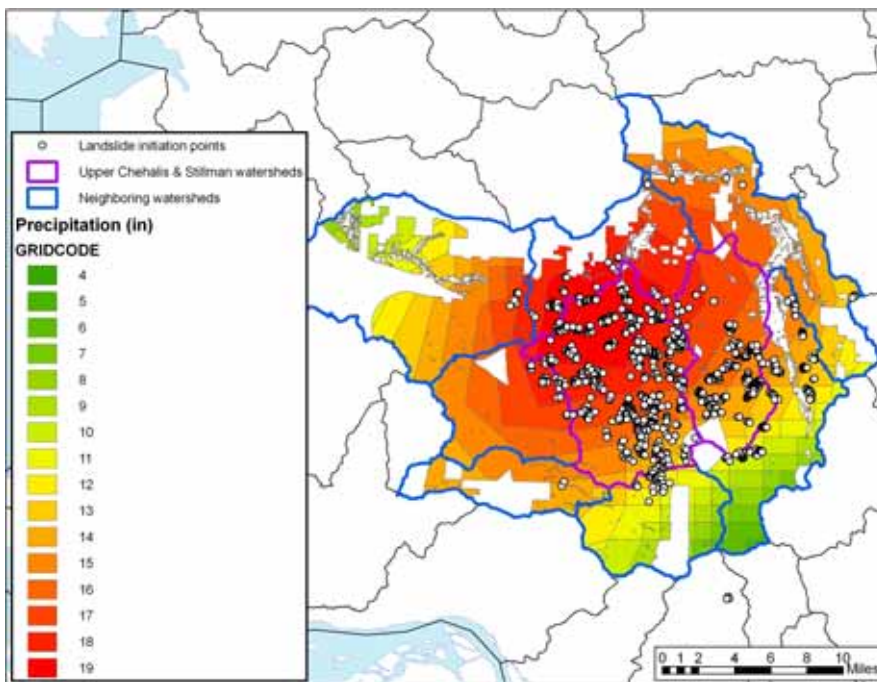
We calculated the landslide density within each isohyetal contour for the two private industrial forest ownership categories in the sampled study area (Fig. 17). The density of landslides inside harvest and road building units (FPA) was compared to that outside of these units to assess the influence of recent forest practices on mass wasting.



**Figure 19.** Precipitation interpolation provided by the NWS.



**Figure 20.** Precipitation derived from ENTRIX interpolation of NWS data.



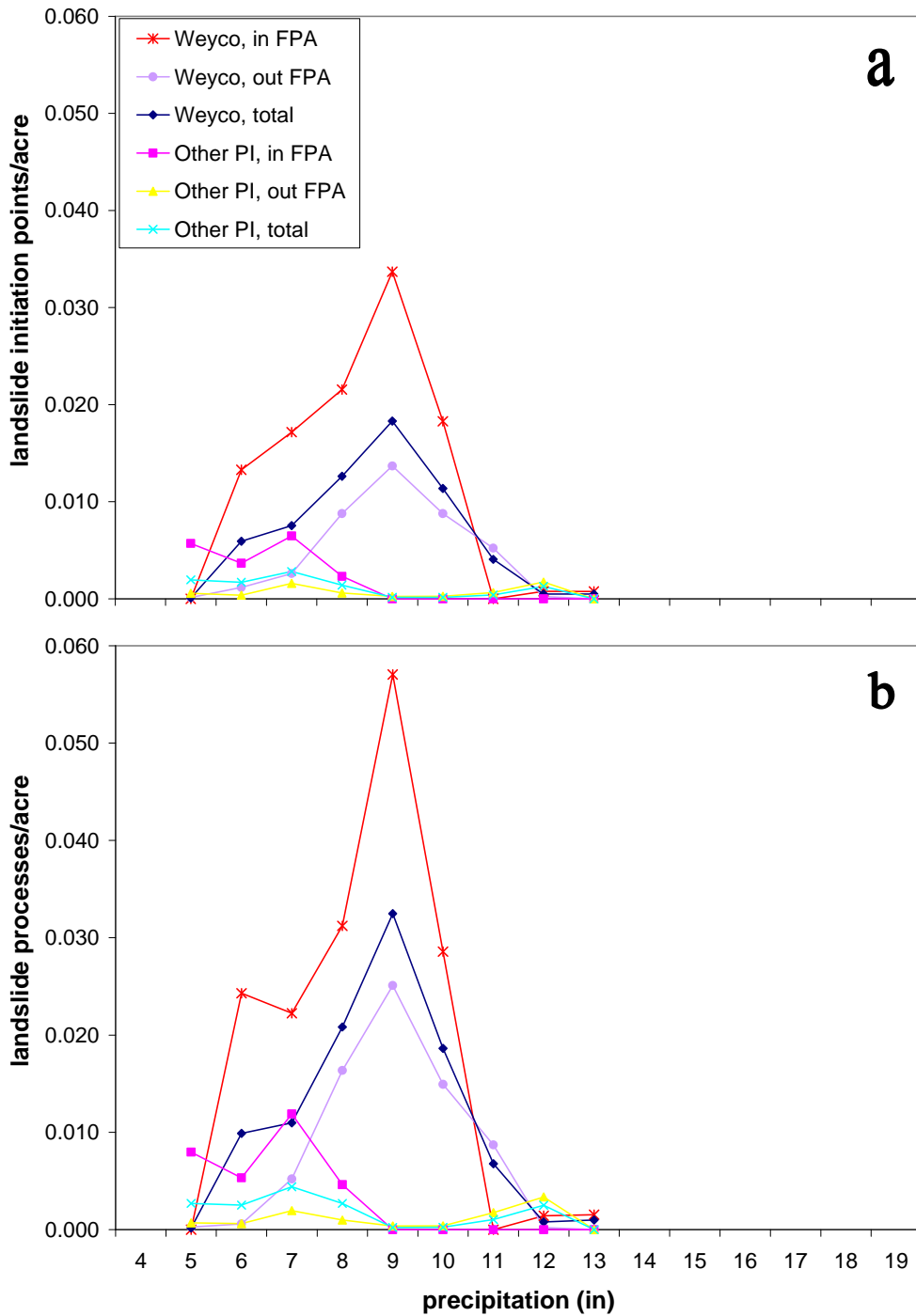
**Figure 21.** Precipitation derived from ENTRIX interpolation of Weyerhaeuser data (Reiter 2008).

We expected landslide density to increase at a threshold level of rainfall and then plateau at all higher rainfall levels (Montgomery and Dietrich 1994), and this is the pattern we observed in two of the three rainfall interpolation methods (Fig. 23-24). The NWS interpolation of precipitation (Fig. 22) showed a different pattern, in which landslide density dropped steeply with increasing precipitation shortly after reaching the threshold level. Based on the well-established relationship between precipitation and landsliding in the scientific literature (Montgomery and Dietrich 1994), the NWS interpolation appears to be inapposite for this storm and scale of analysis. In addition, the NWS data is included in the other two interpolation methods, therefore, we excluded the NWS interpolation from further analysis.

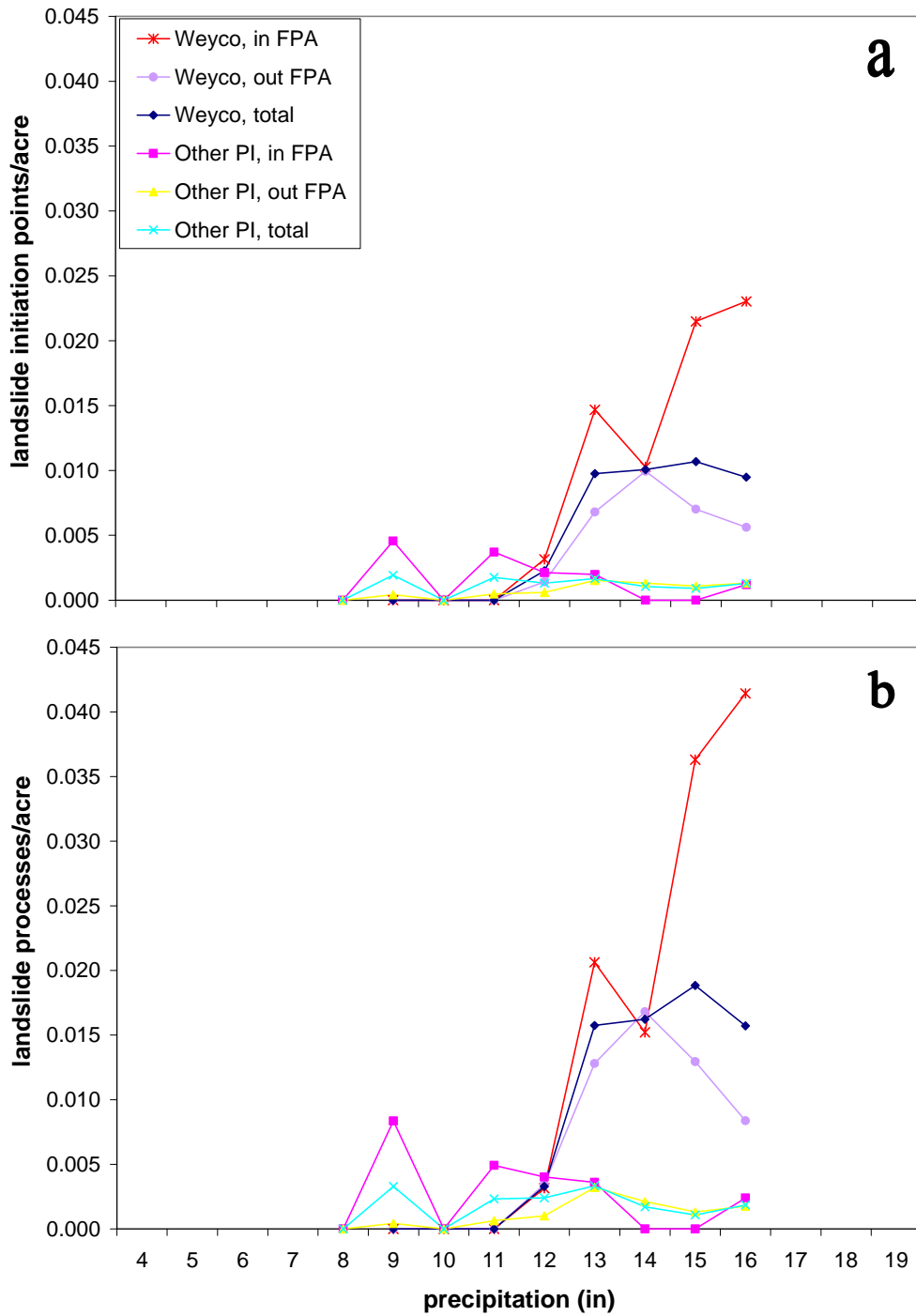
The precipitation threshold for mass movement, where the number of landslides increased sharply, differed according to ownership and forest practices. In the ENTRIX interpolation of the NWS data (Fig. 23), areas that were harvested by Weyerhaeuser from 1996-2007 showed a marked increase in the density of both landslide initiation points and landslide processes relative to other private industrial forest landowners in the study area. Here the threshold occurred at 13 inches for Weyerhaeuser lands, but not for other private industrial forest lands. When using data provided by Weyerhaeuser (Fig. 24), again landslide densities inside Weyerhaeuser FPAs were higher than the other landowners' FPA units with a threshold at 14 inches. Landslide density increased moderately on other private industrial FPAs at 12 inches and then decreased, but Weyerhaeuser FPAs showed a large increase in landslide density with areas of extreme precipitation (>14 inches). Landslides inside Weyerhaeuser FPAs also occurred at higher densities than landslides

outside FPAs on Weyerhaeuser lands, illustrating the effects of Weyerhaeuser's forest practices within the 11 years preceding the storm.

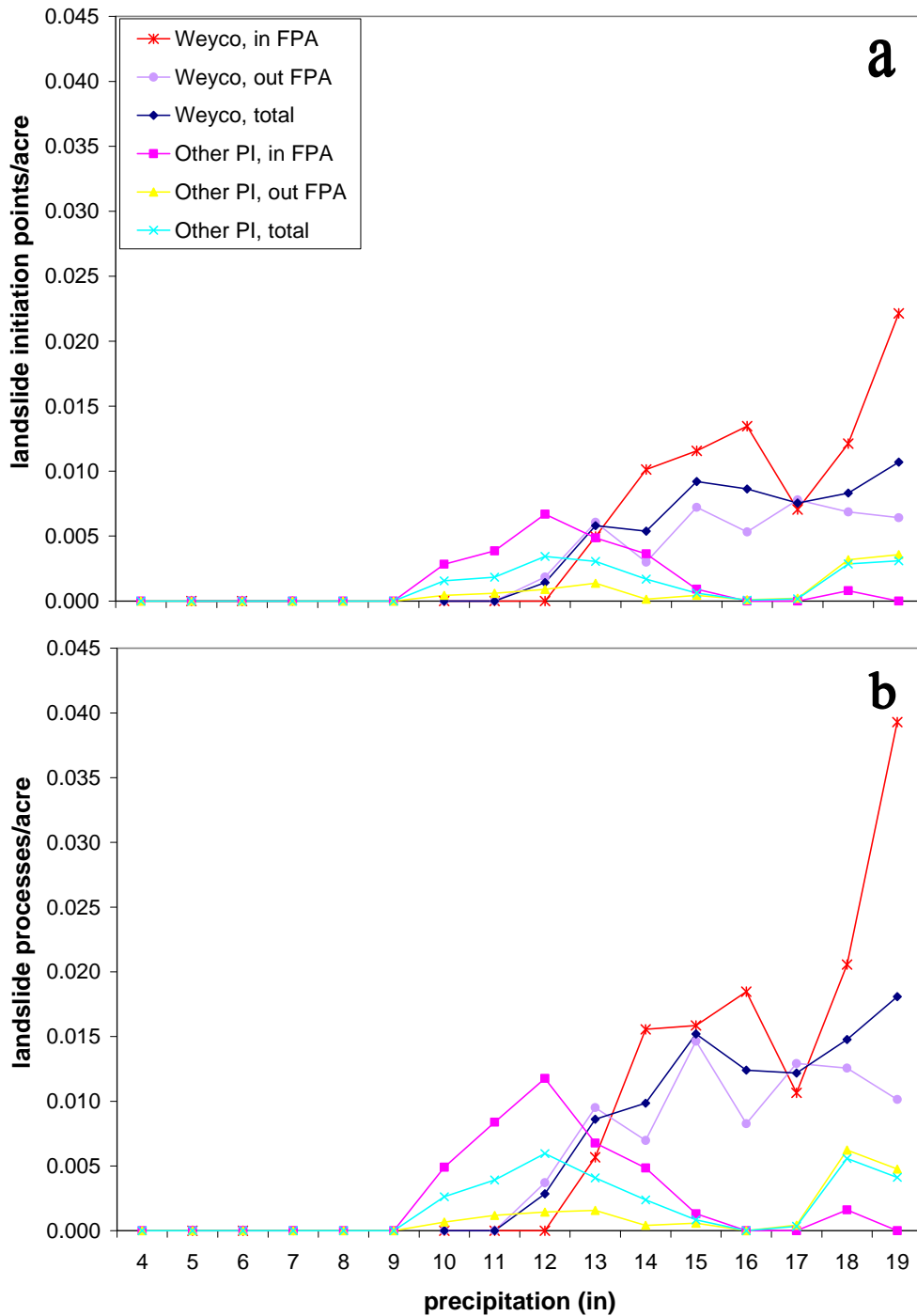
In summary, these results indicate that the density of landslides varied with precipitation, forest practices, and landownership, with the highest density in Weyerhaeuser units where forest was harvested and/or roads were built in the 11 years preceding the storm.



**Figure 22.** Relationship between precipitation and landslide density by ownership and forest practices. Isohyetal contours derived from NWS interpolation and landslide density derived from landslide initiation points (a) and landslide processes (b).



**Figure 23.** Relationship between precipitation and landslide density by ownership and forest practices. Isohyetal contours derived from ENTRIX interpolation of NWS data and landslide density derived from landslide initiation points (a) and landslide processes (b).



**Figure 24.** Relationship between precipitation and landslide density by ownership and forest practices. Isohyetal contours derived from ENTRIX interpolation of Weyerhaeuser data (Reiter 2008) and landslide density derived from landslide initiation points (a) and landslide processes (b).

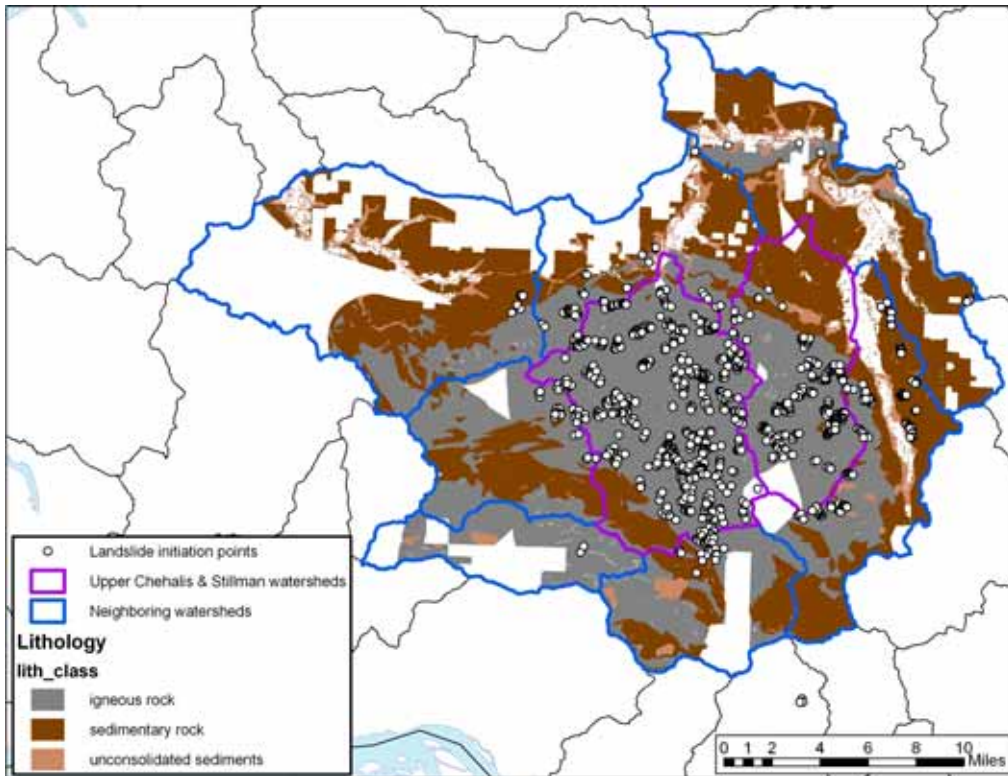
## **B. Landslide Density and Lithology.**

To examine the effects of lithology (type of bedrock) on rates of landsliding, we first mapped the geologic units present within the sampled study area (WDNR 2005, Fig. 25). Then we calculated the density of landslide initiation points and landslide process using the same two private industrial forest ownership categories and the same FPA boundaries as the precipitation analysis. Lithology was clearly a factor related to landslide rates, as expected, with the highest landslide densities found in igneous rock (basalt flows and flow breccias, Crescent Formation; basic (mafic) intrusive rocks; and tuffs and tuff breccias; Fig. 26). These igneous lithologies tend to have higher relief, thinner soils, and are less porous than sedimentary rock or unconsolidated sediments, making them more susceptible to mass wasting (Sarikhani *et al.* 2008).

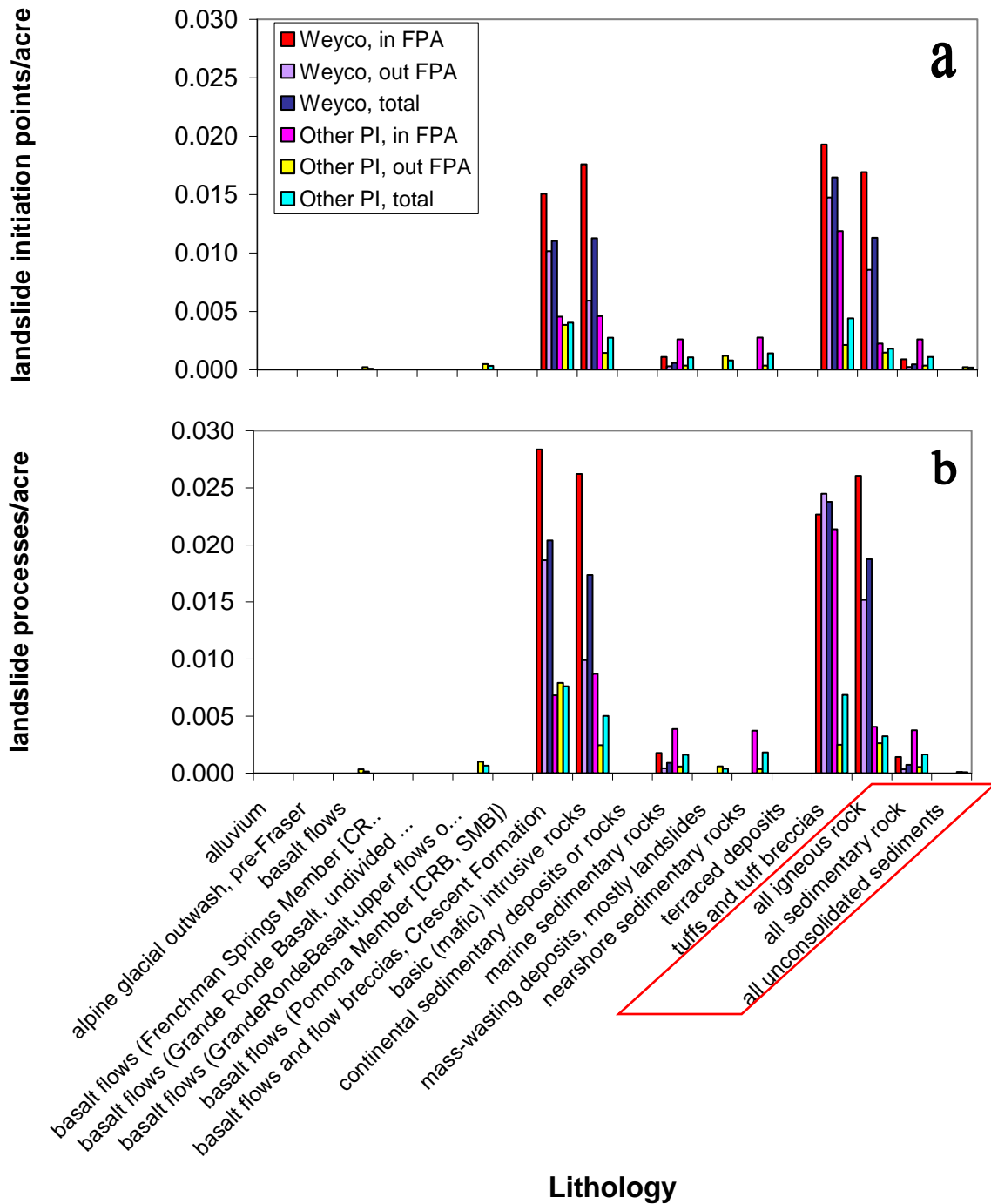
Landslide density also varied by ownership, with the highest rates on Weyerhaeuser lands in these same three igneous lithologies and in all igneous lithologies combined (Fig. 27). Granted, Weyerhaeuser land as a whole covers a greater proportion of igneous rock than other private industrial forest lands, but using landslide density (landslides per acre) corrects for this difference in area, and the area of igneous rock that was in FPAs is very similar between ownership categories (Fig. 27). This shows that lithology alone cannot explain the differences in landslide rates between these ownerships. Other private industrial forest lands had slightly higher landslide densities than Weyerhaeuser lands on all sedimentary lithologies combined, but these rates are much lower than those on igneous rock, as expected by the greater porosity in sedimentary rock (Fig. 26).

As with precipitation, these results indicate that the density of landslides varied with lithology, forest practices and landownership, with the highest rates in Weyerhaeuser units where forest was logged and/or roads were built in the 11 years preceding the storm.

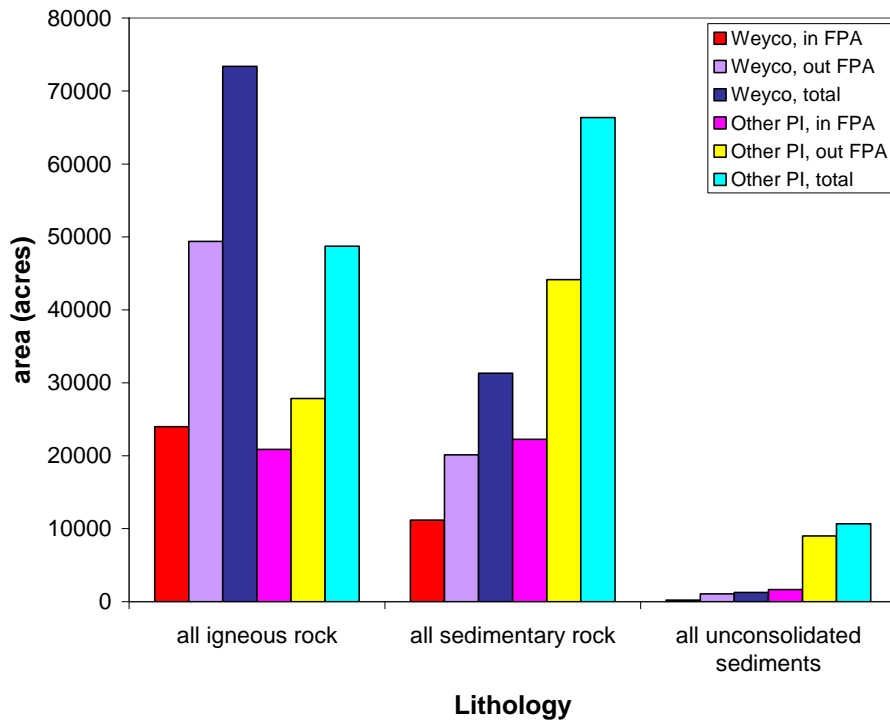
This relationship between lithology and susceptibility to landsliding has been known by Weyerhaeuser since at least 1994. As described in Weyerhaeuser's Watershed Analysis for the Stillman Creek watershed, the dominant mass wasting features of four of six subbasins included "very steep slopes of gabbro/basalt," and generally, "the rock types and their associated residual and colluvial soils are reasonably good predictors of the mass wasting characteristics and transported sediment in the basin" (Weyerhaeuser 1994b, Mass Wasting Assessment pp. 6, 10). In addition, "the hard rock of the gabbro/basalt sills and dikes form the steepest slopes in the Stillman watershed, and this portion of the watershed receives the highest annual precipitation, highest storm intensity and deepest snow accumulation" (Weyerhaeuser 1994b, Mass Wasting Assessment p. 5). Similarly, "the abundance of complex, geologic discontinuity in combination with steep slopes, erodible soils and heavy precipitation in the Chehalis Headwaters WAU provide a landscape vulnerable to mass wasting" (Weyerhaeuser 1994a, Mass Wasting Assessment p. 1).



**Figure 25.** Lithology categories present within the sampled study area (WDNR 2005).



**Figure 26.** Relationship between lithology and landslide density by ownership and forest practices derived from landslide initiation points (a) and landslide processes (b).

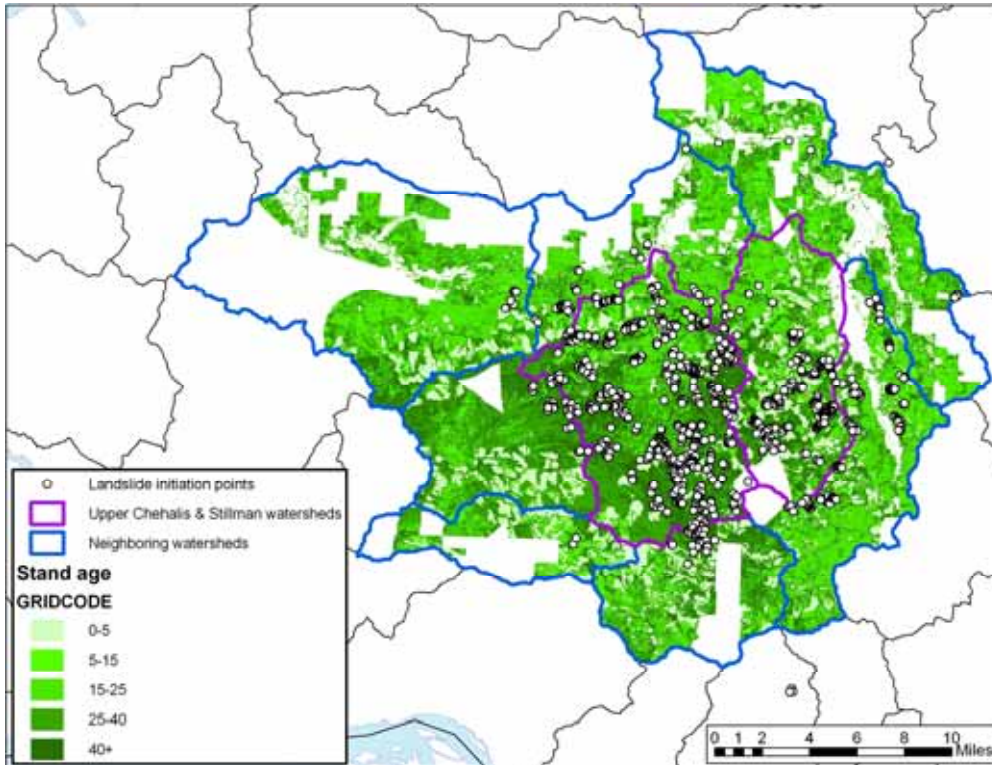


**Figure 27.** Total area by ownership and lithology inside and outside of FPAs.

### C. Landslide Density and Stand Age.

To assess the influence of stand age on landsliding in the study area, we used a GIS layer of forest cover in the Pacific Northwest based on a forest species-size model from 2006 (LEMMA 2009, Fig. 28). We defined meaningful stand age categories that vary with respect to the forest practices rules that were in effect at the time the stands were harvested and the stands' hydrologic maturity at the time of the storm (Table 9). Because some stands were harvested between 2006-2007 (WDNR 2006), we reclassified those stands to reflect their age just before the storm (0-5 yr.). As expected, stands in the youngest age category (0-5 yr.) had the highest landslide densities, but we did not expect to see the next highest landslide densities in the oldest age category (40+ yr., Fig. 29). A similar pattern

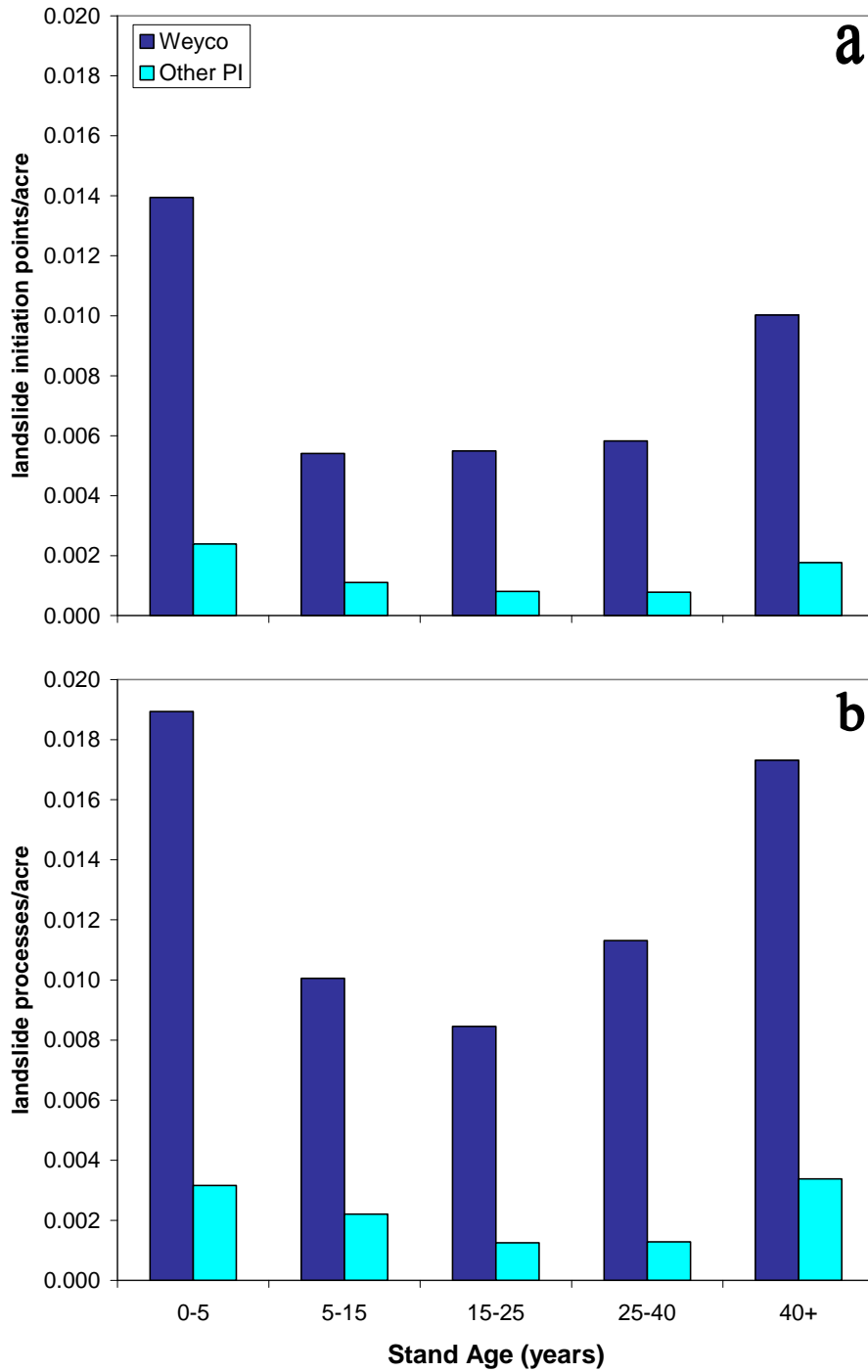
was seen between the age categories of stands where landslides were mapped by WDNR (Table 3). As with precipitation and lithology, these results indicate that the density of landslides varied with stand age, forest practices, and landownership, with the highest rates in the youngest Weyerhaeuser stands.



**Figure 28.** Stand age within the sampled study area.

**Table 9.** Stand age categories as of 2006. The stricter Forests and Fish rules were in effect only at the time the youngest age category was harvested, and only the two oldest age categories were hydrologically mature at the time of the storm.

<b>Years old</b>	<b>Forests and Fish rules at time of prior harvest</b>	<b>Hydrologic Maturity at time of storm</b>
0-5	in effect	immature
5-15	not yet in effect	immature
15-25	not yet in effect	immature
25-40	not yet in effect	mature
40+	not yet in effect	mature



**Figure 29.** Relationship between stand age and landslide density by ownership from landslide initiation points (a) and landslide processes (b).

#### **D. Landslide Density and Slope Instability.**

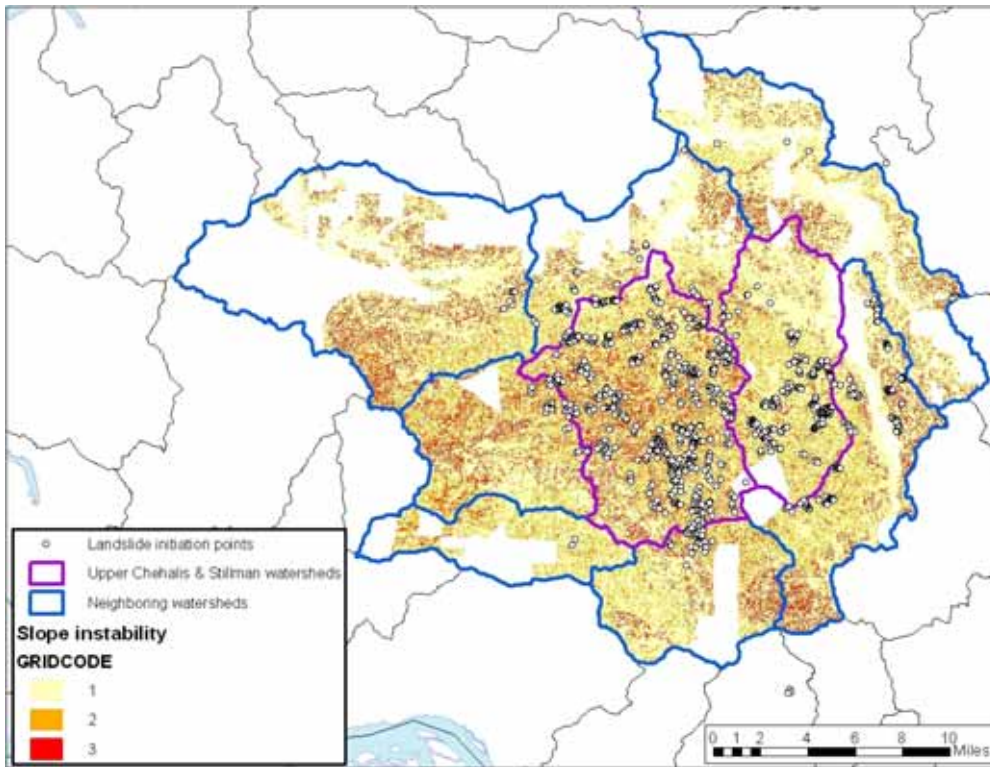
SLPSTAB is a GIS data layer that is used for pre-classification screening of FPAs and screening for slope stability concerns on managed timberlands that predicts 93 percent of shallow rapid landslides in areas modeled with a high probability of instability (Shaw and Vaugeois 1999). SLPSTAB uses two calibrated GIS-based models (SMORPH (Shaw and Johnson 1995) and SHALSTAB (Montgomery and Dietrich 1994)) that use 10-meter digital elevation models (DEMs) to generate slope and curvature information. The calibration of these models to a specific area also includes other information, such as landslide inventories, soils, mass wasting units, geology, and precipitation, making this an invaluable tool for forest managers (Fig. 30).

Because it incorporates so many predictive variables of interest and is easily accessible to forest managers in Washington, we mapped the SLPSTAB instability categories across our study area to compare them with landslide densities after the storm (Fig. 31). As predicted, landslide density increased with slope instability across ownerships, both inside and outside of FPAs (Fig. 32). Areas inside FPAs showed predictably higher landslide densities than areas outside FPAs. As with precipitation, lithology, and stand age, Weyerhaeuser lands had higher landslide densities than other private industrial forest lands at all levels of instability, with the highest rates inside Weyerhaeuser FPAs (Fig. 32).

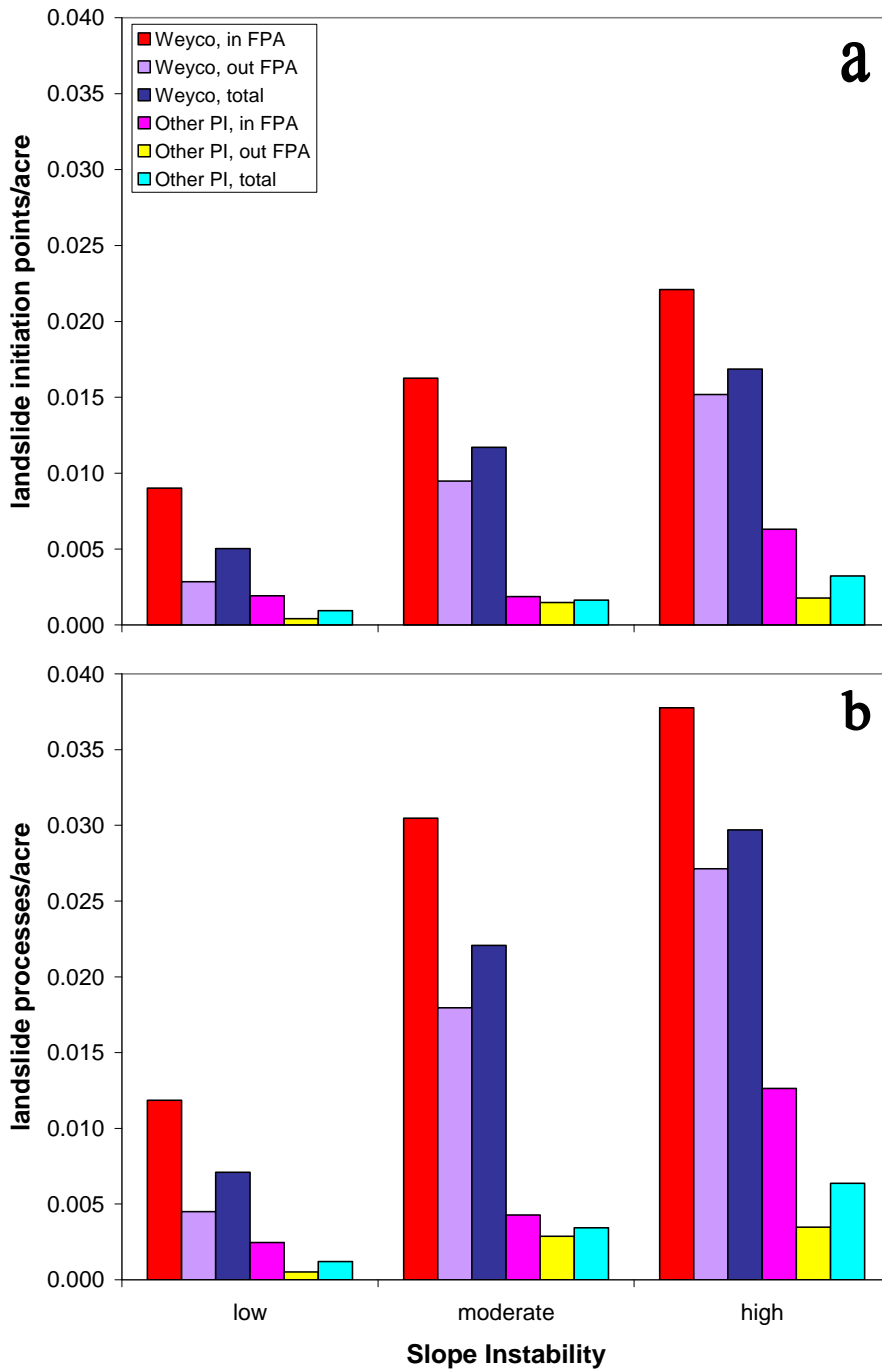
These results indicate that the density of landslides varied with slope instability, forest practices, and landownership, with the highest rates in Weyerhaeuser units where forest was harvested and/or roads were built in the 11 years preceding the storm.



**Figure 30.** (a) Three Weyerhaeuser clearcuts (237 acres) on slopes with high instability (Shaw and Vaugeois 1999), no natural or artificial reforestation (FPA 2511805, far left purple outline: WDNR 2006), and (b) 22 landslide processes (yellow polygons, WDNR 2009b) after the December 2007 storm.



**Figure 31.** Slope instability within the sampled study area.



**Figure 32.** Relationship between slope instability and landslide density by ownership and forest practices derived from landslide initiation points (a) and landslide processes (b).

#### **IV. Multivariate Landslide Model.**

Although many individual factors contribute to the occurrence of landslides (as demonstrated above), in reality, landslides result from the combination of factors in any given space and time. We conducted a binary logistic regression analysis to assess the effects of multiple independent variables on the odds of landsliding at a given point (Table 10). A total of 2014 points in the study area were assessed: all 1007 landslides and 1007 random points. Igneous lithology was chosen as the reference variable to which the other lithologies (dummy variables) were compared because of its importance as an individual variable (Fig. 26-27). We ran two full logistic regression models that differed only in the precipitation interpolation method used to estimate precipitation levels (ENTRIX or Weyerhaeuser, Fig. 20-21). To assess the relative strengths of these two models, we conducted the Nagelkerke  $R^2$  and Hosmer-Lemeshow Chi-square tests (SPSS 2004). Because both of these models performed well (Table 11), we present results from both models to illustrate the range of probable results (Tables 12-13).

**Table 10.** Variables entered into binary logistic regression model (SPSS 2004).

<b>Variable</b>	<b>Type</b>	<b>Values</b>
Landslide	Categorical	Yes/no
Ownership	Categorical	Weyerhaeuser/ Other private industrial forest owner
FPA	Categorical	In/out
Sedimentary lithology	Categorical	Yes/no
Unconsolidated sediments lithology	Categorical	Yes/no
Stand age	Continuous	0-127 years
Precipitation	Continuous	9.0-16.9 in. (ENTRIX) 5.2-19.8 in. (Weyerhaeuser)
Distance to nearest road <sub>1</sub>	Continuous	0-902 m
Slope <sub>2</sub>	Continuous	1-78 percent

1. WDNR 1996.
2. Derived from 30 m digital elevation model (USGS 2005).

**Table 11.** Relative strengths of two full models that vary by precipitation interpolation method (SPSS 2004).

<b>Model estimate</b>	<b>ENTRIX</b>	<b>Weyerhaeuser</b>
Nagelkerke R <sup>2</sup> <sub>1</sub>	0.464	0.455
Chi-square <sub>2</sub>	16.442	13.661
Degrees of freedom <sub>2</sub>	8	8
Significance (p) <sub>2</sub>	0.036	0.091
Overall % of landslides classified correctly <sub>3</sub>	78.2	77.1

1. Larger Nagelkerke R<sup>2</sup> statistics indicate that more of the variation is explained by the model, from a minimum of 0 to a maximum of 1.
2. The Hosmer-Lemeshow Chi-square statistic indicates a poor model fit if the significance value is less than 0.05.
3. Classification threshold value was 0.50.

**Table 12.** Results of logistic regression model using ENTRIX precipitation interpolation (SPSS 2004).

	<b>Beta<sub>1</sub></b>	<b>SE<sub>2</sub></b>	<b>Wald<sub>3</sub></b>	<b>df<sub>4</sub></b>	<b>Sig.<sub>5</sub></b>	<b>Odds ratio (Exp(B))<sub>6</sub></b>	<b>Inverse odds ratio<sub>7</sub></b>
Ownership <sub>8</sub>	-0.775	0.149	27.142	1	0.000	0.461	2.171
FPA <sub>9</sub>	-0.917	0.124	54.535	1	0.000	0.400	2.503
Sedimentary lithology <sub>10</sub>	0.705	0.163	18.827	1	0.000	2.024	0.494
Unconsolidated sediments lithology <sub>11</sub>	1.651	0.751	4.835	1	0.028	5.211	0.192
Stand age	-0.009	0.003	9.426	1	0.002	0.991	1.009
Precipitation	0.229	0.044	26.689	1	0.000	1.257	0.795
Distance to nearest road	0.001	0.000	5.156	1	0.023	1.001	0.999
Slope	0.062	0.004	196.844	1	0.000	1.064	0.940
Constant <sub>12</sub>	-6.490	1.003	41.832	1	0.000	0.002	

1. Unstandardized logistic regression coefficients.
2. Standard error of the estimate.
3. Tests the significance of individual regression coefficients for each independent variable (the squared ratio of the regression coefficient to its standard error).
4. Degrees of freedom.
5. Significance (p).
6. The odds of sliding for the coded variable relative to the odds of sliding for the noncoded variable while holding all other variables constant.
7. The odds of sliding for the noncoded variable relative to the odds of sliding for the coded variable while holding all other variables constant.
8. Coded variable: other private industrial forest owners.
9. Coded variable: outside FPAs.
10. Coded variable: igneous lithology.
11. Coded variable: igneous lithology.
12. Y-intercept.

**Table 13.** Results of logistic regression model using Weyerhaeuser precipitation interpolation (SPSS 2004).

	<b>Beta<sub>1</sub></b>	<b>SE<sub>2</sub></b>	<b>Wald<sub>3</sub></b>	<b>df<sub>4</sub></b>	<b>Sig.<sub>5</sub></b>	<b>Odds ratio (Exp(B))<sub>6</sub></b>	<b>Inverse odds ratio<sub>7</sub></b>
Ownership <sub>8</sub>	-0.977	0.146	27.142	1	0.000	0.376	2.656
FPA <sub>9</sub>	-0.889	0.123	54.535	1	0.000	0.411	2.433
Sedimentary lithology <sub>10</sub>	0.868	0.159	18.827	1	0.000	2.382	0.420
Unconsolidated sediments lithology <sub>11</sub>	1.643	0.755	4.835	1	0.029	5.173	0.193
Stand age	-0.009	0.003	9.426	1	0.001	0.991	1.009
Precipitation	0.062	0.025	26.689	1	0.012	1.064	0.940
Distance to nearest road	0.001	0.000	5.156	1	0.011	1.001	0.999
Slope	0.062	0.004	196.844	1	0.000	1.064	0.940
Constant <sub>12</sub>	-4.408	0.890	41.832	1	0.000	0.012	

1. Unstandardized logistic regression coefficients.
2. Standard error of the estimate.
3. Tests the significance of individual regression coefficients for each independent variable (the squared ratio of the regression coefficient to its standard error).
4. Degrees of freedom.
5. Significance (p).
6. The odds of sliding for the coded variable relative to the odds of sliding for the noncoded variable while holding all other variables constant.
7. The odds of sliding for the noncoded variable relative to the odds of sliding for the coded variable while holding all other variables constant.
8. Coded variable: other private industrial forest owners.
9. Coded variable: outside FPAs.
10. Coded variable: igneous lithology.
11. Coded variable: igneous lithology.
12. Y-intercept.

The results of both full models were similar and consistent with the results of the univariate analyses (section III above). The Wald chi-square statistic was significant ( $p < 0.05$ ) for all independent variables, which indicates all variables were useful to both models. For continuous variables, the odds ratio represents the increase in the odds of landsliding for every unit increase in the independent variable while holding all other variables constant (SPSS 2004). The inverse odds ratio represents the increase in the odds of not landsliding for every unit increase in the independent variable while holding all other variables constant (SPSS 2004). In both models, precipitation and slope both increased with the odds of landsliding, as predicted (Tables 12-13). For every inch increase in precipitation, the odds of landsliding increased by 1.1-1.3, and for every percent increase in slope, the odds of landsliding increased by 1.1. Also as expected, the odds of a point not to slide increased by 1.009 with each year in stand age. Contrary to predicted, the odds of landsliding increased by 1.001 as the distance to the nearest road increased (Tables 12-13).

For categorical variables, the odds ratio indicates the odds of sliding for the coded variable relative to the odds of sliding for the noncoded variable while holding all other variables constant (SPSS 2004). The inverse odds ratio indicates the odds of sliding for the noncoded variable relative to the odds of sliding for the coded variable while holding all other variables constant (SPSS 2004). The odds of sliding on igneous rock were 5.2 times the odds of sliding on unconsolidated sediments, but unconsolidated sediments represented a small proportion of the lithologies on the study area (Fig. 27), which may have influenced this result. The other three categorical variables were highly significant (Tables 12-13). The odds of sliding on igneous rock were 2-2.4 times the odds of sliding

on sedimentary rock, the odds of sliding inside FPAs were 2.4-2.5 times the odds of sliding outside FPAs, and the odds of sliding on Weyerhaeuser lands were 2.2-2.7 times the odds of sliding on other private industrial forest lands in the study area (Tables 12-13).<sup>1</sup>

These results are all consistent with the univariate analyses presented above in section III, but the strength of multivariate logistic regression analysis lies in its ability to isolate the effects of each independent variable while holding all other variables constant. In summary, we found the odds of landsliding were significantly greater at points on Weyerhaeuser lands, inside FPAs, on igneous lithology, in younger stands, with higher precipitation and steeper slope. Because all of the independent variables tested were significant in both models, we can conclude that no single variable, such as precipitation, was solely responsible for the pattern of landslides observed during the Dec. 2007 storm. However, according to Best Available Science, all of the variables tested, except ownership, are expected to affect the probability of landsliding. When all other variables are equal, the odds of landsliding were more than two times greater on Weyerhaeuser lands compared with other private industrial forest lands in the same watersheds. Had ownership not been a significant variable in the model, then the high density of landslides on Weyerhaeuser lands might have been considered an “act of God” or explained by some unique combination of factors in space and time. Because ownership was a significant variable in the model, the higher probability of landslides on Weyerhaeuser lands is attributable to Weyerhaeuser’s forest practices.

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<sup>1</sup> As noted above in the univariate analysis (section III), we found that the overall landslide density on Weyerhaeuser lands (0.013 landslides/acre) was seven times that on other private industrial forest lands (0.002 landslides/acre) in the study area, when the differences in other variables (such as FPAs, lithology, precipitation, and steepness) are not taken into account.

**V. Failure to Use Best Available Science Contributed to Major Damage Downstream.**

The worst damage downstream of the landslides on Weyerhaeuser's lands was related to the flooding of the Chehalis River basin (Fig. 28). Landslides upstream caused widespread deposition of sediment, logs, and debris which clogged channels at bridges and created temporary dams (ENTRIX 2009, Sarikhan *et al.* 2008). The flooding was due in part to the aggradation of sediment in streams. Also known as the "bathtub effect," sediment from harvest units, landslides, roads, and unbuffered riparian zones that builds up in streams increases the likelihood of flooding (Stover and Montgomery 2001). Streamflow and precipitation are typically correlated, but ENTRIX (2009) found that the high streamflow events associated with the December 2007 storm could not be explained by precipitation alone. This discrepancy was probably due in part to the heavy sedimentation and aggradation of lower gradient channels from the debris flows, which reduced flood conveyance and increased flood stage (ENTRIX 2009). Flooding was also magnified downstream of the debris flows due to the scouring of the stream bed and banks to bedrock in the headwaters, which led to more rapid rainfall delivery downstream (ENTRIX 2009).

Woody debris also played a significant role in the flooding. For example, at least three log jams occurred at bridges (Fig. 28a), at least seven bridges were destroyed during the event, and water impounded behind log jams probably increased the magnitude of flooding when it was released in successive pulses (ENTRIX 2009). A conservative (low) estimate of the area of wood debris in these jams is at least 213 acres, most of which appeared to be decayed wood from clearcuts (ENTRIX 2009). In the Upper Chehalis and Stillman watersheds, 1038 landslide processes delivered directly or indirectly to perennial

streams during the storm, and these slides covered a total area of 648 acres (assuming these slides were one to two yards in depth, this would be equivalent to 3.1 to 6.3 million cubic yards of sediment delivered to perennial streams). If it is assumed that trees in riparian buffers within 10 feet of perennial streams contributed to debris flows, then this area totaled 459 acres. In some cases riparian buffers obstructed, rather than contributed to, debris flows (ENTRIX 2009). Based on the characteristics of the wood observed in the log jams and the larger source area, it is likely most of the woody debris in the log jams originated from landslides rather than riparian buffers.



**Figure 28.** (a) Acres of timber and debris backed up behind a bridge in the Boistfort Valley, which was inundated by the flooding of the South Fork of the Chehalis River and (b) a Home Depot store along Interstate 5 resembles a floating barge (Seattle Times 2008b).

## **VI. Weyerhaeuser's Noncompliance With the SFI standards.**

Weyerhaeuser has failed to comply with the 2005-2009 SFI standards with respect to its forest practices on unstable slopes, water quality impairment, and disregard for the social effects of flooding. We document each of these violations below based on the empirical evidence reported above.

### **A. Weyerhaeuser's forest practices fail to conserve soil or protect soil productivity.**

By logging 3461 acres known by Best Available Science to have high soil erosion potential (Table 6, Fig. 11), and by failing to replant all of the stands it harvests (Fig. 30), Weyerhaeuser has violated:

**Objective 2.** To ensure long-term forest *productivity* and *conservation* of forest resources through prompt *reforestation*, *soil conservation*, *afforestation*, and other measures.

**Performance Measure 2.3.** *Program Participants* shall implement management practices to protect and maintain forest and soil *productivity*.

#### **Indicators:**

3. Use of erosion control measures to *minimize* the loss of soil and site *productivity*.
6. Criteria that address harvesting and site preparation to protect soil *productivity*.

In its logging of thousands of acres known to have high soil erosion potential on which 237 landslide processes later occurred, Weyerhaeuser threatened long-term soil and forest productivity across a broad spatial scale. This problem was identified during two surveillance audits as “opportunities for improvement” in ensuring that all shovel operators have maps with sensitive soils information (QMI 2007, before the storm) and in concentrating soil audits on “very high” and “high” risk units (QMI 2008, after the storm). The total area of landslide processes on Weyerhaeuser land within the Upper Chehalis and

Stillman watersheds was about 1002 acres. Assuming these slides were one to two yards in depth, this would be equivalent to 4.8 to 9.7 million cubic yards of soil lost, which reflects inadequate use of soil erosion control measures. Given the scale at which Weyerhaeuser appeared to disregard these mapped areas, these practices should be deemed “major nonconformances,” defined as “systemic failure[s] of the Program Participant’s SFI system to meet an SFI objective, performance measure or indicator” for which an action plan must be written and implemented within 30 days (QMI 2007, 2008).

**B. Weyerhaeuser does not appropriately identify or manage geologically important areas.**

When Weyerhaeuser harvested 841 acres known to have failed in the past (Fig. 6), 1776 acres with a high or very high hazard rating (Table 4), 987 acres with probable or immediate/certain delivery to streams (Table 4), and 1776 acres known to have high or very high instability (Table 5), Weyerhaeuser ignored existing Best Available Science and violated:

**Objective 6.** To manage *Program Participant* lands that are ecologically, geologically, historically, or *culturally important* in a manner that recognizes their special qualities.

**Performance Measure 6.1.** *Program Participants* shall identify special sites and manage them in a manner appropriate for their unique features

**Indicators:**

1. Use of existing natural heritage data and expert advice in identifying or selecting sites for *protection* because of their ecologically, geologically, historically, or *culturally important* qualities.
2. Appropriate mapping, cataloging, and management of identified special sites.

Historic landslides and highly unstable slopes are geologically important sites with special qualities that must be managed appropriately to minimize their risk of slope failure. By logging thousands of acres of such sites, Weyerhaeuser failed to use “existing natural heritage data,” such as Weyerhaeuser’s own Watershed Analyses (1994 a, b), to identify them for protection. Subsequently, inside FPAs during the storm, 33 landslide processes occurred on areas known to have failed before, 80 landslide processes occurred in high hazard zones, 49 landslide processes occurred in areas with probable or immediate/certain delivery to streams, and 80 landslide processes occurred on slopes known to have high instability. Weyerhaeuser itself reported that “the abundance of complex, geologic discontinuity in combination with steep slopes, erodible soils and heavy precipitation in the Chehalis Headwaters WAU provide a landscape vulnerable to mass wasting” (Weyerhaeuser 1994a, Mass Wasting Assessment p. 1). Given the scale at which Weyerhaeuser appeared to disregard this Best Available Science, these practices should be deemed “major nonconformances” of the SFI standard.

**C. Weyerhaeuser does not adequately plan for wet-weather events.**

By logging steep slopes predicted to fail during storms (Fig. 14), Weyerhaeuser violated:

**Performance Measure 3.1.** *Program Participants* shall meet or exceed all applicable federal, provincial, state, and local water quality laws and meet or exceed *best management practices* developed under U.S. Environmental Protection Agency–approved state water quality programs or other federal, provincial, state, or local programs.

**Indicators:**

3. Plans that address wet-weather events (e.g., *inventory* systems, wet-weather tracts, definitions of acceptable operating conditions).

**Performance Measure 8.3.** *Program Participants* shall clearly define and implement policies to ensure that mill inventories and *procurement* activities do not compromise adherence to the principles of *sustainable forestry*.

**Indicators:**

1. *Program* to address adverse weather conditions.

The December 2007 storm brought a large amount of precipitation to Southwest Washington in a highly variable spatial pattern. The storm was unusual in that it concentrated two to three times more precipitation on the Willapa Hills (including the Upper Chehalis and Stillman watersheds) than in surrounding areas (Mote *et al.* 2007). Precipitation and streamflow gauge data reflect this variability. For example, the weather station in Centralia produced a 5-year recurrence interval for the amount of precipitation that fell during the storm while the Frances weather station recurrence interval was determined to be 50-year (ENTRIX 2009). Streamflows had magnitudes ranging from a 500-year event (Chehalis at Doty) to a relatively unexceptional 60-year recurrence (Newaukum River near Chehalis, ENTRIX 2009). Despite the extremity of rainfall and streamflow in localized places, the December 2007 storm event was foreseeable in light of the frequency with which the region experiences Pacific storms compounded by the orographic effects of the Willapa Hills (ENTRIX 2009).

Knowing that large storms are not uncommon in this region (Weyerhaeuser 1994a, b), Weyerhaeuser could have better planned for “wet weather events” by reducing the rate of harvest and area of hydrologically immature forest in the peak Rain-On-Snow zone. Instead, Weyerhaeuser increased the area of hydrologically immature forest in these two watersheds combined by 12 percent, from 17 percent (12765 ac) in 1994 (Weyerhaeuser 1994a, b, App. C), to 29 percent (21834 ac) in 2007 (Table 8). Significant Rain-On-Snow

peak flow increases and associated landslide risk are expected under these conditions.

Weyerhaeuser's disregard of this information qualifies as a "major nonconformance" with the SFI standard.

**D. Weyerhaeuser does not replant all of the forests it harvests.**

By failing to designate all of its harvest units for natural or artificial regeneration

(Fig. 30), Weyerhaeuser violated:

**Performance Measure 2.1.** *Program Participants* shall reforest after final harvest, unless delayed for site-specific environmental or *forest health* considerations, through *artificial regeneration* within two years or two planting seasons, or by planned *natural regeneration* methods within five years.

**Indicators:**

1. Designation of all management units for either *natural* or *artificial regeneration*.
2. Clear criteria to judge adequate regeneration and appropriate actions to correct understocked areas and achieve acceptable species composition and stocking rates for both *artificial* and *natural regeneration*.

Failure to promptly replant clearcuts perpetuates hydrologically immature conditions, minimizes root strength, and maximizes susceptibility to landslides. In its Watershed Analysis (1994b, p. 5), Weyerhaeuser described difficulties in regeneration and that "due to infrequent seed crops and generally poor success rates, tree planting and aerial seeding were developed to replace the seed tree method." With access to this information, Weyerhaeuser should have replanted every stand it harvested in this area.

**E. Weyerhaeuser does not adequately protect riparian zones.**

When Weyerhaeuser clearcut headwater streams (Fig. 6, 8, 11, 14, 30), it violated:

**Performance Measure 3.2.** *Program Participants* shall have or develop, implement, and document *riparian protection* measures based on soil type, terrain, vegetation, and other applicable factors.

**Indicators:**

1. *Program* addressing management and *protection* of streams, lakes, and other water bodies and *riparian* zones.
3. Implementation of plans to manage or protect streams, lakes, and other water bodies.

Although State forest practices regulations do not require the protection of all headwater streams (WAC 222-30-021(2) and WAC 222-30-022(2)), failure to maintain headwater riparian buffers is still noncompliant with the SFI standards and Best Available Science. Headwater streams are ecologically important as the major link between hillslopes and downstream waters (MacDonald and Ritland 1989). They also “have high ecological significance for the entire aquatic ecosystem in terms of the transfer of energy and nutrients” due in part to the species of aquatic invertebrates (insects, crustaceans, and bivalves) and vertebrates (amphibians and non-game fish species) which dwell, sometimes exclusively, in headwater streams (Rashin *et al.* 1999). Increases in stream temperature and sediment are common following clearcut harvest of small streams (Caldwell *et al.* 1991, Knutsen and Naef 1997, Jackson *et al.* 2001, Rashin *et al.* 2006). This problem was also recognized in Weyerhaeuser’s 2007 Surveillance Audit, in which an “opportunity for improvement” was identified to “emphasize with staff and operators the importance of water management to avoid sediment deposition to live water regardless of time of year *i.e.* ditching; use of water bars; silt fencing; hay bales” (QMI 2007, p. 3). Despite their importance, Weyerhaeuser routinely clearcuts headwater streams, which we contend is a “major nonconformance” with the SFI standard.

**F. Weyerhaeuser does not comply with state water quality standards.**

By impairing water quality in the South Fork Chehalis River (pH impaired since 2002) and in Stillman Creek (temperature impaired since 2002, Fig. 29), Weyerhaeuser violated:

**Objective 11.** Commitment to comply with applicable federal, provincial, state, or local laws and regulations.

**Performance Measure 11.1.** *Program Participants* shall take appropriate steps to comply with applicable federal, provincial, state, and local forestry and related environmental laws and regulations.

**Indicators:**

2. System to achieve compliance with applicable federal, provincial, state, or local laws and regulations.

The state Water Quality Standards implement portions of the federal Clean Water Act by establishing numeric or narrative criteria and antidegradation policies designed to set limits on water pollution in order to protect beneficial uses such as aquatic life, swimming and fishing (Ecology 2008). Water quality impairment on Weyerhaeuser lands violates these regulations and precludes these important beneficial uses. This is a “major nonconformance” with the SFI standard that must be remedied.



**Figure 29.** Category 5 impaired waters (303(d) list, yellow lines) in the Stillman Creek watershed on Weyerhaeuser lands (Ecology 2008).

**G. Weyerhaeuser's forest practices are not economically, environmentally, or socially responsible.**

By logging thousands of acres of slopes known to be unstable and upstream of vulnerable communities and public resources, Weyerhaeuser violated:

**Principle 2. Responsible Practices**

To use and to promote among other forest landowners *sustainable forestry* practices that are both scientifically credible and economically, environmentally, and socially responsible.

The high concentration of landslides in the Upper Chehalis and Stillman Creek watersheds had far-reaching and devastating effects downstream. The Stillman Creek watershed provides the water supply for residents of the Boistfort Valley, and in its own Watershed Analysis (Weyerhaeuser 1994b App. G), Weyerhaeuser rated this water supply as “highly vulnerable” to coarse sediment, fine sediment, and peak flow events. This rating was validated when this source of drinking water was polluted with excessive sediment during the December 2007 storm and “more than three months passed before nearly 3,000 valley residents could drink from their taps again” (Seattle Times 2008a, emphasis added). In addition, the flood caused more than \$57 million in property damage to homes, farms and businesses (Seattle Times 2008a, Fig. 28).

Weyerhaeuser was aware of the tendency for these watersheds to flood. According to historic streamflow data, “peak flows exceeding the 5-year event occurred approximately 14 times over [a] 52-year period” (Weyerhaeuser 1994b, p. 6). Like the December 2007 storm, previous major flood events were known to cause debris flows, extensive channel alteration, and substantial sediment accumulation (Weyerhaeuser 1994a, b). Despite knowing the high propensity for these watersheds to flood and the high potential for damage to public resources, Weyerhaeuser still conducted its forest practices

in a way that contributed to and worsened the effects of such flooding (ENTRIX 2009).

This pattern of behavior is neither scientifically credible nor economically, environmentally, or socially responsible, and it represents a “major nonconformance” with the SFI standard that must be remedied.

## **VII. Request for Relief.**

As set forth in this complaint, we have demonstrated Weyerhaeuser’s violation of numerous SFI standards in the Upper Chehalis and Stillman Creek watersheds. These irresponsible forest practices must be prohibited to prevent further loss of soil, degradation of water quality, unnaturally high rates of landsliding, and economic, environmental, and social devastation associated with the flooding that resulted from these violations. As our climate continues to change, a higher frequency and intensity of storms and landslides are expected (Dale *et al.* 2001, Christensen *et al.* 2007, IEG 2007). The Chehalis River will likely see increased streamflows, soil saturation, and subsequent landslides in the coming decades, creating greater risk for more damaging floods due to the interactions between mass wasting, the delivery of woody debris and sediment to the stream network, and flooding (ENTRIX 2009). If Weyerhaeuser lands in these watersheds are less stable than average based on their microclimate, lithology, and topography, then Weyerhaeuser needs to apply stricter forest practices standards that anticipate the known elevated susceptibility to mass wasting to protect public resources downstream, especially in light of the predicted changes in our climate (ENTRIX 2009). These factors must be accounted for in future management plans, and more responsible forest practices based on the Best Available Science must be enforced now. Accordingly, we request that the auditor and SFI:

1. Require Weyerhaeuser to share its on-the-ground plans with the complainants herein;
2. Determine that Weyerhaeuser has committed major nonconformances with SFI standards for which action plans must be written and implemented within 30 days;
3. Direct Weyerhaeuser to discontinue violating SFI standards as outlined in this complaint; and
4. Suspend Weyerhaeuser's SFI certification until it complies with SFI standards.

Respectfully submitted,



Peter Goldman  
Washington Forest Law Center  
Attorney for Sierra Club



Kara Whittaker, PhD  
Washington Forest Law Center  
Staff Scientist and Policy Analyst

cc: Sierra Club  
Ms. Kathy Abusow, President and CEO, Sustainable Forestry Initiative

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