

Implications of the USGS analysis of slope stability at Sulphur Creek

Prepared for the National Marine Fisheries Service

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Summary of comments and calculations

The slope stability equation and values for material properties recommended by USGS geologist Dr. Raymond Wilson were used to map the stability regime of the four units of THP 1-97-307 HUM and the two units of THP 1-96-413 HUM. When calculations are carried out for conditions without trees, results indicate that each unit includes significant areas that would be expected to fail during storms of a size that occurs regularly in the area.

With the exception of unit 413-A, over 50% of each unit has a factor of safety of less than 1.0 for fully saturated conditions without trees; each also includes at least one area with a factor of safety of less than one even under dry conditions. Recurrence intervals for 1-day rainfall at the Kneeland 10 SSE rain gauge indicate that 1-day rainfalls sufficient to saturate a 2.5-foot depth of soil (considered characteristic of the Sulphur Creek slopes by Dr. Wilson) occur on average once every 95 years, and such storms are expected to occur more frequently at Sulphur Creek because it has a 60% higher annual rainfall. These slopes thus would be expected to fail during storms of a size that occurs regularly in the area if trees are not present. Calculations for a 10-year recurrence-interval storm further indicate that over 20% of units 413-B, 307-4, and 307-1 would be expected to fail during even these relatively frequent storms.

That the slopes persist despite their calculated instability is due largely to the presence of tree roots, which add cohesion. Recalculation of the stability regimes assuming the presence of trees indicates that the area susceptible to failure during 10-year storms is significantly reduced. However, the high density of landslides already mapped on the units indicates that even root cohesion is not sufficient to fully stabilize the slopes. Decreased root cohesion due to logging would further decrease the stability of these already unstable slopes (R. Wilson, personal communication, 5 August 1998). Data from nearby Bear Creek demonstrate this effect: rates of landsliding increase by a factor of 9.6 on hillslopes logged less than 15 years previously on the same rock type and soil type as present at Sulphur Creek.

Tree roots take several years to decay, and regeneration of conifers and hardwoods on a logged slope begins to restore a component of root strength after several years. Soil cohesion thus rarely reaches the minimum level indicated by calculations for soils without vegetation. In this case, however, aerial photo observations indicate that conifer regeneration has been minimal in 7- to 8-year-old logged units adjacent to THP 96-413. Those areas are now covered primarily by grass. Although grass provides some root cohesion, rooting depth is shallow, and the cohesion is thus not provided across the potential failure plane. Grass thus provides little protection from landsliding. In the absence of conifer and hardwood regeneration, the minimum levels of cohesion are likely to be approached.

Dr. Wilson noted that slope stability concerns had been considered in the prescription of selective logging for unit 413-B, but also noted that his comments did not apply to the 307 units. Calculations demonstrate that the same slope stability conditions present on unit 413-B are also present on units 307-1, 307-2B, and 307-4, but in each of these cases large portions of the areas calculated to be unstable even under a 10-year storm (as calculated at Kneeland) are to be clearcut

instead of selectively logged. Loss of root cohesion after clearcutting will significantly increase the potential for landsliding on these slopes.

Slope stability calculations for THP 413 and THP 307

On 5 August 1998, Dr. Ray Wilson of the US Geological Survey visited the Sulphur Creek area to assess the potential for slope instability in areas scheduled for logging. Using parameter estimates based on his observations of soil and landslides in the area, he carried out factor-of-safety calculations for characteristic hillslopes on THP 413. The equation used is the standard slope stability equation used in “infinite slope” calculations, as is appropriate for shallow, planar failures such as most debris slides:

$$F = \frac{c}{\gamma z \sin \beta} + \left(1 - \frac{\gamma_w m}{\gamma}\right) \frac{\tan \phi}{\tan \beta}$$

where:

F = factor of safety

c = soil cohesion (without roots) = 50 lb/ft²

γ = specific weight of soil = 112.6 lb/ft³

γ_w = specific weight of water = 62.4 lb/ft³

m = proportion of soil column above slide plane that is saturated (variable)

z = depth of soil above failure plane, measured perpendicular to surface = 2.5 feet

β = hillslope angle in degrees (variable)

ϕ = angle of internal friction = 32°

This equation is essentially a balance of forces between those tending to keep the soil in place and those tending to send it downhill. A factor of safety of 1.0 indicates that the slope is on the brink of failure, and values less than 1.0 imply that the slope should have failed. According to Selby (1982), “most natural hillslopes upon which landsliding can occur have F values between about 1.0 and 1.3.” Slopes with factors of safety above 1.3 thus generally are considered relatively stable while those with factors of safety less than 1.0 are considered extremely unstable. The factor of safety for a slope varies with the wetness of the soil because as soil becomes saturated, it loses strength.

The slope stability equation was used to graph the combination of percent of soil column saturated and hillslope angle that produces a factor of safety of 1.0 for conditions at Sulphur Creek. Calculations are first carried out for conditions in the absence of trees (Figure 1), and later for conditions with trees present (Figure 4, discussed later). In Figure 1, hillslope conditions falling to the left of the “failure” line (which indicates a factor of safety of 1.0) are at least marginally stable, while those falling to the right of the line are considered unstable. Hillslopes with a lower slope than the hillslope angle at which the failure curve intersects the 100% saturation line (25.4°) are expected to require artesian pressure if they are to fail, while those with a higher slope than the hillslope angle at which the failure curve intersects the 0% saturation line (40.7°) would be expected to fail even when dry. Hillslopes with intermediate angles are expected to fail at some point between dry and fully saturated conditions.

Dunne and Leopold (1978, Figure 6-9) indicate that a fine sandy loam soil at field capacity can hold, on average, an additional volume of water equal to 25% of the soil volume. For the estimated Sulphur Creek soil depth of 2.5 feet (R. Wilson, personal communication, 13 August 1998), it would thus require the equivalent of 7.5 inches of rain to saturate the soil. Part of the

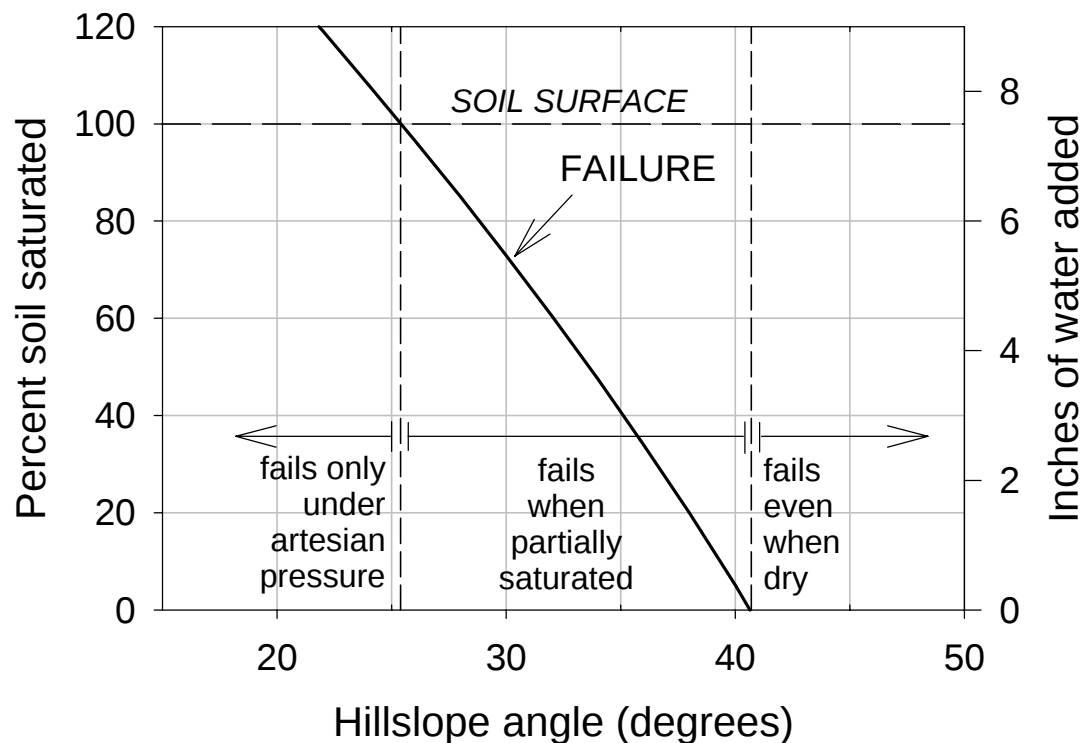


Figure 1. Slope stability curve for the Sulphur Creek area. Hillslope conditions to the left of the “Failure” curve have a factor of safety of greater than 1.0. Those to the right of the curve have a factor of safety of less than 1.0, indicating that they are not stable. “Inches of water” indicates the amount of water that would need to be added to a 2.5-foot soil column to produce the percent saturation noted on the left axis, assuming a 25% storage capacity beyond field capacity in the soil (Dunne and Leopold 1978, Figure 6-9, for “fine sandy loams”).

incoming water drains from the soil during a storm, but drainage can be too slow to prevent saturation if the rainfall occurs over a short enough period. In addition, swale areas into which drainage is concentrated receive water at rates higher than that of the rainfall; these areas will become saturated during storms too small to saturate other parts of the hillslope. The right-hand axis of Figure 1 indicates how much water would need to be added to the soil to achieve the percentage saturation indicated by the left-hand axis.

Influence of storm size

The Sulphur Creek area receives an average of about 100 inches of rainfall a year. Data available from the Kneeland 10 SSE gauge show recurrence intervals for different amounts of daily rainfall (Figure 2), but annual precipitation at that gauge is only 61 inches. Results thus provide a significant overestimate of recurrence intervals likely at Sulphur Creek—large rainstorms will occur considerably more frequently at Sulphur Creek than data from the Kneeland gauge would suggest.

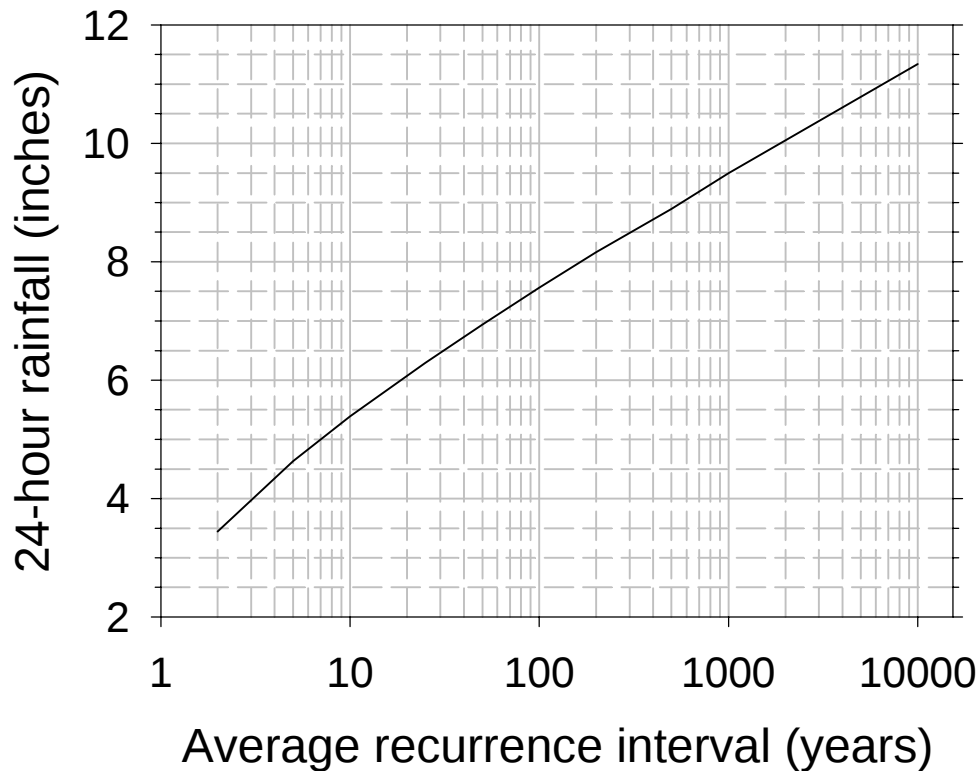


Figure 2. Recurrence intervals for 1-day rainfalls at Kneeland, Humboldt County. At Kneeland, a 5-inch day occurs approximately once every 7 years, while a 7-inch day occurs once every 55 years or so. Storms of these sizes would occur more frequently at Sulphur Creek, where annual rainfall is 60% higher than at Kneeland. (Data from DWR)

Comparison of Figures 1 and 2 indicate that a 1-day storm capable of saturating the Sulphur Creek soil column is expected to occur, on average, once every 95 years at Kneeland, and thus will occur more frequently at Sulphur Creek. At saturation, all slopes of over 25.4° are calculated to be susceptible to failure (i.e., to have a factor of safety of less than 1.0) if trees are not present. A storm with a 10-year recurrence interval at Kneeland provides enough rainfall to saturate 72% of the Sulphur Creek soil depth. At this level of saturation, all slopes over 30.2° are calculated to be susceptible to failure in the absence of trees.

Whether the rainfall period relevant for calculating the potential for soil saturation during a storm is longer or shorter than 1 day depends on the rapidity of drainage in the soil and the moisture conditions in the soil at the time of the storm. Measurements of soil properties would be necessary to refine the calculations. However, results indicate that a large range of intermediate slope angles is susceptible to landsliding during storms of moderate size.

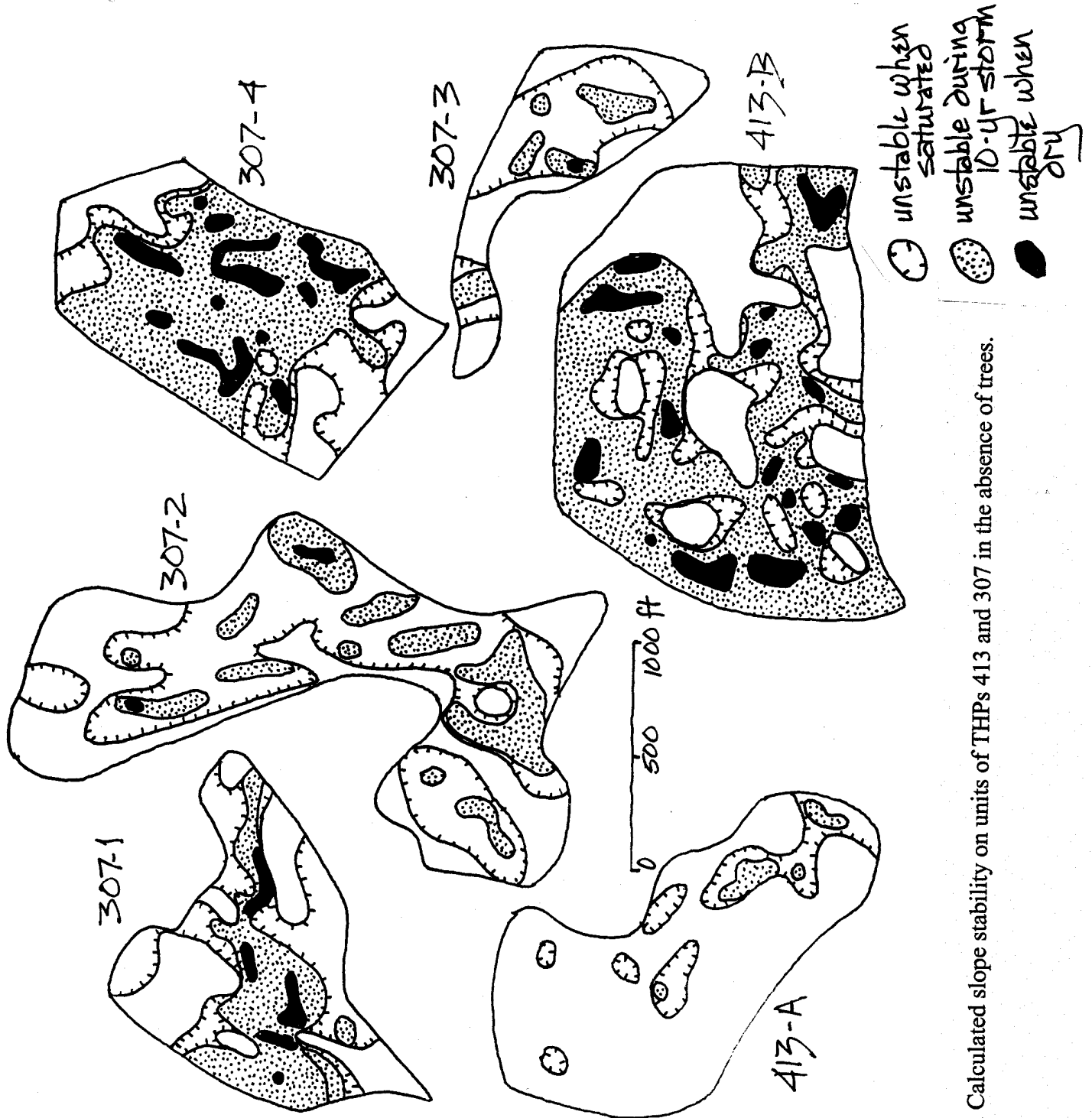


Figure 3. Calculated slope stability on units of THPs 413 and 307 in the absence of trees.

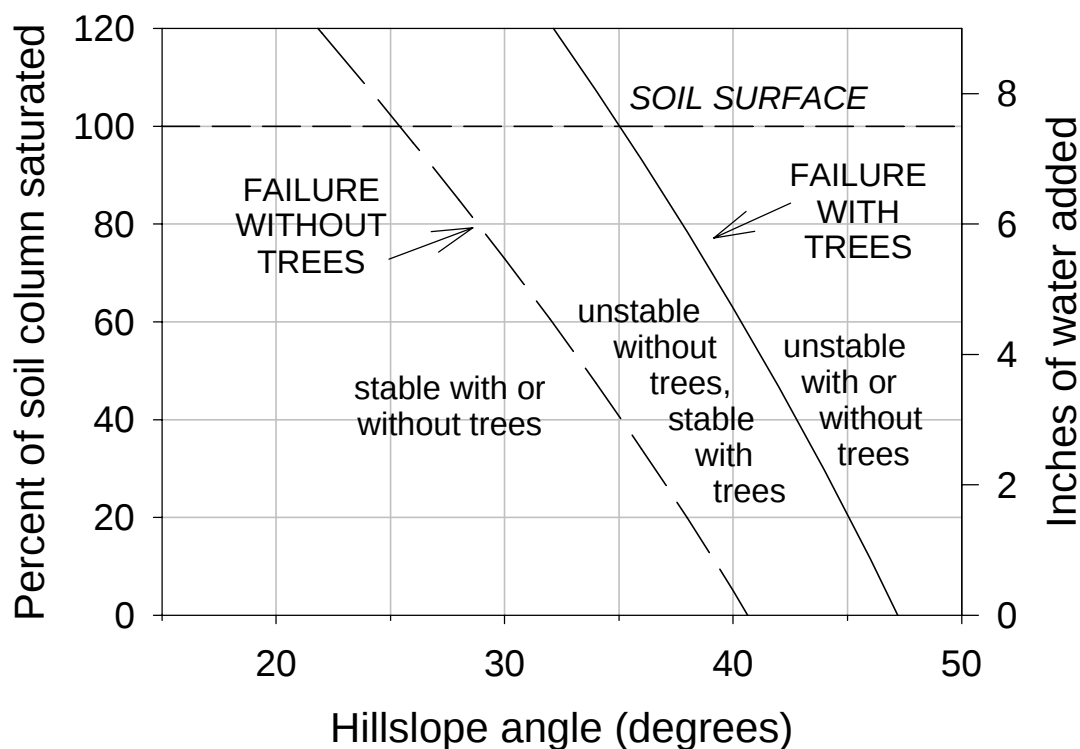


Figure 4. Effect of trees on Sulphur Creek slope stability. The “failure without trees” curve is that plotted in Figure 1. The presence of trees on Sulphur Creek hillslopes raises the lower limit of instability from 25.4° slopes to 35.0° slopes.

The distribution of slopes susceptible to failure in THPs 413 and 307 can be mapped using gradient information from USGS topographic quadrangles (Figure 3). The boundaries indicated reflect the areas susceptible to sliding during dry conditions, those susceptible at saturation, and those susceptible at water contents equivalent to the 10-year, 1-day rainfall at Kneeland. It is evident from the maps that a large proportion of the THP areas should be unstable under existing conditions if trees are not present. A landslide map provided with the engineering geologic report prepared by James Falls for THP 1-97-307 HUM indeed demonstrates that a high proportion of the unit surfaces have failed under current conditions.

Influence of trees

Considerable research has been carried out concerning the role of roots in augmenting soil strength in forested areas (e.g. Ziemer 1981, O’Loughlin 1974). In a summary of available data, Selby (1982) indicates that conifer roots can increase effective soil cohesion by on the order of 20 to 90 lb/ft². If a root cohesion of 50 lb/ft² is assumed in the present case (thus doubling the effective soil cohesion), and an average weight of trees of 41 lbs/ft² is assumed across the

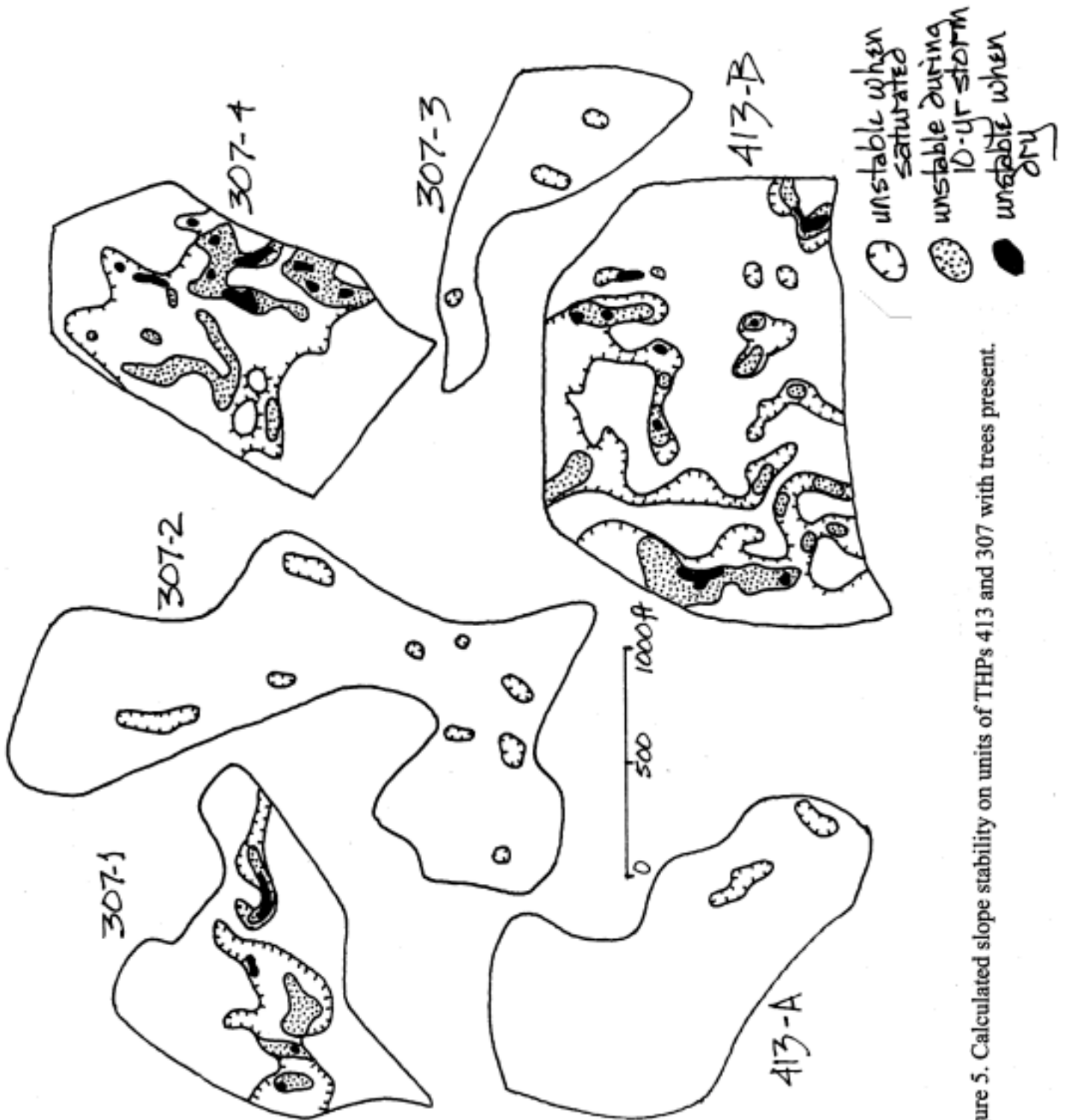


Figure 5. Calculated slope stability on units of THPs 413 and 307 with trees present.

landscape, the slope stability relation can be recalculated to take into account the presence of trees (Figure 4).

The locations of slopes that are potentially unstable even with trees present can now be mapped (Figure 5). For each unit, the difference in areas mapped as unstable between Figures 3 and 5 is an indication of the potential effects of logging on these slopes.

The extent to which the slope stability regime approaches that depicted in Figure 1 after logging depends on the silvicultural prescription employed, the type of vegetation present, and the nature and rapidity of regrowth. Selective logging, for example, results in the loss of fewer roots, and redwoods and other stump-sprouting species maintain a portion of their root system even after they are cut. In addition, roots take several years to fully decay, and regeneration of conifers and hardwoods on a logged slope begins to restore a component of root strength after several years. The minimum root cohesion is thus found several years after logging, and the minimum reached is rarely as low as that measured for soils in the complete absence of roots.

In this case, however, minimum root cohesion after logging is likely to be lower than that expected for many other areas in northwestern California. First, much of the area is to be clearcut rather than selectively logged. Second, the stand is composed primarily of Douglas-fir, which does not resprout from stumps; cutting of the tree kills the root system. Third, aerial photo observations indicate that conifer regeneration has been minimal in 7- to 8-year-old logged units adjacent to THP 96-413, and those areas are now covered primarily by grass. Although grass provides some root cohesion, rooting depth is shallow, and the cohesion is thus not provided across the potential failure plane. Grass thus provides little protection from landsliding. In the absence of conifer and hardwood regeneration, the minimum levels of cohesion are likely to be approached.

Decreased effective soil cohesion after logging is likely to be one of the causes for the dramatic increase in landsliding rates on recently logged hillslopes in nearby Bear Creek watershed. Soils, bedrock, and slope stability characteristics at Bear Creek are the same as those at Sulphur Creek (Pacific Lumber Company 1998), but the forest at Bear Creek is dominated by redwoods instead of by Douglas-firs. Data from Bear Creek demonstrate that rates of landsliding increase by a factor of 9.6 on hillslopes logged less than 15 years previously (PWA 1998), despite the profuse stump-sprouting of redwoods after cutting.

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