5.15 Geology and Soils

This section summarizes the impacts to soils and to geology due to implementing either the Proposed Program or any of the Alternatives.

5.15.1 Significance Criteria

Based on policy and guidance provided by CEQA (PRC Section 21001) and Appendix G of the CEQA Guidelines; the Proposed Program and Alternatives would have a significant effect on soils and geology if it would cause a relatively high magnitude, persistent, or permanent change in:

a) Soil erosion rates, loss of topsoil, or soil quality;

b) Exposure of people or structures to the risk of loss, injury, or death involving landslides;

c) In a geologic unit or soil that is unstable, or that would become unstable as a result of the Program or Alternatives, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction, or collapse.

5.15.2 Thresholds of Determination

The Program and Alternatives are considered to create a significant effect when a treatment or treatments causes:

a) The erosion hazard rating of a soil to increases more than one class or changes to extreme.

b) The hazard rating of a geologically unstable area to increase more than one class or to extreme.

c) The site quality of the soil is degraded by more than one site class or becomes non-productive.

5.15.3 Methodology

Section 4.15 provides the context for describing the consequences to soils from implementing the Proposed Program and Alternatives. The Proposed Program potential treatment acreage by bioregion is described in Tables 5.0.1, 5.0.3, 5.0.4, 5.0.5 and 5.0.7. Total acreage treated over a ten-year period is projected to be approximately 2.16 million acres, which represents about 5.16% of the total acreage of CAL FIRE jurisdiction lands that might be treatable in any ten-year period.

The CAL FIRE Forest and Range Assessment Program (FRAP) digital data on post-fire erosion hazard rating was also used for the analysis. Erosion hazard ratings were based on use of the Revised Universal Soil Loss Equation and are more fully described by the metadata from the FRAP website (http://frap.cdf.ca.gov/). These digital data were overlayed with the watersheds likely to be treated over a five-year period. A five-year period was chosen because, as the literature below shows, most soils are successfully revegetated within 1-4 years after treatment to a point where erosion is usually not a problem. Table 5.15.1 shows the distribution of potential treatments by the Proposed Program over five years by the FRAP post fire erosion hazard rating which is considered as a surrogate for the effects of VTP mechanical and prescribed fire treatments. Although the FRAP erosion hazard data is useful, it does not show the change in erosion hazard (e.g. whether a treated area changed from low to moderate) resulting from effects associated with hand, herbivory or herbicide treatments. However, these VTP treatments are not expected to create significant adverse effects associated with soil erosion because they have minimal soil disturbance.

Table 5.15.1
Acres Potentially Treated by Proposed Program During 5-Year Period by Erosion Hazard Rating

BIOREGION	Low EHR	Moderate EHR	High EHR	Total Acres
	Acres Treated Over 5-Year Period			
North Coast/Klamath	34,509	62,752	29,489	126,750
Modoc	76,238	31,525	3,837	111,600
Sacramento Valley	136,653	16,881	2,466	156,000
Sierra	101,366	89,853	23,282	214,500
Bay Area	28,862	34,321	14,817	78,000
San Joaquin	43,399	13,231	1,869	58,500
Central Coast	67,679	96,337	25,984	190,000
Mojave	8,000	1,536	464	10,000
South Coast	34,373	48,792	19,635	102,800
Colorado Desert	33,845	2,096	359	36,300
Five year total	564,923	397,324	122,203	1,084,450
	Percent by EHR Class Treated per Bioregion			
North Coast/Klamath	27.2%	49.5%	23.3%	100.0%
Modoc	68.3%	28.2%	3.4%	100.0%
Sacramento Valley	87.6%	10.8%	1.6%	100.0%
Sierra	47.3%	41.9%	10.9%	100.0%
Bay Area	37.0%	44.0%	19.0%	100.0%
San Joaquin	74.2%	22.6%	3.2%	100.0%
Central Coast	35.6%	50.7%	13.7%	100.0%
Mojave	80.0%	15.4%	4.6%	100.0%
South Coast	33.4%	47.5%	19.1%	100.0%
Colorado Desert	93.2%	5.8%	1.0%	100.0%
Total	50.7%	37.4%	11.9%	100.0%

CAL FIRE's erosion hazard rating system, Technical Rule Addendum 1 (CAL FIRE, 1990) was also used to help assign qualitative factors for rainfall intensity and slope steepness. For this analysis two-year, six-hour rainfall intensities were obtained from NOAA Atlas 14 for southeastern California and from Atlas 2 for the balance of the state. No data were available in a digital form to calculate 2-year 1-hour rainfall intensities, which are the values used to calculate soil erosion hazard in Technical Rule Addendum 1.

Table 5.15.2 2 Year 6-Hour Rainfall Intensity		
Bioregion	**Average 2-Year 6-Hour Rainfall in Inches**	**Standard Deviation of Mean**
Klamath/North Coast	2.066	0.541
Bay Delta	1.991	0.543
South Coast	1.725	0.434
Sierra	1.638	0.448
Central Coast	1.618	0.237
Sacramento Valley	1.464	0.232
Modoc	1.154	0.663
San Joaquin	1.093	0.240
Colorado Desert	1.068	0.279
Mojave	0.969	0.543

Another important factor in determining soil erosion is steepness of slope. For this analysis, a 30-meter digital elevation model of the state was used to calculate slope categories by bioregion consistent with the categories in CAL FIRE Technical Rule Addendum 1 (CAL FIRE, 1990).

Table 5.15.3 Slope of Bioreigons and of Area Potentially Treated in Five Years							
Proportion of Entire Bioregion by Slope Category							
	0-5%	5-15%	15-30%	31-40%	41-50%	51-70%	71%+
Klamath/North Coast	10.1%	11.5%	23.3%	19.5%	15.6%	16.4%	3.7%
Modoc	43.1%	27.1%	18.7%	5.9%	3.0%	2.0%	0.2%
Sacramento Valley	78.7%	13.4%	4.7%	1.4%	1.6%	0.1%	0.0%
Sierra	12.0%	21.6%	27.9%	14.5%	9.8%	10.3%	3.9%
Bay Area/Delta	41.2%	13.9%	19.8%	10.0%	8.4%	6.5%	0.3%
San Joaquin Valley	82.8%	8.4%	5.0%	1.3%	1.2%	1.2%	0.1%
Central Coast	14.3%	19.4%	25.7%	15.3%	11.2%	11.9%	2.3%
Mojave	47.9%	23.4%	12.7%	5.6%	4.7%	4.6%	1.1%
South Coast	28.8%	19.1%	20.8%	11.8%	8.3%	7.5%	3.8%
Colorado Desert	63.4%	14.4%	9.2%	4.3%	4.2%	3.6%	0.9%
Proportion of Area Treated Over Five Years by Slope Category							
Klamath/North Coast	7.9%	14.0%	27.7%	18.9%	15.4%	13.7%	2.3%
Modoc	34.7%	28.8%	20.6%	7.6%	5.3%	2.9%	0.0%
Sacramento Valley	76.1%	14.7%	6.0%	1.5%	1.6%	0.1%	0.0%
Sierra	9.3%	25.4%	31.5%	13.0%	10.5%	8.2%	2.3%
Bay Area/Delta	34.2%	15.6%	20.2%	11.2%	9.6%	8.7%	0.5%
San Joaquin Valley	79.6%	8.9%	6.3%	1.9%	1.7%	1.6%	0.0%
Central Coast	9.0%	21.8%	29.4%	15.2%	12.0%	11.1%	1.6%
Mojave	47.4%	23.0%	14.1%	6.7%	3.0%	5.2%	0.7%
South Coast	31.3%	19.2%	19.9%	12.7%	7.4%	7.0%	2.4%
Colorado Desert	60.1%	13.8%	10.2%	5.1%	5.4%	4.1%	1.3%

For landslide hazard, the USGS US-wide digital data of landslide hazard was used, as California-wide landslide hazard digital data is unavailable. These data were overlayed with the watersheds likely to be treated over five years to determine the proportion of a bioregion that might be classified as high landslide hazard as well as the proportion of the Program area treated acreage that might be classified as high landslide hazard.

5.15.4 Direct Effects Common to all Bioregions From Implementing the Program/ Alternatives

There are several landscape constraints and MMRs that help reduce impacts to soils and geology when the Proposed Program is implemented. Landscape Constraint 3 restricts the use of heavy equipment on known potential or active geologically unstable areas, unless the equipment use can be justified by the particular goals of the project (e.g., improving wildlife habitat). Operations on known geologically unstable areas must include specific measures to minimize impacts. This constraint would limit prescribed fire and heavy equipment operations on unstable areas including areas classified as landslides, headwalls of unstable areas, areas that might experience debris slides, etc. MMR 2 disallows heavy equipment operation on soils that are saturated. Operations could still take place when soils were damp or wet, but operations could not take place when soil displacement (e.g. erosion) would cause a visible increase in turbidity in Class I, II, III or IV waters.

Table 5.15.4 summarizes the information from the balance of this chapter on the effects of implementing the Program across the state by bioregion in terms of effects to soils and geology.

Table 5.15.4
Summary of Effects [1/] on Soils and Geology from Implementing the Proposed Program

Bioregion	Prescribed Fire	Mechanical	Hand	Herbivory
Klamath/North Coast	**MA**	**MA**	NA	NA
Modoc	NA	NA	NA	NA
Sacramento Valley	NA	NA	NA	NA
Sierra	**MA**	**MA**	NA	NA
Bay Area	**MA**	**MA**	NA	NA
San Joaquin	NA	NA	NA	NA
Central Coast	**MA**	**MA**	NA	NA
Mojave	NA	NA	NA	NA
South Coast	**MA**	**MA**	NA	NA
Colorado Desert	NA	NA	NA	NA

1/ Key to effects; adverse effects are those effects which degrade the diversity, structure, size, integrity, abundance or number of; or are outside the natural range of variability, for the resource at issue. Beneficial effects are those effects that improve the diversity, structure, size, integrity, abundance or number of; or are within the natural range of variability, for the resource at issue. SA/SB – significant adverse effects are those effects that are substantial, highly noticeable, at the watershed scale; and often irreversible. MA/MB - moderately adverse or beneficial effects - those effects that can be detected beyond the affected area, but are transitory and usually reversible. NA/NB - negligible adverse or beneficial effects - those effects that are imperceptible or undetectable.

Proposed Program Prescribed Fire Effects and Soil Erosion

The effects of prescribed fire can vary from merely removing some of the litter (low burn severity) to completely consuming the duff layer and the organic matter in the upper soil layers (high burn severity). The amount of duff consumption during prescribed fires is controlled primarily by the thickness and water content of the duff prior to burning. If the duff is completely consumed by a fire, the mineral soil is exposed to rain splash and overland flow. However, as noted in Section 5.7, Robichaud, et al., (2007) state that:

> *"Erosion rates tend to be positively correlated with percent bare soil and the amount of surface disturbance, and these two factors generally are proportional to the number of trees being harvested (Haupt and Kid 1965). In general, erosion rates are acceptably low when the proportion of bare soil is less than 30 to 40 percent (Benavides-Solorio and MacDonald 2005; Gary 1975; Swank and others 1989)."*

Section 5.7 also cites research indicating that when cover of vegetation and litter exceeds 75%, only about 2% of rainfall becomes runoff and erosion is low (Robichaud et al., 2000). Conversely, when ground cover is reduced to less than 10% through severe disturbance, erosion can increase by three orders of magnitude (Robichaud et al., 2000). Robichaud et al., (2000) also found that post-fire erosion rates in forested areas returned to baseline conditions in 2-4 years after low intensity fires, but took as long as 7-14 years following severe wildland fire.

As Section 5.7 notes, prescribed fire in chaparral systems often burn at moderate to high severity, which is more similar to wildfire than the low intensity broadcast burns conducted in the understory of forested systems (DeBano, 1989; Wohlgemuth pers. comm., 2007). In chaparral, sediment yields after moderate severity prescribed fires have been reported as generating 10 to 30% of the sediment yields generated after high severity wildfires (Wohlgemuth, 2001). Compared to erosion rates from unburned areas, sediment yields increased 300 to 700% after prescribed fire and from 3,000% to 67,000% after wildfire (Robichaud et al., 2000). Wohlgemuth (2001) reported that in one Southern California chaparral watershed a high severity wildfire that burned through an area that was previously treated by prescribed fire burned at lower intensity and produced only 10-20% of the sediment produced by wildfire in adjacent areas. Wohlgemuth also reported that post-fire sediment yields returned to background levels in 2-4 years for both high and low severity fires. High severity fires are of particular concern because the loss of protective cover and fire-induced soil water repellency can induce severe flooding and erosion after even moderate rain events (Robichaud et al., 2005).

As Neary, 2005 states:

> "*Soil erosion following fires can vary from under 0.1 tons/acre/year to 6.7 tons/acre/year in prescribed burns, and from less than 0.1 tons/acre in low severity wildfire, to more than 164.6 tons/acre/year in high-severity wildfires on steep slopes. For example, Radek (1996) observed erosion of 0.13 tons/acre/year to 0.76 tons/acre/year from several large wildfires that covered areas ranging from 494 to 4,370 acres in the northern Cascades Mountains. Three years after these fires, large erosional events occurred from spring rainstorms, not from snowmelt. Most of the sediment produced did not leave the burned area. Sartz (1953) reported an average soil loss of 1.5 inch (37 mm) after a*

wildfire on a north-facing slope in the Oregon Cascades. Raindrop splash and sheet erosion accounted for the measured soil loss. Vegetation covered the site within 1 year after the burn. Robichaud and Brown (1999) reported first-year erosion rates after a wildfire from 0.5 to 1.1 tons/acre decreasing by an order of magnitude by the second year, and to no sediment by the fourth, in an unmanaged forest stand".

For surface fire regime vegetation types, most VTP treatments will typically retain >75% ground cover (Table 5.0.3). About 25% of all treatments would consist of prescribed fire treatments in surface/mixed fire regimes and about 29% of all treatments would consist of prescribed fire treatments in crown fire vegetation types. In crown fire vegetation types, the amount of undisturbed soil is often much lower after prescribed burning (Table 5.0.3) compared to surface/mixed fire regimes: sometimes as low as 50% residual soil cover. However, for both treatment types, vegetative recovery after fuel treatments is generally very rapid, with erosion rates typically dropping to pre-fire levels within one to two years.

The effects of prescribed burning on soil erosion and productivity depend on the temperature of the prescribed burn, the amount and type of vegetation cover removed, the erosion hazard rating, and soil moisture. For this impact and all other erosion-related impacts, erosion hazard ratings are based on the data and assumptions noted in Section 5.15.3. Approximately 12% of all treatments might result in an erosion hazard rating post treatment of high. On areas with a pre-fire low or moderate erosion hazard rating, prescribed burns that reduce the litter layer but have little effect on the duff layer will not interfere with the maintenance of sufficient soil cover, substantially increase soil erosion, or reduce productivity. For treatment areas currently rated low or moderate from an erosion hazard standpoint, prescribed fire treatments that result in no more than 30%-40% bare ground remaining after treatment are not likely to change to an erosion hazard rating of high. For soils which are currently rated on the high end of moderate, a reduction in surface cover of more than 40% could result in a change to an erosion hazard rating of high, or if 70% or more of the treated area is classed as bare ground the resulting treatment erosion hazard rating could change by two classes and/or to extreme.

Prescribed burns can remove cover, expose soil to excessive force from raindrops and cause overland flow. Under this condition, there can be a substantial increase in water-borne erosion and a reduction in soil organic matter, which can result in a substantial loss in soil productivity. As Section 4.15 points out; "*Prescribed burns can alter erosional processes, including dry ravel. Dry ravel as an erosional process has also been documented in Southern California watersheds. Following the 1985 Wheeler fire, fine gravel was delivered to the stream channel at a rate of 0.29 m3/km2/month (Florsheim et al., 1991)*".

The potentially adverse effects from prescribed fire causing dry ravel are likely to be limited to the Southern California Bioregions, particularly the Central Coast and South Coast Bioregions. Rates of dry ravel resulting from prescribed fire are not expected to be as high as the rate of dry ravel experienced after wildland fire because the amount of surface cover remaining after prescribed fire is expected to be much higher than surface cover remaining after wildfire.

Because significant plant litter and skeletal (rock fragments) remains would be retained after burning in all vegetation types except grasslands, only the soils underlying grasslands are potentially subject to wind erosion. However, because grassland burning is not expected to disturb the soil and would be conducted in spring when the grasses and soils are relatively moist and air temperature and humidity are usually moderate, grass fires would be relatively cool. As a result, plant root systems would typically remain intact and provide substantial resistance to wind erosion.

<u>Proposed Program Mechanical and Hand Treatment Effects and Soil Erosion</u>

For all treatments discussed below, it should be remembered that changes in erosion hazard rating are heavily influenced by the inherent erosion potential of the soil, slope steepness and likely rainfall intensity expected in the bioregion.

Treatments such as blading, tilling, plowing, chaining, or soil disking drastically disturb the top 8 to 12 inches of the soil profile, while ripping may go as deep as 36 inches. Other types of mechanical treatment, such as roller chopping, maceration, and mowing directly disturb only the top few inches of topsoil and organic matter. During mechanical thinning to reduce fuel loads, cutting, skidding, and decking can all result in disturbance to soils. Roller chopping, maceration, and mowing result in minimal soil disturbance, reduce the aboveground biomass, and can provide a layer of mulched organic material to protect the soil from erosion and other effects. With some systems, mowing and mulching occurs in front of the machine, leaving a cushion of mulch to travel over, thereby reducing surface disturbance.

Neary et al., (2005) report that landscape-disturbing activities such as mechanical site preparation can generate as much as 6.7 tons/acre of soil erosion. Page-Dumroese et al., (2006) found that on average about 16% of areas treated mechanically had detrimental soil disturbance, which they defined as more than 15% of an area in wheel/tractor ruts, excessively deformed soils, etc. In addition, they also found there was a substantial difference between rubber-tired and tractor mechanical equipment, with rubber tired equipment leaving only 15% of the treated area in a detrimental condition compared to 45% with a tractor. Powers et al., (1998) cites information from the U.S. southeast that tractor piling and windrowing increase growth of planted trees for up to 10 years, but there are subsequent declines in growth thereafter. Powers cites reduced weed competition as the reason for growth increases, which mask longer-term soil declines. Powers also states that focusing on tree growth often misses the fact that total productivity of all vegetation is often the greatest with the least severe treatment and that such a narrow focus can lead managers to repetitive practices that degrade the soil until it is obvious to everyone.

Mastication of understory vegetation is one of the more intensive mechanical treatments, however it may have minimal effects on erosion or runoff rates where vegetation volumes are high prior to treatment. Hatchet et. al., (2004) found that an excavator-based masticator working in mixed conifer forests in the Tahoe basin generated 0-9% bare ground and insignificant soil compaction after treatment, and concluded that "erosion impacts would be slight to insignificant" where a mulch layer four to eight inches thick was developed during the mastication process. In vegetation types such as desert scrub, where the volume of vegetation is relatively low, mastication may have a much more dramatic impact on erosion rates due to the minimal mulch cover created during treatment.

The BLM notes in its 2005 PER (USDI BLM, 2005) that, "Increased erosion and reduced water infiltration have been observed in pinyon-juniper (Roundy et al., 1978), sagebrush (Brown et al., 1985), and creosotebush (Tromble 1980) treatment areas". These effects would typically last until vegetation was able to recover at the treatment site". The BLM also notes that, "For example, in areas with scarce vegetation (less than 40% cover), minor reductions in plant biomass have been shown to cause significant erosion, whereas areas with more extensive cover experience little change in soil loss under similar conditions. The effects of loss of plant cover and organic matter are most pronounced on steep slopes."

Robichaud, (2007) indicates that in a masticator treated stand in Colorado, the use of a Hydro-Ax Masticator redistributed existing litter and scattered wood chips over 21 percent of the surface area while percent bare soil increased from 9 to 15 percent. The data also showed no evidence of surface runoff or hillslope erosion from either the thinned or the control plots, even though the steepest plots (>50 percent slope) were subjected to a 1.6-inch storm with a maximum 30-minute intensity of 2.4 in./hour (e.g., 1.2 inches fell in 30 minutes and the remaining 0.4 inches fell during the balance of the storm).

Mastication treatments also significantly alter the fuel profile, resulting in an approximate 200 percent average increase in woody fuel cover for 1-hr and 1000-hr. size classes, and greater than 300 percent average cover increase in 10-hr and 100-hr size classes (Bradley, Gibson and Bunn, 2006). Also, adding large amounts of organic matter to the soil surface may result in short-term reductions in nutrient availability for plant reestablishment.

Mechanical treatments that involve mowing (generally in grasslands and in oak woodlands) are not expected to result in soil erosion.

According to Robichaud, (2007), in a comparison of clearcut and thinned plots to control plots hand felling without mechanized yarding caused minimal surface disturbance and no increase in erosion.

Non-commercial thinning operations (without yarding) have small, short-lived impacts on runoff and sediment production, even when operations extend over large areas (Neary et al., 2005)

Mechanical treatments can potentially result in excessive soil erosion and loss of productivity. Mechanical treatments along contours in surface fire regimes are not likely to substantially increase soil erosion or reduce productivity because annual plant species germinate after fall rains and provide cover that reduces erosion and maintains productivity. Approximately 12% of all mechanical treatments might result in an erosion hazard rating post treatment of high. As long as the uprooting of vegetation on areas with low or moderate erosion hazard rating is limited so that less than 30%-40% of the treated area is left as bare ground, erosion should decrease substantially beyond the first few years after treatment (Robichaud et. al., 2007). For soils which are currently rated as on the high end of moderate, a reduction in surface cover due to mechanical treatments of more than 40% could result in a change from moderate to high erosion hazard; or, if 70% or more of the treated area is classed as bare ground after treatment, the resulting mechanical treatment-related erosion hazard rating could change by two classes and/or change to extreme.

Non-mastication mechanical treatments in crown fire regimes can result in up to 75% bare ground as a result of treatment. In crown fire ecosystems treated by non-mastication mechanical treatments, the erosion hazard rating could change to high if more than 30-40% bare ground results from treatment on moderate erosion hazard lands. If the same treatment in crown fire ecosystems results in as much as 70% bare ground or more, the erosion hazard rating could change by two classes and/or change to extreme.

Mechanical treatment using mastication in crown fire ecosystems that have high biomass volume (e.g., in chaparral) is likely to result in a small amount of bare ground post treatment and therefore the change in soil erosion potential is not likely to change by more than one class. Mechanical treatment of crown fire ecosystems with low biomass volumes are likely to have higher percentages of bare ground remaining after treatment. Erosion potential from these systems (such as coastal sage scrub, desert scrub, grasslands) will be heavily dependent on the slope steepness and on rainfall intensity.

<u>Proposed Program Prescribed Fire Effects and Soil Temperature</u>

Soil temperature increases generated during a cool burn prescribed fire in mixed conifer forests are low and of short duration. This type of fire would be carried by the surface litter and would probably not consume much standing vegetation, although it might affect some smaller seedlings.

Nearly et al., (2005) states that the difference between wild and prescribed fires in crown fire ecosystems is mainly the amount and rate at which the plant canopy is consumed. During wildfires, the entire plant canopy can be consumed within a matter of seconds, and large amounts of heat that are generated by the combustion of the aboveground fuels are transmitted to the soil surface and into the underlying soil. In contrast, crown fire ecosystems can be prescribe-burned under cooler burning conditions (for example, higher fuel moisture contents, lower wind speeds, higher humidity, lower ambient temperatures, using northerly aspects) such that fire behavior is less explosive. Under these cooler burning conditions the shrub canopy may be not be entirely consumed, and in some cases a mosaic burn pattern may be created, particularly on north-facing slopes.

Busse et. al., 2010) found that when the volumetric moisture content of soils was 20% or greater such moisture content quenched the heat pulse in all soils at depths of 2.5 cm and lower. In comparison, soil temperatures in dry soil far exceeded the lethal threshold to a depth of 10 cm. Also, they found that differences in heating characteristics among the four soil types they investigated (sandy loam, sandy loam–pumice, loam, clay loam) were minor despite their dissimilarities in texture, porosity, bulk density, and presumed thermal conductivity.

Smoldering fires do not have flames, are slow moving and visually unimpressive, but frequently have long burnout times and may have a deep burning front. Soil heating during this long duration smoldering process may be substantial. Temperatures within smoldering duff often are between 932 and 1,112 F (500 and 600 C). The duration of burning may last from 18 to 36 hours, producing high temperatures in the underlying mineral soil.

The highest soil temperatures are reached when concentrated fuels such as slash piles and thick layers of duff burn for long periods. Neary (2005) reports that soil temperatures under a pile of burning eucalyptus logs reached lethal temperatures for most living biota at a depth of almost 22 cm in the mineral soil. It must be kept in mind, however, that this extreme soil heating occurred on only a small fraction of the area, although the visual effects on plant growth were observed for several years.

Bradley et al., (2006) state that in Northern California shrub ecosystems which were masticated and then prescribed burned, the mean flame length was significantly greater (29 vs. 10 inches) as was the flame zone depth (20 vs. 6 inches) in the masticated units than in unmanipulated units, as were the mean temperatures at the litter surface (657°F vs. 219°F) and at 1.64 ft (0.5 m) above the litter surface (277°F vs. 59°F). Greater flaming and heat release in the masticated units led to increased mortality of overstory and pole-sized oaks and conifers, posing conflicts with the management objective of retaining overstory vegetation.

Prescribed fire applied to surface/mixed fire regimes is not expected to adversely degrade soil productivity due to excessive temperatures, except under piles and concentrations of slash, as most prescribed fire would be conducted using ignition and timing techniques that result in a short duration flaming front. Prescribed fire applied to crown fire ecosystems such as coastal sage scrub, chaparral and desert shrub ecosystems has the potential to result in high temperatures if conducted under ignition and timing techniques that lead to long duration/long flame length conditions. Prescribed fire applied to grasslands is not likely to result in high soil temperature, as duration and intensity are likely to be too low to create an adverse change in soil productivity.

<u>Proposed Program Prescribed Fire Effects to Soil and Water Repellency</u>

Soil heating during a fire can produce a water-repellent layer at or near the soil surface that further impedes infiltration into the soil. The severity of the water repellency in the surface soil layer, however, decreases over time as it is exposed to moisture; in many cases, it does not substantially affect infiltration beyond the first year.

Neary et al., (2005) state that in some vegetation types a moderate or high severity fire can change or induce water repellent soil conditions at or near the soil surface. The fire-induced soil water repellency and disaggregation of soil particles will reduce the infiltration rate of the mineral soil, and the loss of organic material reduces the water storage capacity above and in the mineral soil. These changes result in increased runoff, especially from short duration, high intensity rain events (Baker, 1990). However, heat-induced water repellency typically persists for only a few years.

Knapp et al., 2009) report in their literature synthesis of the ecological effects of prescribed fire season that plant roots are killed starting at soil temperatures between 118 and 129 F, microbes are killed between 122 and 250 ^{o}F, and buried seeds have been reported to die at temperatures between 158 and 194 ^{o}F. Knapp et. al., also report on research by Hamman et al., (2008) who reported soil temperature, moisture and pH, plus mineral soil carbon levels and microbial activity following late spring/early summer (June) prescribed burns to be generally intermediate between fall (September/October) prescribed burns and unburned controls. Knapp also reports on research by Smith et al., (2004) which found that the October prescribed burns significantly reduced fine root biomass to a depth of 4 in and depressed the number of ectomycorrhizal species, relative to units burned in June. Fine root biomass and ectomycorrhizal species richness following the June burns did not differ from the unburned control. Soil moisture values were not provided, but given the rainfall patterns, it was likely considerably higher at the time of the June burns. Other studies corroborate findings of a greater loss in soil microbes following burns when soils were dry than when soils were moist (Klopatek et al., 1988, 1990), corresponding to the amount of soil heating.

Coarse-textured soils (e.g., sand and loamy sand) with low particle surface area are more prone to the formation of water-repellant layers than fine-textured soils (e.g., clay). The soil's moisture content also affects the depth to which hydrophobic substances generated by fire penetrate. In dry soils these substances tend to penetrate to a greater depth than in wet soils (DeBano et al., 1979). In field measurements conducted during a fire, a greater reduction in infiltration capacity was observed in dry soil than in moist soil (DeBano, 1991), presumably because the hydrophobic substances were concentrated in a dense layer at the soil surface.

The creation of water repellency in soils treated by prescribed fire is likely to be localized to crown fire ecosystems with coarse textured soils. In all bioregions, the total acreage treated over ten years in crown fire ecosystems is never more than 7.6% of all jurisdiction lands, let alone the entire acreage in the bioregion (Table 5.0.5), except for the Sacramento Bioregion. Ignition timing and other prescribed fire techniques are expected to reduce duration of heating and flame lengths on most treatment areas so that production of water repellent substances is reduced. As a result, though there may be adverse effects to soil productivity through creation of water repellency, these effects are likely to last only a few years, though if repellency occurs during high rainfall events runoff can lead to debris slides (see below).

Prescribed burns that occur on coarse-textured soils with low moisture content could result in a hydrophobic layer that impedes infiltration, resulting in an increase in erosion and an adverse change in soil productivity.

<u>Proposed Program Prescribed Fire Effects on Soil Biota</u>

Soil microorganisms are complex. How they respond to fire depends on numerous factors, including fire intensity and severity, site characteristics, and pre-burn community composition. Most studies have shown strong resilience by microbial communities to fire. Recolonization to pre-burn levels is common, with the amount of time required for recovery generally varying in proportion to fire severity.

Neary et al., (2005) state that almost by definition, low-severity prescribed fire has a minimal effect on soil biota. The maximum temperatures are generally non-lethal, except in the upper litter layer, and therefore the consumption of forest floor habitat is limited. Changes in microbial activity, in fact, often show a positive response to this type of fire, particularly with respect to nitrogen fixation and availability. Rates of litter decay and enzyme activity are generally unaffected by low severity underburning. Such results are not universal, however, as others have found that nitrogen mineralization was reduced at sites burned either 5 or 12 years earlier by low- to medium-severity prescribed fire. They suggested that fire-induced changes in nitrogen mineralization possibly contributed to a decline in the long-term site productivity of ponderosa pine stands in central Oregon.

Neary, (2005) states that "*while single-entry underburning is generally considered harmless, repeated burning has been shown to substantially reduce microbial population size and activity (Jorgensen and Hodges 1970, Bell and Binkley 1989, Tongway and Hodgkinson 1992, Eivazi and*

Bayan 1996). This observation reflects a cumulative reduction in forest floor and total nutrients with frequent burning. Most studies have compared either annual burning or short-term repeated fires (2 to 4 years). The long-term impact of repeated burning every 7 to 20 or more years on soil organic matter, nutrient content, and microbial processes is not understood. As a consequence, Tiedemann and others (2000) urge caution in the use of frequent fire and suggest including partial harvesting as a complementary practice to reduce wildfire risk and extend the period between prescribed burning".

Mycorrhizal fungi are easily affected by fire, and the extent of damage depends upon fire severity, the reproductive structures exposed to soil heating and the type of fungi (such as endo or ectomycorrhiaze). Mycorrhizae and roots frequently occupy the uppermost duff layers of soil and as a result are subjected to lethal soil temperatures during a fire because these layers are frequently combusted, particularly during medium- and high-severity fires.

Prescribed fire treatments are not likely to result in adverse effects to soil biota because, other than the Sacramento bioregion, less than 7.6% of any bioregion is likely to be treated with prescribed fire in ten years. However, repeated burning, particularly annual or short interval burning, can potentially cause adverse effects to soil biota and thus to soil productivity. Ignition timing and other prescribed fire techniques are expected to reduce duration of heating and flame lengths on most treatment areas, and likewise reduce impacts to soil biota.

<u>Proposed Program Prescribed Fire Treatment Effects On Soil Structure</u>

The physical processes occurring during fires are complex and include both heat transfer and the associated change in soil physical characteristics. The most important soil physical characteristic affected by fire is soil structure, because the organic matter component can be lost at relatively low temperatures. The loss of soil structure increases the bulk density of the soil and reduces its porosity, thereby reducing soil productivity and making the soil more vulnerable to post-fire runoff and erosion. Although heat is transferred in the soil by several mechanisms, its movement by vaporization and condensation is the most important. The result of heat transfer in the soil is an increase in soil temperature that affects the physical, chemical, and biological properties of the soil. The magnitude of change in soil physical properties depends on the temperature threshold of the soil properties and the severity of the fire. The greatest change in soil physical properties occurs when smoldering fires burn for long periods.

Powers (1998) states that on a sandy textured soil in California, moderate compaction improved seedling growth (due to increased water holding capacity), but that moderate compaction of a clay loam soil reduced conifer seedling growth due to reduced soil moisture availability. Powers also cites work from western Washington which showed that increasing bulk density of a loam by 28% reduced aeration capacity below the standard (0.1 cubic meters per cubic meter) considered vital for root respiration in forest soils.

Powers also cites work from the South showing a decline in second rotation height growth of planted trees on sites that were disked and slash burned compared to sites where only the slash was burned. These reductions were speculated to be due to an increase in bulk density (compaction).

Grier et al., (1989) state that light to moderate burns usually have little effect on the physical properties of the mineral soil; however, intense fires can cause the breakdown of soil aggregates and the fusion of clay particles.

About 115,000 acres of prescribed fire treatments are expected annually, which is about 0.3% of the total jurisdiction lands statewide. Over 10 years 42.5 % of all watersheds are never treated and another 42% of all watersheds never wind up with more than 10% of the watershed being treated. In the watersheds with 1-10% treated only half of the treatments would be conducted using prescribed fire. As a result, prescribed fire treatments in surface fire ecosystems are not likely to result in substantial adverse effects to soil productivity through changes in soil structure since 1) most burns are light to moderate and soil physical properties are not expected to be affected (Grier et al., 1989) and 2) the extent of such treatments across the state is extremely low even after 10 years of treatments. Most such prescribed fire treatments are short duration (at any one spot) and flame lengths are low. Prescribed fire in crown fire vegetative ecosystems could conceivably result in adverse effects to soil productivity due to changes in soil structure, but ignition timing and techniques are likely to reduce these effects.

Proposed Program Mechanical Treatment Effects On Soil Structure

Grier et al., (1989) note that soil compaction is a problem commonly associated with a variety of harvesting and site preparation techniques, mostly using tractors and rubber tired skidders. They note that changes in bulk density can occur with less than three passes of heavy equipment. As soil compaction increases, root penetration is impeded until plant growth is reduced and can lead to greater surface runoff and erosion, particularly on steep slopes. Grier et al., also note that some site preparation techniques can have major impacts on soil physical properties, especially those where the integrity of the soil profile is deeply disturbed or surface horizons are removed, such as in mechanical scalping, root raking and some forms of brush piling.

Any loss of organic matter in the uppermost layers of the mineral soil will alter the structure of the surface soil, and the resultant disaggregation of the soil particles can greatly increase its susceptibility to erosion.

About 39,000 acres (less than 0.1% of jurisdiction lands) per year would be treated across the state with mechanical treatments. Over 10 years 42.5 % of all watersheds are never treated and another 42% of all watersheds never wind up with more than 10% of the watershed being treated. In the watersheds with 1-10% treated, only one third of the treatments would be mechanical treatments. At any time, however, whether from wet weather patterns or from intensive operations on soils that are not saturated, compaction from heavy equipment can compact soil and cause adverse impacts to soil productivity. The compacted soil may have reduced infiltration rates, causing increased runoff and substantially accelerated erosion. The bulk density of severely compacted soils is also increased, reducing root penetration and gas exchange, lowering the soil's productivity. Tracked equipment is less likely to cause soil compaction than wheeled equipment, whether soils are dry or soils are wet but not saturated.

Mechanical treatment using heavy equipment could occur throughout the year when soils are dry, with the majority of operations occurring in the dry season, ~May 1 to November 15. When mechanical equipment is used on dry soils, there are likely to be no adverse effects to soil productivity due to soil compaction.

Proposed Program Prescribed Fire Treatment Effects On Soil Chemistry

The most basic soil chemical property most affected by soil heating during fires is organic matter. Organic matter not only plays a key role in the chemistry of the soil, but it also affects the physical properties and the biological properties of soils as well. Soil organic matter plays a key role in nutrient cycling, cation exchange, and water retention in soils. When organic matter is combusted, the stored nutrients are either volatilized or are changed into highly available forms that can be taken up readily by microbial organisms and vegetation. Those available nutrients not immobilized quickly by soil particles or organisms are lost by leaching or surface runoff and erosion. Nitrogen is the most important nutrient affected by fire, as it is easily volatilized and lost from the site at relatively low temperatures. The amount of change in organic matter and nitrogen is directly related to the magnitude of soil heating and the severity of the fire. High and moderate severity fires cause the greatest losses. Nitrogen loss by volatilization during fires is of particular concern on low-fertility sites because only nitrogen-fixing organisms can replace nitrogen in the soil and nitrogen fixing occurs at slow rates. On the other hand, these elements are not easily volatilized and usually remain on the site in a highly available form. An abundance of cations can be found in the thick ash layers (or ash-bed) remaining on the soil surface following high-severity fires.

Grier et al., (1989) state that nutrient losses associated with removing organic matter from a site are affected not only by the magnitude of the removal but also by the frequency of removal. If rotation lengths were shorter than the time required for a site to naturally replace nutrients lost in harvest (or treatment) then productivity losses due to depletion of these nutrients would tend to occur.

Grier et al., (1989) also observe that fire speeds up decomposition, since organic matter that would normally take several years to decompose is converted almost instantly to ash, while its carbon, nitrogen and other elements are released as gases. They also note that many researchers report an increase in pH after burning, but the increase is short lived in areas of high precipitation. As long as nutrients in the ash are not immediately lost through erosion or leaching, they become available for plant growth and may increase productivity temporarily.

About 115,000 acres of prescribed fire treatments are expected annually, which is about 0.3% of the total jurisdiction lands statewide. Over 10 years 42.5 % of all watersheds are never treated and another 42% of all watersheds never wind up with more than 10% of the watershed being treated. In the portion of the watersheds with 1-10% treated only half of the treatments would be conducted using prescribed fire. Prescribed fire treatments used for the VTP are not likely to adversely affect soil productivity because most prescribed fire effects to soil chemistry are limited in intensity, and in some cases result in beneficial effects. Changes to soil productivity are directly linked to the temperature of the prescribed fire. Ignition timing and firing techniques are expected to result in most cases in “cool” prescribed burns. Given the fact that less than 0.5% of all jurisdiction acreage is likely to be treated across the state on an annual basis, there is not likely to be an adverse effect to soil productivity as a result of prescribed fire effects on soil chemistry.

Proposed Program Prescribed Fire and Mechanical Treatment Effects and Geologically Unstable areas (Debris Slides)

Hassan et al., (2005) report that episodic mass wasting produces the most significant erosion, while continually recurring processes such as surface erosion and soil creep are relatively minor sources. They suggest that soil transported by surface erosion is on the order of 1-10 cubic meters per square kilometer per year while erosion from landslide scars, gullies, etc., is on the order of 1,000 cubic meters per kilometer per year, and that surface erosion from active road surfaces could be as much as 10,000 cubic meters per square kilometer (of actual road surface) per year.

Consumption of the rainfall intercepting canopy and the soil mantling litter and duff, drying of the soil, generation of vegetative ash, and the enhancement or formation of water repellent soils can result in decreased rainfall infiltration and significantly increased runoff and movement of soil which can lead to in-channel flooding, debris torrents, and debris sliding (Spittler, 1995; Ice, 2003; Cannon and others, 2009). This can adversely impact the public safety of high-value features (for example homes, roads, public buildings, transmission lines) near, within, or downslope of burned stream channels where they may be in positions to be affected by possible flooding and/or landsliding (Cruden and Varnes, 1996; Spittler, 2005; Cannon and others, 2007). This can also lead to adverse environmental impacts through erosion and sediment delivery to burned watersheds.

Neary et al., (2005) state that, based on work by DeBano and others, most fire-associated mass failures are debris flows associated with development of water repellency in soils. Chaparral occupying steep slopes in southern California has a high potential for mass failures, particularly when deep-rooted chaparral species are replaced with shallower-rooted grass species (Rice, 1974). These mass failures are a large source of sediment delivered to stream channels. Neary et al., quote information from Wells (1981) that wildfire in chaparral vegetation in coastal southern California can increase average debris avalanche sediment delivery in large watersheds from 18 to 4,845 cubic yards/square mile/year; however, individual storm events in smaller basins can trigger much greater sediment yields. Debris slide volumes have been measured as high as 221,026-cubic yards per square mile after single storms in California chaparral. Cannon (2001) describes several types of debris flow initiation mechanisms after wildfires in the southwestern United States. Of these, surface runoff, which increases sediment entrainment, was the dominant triggering mechanism.

Rice et al., (1981) report that in southern California chaparral one percent of an area prescribed burned six years earlier was in “soil slips” following a 9-year return interval storm. Following a much larger storm the number increased to 6% soil slips on the burned area, compared to 0.7% soil slips in unburned areas.

Cannon (2001) analyzed 95 basins burned by fires in the western United States in 1997 (86 in southern California) and found that 23 of those sustained debris flows after “significant” rainfall events. Most debris flows were in high relief watersheds where the ratios were on the order of 0.4 to 0.6 (relief ratio is a measure of basin steepness, the elevation difference divided by the longest stream channel extended to the divide).

Vegetation removal can increase soil moisture levels by reducing transpiration rates. As soil moisture levels and pore water pressures increase, frictional forces between bedding planes and soil particles decrease, increasing the potential for landslides (California Division of Mines and

Geology, 1997). Using heavy equipment on landslides or areas prone to land sliding can reactivate or cause landslides (California Division of Mines and Geology, 1997).

As noted above, Landscape Constraint 3 restricts the use of heavy equipment on known potential or active geologically unstable areas, requiring that operations include specific measures to minimize impacts. This constraint would limit prescribed fire and heavy equipment operations on unstable areas including areas classified as landslides, headwalls of unstable areas, areas that might experience debris slides, etc. Also, Landscape Constraint 4 requires that California Geological Survey (CGS) be contacted when a project is proposed on high or very high landslide hazard slopes. CGS has performed numerous reviews of CAL FIRE VMP projects, several of which resulted in changes to prescribed burn acreage when there was a potential to adversely impact slope stability and public safety.

About 115,000 acres of prescribed fire treatments and 39,000 acres of mechanical treatments are expected annually, which is about 0.4% of the total jurisdiction lands statewide. Over 10 years 42.5 % of all watersheds are never treated and another 42% of all watersheds never wind up with more than 10% of the watershed being treated. In the watersheds with 1-10% treated, only half of the treatments would be conducted using prescribed fire. Prescribed fire treatments in crown fire vegetative types in high relief small watersheds can potentially lead to unacceptable adverse consequences to the landscape resulting in debris slides. In addition, mechanical treatments on geologically unstable areas such as headwalls, margins of dormant landslides or areas prone to land sliding can also lead to adverse consequences to landscapes resulting in debris slides.

Proposed Program Prescribed Herbivory Treatment Effects to Soils

Biological control of vegetation using domestic animals could result in some effects to soils. The effects would depend on the type of animal used and the intensity and duration of the treatment in a particular area. Goats and other browsing animals are used more frequently than cattle for prescribed herbivory treatments.

The action of animal hooves could cause some disturbance, shearing, and compaction of soil, increasing its susceptibility to both water and wind erosion. These effects can be severe in heavily grazed areas, but may be less so under light and moderate grazing intensities (Trimble and Mendel, 1995). Severe compaction often reduces the availability of water and air to the roots, sometimes reducing plant vitality. Soil organisms can be negatively affected as herbivory causes the loss of surface organic matter, soil compaction, and structural habitat alterations. Recovery time from grazing-induced compaction is site-dependent, with recovery observed within one year at a site with frequent freeze-thaw events and high soil organic matter content (Wheeler et al., 2002). In some instances goats and other animals can improve soils by increasing tilling, mixing of organics, aeration, nutrient enrichment from droppings, etc.

Over ten years, only about 200,000 acres would be treated using prescribed herbivory, which is about 0.57% of the entire jurisdiction landscape. While the impacts of prescribed herbivory might cause some very localized compaction, these impacts are likely to be short lived. As a result, the consequences of prescribed herbivory are not expected to cause an adverse change in soil productivity.

Proposed Program Effects and Goals

The Proposed Program would help to reduce the detrimental environmental effects of wildfire to watersheds and thus to soil resources (Goal 6) by helping reduce fire severity across the landscape, particularly in watersheds where 35% or more of the watershed is treated which helps to reduce wildfire extent and severity.

Herbicide Effects to Soils

The consequences of treating vegetation with herbicides and the potential for these treatments to cause adverse consequences to soils and geology are described in Section 5.17.

Consequences to Soils and Geology From Implementing Alternatives to the Program

Alternative 2 would likely have consequences similar to those from the Program, as they treat the landscape using approximately the same number of acres of treatments by treatment type, by bioregion, as the Program. As a result, the effects to soils and geology from implementing Alternative 2 would be approximately the same as the Program. Thus, there could potentially be adverse consequences to soil productivity from prescribed fire and from mechanical treatments due to soil erosion, increased water repellency and soil compaction. There could also potentially be adverse consequences to the landscape from debris slides associated with prescribed fire or mechanical treatments on unstable slopes.

Implementation of Alternative 3 would likely cause fewer impacts to soils and geology than the Program, because Landscape Constraint 6 would be implemented, which limits mechanical and prescribed fire treatments to locations where the resulting post-treatment erosion hazard rating is either low or moderate and would limit treatments in watersheds designated as high priority by the EPA. The effect of this additional landscape constraint is expected to drastically reduce the number of acres that could be mechanically treated statewide, from about 10 million acres to 4 million acres. However, the same number of acres of mechanical and prescribed fire treatments would take place annually as under the Proposed Program. As a result, the location of treatments would be limited to low and moderate erosion hazard lands even while the annual number of acres treated and the types of treatments applied would be similar to the Proposed Program. Adverse consequences to soil productivity due to soil erosion and soil compaction from prescribed fire and mechanical treatments would be expected to be less than the Proposed Program because treatments would likely take place on gentler slopes – slope being an important component in erosion hazard ratings. Implementation of Alternative 3 might result in fewer acres of prescribed fire being applied to steep land in crown fire ecosystems since these areas have a greater chance to exceed the low to moderate erosion hazard, post-treatment threshold.

Implementation of Alternative 1, the status quo, would only treat about 47,000 acres annually compared to 216,910 acres of annual treatments under the Proposed Program. Since the mix of treatments is about the same as the Proposed Program, the expected consequences from any particular treatment are expected to be similar at the project level as the Proposed Program. Treatments under Alternative 1 are implemented under procedures contained in environmental and procedural documents described in Chapter 1, which helps ensure that treatments do not create adverse effects to soils and geology.

Implementation of Alternative 4 would have substantially different consequences than the Proposed Program. Substantially fewer acres would be treated with prescribed fire (approximately 7,000 acres) compared to the 115,000 acres in the Proposed Program. Mechanical treatments would also be substantially reduced compared to the Proposed Program treating only about 23,250 acres annually compared to the approximately 39,000 acres treated annually by the Proposed Program. Treatment effects under Alternative 4 would be similar to the Proposed Program for specific treatments applied to surface/mixed and crown fire ecosystems. Thus, there is a potential for treatments to create soil erosion and soil compaction which could result in adverse effects to soil productivity, however these effects would generally be nearly two orders of magnitude less for prescribed fire treatments and substantially less for mechanical treatments, compared to the Proposed Program. On the other hand, since Alternative 4 treats so few acres, a larger number of acres burn at high severity due to wildfire than under the other alternatives, as a result, the overall combination of treatment effects and wildfire effects is expected to be similar to the Proposed Program.

Implementation of Alternative 2 would meet Goal 6 at approximately the same rate and to the same extent as the Proposed Program. Alternative 3 would initially meet Goal 6 at approximately the same rate and to the same extent as the Proposed Program. However over the long term, Alternative 3 only treats about 13.7 million acres with prescribed fire and mechanical treatments which is only about 40% of the acres that would be treated under the Program, thus, Alternative 3, over the long term, would not meet Goal 6 as effectively as the Proposed Program. Alternative 1 would not meet Goal 6 at the same rate or to the same extent as the Proposed Program since it would treat so few acres and substantially more acres would likely burn at high intensity due to wildfires. Alternative 4, like Alternative 1, would not meet Goal 6 at the same rate or to the same extent as the Proposed Program since it would treat so few acres and substantially more acres would likely burn at high intensity.

5.15.5 Bioregion Specific Direct Effects of Implementing the Program/ Alternatives

Based on FRAP data (see Table 5.15.1) about 12% of treatments over five years might result in a soil erosion hazard rating of high after treatment. However, several bioregions have a higher proportion of treatments that might be high, including the North Coast Bioregion where 23% of treatments have potential to be rated high for post-treatment erosion hazard, followed by the South Coast and Bay Delta Bioregions where 19% of all treatments could result in a high rating, the Central Coast with nearly 14% of all acres treated estimated at high after treatment and the Sierra Bioregion where 11% of all treatments might be rated high after treatment. As a result, there is a potential for adverse effects to soil productivity from treatments under the Program and Alternatives resulting in erosion on soils having a high erosion hazard immediately after treatment.

Several bioregions including the North Coast, South Coast, Central Coast, Sierra and Bay Delta have landscapes where adverse treatment effects could potentially represent a large proportion of the landscape compared to the other bioregions. The South Coast and the Sierra both contain large areas of coarse textured soils where water repellency from prescribed fire treatments could create adverse soil erosion and productivity effects, compared to the other bioregions. As Table 5.15.1 notes, rainfall intensities for the North Coast, Bay Delta, South Coast and Central Coast are much higher than for the other bioregions. Higher intensity rainfall events are linked with both soil erosion and with debris sliding (e.g. see Cannon, 2001).

Virtually the same bioregions with high rainfall intensities also have a much higher proportion of their landscape in steep slopes, as categorized by Technical Rule Addendum 1 (CAL FIRE, 1990). The North Coast bioregion has the most steep (71%+) ground followed by the Central Coast, Sierra, Bay Delta and the South Coast. The other bioregions have substantially less acreage, proportionally, of steep slopes. Steeper ground can lead to more erosion and a higher likelihood of debris sliding, particularly for projects on slopes exceeding 65%, which is the average angle of repose for most soils in the State of California. All else being equal, a project with high residual ground cover remaining after treatment would likely be rated as either low or moderate when on gentle (5-15%) slopes but could "jump" more than one erosion hazard class or to extreme, if the project were on 71%+ slopes. As noted above, bioregions with coarse soils such as decomposed granitics, and which are easily detachable (due to raindrop splash) are common in the Sierra and South Coast Bioregions. For these bioregions in particular, and for all projects in general which occur on steep (71%+) slopes and coarse textured soils, there is a potential for adverse effects to both soil productivity and to the landscape through potential soil erosion and debris sliding related to vegetation treatments.

Soils in bioregions with a high proportion of crown fire vegetation types, such as the South Coast, are particularly at risk given the relatively high rainfall intensities, steep slopes and amount of vegetation in crown fire types. For this bioregion in particular, and for all projects in general which occur in crown fire ecosystems and on coarse textured soils, there is a potential for adverse effects to both soil productivity and the landscape through potential soil erosion, creation of water repellency and debris sliding, respectively.

5.15.6 Indirect Effects of Implementing the Program/Alternatives

There are potential indirect effects to water quality and to vegetation through implementation of the Proposed Program. Water quality could be impaired due to excessive soil erosion and due to debris slides from burned project areas or from mechanical treatments on geologically unstable areas, which activate unstable features. There are also potential indirect effects to water quality from treatments that result in both the creation of water repellency due to overly hot soil temperatures from prescribed fire and from the creation of compacted soils due to either prescribed fire or from mechanical treatments. There could also be indirect effects to aquatic species if water quality is degraded due to soil erosion.

There are also potential indirect effects to vegetation due to degradation of soil productivity resulting from treatments. Compaction of soil, reduction of soil biota and/or reduction of soil nutrients on treated areas could lead to an adverse effect on soil productivity, which could indirectly lead to a reduction in vegetation growth and further to a decline in the health of vegetation. These indirect effects to vegetation could also have indirect, long-term effects on wildlife that depend on vegetation.

5.15.7 Determination of Significance

Implementation of the Proposed Program could result in increasing the erosion hazard rating by more than one class or to extreme and create a substantial adverse effect to soil condition, topsoil or to soil productivity (the threshold of significance) through effects such as an adverse increase in soil erosion or the creation of a water repellent layer. These potentially substantial adverse effects will have a less than significant impact as a result of implementation of Mitigation Measures 5.15- 1, 2, 9, 11, 12 and 13. A detailed description of the potentially substantial adverse effects of soil erosion is found in Section 5.15.4 at the end of each subsection.

Implementation of the Proposed Program could result in lowering soil site class by more than one category (the threshold of significance) and create a substantial adverse effect to soil productivity through effects such as an increase in soil bulk density (compaction), a decline in soil biota or nutrient status, or the creation of a water repellent layer. These potentially substantial adverse effects will have a less than significant impact as a result of implementation of mitigation measures 5.15-3, 4, 5, 6 and 7. (A detailed description of the potentially substantial effects to soil productivity that require mitigation is found in Section 5.15.4 at the end of each subsection.)

Implementation of the Proposed Program could result in the landslide hazard rating of a geologic unit to change more than one class or change to extreme (the threshold of significance) which could expose people or structures to the risk of loss, injury, or death involving landslides which would be a substantial adverse effect on the landscape due to treatments which cause an adverse increase in debris slide potential or create a water repellent layer. These potentially substantial adverse effects will have a less than significant impact as a result of implementation of Mitigation Measures 5.15- 8 and 10. A detailed description of the potentially substantial adverse effects to soil productivity is found in Section 5.15.4 at the end of each subsection.

5.15.8 Similar Effects Described Elsewhere

The effects of Program implementation associated with soil erosion as they relate to water quality are described in detail in Section 5.7.

5.15.9 Mitigation Measures for the Proposed Project

Adopt Mitigation Measures 5.15-1 through 5.15-13 to help ensure that adverse effects to soil productivity and to the landscape remain below significant. Mitigation measures 5.15-1 through 5.15-6 are based on Powers (1998), which are based on threshold values adopted by the USDA Forest Service (see Powers, 1998, pages 64-66).

Mitigation Measure 5.15-1. The operational area shall not have detrimental (see description below) conditions on more than 15% of the area. Detrimental soil conditions occur when any of the following are found within the operational area of the project:

1. Trail used by harvester, forwarder, skidder, bulldozer, etc.
2. Wheel ruts or tracks are >10 cm deep
3. Forest floor is missing/partially intact
4. Trails have a high level of soil compaction
5. Evidence of mineral soil displacement from tractor trails
6. Mineral soil displacement from area between skid tractor trails

Mitigation Measure 5.15-2. Mechanical equipment and prescribed fire shall be limited so soil cover on treated areas will exceed 30-50% of the operational area the first year and 50-70% the second year.

Mitigation Measure 5.15-3. Mechanical equipment and prescribed fire shall be limited so soil organic matter will cover more than 50% of the operational area, post-treatment.

Mitigation Measure 5.15-4. Mechanical equipment and prescribed fire shall be limited so soil bulk density (compaction) does not exceed 15% over natural conditions.

Mitigation Measure 5.15-5. Mechanical equipment and prescribed fire shall be limited so that after treatment there is still at least ½ of the natural litter layer.

Mitigation Measure 5.15-6. Mechanical equipment and prescribed fire shall be limited so that displacement of humus does not exceed 15% of the soil organic matter under natural conditions.

Mitigation Measure 5.15-7. Mechanical equipment shall not be used on wet or saturated soils**.** The use of heavy equipment for mechanical treatment shall be limited to periods when there has been no significant (i.e., one inch or more) rainfall within the previous week.

Mitigation Measure 5.15-8. Prescribed burning shall not occur on active landslides. On dormant landslides or areas with high landslide potential, canopy cover provided by woody vegetation shall exceed 50% cover following treatment. Vegetation shall not be removed from the headwalls or margins of dormant landslides

Mitigation Measure 5.15-9. Sufficient soil cover shall be maintained to control accelerated erosion and protect soil productivity. Maintaining sufficient soil cover will reduce the effects of prescribed burns on soil erosion and productivity. Guidelines for minimum soil cover for different vegetation types, soil textures, and erosion hazard ratings are described in Table 4-2, page 4-20 of the Klamath National Forest Land and Resource Management Plan (USDA Forest Service, 2010) and on professional judgment.

Mitigation Measure 5.15-10. Heavy equipment shall not operate on geologically unstable areas except as prescribed below**.** No heavy equipment will be operated on active landslides, the headwalls or margins of dormant landslides, or areas with high geologic hazard, except on existing stable roads within such areas. If it is not feasible to completely avoid treatment actions on identified geologically unstable areas with high hazard potential, then a licensed geologist shall be consulted to develop appropriate additional mitigation measures.

Mitigation Measure 5.15-11. Mechanical treatments shall not be implemented perpendicular to contours on areas with high or extreme erosion hazard ratings. Mechanical treatment of vegetation shall be limited to work along topographic contours on areas with a high erosion hazard rating in order to reduce soil disturbance and erosion. Where mechanical clearing is aligned along the slope on highly erodible soils, soil disturbance shall be limited by restricting the hillslope length of cleared areas and interspersing cleared areas with untreated buffers.

Mitigation Measure 5.15-12. No mechanical treatment that removes/uproots the roots of vegetation shall be conducted on areas with a very high or extreme erosion hazard rating.

Mitigation Measure 5.15-13. No more than 25% of the original woody vegetative stems shall be uprooted every two years within project areas with moderate or higher erosion hazard ratings. 0