Draft Assessment
Forest Plan Revision

Soil Report

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February 6, 2024

Soil

Introduction

Soil Resource information is a core component of national forest planning. Soil productivity is the inherent capacity of a soil to support the growth of specified plants, plant communities, or a sequence of plant communities. Soil productivity may be expressed in terms of volume or weight per unit area per year, percent plant cover, or other measures of biomass accumulation. Maintaining soil productivity and minimizing soil erosion are primary concerns when managing soil resources on National Forest System (NFS) lands. Understanding the inherent soil capabilities and limitations of the landscape also assures that planned activities are both obtainable and sustainable over time.

Portions of this report utilized the 2018 Blue Mountains Plan Revision Final Environmental Impact Statement to the extent practicable. Current and up to date research, monitoring, and information has been used where appropriate.

Regulatory Framework

Land potential is generally referred to as productivity of the land or soil. National environmental regulations, including the National Environmental Policy Act (NEPA) and the National Forest Management Act (NMFA), mandate that productivity of the land (and soil) should not be permanently degraded due to Forest Service management activities. Thus, understanding the variability of those complex but predictable patterns becomes an important part of both good natural resource management and ensuring compliance with national environmental laws.

Forest Service Soils Manual and Region 6 Soil Quality Standards provide guidelines and methods to show compliance with NFMA. The Forest Service Manual, FSM 2550, has an objective to “manage resource uses and soil resources on NFS Lands to sustain ecological processes and function so that desired ecosystem services are provided in perpetuity”. Soil policy recommends the use of “soil properties to assess the condition and potential effects on soils, when planning and implementing project activities” and includes an assessment of soil function and processes. The manual also identifies Forest Service Disturbance Monitoring Protocol (Page-Dumroese et al. 2009) as a recommended method for assessing soil disturbance in forested landscapes.

Scale

The scale used for this analysis is roughly 1:100,000. At this scale, the variables that define soil landscapes become most apparent.

National Soil Quality Standards established definitions and some minimum size requirements for detrimental soil conditions. Region 6 standards (USDA 1998) state that 80 percent of an activity area should be maintained in a condition of acceptable productivity potential for trees and other managed vegetation. The threshold value of 20 percent is established for assessing pre and post detrimental soil conditions at the stand or harvest unit scale.

Current Management Direction

Forest plans for Malheur (1990b), Umatilla (1990c), and Wallowa-Whitman (1990d) National Forests provide limited direction with respect to the management of soil resources. Between the three forests, the direction can be paraphrased as follows:

1. Manage Forest lands to maintain or enhance soil and land productivity,
2. Maintain or improve soil productivity,
3. Project design criteria will be applied,
4. Monitor effects of activities and long-term changes in soil productivity, and
5. The Forest soil survey will be incorporated into resource analysis (USDA Forest Service 1978 (Umatilla); USDA Forest Service 1974 (Malheur); USDA Forest Service 1975 (Wallowa-Whitman).

As a result of limited guidance at the Forest Plan level, activity procedures have relied primarily on national and regional guidance, the professional expertise of forest soil scientists, and their ability to use best available science information to maintain the productivity of soil and land resources.

Soil Survey Data and Terrestrial Ecology Unit Inventories

A summary of general soil types in the Blue Mountains is in the land type associations (LTAs) description (Sasich and Ottersberg 2006) and GIS layer. Land type associations are differentiated based on vegetation zones, geology groups, and landforms. There are 80 land type associations in the Blue Mountains. In addition to the three characteristics that differentiate the land type associations, Sasich and Ottersberg (2006) give information on volcanic ash, texture, rock fragments, depth to bedrock, soil climate, hydrologic and sedimentation properties and responses, productivity, vegetation recovery, limitations for roads and heavy machinery operability, timber and range suitability, and other characteristics.

Soil inventories allow for improved soil management and maintenance of soil productivity for decision makers. More detailed, site-specific soil information for most of Umatilla and Wallowa-Whitman National Forests and the northern part of the Malheur National Forest is in the Terrestrial Ecological Unit Inventory (TEUI) GIS layer and database. For areas that lack TEUI, Soil Resource Inventory information is available for each national forest at an intermediate scale. The Forest Service has direction to create TEUI as needed that will closely define the relationship between soils and native plant communities within land units (Winthers et al. 2005). To date, the vegetation level work does not meet all the requirements needed to officially meet TEUI geospatial information layer coverage. This inventory requires that corresponding soils data meets National Cooperative Soil Survey standards for classification, description, and documentation (Winthers et al. 2005). The Malheur National Forest currently has a proposed plan to rectify these deficiencies once the opportunity exists. Good quality, point sample soil profile data was collected as part of the initial field work for this project. This data will be useful in completing the Terrestrial Ecological Unit Inventory.

Existing Condition

The Malheur, Umatilla, and Wallowa-Whitman National Forests encompass the Blue Mountains region, a unique island arc with a wide diversity of soil types. These soil types form minimally developed, nutrient poor soil and rock-outcrop complexes of the steep mountain slopes and ridges to the deep fertile soils of the lower valleys.

Individual soils are a product of geologic parent material as modified by the effects of weather, topography, biota, and time (Jenny 1941). Paul and Clark (1996) expand the definition of biota to include above ground vegetation along with soil organisms responsible for nutrient exchange between soils, vegetation, and the decomposition of organic material that develops upper soil horizons.

Soils in the Blue Mountains are derived from a variety of geologic parent materials that include Paleozoic and Mesozoic sedimentary, metamorphic, and igneous rocks, of which the oldest are associated with parts of at least five known accreted terranes in northeast Oregon. These older rocks are overlain by Cenozoic Columbia River basalts, and younger volcaniclastic sediments, volcanic ash, lake sediments, glacial debris, and other rocks (Vallier and Brooks 1995).

About 68 percent of soils in the Blue Mountains national forests are derived from volcanic rocks, 10 percent are from igneous intrusive, 11 percent from metamorphic, 7 percent from sedimentary, and 3 percent from other rock types. Of the soils from volcanic rocks, 74 percent (approximately 40 percent of the total) are derived from Columbia River basalts and 26 percent (28 percent of total) from other volcanic rocks. From 30 to 60 percent of all soils have volcanic ash deposits of varying thickness derived from the eruption of Mount Mazama roughly 6800 years ago that overlie previously developed soils (USDA Forest Service 1990b, 1990d). Ash soils developed on top of pre-existing soils of all types and are among the most, if not the most productive, of all soils in the Blue Mountains (Geist and Strickler 1978). The productivity of volcanic ash soils is derived from higher water holding capacity and higher organic matter content compared to all other soils.

The Blue Mountains physiographic province, which includes the three national forests, is characterized by a diverse landscape ranging from river and valley bottoms to steep mountain slopes, deeply dissected canyons, and mountain and plateau tops (USDA Forest Service 2006). Landform type and topography directly influence soil characteristics and productivity and erosional, sedimentation, and hydrologic processes; specifically mass wasting, surface erosion, and runoff (USDA Forest Service 2006). Individual soils are a product of geologic parent material being modified by the effects of weather, topography, biota, and time (Brady and Weils 1999). Soils provide water and nutrients for vegetation, provide support for individual plants, absorb precipitation, and regulate quantity and timing of stream flow, provide habitats for a wide variety of wildlife (above and below ground), buffer effects of pollutants, and store and release carbon. Other resource values, such as water quality and quantity, wildlife habitat, and biomass production, are often dependent on and closely related to properly functioning soils.

Soil moisture and temperature significantly influence each soil's productive potential and how it responds to disturbances. Given the variation in topography and atmospheric moisture within the Blue Mountains, there is a consequent variation in local climatic conditions. Diurnal fluctuations in both temperature and moisture are also important environmental variables and are influenced largely by elevation and aspect. Soil moisture and temperature regimes are reflected by the kinds of vegetation occurring on a landscape. Both yearly and daily fluctuations in temperature and moisture can be influenced by management activities (vegetation management and surface soil removal).

The Blue Mountains are a moisture-limited region when compared to the Cascade Range. Many lower elevation soils in the area are dry for 40 or more days during summer (xeric moisture regime). The active growing season is effectively shortened by early moisture stress. In addition, many lower elevation soils lack a volcanic ash mantle which reduces the effective soil depth. This, coupled with generally more coarse rock fragments (gravel-size and larger) throughout the profile decreases available water capacity for plant use. Within this moisture regime, grass and shrubby plant communities produce organic matter accumulations, observed as dark topsoil. These dark colored soils are highly productive. Productivity on soils that lack organic rich topsoil are dependent on a surface organic matter layer (forest floor) as well as topsoil to be productive. Some soils benefit from regular low intensity fires to release nutrients accumulated in woody debris and the forest floor.

Soils have biological, chemical, and physical properties that are fundamental to the productivity of forest ecosystems and play an integral role in the hydrological behavior of watersheds (Neary et al. 2009). Soils provide water and nutrients for vegetation, provide support for individual plants, absorb precipitation and regulate the quantity and timing of stream flow, provide habitats for a wide variety of wildlife (above and below ground), buffer effects of pollutants, and store and release carbon. Other resource values, such as water quality and quantity, wildlife habitat, and biomass production, are often dependent on and closely related to properly functioning and productive soils.

Undisturbed forest soils have forest floors composed of litter and organic material that protect the soil surface. Litter layers are underlain by a layer of decomposed organic matter, or humus, which is underlain by mineral soil. The high porosity of surface soil layers normally results in high infiltration capacities and low erosion rates when undisturbed. Disturbance that results in loss of surface layers can result in loss of a substantial portion of soil organic matter, nutrients, and soil biota that are key to soil productivity (Everett et al. 1991).

Biological Soil Crusts

Shrubland and grassland soils may have a surface that is protected by a biological crust consisting of cyanobacteria, green algae, lichens, mosses, microfungi, and other bacteria (Belnap et al. 2001). Biological soil crusts occupy the spaces between higher plants and form a thin matrix on the soil surface that protects against erosion, fixes atmospheric nitrogen, plays a key role in the dynamics of other nutrients, and helps retain soil moisture. Under undisturbed conditions, biological soil crusts may consist of nearly 100 distinct species (Root and McCune 2012) and are critical for stabilizing the surface soil and trapping sediment in grazing lands, particularly in dry non-forested and dry forested grazing lands. Biological soil crusts also function as living mulch by retaining soil moisture and discouraging annual weed growth on moisture-limited sites (Belnap et al. 2001).

Disturbances, such as grazing, fire, areas of seasonally (winter and spring) intense wild ungulate use, natural erosion processes (specifically sheet erosion), and off-road vehicle use, contribute to a complex mosaic of biological soil crust composition and abundance. Frequent or continuous disturbance from grazing keeps the biological soil crust communities at an early successional stage (USDA Forest Service 1999; Brooks 2009). The degree of degradation of soil crusts is related to soil type (specifically soil texture) and soil moisture. Disturbance of soil crusts may result in lowered species diversity or loss of the crust and exposure of mineral soil to erosion and profile loss, depending on the severity of disturbance (Ponzetti and McCune 2001). Partial breakdown of soil crusts is also observed to create areas of bare ground that may be more easily colonized by invasive, non-native species (Reisner et al. 2013).

Soil Quality and Inherent Soil Productivity

FSM chapter 2550 Soil Management directs soil resource management on National Forest System lands. The objectives of the national direction are (1) to maintain and restore soil quality on National Forest System lands, and (2) to manage resource uses and soil uses on National Forest System lands to sustain ecological processes and function so that desired ecosystem services are provided in perpetuity. Soil function is any ecological service, role, or task that soil performs.

Soil quality is the capacity of a specific kind of soil to sustain plant and animal productivity, maintain or enhance water and air quality, support human health and habitation, and provide for ecosystem health. Soil productivity is the inherent capacity of the soil resource to support appropriate site-specific biological resource management objectives, which include the growth of desirable plant species, plant communities, or a sequence of plant communities, all to support multiple land uses. Both can be described as the sum of the six ecological soil functions: soil biology, soil hydrology, nutrient cycling, carbon storage, soil stability and support, and filtering and buffering. The main function drivers of inherent soil productivity on Blue Mountain national forests are soil hydrology, soil organic matter, and nutrient cycling. Inherent soil productivity influences what plant communities can grow on the forest and how well they grow. Maintaining soil quality and productivity are important considerations in determining the level of natural resource extraction, like timber harvest, that the land can sustain, as well as other forest values, such as wildlife habitat and biodiversity.

Soil Biology

Soil Biology is the ability to provide habitat for a wide variety of organisms including plants, fungi, microorganisms, and macro-organisms in the upper sections of the soil. The major drivers of soil biological function are presence of organisms and thermodynamics. Organism influences on the soil include plant and animal actions from root growth and distribution to macro pore creation by small animals. The thermodynamics of the site control moisture and temperature of the soil profile. Vegetation canopy and soil cover (forest floor, fine and coarse woody debris) provide macro and microhabitat and climate conditions on-site to support soil organisms.

Soil Hydrology

Soil hydrology is the ability of the soil to absorb, store, and transmit water both vertically and horizontally. Soil hydrology is extremely important in Blue Mountains national forests, because the ecosystem productivity is typically limited by water. Soil can regulate the drainage, flow and storage of water and solutes, including nitrogen, phosphorous, pesticides, and other nutrients and compounds dissolved in the water. With proper functioning, soil partitions water for groundwater recharge and use by plants and animals. Sensitive soils for the hydrologic function are soil with volcanic ash deposits, soils susceptible to drought, very shallow soils, and hydric soils (wetlands).

Volcanic Ash Soils

Surficial volcanic ash deposits, or ash cap, on Blue Mountain Forests are instrumental to high forest productivity. Ash-caps are characterized by low bulk density, high water-holding capacity, and high cation exchange capacity that can lead to a concentration of nutrients. Ash-caps found in Blue Mountains national forests consist of varying forms, from thick mantles of pure ash to layers of ash mixed with weathered mineral soil. These deposits tend to be fine particle forming loam and silt loam textured soils. The high water-holding capacity of ash-caps is arguably their most important feature. Volcanic ash was originally deposited over rocky and sandy coarse-textured soils with relatively low water-holding capacities in northeastern Oregon and southeastern Washington, and therefore most plant-available water in this landscape is held in the ash cap.

Ash-caps are extremely susceptible to decreased soil quality due to compaction, erosion, and soil mixing. Ashy soils have low soil-bearing capacity and compact very easily within a large range of soil moisture levels. Compaction restricts plant rooting and decreases water-holding capacity which, results in lower infiltration rates. Ashy soils also do not recover from compaction as quickly as other soil types. Several hypotheses exist regarding the slower recovery times. Low amounts of clay may limit the natural shrink and swell cycles of soil. Another possibility relates to the physical locking of jagged edge ash particles during compaction.

Ash-cap layers tend to be resistant to erosive forces when fully vegetated due to high infiltration rates and strong soil structure. When vegetation and litter layers are removed, the texture of the ashy soil is highly susceptible to severe erosion. Loss of the ash-cap layer would reduce the water-holding capacity and increase the overall soil bulk density of the profile. These effects would decrease available soil moisture and tree root penetrability. The effects of ash-cap mixing with subsoil are similar and would result in comparable productivity decreases. Since volcanic ash is not replaced, the effects of erosional losses of the ash-cap would be long term.

Droughty Soils

Drought affects trees directly by slowing or arresting growth and causing injury or death. It also affects them indirectly, by increasing their susceptibility to wildfire, insect pests, and disease. A drought may be short-lived, perhaps lasting one growth season, but its impact on tree health—and ultimately, forest health—can last much longer. Trees have evolved protective mechanisms to deal with water stress, but there are many external factors that determine the effects of drought, including soil composition and topography, as well as the species mix, age, and density of trees. Soils that are susceptible to drought can inform management as to desired tree density and areas at risk to insect and disease outbreaks.

Oregon State University has created a soil drought index layer for the Pacific Northwest Region of the Forest Service (Ringo et.al.). This layer represents an initial approximation of the potential for droughty soil conditions in forested landscapes in Washington and Oregon. The index is based upon best available soils data and satellite-derived estimates of actual and potential evaporation. Potential evapotranspiration is an estimate of the evaporation and transpiration that would occur if an adequate supply of moisture were available. Actual evapotranspiration measures the actual loss of moisture from soil and plant surfaces. The degree to which actual evapotranspiration falls below potential evapotranspiration is interpreted as an indicator of moisture limitation. Some studies have found that prolonged periods of low actual evapotranspiration to potential evapotranspiration ratio during a growing season are highly correlated with reduced dryland crop yields.

The actual to potential evapotranspiration ratio has been used as a broad-scale indicator of potential drought stress. See Climate Change and Vulnerability Assessment for the Blues Mountains (PNW-GTR-939) for further information on droughty soils.

Very Shallow and Low Nutrient Soils

Very shallow soils are less than 25 cm thick and have a root limiting layer, usually bedrock. These soils are highly sensitive to temperature fluctuations, erosion, and displacement. These soils generally support plant communities that are spatially limited within the three Blue Mountains national forests. Grasses, forbs and small shrubs unique to these soils are conditioned to saturated and droughty periods. Alteration of these soils by erosion or displacement makes very shallow soils more droughty than the native vegetation can handle making room for invasives to take over. Restoration actions, such as decompaction or biochar, is difficult on very shallow soil because of the limited thickness of the soil profile.

Hydric Soils

Hydric soil forms under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions within the upper part. Saturation is when all pores are filled with water, excluding all air. The saturated soil closest to the soil surface indicates the level of the water table. Anaerobic conditions exist when biologically available oxygen is absent from the soil. In hydric soils, soil organic matter accumulates because the microorganisms decompose plant and animal material more slowly than in anaerobic soils. This decrease in decomposition causes organic matter to build up at the surface. As a result, anaerobic soils usually have a dark or almost black surface. Common rates of organic accumulation may average 2 inches every 100 years. A common indicator of hydric soil is a dark surface horizon, underlain by a gray horizon. Another indicator is a horizon that is predominantly gray with accumulations of iron along root channels or in masses. In the horizons with accumulated iron, there are also areas that are depleted, making them lighter than the main horizon color (Hurt et al. 1996).

The presence of hydric soils is one-third of the requirements needed to meet a jurisdictional wetland. The two other requirements include wetland hydrology and hydrophytic vegetation. Hydrology refers to the movement of water in the environment. However, wetland hydrology specifically implies the soil is saturated to the surface for approximately five percent of the growing season or is frequently flooded or ponded. Hydrophytic vegetation is adapted to survive in saturated and anaerobic soils. Wetlands are universally sensitive to machine traffic due to saturation throughout the growing season and high organic matter content of the soils.

Hydric soils are generally located in floodplains of drainages in the incised Blue Mountains landscape, making them spatially limited. Some hydric soils are located on the tops of plateaus in slightly low lying areas where bedrock directs subsurface water flow to the surface. This same phenomenon on the backslopes and toeslopes of mountains and hills produces seeps. In some instances, these areas form fens. Fens are groundwater dependent ecosystems that produce continuously growing, thick mats of organic matter that can be thousands of years old. All these hydric soil areas filter water and maintain lower water temperatures as it slowly passes through the system.

Hydric soils are identified in soil mapping by the Natural Resources Conservation Service differently based on their spatial extent on the landscape. For this reason, estimating the amount of hydric soil for Blue Mountains national forests is difficult and likely underestimated. What can be determined is that hydric soil spatial extent is significantly less than upland soils and slightly greater than very shallow soils. Disturbance to these soils can affect water quality and rates of flow through the landscape. For these reasons, hydric soils are sensitive to human interactions.

Nutrient Cycling

Nutrient cycling is the movement and exchange of organic and inorganic matter back into the production of living matter. Soil stores, moderates the release of, and cycles nutrients and other elements. In contrast to the annual harvests associated with agriculture, forest harvest—and hence nutrient removal—typically occurs only once per management action, or every 40 to 120 years. This not only reduces the rate of removal of soil nutrients, but also maintains nutrient content by long-time additions of nutrients by atmospheric deposition and by weathering of soil minerals. Sensitive soil attributes for nutrient cycling include the forest floor vegetation quantity composition and coarse soil texture subject to leaching. Soils formed on quartzite or granites are very low in nutrients from parent material and have little capacity for retaining deposited nutrients.

During these biogeochemical processes, analogous to the water cycle, nutrients can be transformed into plant-available forms, held in the soil, or even lost to atmosphere or water. Carbon, nitrogen, phosphorus, and many other nutrients are stored, transformed, and cycled through soil. Decomposition by soil organisms is at the center of the transformation and cycling of nutrients through the environment. Decomposition liberates carbon and nutrients from the complex material making up life forms and puts them back into biological circulation, so they are available to plants and other organisms. Decomposition also degrades compounds in soil that would be pollutants if they entered ground or surface water. Nutrient cycling can be assessed by considering organic matter composition on a site (forest and rangeland floor, fine and coarse woody material) and the nutrient availability (topsoil horizons and nutrient deficiencies).

Nearly all the nitrogen in forest systems is bound to organic matter. Very little of the total pool of nitrogen is available to plants; only about 2.5 percent of total organic nitrogen is released annually (Grigal and Vance 2000). The rate of nitrogen release from organic matter (mineralization) is controlled by microbial decomposition, which in turn is controlled by environmental factors as well as the amount and chemical composition of organic matter (Grigal and Vance 2000). Rates of nitrogen mineralization are highly spatially variable within stands (Johnson and Curtis 2001). The availability of nitrogen from organic matter has been said to “most often limit the productivity of temperate forests” (Hassett and Zak 2005). Logging residues are a source of nitrogen during early periods of stand growth after harvest (Hyvönen et al. 2000, Mälkönen 1976). Dead woody material left after logging provides carbon-rich material for microbes to feed upon, and microbial populations typically increase after forest harvests due to the input of logging residues. Microbes immobilize nitrogen in their tissues and limit losses that could otherwise occur through leaching or volatilization. As dead woody material gradually decomposes during the 15 to 20 years following harvest, microbial populations decline and slowly release the nitrogen to growing vegetation (Wilhelm et al. 2017).

One research study in the southeastern United States found that nearly all the nitrogen and much of the phosphorous that moved down through the litter layer into mineral soil was in organic forms because of microbial transformations of organic matter in the forest floor (Qualls et al. 1991). This indicates that some nitrogen and phosphorous can be moved from the litter layer into mineral soil where it may be stable for a longer period. Phosphorus is another essential nutrient that is mainly supplied, in forms available to plants, by the microbial breakdown of organic materials. A deficiency of available phosphorus can limit plant metabolism of nitrogen, and some forests may be limited by phosphorus availability (Trettin et al. 2003). Inorganic phosphorus is often present in soil minerals, but under low-pH conditions, soluble aluminum and iron often react with inorganic phosphorus to form insoluble compounds that are unavailable to most plants (Pritchett 1979). Sulfur, like nitrogen, occurs in soil primarily as organic compounds and is made available for plant growth through oxidation by microbes to sulfate forms (Fisher and Binkley 2000). A rating of soil nutrient availability based on geology types has been developed by the Intermountain Tree Nutrient Cooperative at the University of Idaho. Tree nutrition value is an interpretation of rock geochemistry and its nutritive status. Soils formed from quartzite geologies tend to be very nutrient poor. This is especially true when the volcanic ash layer is no longer on site. Soil wood loss may alter processes of forest regeneration and growth to favoring species with lower soil moisture and nutrient requirements and provide for a greater potential for soil erosion. Potential loss or reduction of organic matter can lead to a decline in several key soil and foliar nutrients (Powers et al. 2005). Further effects also include a reduction of habitat for species requiring soil wood as dens or as substrate for invertebrates, bacteria, and fungi, which affect food availability for small rodents and their predators.

Soil Organic Matter – Coarse Woody Debris

Soil organic matter and coarse woody debris are good indicators of soil productivity and overall forest health. Organic matter, including the forest floor duff, litter, and large woody material, is essential for maintaining ecosystem function by moderating soil temperatures, improving soil water availability, providing an important seed source, and promoting biodiversity (Powers 2006 and Page Dumroese et al. 2010). The soil organic layer is extremely important to all soils in Blue Mountains national forests, especially those formed from low nutrient geology like granite and quartzite, which weathers slowly. Soil organic matter is fundamentally important to sustaining soil productivity. Soil organic matter is influenced by fire, silviculture activities, as well as decomposition and accumulation rates. The organic component of soil is a large reserve of nutrients and carbon and is the primary site for microbial activity. Forest soil organic matter influences many critical ecosystem processes, including the formation of soil structure. Soil structure influences soil gas exchange, water infiltration rates, root penetration, and water-holding capacity. Soil organic matter is also the primary location for nutrient recycling and humus formation, which enhances soil cation exchange capacity and overall fertility. Soil organic matter depends on inputs of biomass (e.g., vegetative litter, fine and coarse woody debris) to build and maintain the surface soil horizons, support soil biota, enhance moisture-holding capacity, and prevent surface erosion. Nevertheless, in natural systems organic matter fluctuates with forest growth, mortality, fire, and decay.

Along with the evolution in monitoring soils, organic matter rose in significance to assure soil productivity (Powers 1990, Jurgensen et al. 1997, Page-Dumroese et al. 2010). Woody debris, fungi, mycorrhizae, and associated decomposition functions all play critical roles in soil development and function, in turn contributing to soil productivity. Harvesting timber and addressing fuels reduces the above ground biomass on a site, and thus the residual vegetation has high value towards contributing to soil function as both mulch and substrate for soil nutrient cycling. Soil organic matter is also vitally important to sustaining soil productivity (Jurgensen et al. 1997).

Soil biological processes and nutrient cycling are two main functions of soil organic matter. Soil provides habitat for a wide variety of organisms including plants, fungi, microorganisms and macro-organisms in the upper sections of the soil that promote root growth, control moisture and temperature within the soil profile, and provide for nutrients available to plants (Barrios 2007). These organisms, which include mycorrhizae fungi, are important for soil health and overall soil function. There has been some evidence to suggest that maintaining mycorrhizae diversity may be a factor in maintaining forest ecosystem health (Amaranthus et al. 1990, Wiensczyk et al. 2002). The presence of coarse woody debris as at least one form of habitat is an important factor in maintaining mycorrhizae diversity in forest soils (Harvey et al. 1987, Graham et al. 1994).

The forested soils in Blue Mountains national forests typically hold most of the soil organic matter towards the surface and form a forest floor. Coarse woody debris lines the surface but decays to soil wood and integrates deeper into the soil via bioturbation. Forest litter and duff in the Blue Mountains range from a few cm to six cm or more depending on the last fire disturbance and habitat type.

Another component of coarse woody debris and organic matter in the forest floor is brown cubicle rot or soil wood. Residue left after advanced brown-rot decay is a brown, crumbly mass composed largely of lignin. In healthy forest ecosystems, especially coniferous forests, the upper-most soil horizon contains a significant portion of brown-rotted wood residues. The sponge-like properties of advanced, brown-rotted wood act as a moisture and nutrient sink and provides habitat. Early logging techniques removed much of the soil wood with follow up burning, significantly reducing the occurrence of soil wood in these forests.

Carbon Storage

The carbon cycle includes the role of soil in cycling nutrients through the environment (see Carbon Report). Limiting factors of soil carbon storage are depth and rockiness. Carbon compounds are inherently unstable and owe their abundance in soil to biological and physical environmental influences that protect carbon and limit the rate of decomposition (Schmidt et al. 2011). Soil organic matter is formed by the biological, chemical, and physical decay of organic materials that enter the soil system from sources belowground (e.g., roots, soil biota) or aboveground (e.g., leaf fall, crop residues, animal wastes and remains). Organic compounds enter the soil system when plants and animals die and leave their residue in or on the soil. Immediately, soil organisms begin consuming the organic matter; extracting energy and nutrients, and releasing water, heat, and carbon dioxide back to the atmosphere. Thus, if no new plant residue is added to the soil, soil organic matter would gradually disappear. If plant residue is added to the soil at a faster rate than soil organisms convert it to carbon dioxide, carbon would gradually be removed from the atmosphere and stored (sequestered) in the soil. Large quantities of soil organic matter accumulate in environments such as wetlands, where the rate of decomposition is limited by a lack of oxygen, and high-altitude sites where temperatures are limiting to decomposition. Most carbon in mineral soil comes from root turnover (Schmidt et al. 2011), although some is moved from the forest floor into upper mineral soil layers (Qualls et al. 1991) or slow to decompose wood contributions (Pierson et al. 2021).

Soil carbon also plays a role in developing soil structure and soil stability. The maintenance of active soil carbon is important in maintaining soil stability, which influences water infiltration, reducing surface runoff, lowering sedimentation, and improving air infiltration into the soil to support plant root respiration and other soil biota.

Support and Stability

Soil stability and support is necessary to anchor plants and structures. Inherent soil properties, like soil texture and particle size distribution, play a major role in physical stability. Soil has a porous structure that allows passage of air and water, withstand erosive forces, and provides a medium for plant roots. Soils also provide anchoring support for human structures and protect archeological artifacts. The need for structural support can conflict with other soil uses. For example, soil compaction may be desirable under roads and houses, but it can be detrimental for the plants growing in these compacted sites. The conflict of stability and support with plant growth capabilities is constant when dealing with roads, skid trails, recreation trails, and forest productivity. Sensitive soils for the support and stability function are soils with high erosion hazards and soils with high mass wasting hazards. Support and stability can be assessed by evaluating risk of erosion and mass wasting and observing soil deposition. Skid trails, fire lines, machine piles areas, and severely burned areas are examples of practices and conditions that expose soils to erosional forces such as wind and rain. Soils with ash caps are easily eroded when disturbed and surface protections such as soil crusts and organic matter cover are removed. Further discussion on mass wasting(landslide) hazards can be found in the Geological Hazards Report.

Filtering and Buffering

Soil acts as a filter to protect the quality of water, air, and other resources. Toxic compounds or excess nutrients can be degraded or otherwise made unavailable to plants and animals. The minerals and microbes in soil are responsible for filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposits. Soil absorbs contaminants from both water and air. Microorganisms in the soil degrade some of these compounds; others are held safely in place in the soil, preventing contamination of air and water. Wetlands soils especially function as nature's filters. Filtering and buffering in Blue Mountains is impacted by chemical pollutants and industrial contamination at a very small scale. Wetlands are also discussed in the Hydrology section.

Soil Quality and Productivity Monitoring

Soil function is difficult to measure in the field. Consequentially, factors that can be readily observed and measured are utilized. These factors include the degree of disturbance to surface organic matter and disturbance to topsoil. Most management activities affect surface organic matter, but it can rebound relatively quickly as surface leaf litter and roots in the soil rebuild organic matter stocks. In contrast, the mineral topsoil could be considered a summation of a site’s potential to support growth based on bedrock, terrain, climate, and rate of soil development. When management activities displace or remove portions of the topsoil, this impact involves a longer-term recovery than disturbance to forest floor. These consequences last longer on thin soils with less overall nutrient capitol. Topsoil disturbance on drought-prone sites could proportionally affect the soil’s ability to provide water to trees more than on wet sites where seasonal moisture stress is less.

Most management activities and natural disturbance processes affect soil resources depending on site productivity and recovery potential. To test the relationship between soil disturbance and productivity, the Forest Service established the Long-Term Soil Productivity Experiment in 1988 (Powers 1990). Over 100 sites across the Nation provide insight on the variable response to compaction, displacement and forest floor removal treatments depending on soil type and inherent productivity.

Following passage of the National Forest Management Act in 1976, regions of the U.S. Forest Service developed standards and guidelines for the protection of forest soils. In the Pacific Northwest region (Region 6), forest soil quality standards were in effect by 1979 and formalized in 1983 (Howes et al. 1983).

Region 6 standards addressed changes in soil compaction and displacement and set limits on the areal extent of disturbance that was considered detrimental to soil productivity. In 1998, an R6 supplement to the Forest Service Watershed Protection and Management Manual (FSM 2520, 1998) defined the soil quality standards and guidelines that are still in effect on forests in the Pacific Northwest region:

> Leave a minimum of 80 percent of an activity area in an acceptable soil quality condition. Detrimental conditions, as defined below, also include landings and system roads. It is assumed that roads and landings comprise 5 percent of an activity area, and that all other soil disturbance should not be more than 15 percent of any area. Detrimental soil conditions and the accompanying criteria for determining when and where these conditions occur were defined for compaction, puddling, displacement, and detrimentally burned soils as follows:
>
> **Detrimental compaction** for volcanic ash soils, an increase of 20 percent bulk density, or more, above undisturbed soils of the same type. For all other soils, an increase of 15 percent bulk density, compared to undisturbed soils, a 50 percent reduction in macropore space, and/or a reduction in macropore space below 15 percent is defined as detrimental compaction disturbance.
>
> **Detrimental puddling** is defined as depth of ruts or imprints of six inches or more, accompanied by deformation of the soil profile.
>
> **Detrimental displacement** is the removal of more than 50 percent of the A horizon from an area greater than 100 square feet, which is at least 5 feet in width.
>
> **Detrimental burned soils** are soils in which the mineral soil surface has been significantly changed in color, oxidized to a reddish color, and the next one-half inch blackened from organic matter charring by heat conducted through the top layer. The detrimentally burned soil standard applies to an area greater than 100 square feet, which is at least five feet in width.
>
> **Detrimental surface erosion** is visual evidence of surface loss in areas greater than 100 square feet, rills or gullies and/or water quality degradation from sediment or nutrient enrichment.
>
> **Detrimental soil mass wasting** includes any visual evidence of landslides or mass movement associated with land management activities and/or that degrades water quality.

In addition to soil quality standards, guidelines were implemented that included retention of soil organic matter, coarse woody material, and maintenance and protection of soil moisture regimes.

Methods were established for monitoring the disturbance following timber harvest (Howes et al. 1983) and implemented in the Blue Mountains national forests. Early monitoring reports on the Wallowa-Whitman National Forest revealed very high disturbance in some harvest units, indicating that soil quality standards were not being met. Reports on the La Grande Ranger District indicated total disturbance on some harvest units of up to 97 percent of the area, and nearly 60 percent of the area detrimental disturbed. Review of these early reports was followed by the implementation of additional actions to protect soils and included limiting the density of skid trails, limiting the distance from established trails that equipment would be allowed to operate, retaining slash and coarse woody debris on site to cushion soils and prevent compaction. It was found that by following these additional guidelines during timber harvest and slash treatment that regional soil quality standards could be met.

It has also been observed that the amount of disturbance varies by harvest type and the type of equipment used. Ground based and tractor harvest operation typically resulted in high detrimental soil disturbance rates. Skyline logging and cut-to-length harvest resulted in lower levels of soil disturbance.

Sullivan (1988) reported the results of monitoring of 24 harvest units on the Malheur National Forest between 1981 and 1985. Fifteen of 24 harvest units were found with detrimental soil conditions exceeding regional standards with most disturbance resulting from soil compaction.

Geist et al. (1989) reported that compaction on five of eleven harvest units monitored 14 to 23 years following harvest on the Malheur, Umatilla and Wallowa-Whitman National Forests exceeded regional standards. Review of these results by Miller et al. (2010) suggests that all the units would be considered as having exceeded regional standards after including the area disturbed by roads, but caution that the results depend on the accurate determination of undisturbed soil bulk density.

The 2001 monitoring report for the national forests documented evaluations of soil conditions on several planned and completed projects. Within the Malheur National Forest, all but 4 of the 18 units sampled had less than the 20 percent maximum detrimental soil impact specified by the forest plan. Over-the-snow operations resulted in greatly reduced detrimental soil conditions versus levels resulting from dry season operations.

Monitoring results for 18 harvest units on the Umatilla National Forest in 2001 showed that none exceeded soil quality standards and that 12 units used cut-to-length harvest methods and averaged 4.5 percent detrimental disturbance. Adjustments in treatment methods made after the 1990 forest plan was implemented and resulted in a reduction in detrimental impacts to soils. No sampled units exceeded the forest plan thresholds for detrimental soil conditions.

Pre-activity surveys for the Wallowa-Whitman National Forest documented that all but one proposed timber sale project areas had some units that exceeded the threshold (exact statistics were not disclosed). The lone exception was the Reservoir Timber Sale where post project monitoring found that all soil standards had been met. Subsoiling on one project was found to be enhancing the soil recovery process (unpublished).

Monitoring indicates that, in general, current operations meet current forest plan standards. Additional mitigation measures incorporated into project design criteria, such as seasonal timing restrictions or appropriate ground-based equipment for increased slope, are designed to minimize detrimental soil disturbance. Designating skid trails during summer timber harvest and use of moderate and coarse wood as amendment in lieu of waterbars are additional effective measures to limit soil damage (Cambi et al. 2015). All current unpublished raw soil monitoring data collected in recent years supports the findings and exhibits similar trends indicated above.

Past Management Impacts of Soil Quality and Productivity

Historically (pre-European settlement) and without major anthropogenic (human caused) disturbances on soil from heavy machinery, soil loss, soil compaction, and nutrient cycling would probably have been within functional limits to sustain soil function and maintain soil productivity for most soils. The exception to this could be relatively short-term effects of wildfire during times of drought. Since there were no political boundaries historically, soil condition would have been similar on similar soils throughout the range of the vegetation types.

Much of the current soil condition on the Malheur, Umatilla, and Wallowa-Whitman National Forests is related to management since the late 1800s. Soil condition is affected by activities that occur or re-occur at the same place over time. Permanent loss of soil productivity has and could affect the level of goods and beneficial use of the forests in the future. Management activities that have affected soil condition include timber harvesting, site preparation, mechanical fuels treatments, prescribed fires, wildfires, road construction and use, recreation facility maintenance and use, grazing, and special uses.

Some examples of impacts that have affected current soil condition include:

- Heavily compacted soils from forest vegetation treatments, grazing and recreation activities have caused or may cause reduced productivity.
- Land-disturbing activities caused erosion of topsoil at rates greater than the soils natural ability to replace it, referred to as soil loss tolerance rate. This has resulted in permanent loss of soil productivity, as soils are considered a non-renewable resource.
- During the 19th and 20th centuries, as more livestock numbers and acres were grazed over long seasons, range condition (vegetation and soil condition) declined. The effects of this historic livestock use can still be seen on the ground.
- Road corridors that make up Forest Road systems resulted in loss of soil productivity.
- Mineral extraction pits and mines resulted in permanent loss or reduction in soil productivity.
- Uncharacteristic wildfire resulted in erosion rates well beyond tolerance erosion rates.
- Footprints of administration and recreation sites, such as developed campgrounds, have reduced soil productivity.
- Permanent special use sites, such as communication towers and buildings eliminated soil productivity.

There are activities that have improved soil condition, as well as removing risk to soil productivity such as:

- Prescribed fire has removed fuels and undesirable plant material that impedes vegetation growth and condition.

- Thinning dense forest, woodland, and invaded grassland has increased light and reduced water competition for desired understory grasses and shrubs allowing for increased development of organic matter storage in upper soil profiles.
- Decommissioning of unneeded roads has returned old roadbeds back to producing vegetation.
- Implementation of USDA Forest Service Best Management Practices has resulted in decreased erosion and sedimentation from roads and timber harvests.

Status and Trends

Timber harvest, road building, and intense wildfire are the primary stressors that affect soil productivity on Blue Mountains national forests over the past planning period. Recreation, mining, and grazing have lesser impacts. The Forest now considers how these stressors may be affected by the impacts from climate change. The impact of climate change will likely influence the extent of disturbance such as wildfire and frequency of drought along with revegetation after disturbance (Halofsky et al. 2017, Davis et al. 2020).

Prescribed Fire and Wildfire

Wildland fires are a natural ecological process within Blue Mountains national forests. However, high intensity fire and severe burns over large portions of landscapes can occur, which can cause an array of ecosystem responses, including vegetation dynamics: regeneration, compositional changes, mortality, diversity, faunal community dynamics, and changes in soil productivity and nutrient and carbon cycling. Impacts to watersheds include increased soil erosion, sedimentation, flooding, debris flows, and landslides (Keeley 2009). Understanding the effects of fire throughout the plan area is difficult. The variation in natural potential vegetation and the variation in the natural historic fire regime include community composition and structure, fuel quality and quantity, climate, soil properties, topography, the long period of fire exclusion since Euro-American settlement and fire suppression, post fire restoration, and post fire timber salvage activities. The extent, intensity, fire or burn severity, and resulting impacts have varied widely. An increase in wildland fire size and frequency has been documented since the early 1960s, with greater increases documented starting in the 1980s. Significant increases in wildfire ignitions and severity have been documented in the 2000s.

Wildland fires or prescribed fires characteristic of the historic fire regime with low or moderate burn severities can improve soil fertility by facilitating periodic release of nutrients (DeBano 1990). However, high intensity, long duration fires that result in high burn severity can have significant impacts on ecosystem processes due to the total consumption of the forest floor and the loss of coarse woody debris that serve as nutrient reserves for long term storage of forest nutrients necessary for sustaining plant growth, biological activity (Harvey et al. 1987). High burn severity can also lead to soil erosion, especially on steep slopes. Loss of the forest floor effective ground cover and coarse woody debris has been related to an increase in sheet, rill, and gully erosion and reduced infiltration rates leading to increased rates of erosion, sedimentation, and flooding (Robichaud and Brown 1999).

The predominant erosion process is the reduction in canopy cover and effective ground cover and the subsequent increase in mineral soil exposed to raindrop splash and surface sealing. Increased erosion because of burning is also influenced by fire intensity and burn severity. Other factors for increased erosion include creation of water repellant soil (hydrophobic) and the resultant increased runoff and overland flow. Coarse textured soils are more prone to becoming hydrophobic following a wildfire than fine textured soils. Hydrophobic compounds are slightly water soluble; therefore, hydrophobicity is broken up or washed away after the first one or two rain events or after a winter of slow wetting and freeze-thaw (Neary et al. 2005).

Fire also has beneficial effects by increasing the available nutrient base by volatilizing organic matter and stimulating decomposition processes. Almost immediately, burning increases the amount of mineral nitrogen levels for plants and soil organisms (Choromanska and DeLuca 2002, Hart et al. 2005), a limiting nutrient in most forest ecosystems (Binkley 1991). In drier habitats, this increase can be detected as much as 50 years after fire (McKenzie et al. 2004). Nitrogen-fixing plants can colonize sites following fire and help restore nitrogen in the ecosystem (Jurgensen et al. 1997, Newland and DeLuca 2000). Generally, if plants colonize sites following fire, nutrient levels can reach pre-fire levels quickly (Certini 2005). Charcoal deposited following fire (DeLuca and Aplet 2008) increases the carbon stored in surface and soil carbon pools.

In prescribed burn areas, litter layers and organic matter likely stay intact, and nutrient losses are minimal due to low burn severity (Certini 2005). Wildland fires are unpredictable and burn severities tend to be higher than for prescribed burns. In wildfire, there is generally greater loss of organic matter and soil cover that may shift soil microbial structure (ibid) along with increase susceptibility of erosion (Wondzell and King 2003, Larsen et al. 2009).

Since about 2000, surveys have been conducted within Wallowa-Whitman National Forest to estimate the amount of coarse woody debris following fires and salvage activities. These surveys indicated that the units generally meet or exceed the minimum recommended amounts of coarse woody debris. Recruitment of fine organic debris from needle cast and limbs both post fire and after salvage activities has contributed to sustaining the long-term nutrient stores throughout the plan area (Schnepf et al. 2009).

Salvage logging following wildfires was identified as a cause of erosion affecting stream sedimentation and productivity in central Washington (Klock 1975). Published studies reported that the implementation of resource standards and guidelines for site protection at salvage logging sites within the Wenatchee National Forest in central Washington (Klock 1975) and within the Malheur National Forest in the Blue Mountains (McIver and McNeil 2006) were the most important factors that influenced soil erosion. In addition, ground-based yarding systems resulted in far more soil disturbance than aerial systems (Klock 1975).

Assessing or quantifying soil conditions after wildland fire and prescribed fire is difficult due to the many variables affecting ecosystem response to fire. Johnson (1998) compared reported burn intensity of fires in the Blue Mountains from 1986 through 1994 to estimates of burn severity of historical fires in the region by Agee (1996) and concluded the burn severity is likely higher now than in the past but varies geographically within the Blue Mountains.

The overall effect of wildland and prescribed fire on above-ground organic matter (dead and down material) and subsequent soil fertility, soil carbon, and nitrogen changes are difficult to quantify on a landscape scale (Johnson and Curtis 2000). There are potentially conflicting results in the literature about effects on soil carbon from wildfire and from prescribed fire. In the meta-analysis by Nave et al. 2022, wildfire was found to reduce carbon in all soil horizons from studies less than 10 years since wildfire; prescribed fire experienced losses in just the O horizon – and experienced less loss than from wildfire. Johnson and Curtis 2000 found time after a fire event to be a significant factor in soil carbon changes, with an increase (compared to study plots) in both soil carbon and nitrogen documented after approximately 10 years. In addition, they documented decreases in soil carbon following prescribed fire and increases in soil carbon and nitrogen following wildfire. The increases following wildfire were attributed to the sequestration of charcoal and recalcitrant and hydrophobic organic matter, as well as establishment of nitrogen fixing plants following wildfires. Fire suppression activities (e.g., fireline and fuel break construction and construction of fire camps and aircraft landing zones) tend to compact or displace surface soil and have had indirect impacts on long term soil productivity and hydrologic function throughout the plan area. It is assumed that within the plan area, high wildland fire severity and fire suppression have caused an array of ecosystem responses, including vegetation changes, increased erosion, and reduced organic materials and coarse woody debris amounts to less than the optimum levels needed to sustain soil productivity and soil health (Kerrick et al. 1989).

Vegetation Management

Management of large acreages of overstocked stands in the second half of the 1900s (see Forest Management Report and Terrestrial Ecosystems Report) while meeting soil quality guidelines required the use of efficient, less costly, low ground pressure mechanized harvest and yarding equipment and the use of prescribed fire to reduce fuel loads and fire hazard. Research and local soil monitoring summarized in the following pages indicate a corresponding overall reduction in adverse soil impacts to soils following the 1998 regional soil quality direction (USDA Forest Service 2001).

From the late 1920s to approximately the early 1990s, management focused on regeneration harvest and selection harvest activities to remove large diameter trees with high ground pressure, ground-based equipment and intense site sanitation and seedbed preparation techniques. Research and monitoring surveys estimated the amount of detrimental soil conditions throughout the Blue Mountains national forests to range from approximately 17 percent to greater than 55 percent of an individual activity area. These values exceed or came close to the threshold of no more than 20 percent of an activity area resulting in detrimental soil disturbance, specified by regional guidance and revised forest plans (USDA Forest Service 1998). In 1979, Harkenrider (Miller et al. 2010) found that a clearcut lodgepole pine stand within the La Grande Ranger District that was harvested with a feller-buncher, yarded to a landing with a rubber-tired skidder, and slash dozer-piled and burned resulted in approximately 55 percent of the area's soils detrimentally compacted and 12 percent moderately compacted.

Sullivan (1988) found that 15 of 24 timber harvest units had post activity soil impacts that exceeded the regional standard of 20 percent of the area, and another 5 units had soil impacts on more than 15 percent of their area.

In the early 1990s, harvest activities focused on use of new technologies and project design criteria to comply with revised management direction and policies (USDA Forest Service 1990a). Commonly used design criteria included designated trail spacing, low ground pressure machinery, mechanical harvesters, processers and loaders/forwarders, season of operation, operating over frozen ground, snow and slash, hand piling of slash, and restoration (including subsoiling). After approximately 1990, research and local soil monitoring results (USDA Forest Service 2001) indicate that the use of updated technology corresponds to an overall reduction in areal extent of detrimental soil disturbance and often results in compliance with the standard of no more than 20 percent of an activity area's soils being detrimentally impacted (USDA Forest Service 1998).

Published data for detrimental soil compaction from timber harvest activities range from approximately 5 to 30 percent of an area. Areas in the high end of the range were generally harvested in the mid to late 1990s, while areas in the low end of the range were generally harvested from the late 1990s to early 2000s. Less detrimental impacts are generally attributed to the use of multiple mitigation measures to limit soil disturbance. The variation is generally the result in changes in project design criteria, including the amount of timber removed and type equipment used. Similar soil disturbance characteristics can occur in areas of thinning harvests, clearcuts, and partial cuttings if ground-based equipment is used, although traffic patterns are likely to be less concentrated in partial cut activities, which results in less soil impacts overall (Page-Dumroese et al. 2009, Miller et al. 2010, Chanasyk et al. 2003). This trend is indicated in the research findings, where lower areal extent of detrimental soil conditions is generally associated with thinning operations (McIver et al. 2003, and McIver 1998), operating over snow (Craigg and Howes 2007), or use of a skyline logging system (Allen et al. 1999).

Allen and Adams (1997) found that thinning of second-growth Douglas-fir with a skyline logging system resulted in only 2 percent of the area soil being detrimentally disturbed.

McIver (1998) found that 6 of 7 thinning units on the Wallowa Whitman National Forest had total disturbance levels less than 10 percent. Unit 7, yarded using a rubber-tired skidder, had the greatest amount of detrimental soil disturbance. McIver (1998) also found that mechanized cut-to-length harvesters tended to result in displacement, rather than compaction, as the primary form of detrimental soil disturbance.

Allen et al. (1999) found that utilizing a cut to length harvester and skidding operation for partial cuttings in western and northeastern Oregon resulted in detrimental soil compaction on 21 percent of the area. Skyline yarding resulted in detrimental soil disturbance (compaction and displacement) on about 6 to 7 percent of the harvested area. Results indicated that skyline yarding created more displacement than compaction. After one year, Allen et al. (1999) found that there was no off-unit sediment transport from these areas, apart from very limited amounts from skyline corridors.

McIver et al. (2003) found that uneven-aged and intermediate treatment activities using a cut-to-length forwarder system resulted in detrimental soil conditions in no more than eight percent of an activity area.

Craigg and Howes (2007) found that a thinning project using a low ground-pressure Timberjack cut-to-length harvester and forwarder and a variety of mitigation measures designed to reduce soil impacts, including, operating on frozen ground, snow and slash, designated trail spacing, and hand piling of slash, resulted in detrimental soil conditions on approximately three percent of the activity area.

Bliss (2006) assessed several published and non-published detrimental soil conditions surveys for the Wallow Whitman National Forest and compiled a summary of findings. Adjustments in treatment made after the 1990 forest plan was implemented resulted in a reduction in detrimental impacts to soils. In general, post-harvest ground disturbance ranged from approximately 10 to 20 percent, with a range of 6 to 12 percent of new detrimental soil conditions. The amount of new disturbance was found to vary depending on the amount of new skid trails created and used.

Detrimental soil conditions on the landscape were analyzed through GIS from past harvest and National Forest System roads and temporary roads using an effects assumption models (Bliss 2006, Craigg and Howes 2007, Miller et al. 1990, and Allen and Adams 1997) that consolidates effects of different disturbances based on applicable monitoring and research. The soils on the Malheur, Umatilla, and Wallowa-Whitman forests are within the 20% detrimental soil disturbance threshold on the forest scale and meet Region 6 Soil Quality Standards. br

Ground-based timber activities have generally been implemented on slopes with less than 30 percent rise because of increased risk of erosion when ground cover is removed, or soils are disturbed. In some cases, ground-based harvesting may have occurred on slopes with greater than 30 percent rise. Skyline or aerial timber activities have generally been implemented on slopes with greater than 30 percent rise and in some areas where protection of soils and other resources is a priority (e.g., post wildfire salvage operations). Recent economic and safety concerns of skyline harvest have fallen out of favor with implementors in the Blue Mountains area in favor of technologically advanced ground-based systems for treatment of the same slopes.

Livestock Grazing

Commercial livestock grazing began in the late 1800s with Euro-American settlement. From the late 1800s to mid-1900s, livestock grazing management was very limited and generally involved continuous, year-round grazing. As a result, much of grazing lands in Blue Mountains national forests were severely impacted. These impacts are still evident on the landscape (Quigley et al. 1997). Soil disturbances caused by historic grazing generally consist of compaction, displacement, alteration of vegetation community (ground cover diversity and composition), and invasion by non-native vegetation.

Soil disturbance and the degree of impact from livestock grazing activities throughout the plan area is variable. It has been influenced by many factors, including the type and intensity of historic and current livestock grazing (i.e., season of use, livestock use patterns, degree of disturbance, and type of livestock: cattle, sheep, horses, or goats), soil type (i.e., soil depth and volcanic ash content), compaction or displacement potential of the soil, slope gradient, aspect, and other inherent and dynamic properties (Heady 1975).

The greatest concentration of detrimental soil disturbance and related decrease in soil quality due to livestock grazing is associated with historic commercial livestock grazing areas. These areas generally include holding pastures, animal trails (both in the uplands and along fence lines), historic homestead sites, historic irrigation canals, abandoned cropland (potentially seeded to pasture), roads and developed motor vehicle trails, springs and developed water sites, salting areas, and loafing areas associated with capable grazing lands (Platts 1991). Capable grazing lands are associated with land type associations having slopes with less than 60 percent rise, considered capable for sheep grazing, and slopes with less than 45 percent rise, considered capable for cattle grazing. Capable grazing lands also have a tree canopy and/or unpalatable shrub canopy of less than 60 percent and/or have the inherent capacity to produce more than 200 pounds of forage per acre (e.g., limited amounts of rock outcrops or nutrient poor or shallow soils).

Sites associated with land type associations determined to have poor suitability for grazing (i.e., greater than 40 percent slope rise for cattle, greater than 60 percent slope rise for sheep, and low forage production rates) are considered to have less resistance and decreased resiliency to grazing effects on the soil and vegetation components (USDA Forest Service 2006). However, due to the severity of topographic features, including steepness of terrain and high amount of rock outcrops limiting access to slopes with greater than 60 percent rise, these areas are generally grazed incidentally and used lightly and are assumed to have little to no detrimental soil impacts associated with livestock grazing and management.

Road Building and Landings

Roads and landings are considered part of the permanent national forest management infrastructure and transportation system and are estimated to be five percent of the managed acres within a national forest. These acres are in a permanent detrimental soil condition.

The trend for road building has dropped off precipitously from 1980s levels. Building system roads dedicates soils to administrative purpose and out of productive land base. Over the planning period, roads were decommissioned to limit runoff and sediment production. From a restorative standpoint, partial and full contour treatments restore soil function much more effectively (Lloyd et al. 2013). Road decommissioning and obliteration efforts may continue under the current 1990 forest plans and existing travel management plans.

Recreation made or user made trails have the same effect as low level system roads that keep the soil in a permanent state of degraded soil productivity. Reuse of user made trails as temporary roads for harvest activities increases the difficulty of natural process to return the disturbed area to natural conditions post-harvest. Also, limits associated with Blue Mountains national forests contracting of harvest activities usually result in a user made trail that is also used for harvest to remain on the landscape into to the future with great difficulty and cost to restore. Many non-system roads started out as user made trails that were later used during harvest activities and not returned to their natural state.

Geologic Hazards

Slope stability remains a hazard on Blue Mountains national forests where roads cross unstable geology and wildfire bares large sections of watersheds. Strong precipitation following wildfire during spring and summer months can induce debris flow. Typically, intense thunderstorms with rates of 2 inches per hour can trigger these events.

Slope failure or landslide type events do occur and are commonly associated with rock and soil slopes weakened through saturation by snowmelt, heavy rains, groundwater influence or a combination. Natural drivers such as earthquakes, river erosion, wildfire, and human influences such as forest management and road access in unstable geologic types may elevate the risk. The level of hazard relies on professional input informed by soil survey and geology layers. Information to assess risk continues to advance during the planning period with refined geology mapping completed, Lidar derived products that show terrain, and a preponderance of hazard models. Risk will remain highest where forests burn severely across shrub and forested watersheds (Hyde et al. 2016, Jordan 2016). See the Geological Hazards Report for further information.

Climate Change

In the Blue Mountains geographic region, average temperatures have been increasing (see Climate Change Report) and are projected to continue to increase. Climate change is expected to bring mor rain on snow events especially at mid-elevations (Halofsky and Peterson 2017) and decreasing snowpack that can prolong soil moisture deficit during summer. The increase in rain events during snow melt periods in late winter and early spring can induce flooding, erosion, and debris flow. The most susceptible areas are where erodible parent material such as granitic soil types.

The expected rise in soil temperature can cause the growing season to shift. Higher temperatures at the lower elevations may push greater summer soil deficits where water becomes limiting for growth. These shifts affect the timing of nutrient cycling. Since nutrients are a biogenic process, minimum temperature and moisture are needed to advance decomposition that also includes storing carbon.

As drought potential increases, the potential for wildfire increases, and forest management of fuel loading and other factors makes this relationship complex. Much of the big fires occur during extended summer periods of no rain and not necessarily tie to winter precipitation (Holden et al. 2018). Although drought likely increases wildfire potential, how climate change will affect that at a local and regional level is still uncertain (Littell et al. 2016). Wildfire potential to burn soil severely will have more to do with specifics of locations and summer flash drought situations. Increases in wildfire intensity could lead to reductions and/or changes to nutrient cycling and organic matter overall with the potential for increases in soil loss from erosion (Neary et al. 2005).

Key Findings

- Current forest plans for the Malheur, Umatilla, and Wallowa-Whitman National Forests provide limited direction with respect to soil quality and productivity. Greater direction in the Blue Mountains forest plans would maintain and improve soil productivity through the next planning period.
- Maintaining soil productivity is as an important part of managing the forest. Over the last decades, the Malheur, Umatilla, and Wallowa-Whitman National Forests established soil monitoring programs. Additionally, long term research plots across the nation were installed to understand the linkage between disturbance and productivity. Past and present monitoring inform project designs to maintain soil productivity.
- Vegetation Management technologies shift over time and past detrimental soil disturbance data may need to be updated with the current national protocols and effects.
- Soil productivity is limited to some extent in all areas of the Blue Mountains due to one or more terrain, soil, and or climate constraints.
- Design criteria to conserve soils will continue to evolve for treating steep slopes mechanically as a transition to new ground-based systems to treat steep ground occurs. Soil monitoring of these new systems will usher in new protection measures.
- Wildfire burn severity impacts soil productivity both positively and negatively. Low severity burning can ameliorate soils boosting nutrient cycling and leaving beneficial charcoal. In contrast, soils in high severity burns recover slower in dry areas and soil material erodes. Fire remains the primary vegetation change agent on the Malheur, Umatilla, and Wallowa-Whitman National Forests.
- There is pressure to conduct hazardous fuels reduction treatments while meeting needs to maintain soil productivity and ecological integrity. The need to keep adequate residual organic matter to supplement soil processes remain with site specific ties to habitat type. The needs are adjusted based on hazard fuel reduction and ecological integrity factors.
- Conducting soil restoration activities is likely to continue to increase. The level of road decommissioning has increased over the past planning period. As travel management continues, unneeded roads may continue to be decommissioned and shift to Forest Service designated productive land base. Restoration actions, such as decompaction, in timber harvest areas, particularly on large burn piles, will restore soils for productive purpose.
- Climate-based limitations to soil productivity, dry soils in the later part of the growing season, and slower warming soils in the spring, have important implications with respect to the management of coniferous forests.
- Soils vary in their susceptibility to specific types of detrimental soil disturbance as well as their ability to recover from disturbance either naturally or as a result of mitigation actions.

- Recovery response curves vary among different types of detrimental soil disturbance and severity of disturbance. They are also affected by the local soil-landscape type.
- Some types of detrimental soil disturbance, such as excessive soil erosion or soil displacement on soils highly susceptible to degradation will not recover unless active land reclamation actions are implemented.
- Climate change may place higher evaporative demand on soil and increase potential for soil loss due to heavy water flows during snowmelt or after wildfire.

Information Needs

The information needs identified in this section provides for more effective management of the Blue Mountains. They are not necessary for revising the existing plans.

Soil Disturbance Monitoring

- Detrimental soil disturbance monitoring was collected over twenty years ago measuring vegetation management disturbances from older logging extraction techniques utilizing outdated protocol. Additional monitoring is needed to adequately cover the full range of past timber harvest techniques, intensity, and resulting soil disturbances.
- Detrimental soil disturbance monitoring data needs to be collected on all three forests using current National and Region 6 Soil Quality Standards and recommended monitoring procedures identified in the National Soil Management FSM.
- An understanding of soil quality and productivity on new vegetation management logging technology and slope thresholds is needed.
- Monitoring effects of soil quality from livestock and understanding soil thresholds by different soil types.

Soil Resource Inventories

- Complete TEUI soil mapping for the Malheur National Forest.
- Existing soil surveys for Umatilla and Wallowa-Whitman National Forests are available by the NRCS on Web Soil Survey for use by forest managers, staff, and the public. Mapped areas of Malheur National Forest are also available on Web Soil Survey.

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