Rangeland Hydrology and Erosion Model guide for:
Mountain Big Sagebrush and Bluebunch Wheatgrass, with Western Juniper Encroachment and Cheatgrass Invasion, southeast Oregon

1 General Background

The ecological site for this example is South Slopes 12-16 in PZ (R023XY302OR). The ecological site is located in Major Land Resource Area (MLRA) 23, Malheur High Plateau, in southeast Oregon (Figure 1). The dominant vegetation is composed of a bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve ssp. *spicata*) and Idaho fescue (*Festuca idahoensis* Elmer) grass understory and a mountain big sagebrush (*Artemisia tridentata* Nutt. subsp. *vaseyana* [Rydb.] Beetle) and antelope bitterbrush (*Purshia tridentata* [Pursh] DC.) shrub overstory. Vegetation composition is approximately 70 percent grass, 20 percent shrubs, and 10 percent forbs. The site is subject to encroachment by native western juniper (*Juniperus occidentalis* Hook.) conifers and invasion by cheatgrass (*Bromus tectorum* L.), a fire-prone non-native annual grass.

The Malheur High Plateau (22,895 mi^2) extends from southeastern Oregon (15,340 mi^2, Figure 1) into northwest Nevada (5,742 mi^2) and northeast California (1,832 mi^2). More than half the area is federally owned. Approximately 17% of the land is range and pasture (3,892 mi^2) and 72% consists as forest (16,484 mi^2, USDA, 2006). The MLRA is subdivided across the Intermountain Plateaus, with most of the northern third in the Harney Section of the Columbia Plateau Province, a small portion of the northern third in the Payette Section of the Columbia Plateau Province, and the southern two thirds in the Great Basin Section of the Basin and Range Province (USDA, 2006). The land area is primarily comprised of level to moderately steep plateaus, basins, and valleys positioned adjacent to gently sloped alluvial fans (USDA, 2006). Elevation across the MLRA primarily ranges from 3,900 to 6,900 ft, but exceeds 9,000 ft in some mountainous locations. Average annual precipitation is 6 to 12 in through most of the MLRA, but can exceed 55 in mountainous areas. Precipitation is low in summer months, occurs mostly as snow in winter months and is evenly distributed throughout fall, winter, and spring seasons. Average annual temperature is 39 to 52 ˚F and decreases with elevation. The primary management concerns for the area are soil erosion by water, resource degradation associated with catastrophic wildfire, and maintenance of soil organic matter (USDA, 2006).

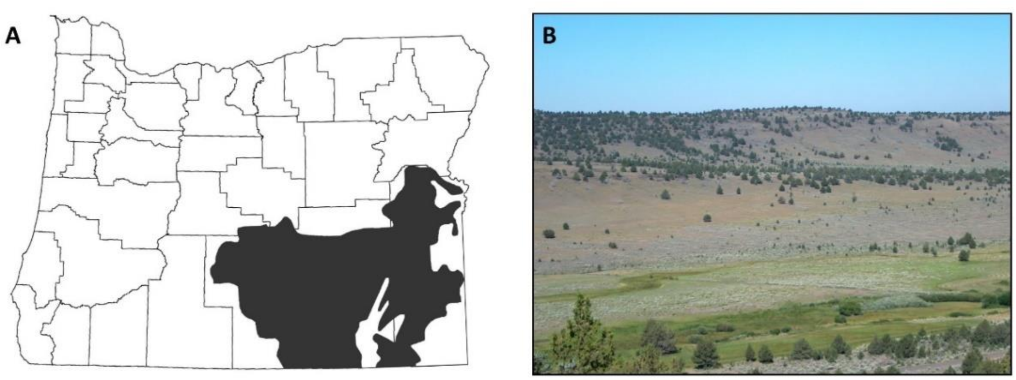

Figure 1. Location of the Malheur High Plateau, Major Land Resource Area 23, in southeastern Oregon (A) and photograph of the South Slopes 12-16 in PZ ecological site with western juniper encroachment into sagebrush vegetation (B).

2 Ecological Site Description

Five ecological states have been described for the South Slopes 12-16" PZ ecological site (NRCS, 2016). A generalized state-and-transition model for the site is provided as Figure 2. The Reference State (State 1) contains two community phases: (1.1) a reference plant community phase with an understory of bluebunch wheatgrass, Idaho fescue, Sandberg bluegrass (*Poa secunda* J. Presl) and Thurber's needlegrass (*Achnatherum thurberianum* (Piper) Barkworth), and other perennial grasses, and a shrub component of mountain big sagebrush and basin big sagebrush (*A. tridentata* Nutt. ssp. *tridentata*), and antelope bitterbush (*Purshia tridentata* [Pursh] DC.); and (1.2) a second phase, promoted by burning, that is dominated by bluebunch wheatgrass, Idaho fescue, Thurber's needlegrass, and other perennial grasses and forbs. Burning of the reference community phase (Phase 1.1) reduces sagebrush cover and increases coverage by Idaho fescue, Thurber's needlegrass, and other grasses. Yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.) and gray rabbitbrush (*Ericameria nauseosa* [Pall. ex Pursh] G.L. Nesom & Baird) temporarily increase following burning, but sagebrush cover returns with time.

Invasion of the Reference State by annual forbs and grasses facilitates transition to State 2 (Figure 3A). State 2 includes three community phases: (2.1) one with sagebrush-steppe vegetation and trace cover of cheatgrass and annual weeds; (2.2) a second phase, facilitated by mismanaged grazing or reduced fire, with increased coverage of sagebrush and Sandberg bluegrass and trace cover of cheatgrass and annual weeds; and (2.3) a fire-limited phase with early-succession western juniper encroachment, sagebrush, Sandberg bluegrass, and trace cover of cheatgrass and annual weeds. For State 2, fine fuel reductions through drought and/or improper grazing pressure promote the woody plant component (Phases 2.2 and 2.3). Periods of fire exclusion allow western juniper to encroach from adjacent fire-safe ridges into the sagebrush-dominated community (Miller et al., 2005, 2008; Davies et al., 2011; Miller et al., 2011). Sagebrush, grasses, and forbs decline with increasing juniper cover due to competition for limited soil and water resources (Miller et al., 2000, 2005; Roundy et al., 2014). Prolonged drought and improper grazing and the associated fire-exclusion in State 2 promote transition to State 3.

In State 3, western juniper dominates site resources, sagebrush and other shrubs decline substantially, and extensive bare ground (often > 50% bare) develops in the intercanopy (Figure 3B). Sandberg bluegrass becomes the dominant grass species in State 3 and other perennial grasses are reduced in abundance and productivity. Extensive intercanopy bare ground in State 3 results in increased connectivity and concentration of surface runoff, decreased aggregate stability, and amplified erosion (Pierson et al., 2007; Petersen and Stringham, 2008; Williams et al., 2014a). Juniper woodland development is complete in State 3. Prolonged soil erosion in State 3 drives the site beyond an ecological threshold to State 4. Tree removal conservation practices such as tree cutting, mastication, and/or burning (prescribed fire) are often applied in State 3 in hopes of recruiting the State 2 vegetation community and good hydrologic function (Figure 3C; Miller et al., 2005; Pierson et al., 2007, 2013; Bates et al., 2014; Bates and Davies, 2016; Bates et al., 2017).

In State 4, the site is dominated by western juniper, surface soil loss is evident, and all ecological processes have been significantly altered (Figure 3D). Intercanopy area commonly represents 70% of the total area in State 4 and intercanopy bare ground may exceed 90%. Water flow paths and terracettes are clearly evident. Restoration of vegetation and hydrologic function to that of States 2-3 is considered improbable in State 4. Catastrophic wildfire in State 4 promotes transition to State 5.

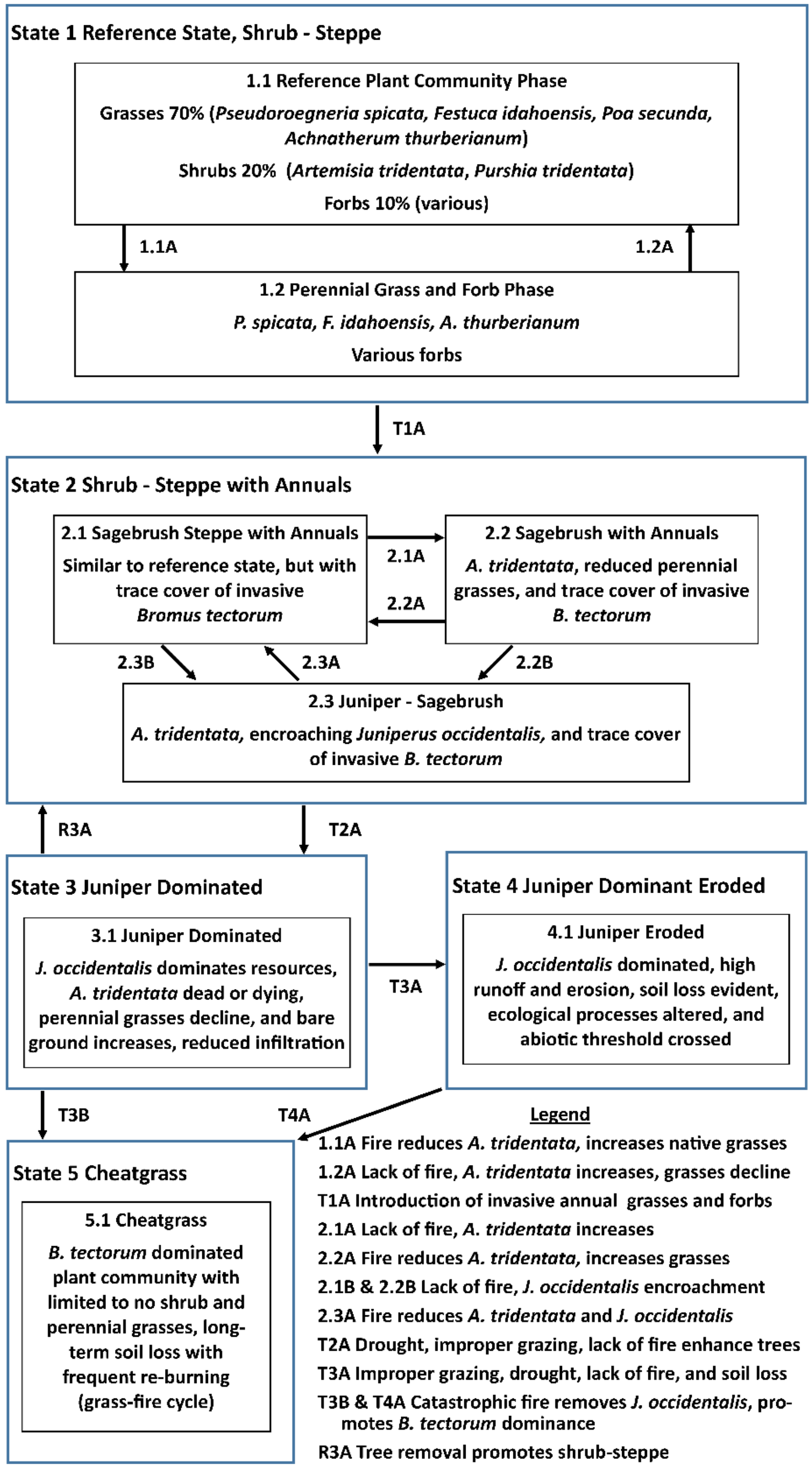

Figure 2. State-and-Transition Model for the South Slopes 12-16 in PZ ecological site, adapted from NRCS (2016).

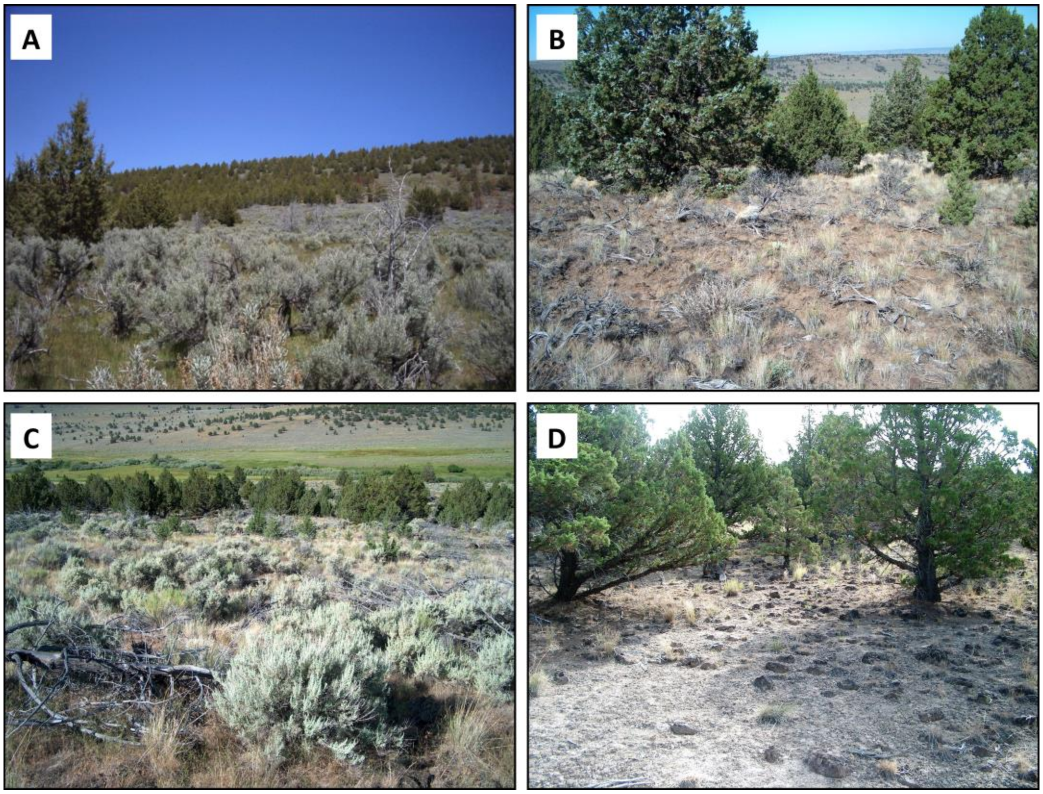

Figure 3. Photographs of State 2 (Shrub-Steppe with Annuals) with surrounding lands dominated by western juniper (Juniperus occidentalis Hook.) (foreground of A), State 3 with western juniper dominance and declining shrub cover (B), State 3 approximatley10 yr after tree cutting (foreground of C), and State 4 with extensive bare ground and evidence of soil loss (D).

In State 5, cheatgrass dominates the site, the shrub or perennial grass component drops out, and the hydrologic and nutrient cycles are negatively affected through changes in dynamic soil properties and soil loss. Cheatgrass invades bare patches and capitalizes on and outcompetes native species for available water and soil resources (Chambers et al., 2007; Reisner et al., 2013; Rau et al., 2014). Infilling by cheatgrass increases horizontal fuel continuity and increases the risk for ignition and landscape-scale burns (Brooks et al., 2004; Link et al., 2007; Miller et al., 2011; Balch et al., 2013). Fire return intervals for cheatgrass-dominated sites are 10-fold less than for sagebrush-bunchgrass dominated communities (Miller et al., 2011). Cheatgrass is a prolific seed producer and readily re-establishes in the post-fire environment, establishing a recurring grass-fire cycle (Arredondo et al., 1998; Melgoza et al., 1990; Knapp, 1996; Brooks et al., 2004; Chambers et al., 2007). Recurring periods of high erosion associated with frequent burning may result in long-term loss of surface soil (Pierson et al., 2011; Wilcox et al., 2012; Williams et al., 2014b). Cheatgrass dominance and establishment of the grass-fire cycle is most likely at lower, warmer and drier elevations of the ecological site (Chambers et al., 2007; Miller et al., 2013; Chambers et al., 2014a, 2014b).

3 Soil

Soils for the South Slopes 12-16 in PZ ecological site range in thickness from 14 in to 40 in over bedrock and are commonly well drained. Soils are formed in colluvium and/or residuum weathered from basalt, andesite, or welded tuff. Surface soil texture may be extremely gravelly sandy loam, gravelly silt loam, or cobbly clay loam. Stone and cobble content in surface soils ranges 20 to 60 percent. The profile available water holding capacity is 1 to 4.5 in. Permeability is rated as moderately slow to moderately rapid. Aggregate stability is generally good for the Reference State and declines with juniper encroachment, increasing bare ground, and transition to States 3 and 4.

4 Climate

Climate for the site is characterized by hot summers and cold winters (NRCS, 2016). Annual precipitation is 12 to 14 in. Precipitation is low in summer and primarily falls as snow during the months of December through March. Spring rainfall is common. Air temperatures may exceed 100 ˚F in summer months and reach -30 ˚F in winter. The frost free period ranges 30 to 90 days each year and optimum plant growth occurs in May to early June. The soil temperature regime is frigid at low elevations and cryic at high elevations.

5 RHEM Modeling Results and Discussion

Table 1. Rangeland Hydrology and Erosion Model (RHEM) inputs for evaluation of hydrologic impact of state transitions and for various disturbances and land management actions for the South Slopes 12-16 in PZ ecological site.

Input Parameter	Ref. State Phase 1.1	State 2 Phase 2.1	State 3 Phase 3.1[a]	State 4 Phase 4.1[a]	State 5 Phase 5.1	States 1, 2, 5 1st Yr Post Wildfire	State 3[b] 1st Yr Post Rx Fire	State 3 10 Yr Post Rx Fire	State 3 10 Yr Post Cutting
State ID	OR	OR	OR	OR	OR	OR	OR	OR	OR
Climate station	Sheaville	Sheaville	Sheaville	Sheaville	Sheaville	Sheaville	Sheaville	Sheaville	Sheaville
Soil texture	Loam	Loam	Loam	Loam	Loam	Loam	Loam	Loam	Loam
Soil water saturation (%)	25	25	25	25	25	25	25	25	25
Slope length (ft)	164	164	164	164	164	164	164	164	164
Slope shape	Uniform	Uniform	Uniform	Uniform	Uniform	Uniform	Uniform	Uniform	Uniform
Slope steepness (%)	35	35	35	35	35	35	35	35	35
Foliar canopy cover (%)									
Bunchgrass foliar cover (%)	14	20	10	6	1	0	5(1)	15	15
Forbs and/or annual grass foliar cover (%)	12	10	3	2	39	0	1(1)	10	10
Shrub foliar cover (%)	28	16	7	2	1	1	1(1)	10	15
Sodgrass foliar cover (%)	0	0	0	0	0	0	0(0)	0	0
Total foliar cover (%)	54	46	20	10	41	1	7(3)	35	40
Ground cover %									
Basal cover (%)	25	20	10	4	20	1	5(1)	20	20
Rock cover (%)	3	3	12	14	5	5	19(14)	5	5
Litter cover (%)	40	40	18	10	40	5	6(16)	35	40
Biological crusts cover (%)	2	2	0	0	0	0	0(0)	0	0
Total ground cover (%)	70	65	40	28	65	11	30(30)	60	65

[a]Foliar canopy cover and ground surface cover values represent the intercanopy only (70% of total site area). Areas underneath tree canopy are nearly 100% litter covered and generate negligible runoff and erosion (Pierson et al., 2007). RHEM runoff and erosion estimates for unburned and uncut State 3 are area weighted by 70% to account for the negligible runoff and erosion from tree covered areas.

[b]Foliar canopy cover and ground surface cover values outside of parenthesis are for intercanopy area (70% of total site area) and respective values within parenthesis are for areas previously underneath live tree canopy (30% of total site area). Values are area weighted to determine final RHEM inputs for the respective model run.

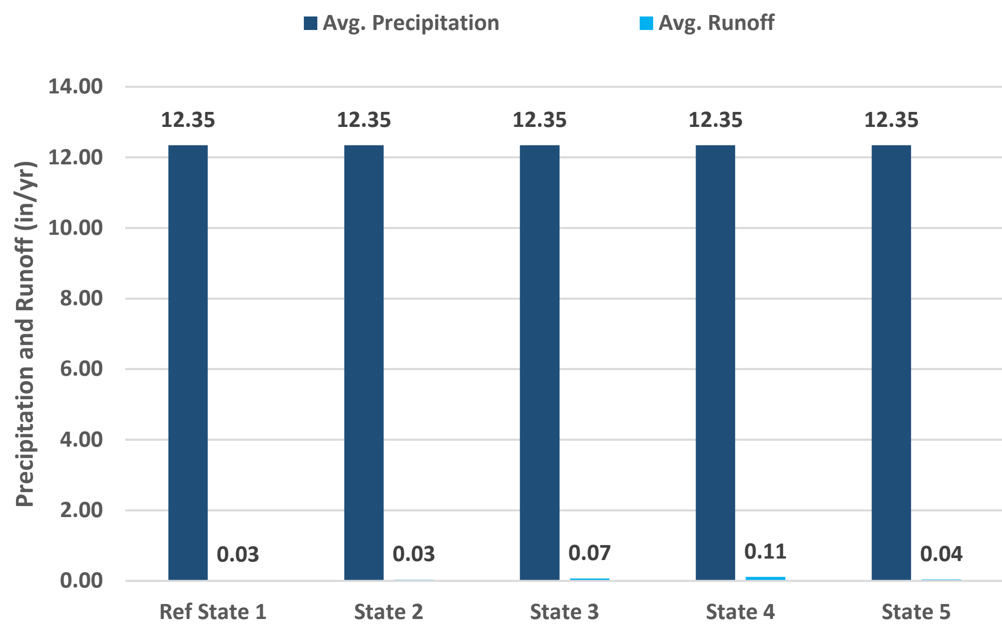

Figure 4. Rangeland Hydrology and Erosion Model estimated average annual precipitation and runoff for the various states of the South Slopes 12-16 in PZ ecological site.

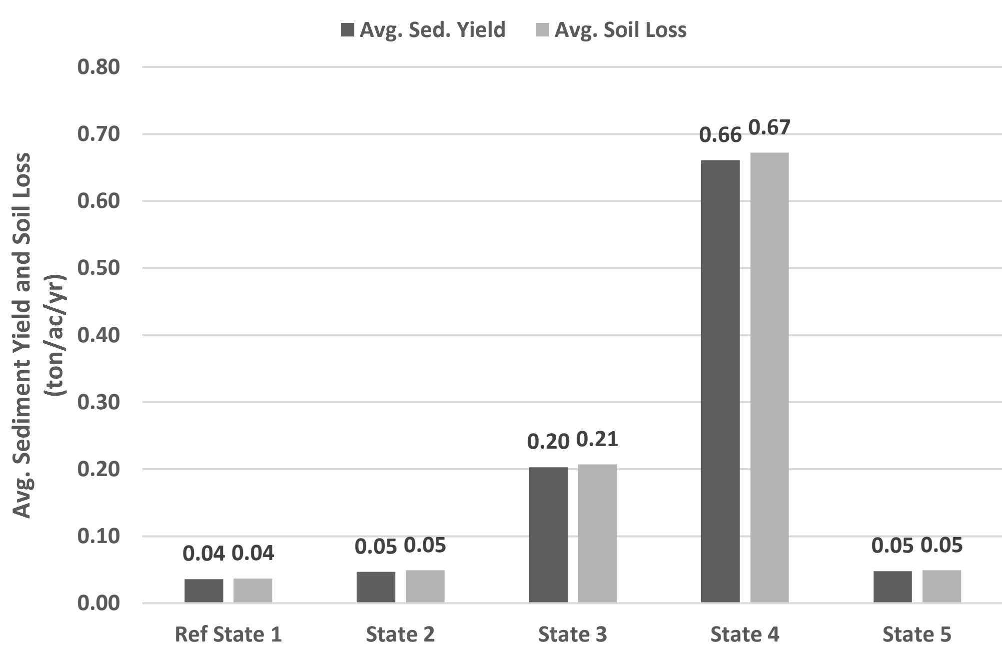

Figure 5. Rangeland Hydrology and Erosion Model estimated average annual sediment yield and soil loss for the various states of the South Slopes 12-16 in PZ ecological site.

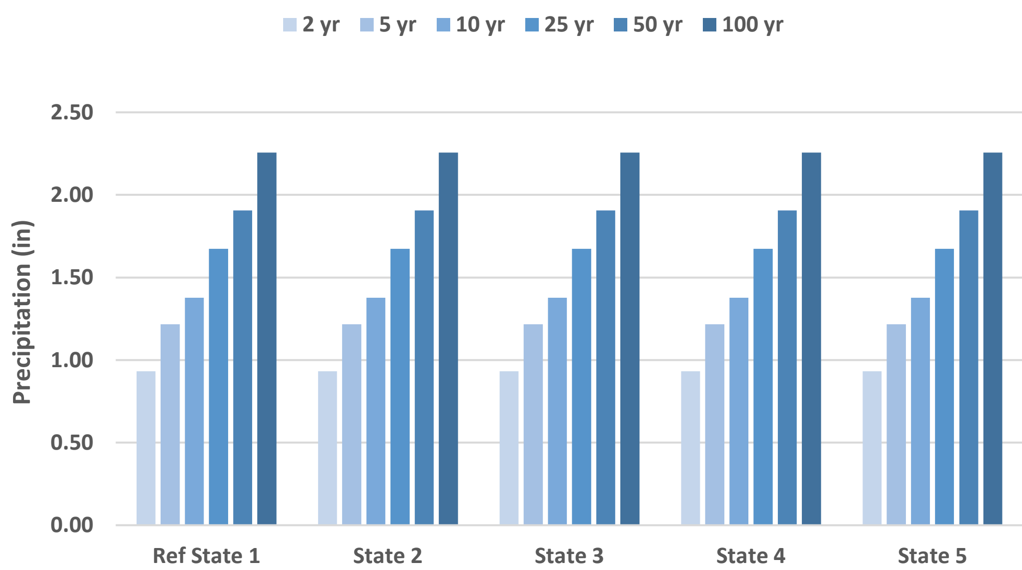

Figure 6. Rangeland Hydrology and Erosion Model estimated return period precipitation for the various states of the South Slopes 12-16 in PZ ecological site.

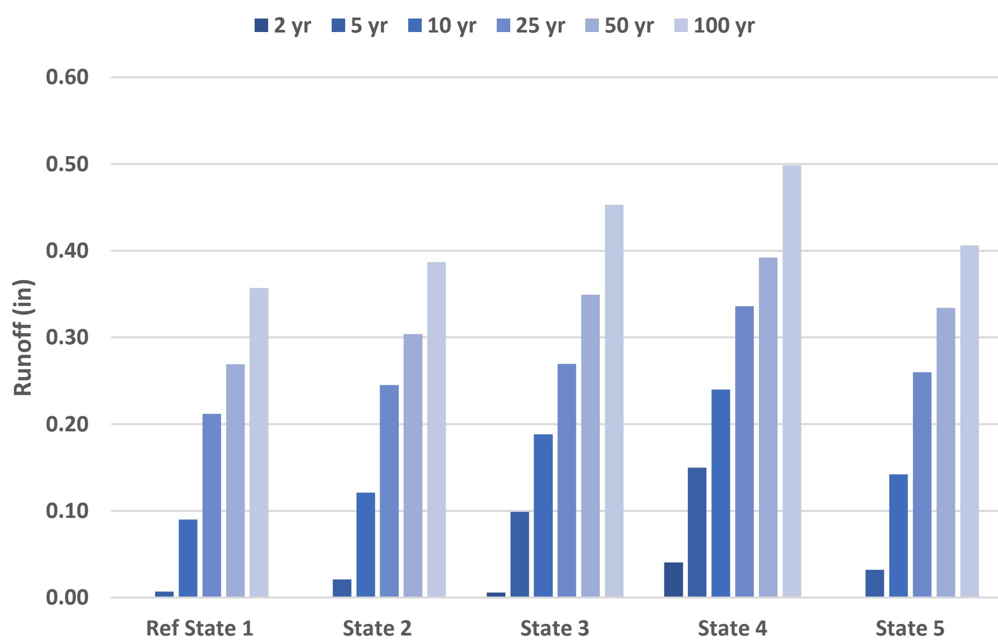

Figure 7. Rangeland Hydrology and Erosion Model estimated return period runoff for the various states of the South Slopes 12-16 in PZ ecological site.

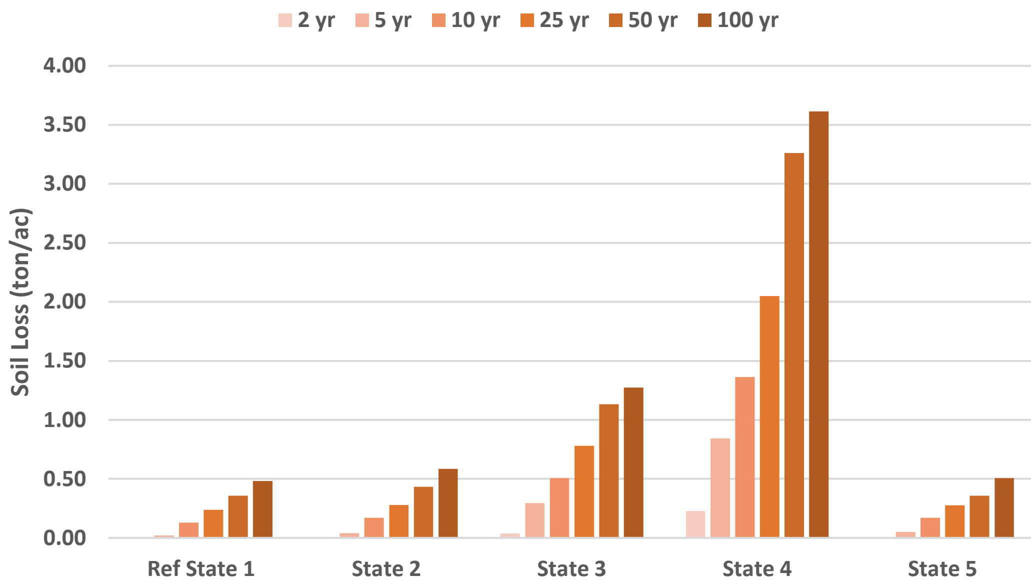

Figure 8. Rangeland Hydrology and Erosion Model estimated return period soil loss for the various states of the South Slopes 12-16 in PZ ecological site.

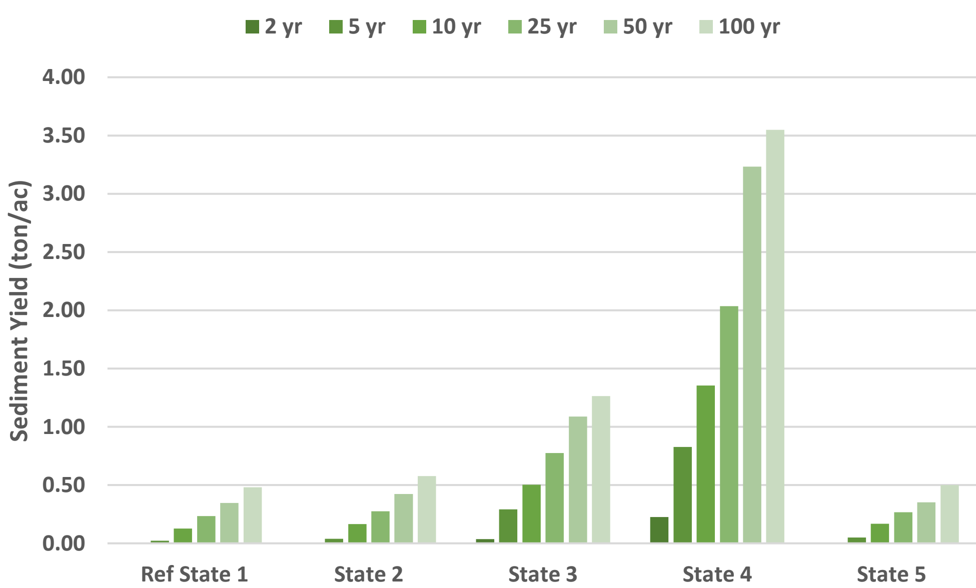

Figure 9. Rangeland Hydrology and Erosion Model estimated return period sediment yield loss for the various states of the South Slopes 12-16 in PZ ecological site.

Table 2. Probability (%) of occurrence of soil loss for any year by soil loss severity class for each state of the South Slopes 12-16 in PZ ecological site.

Range of Annual Soil Loss (ton/ac/yr)	State 1	State 2	State 3	State 4	State 5
Low $X < 0.171$	0.50	0.52	0.23	0.13	0.56
Medium $0.171 \leq X < 0.289$	0.30	0.26	0.20	0.10	0.23
High $0.289 \leq X < 0.535$	0.15	0.17	0.23	0.16	0.16
Very High $X \geq 0.535$	0.05	0.05	0.34	0.61	0.06

Table 3. Frequency analysis by annual soil loss (ton/ac/year) for any year by return period for each state of the South Slopes 12-16 in PZ ecological site.

Return Period (yr)	Ref State 1	State 2	State 3	State 4	State 5
2	0.000	0.000	0.053	0.326	0.000
5	0.021	0.040	0.419	1.193	0.046
10	0.126	0.165	0.724	1.933	0.165
20	0.208	0.262	0.969	2.543	0.253
30	0.266	0.299	1.122	2.960	0.285
40	0.320	0.363	1.428	3.885	0.329
50	0.352	0.402	1.524	4.472	0.349
60	0.356	0.434	1.619	4.659	0.357
70	0.402	0.493	1.632	4.656	0.393
80	0.442	0.540	1.637	4.753	0.435
90	0.449	0.545	1.691	4.938	0.463
100	0.442	0.535	1.757	5.124	0.479

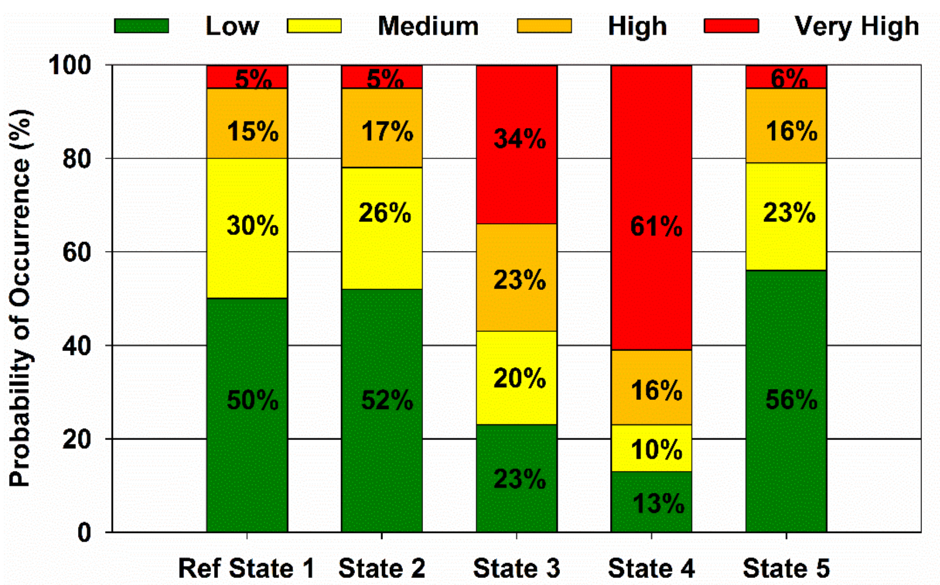

Figure 10. Probability (%) of occurrence of soil loss for any year for each state of the South Slopes 12-16 in PZ ecological site by erosion classes (Low, Medium, High, Very High, see Table 2 for respective values).

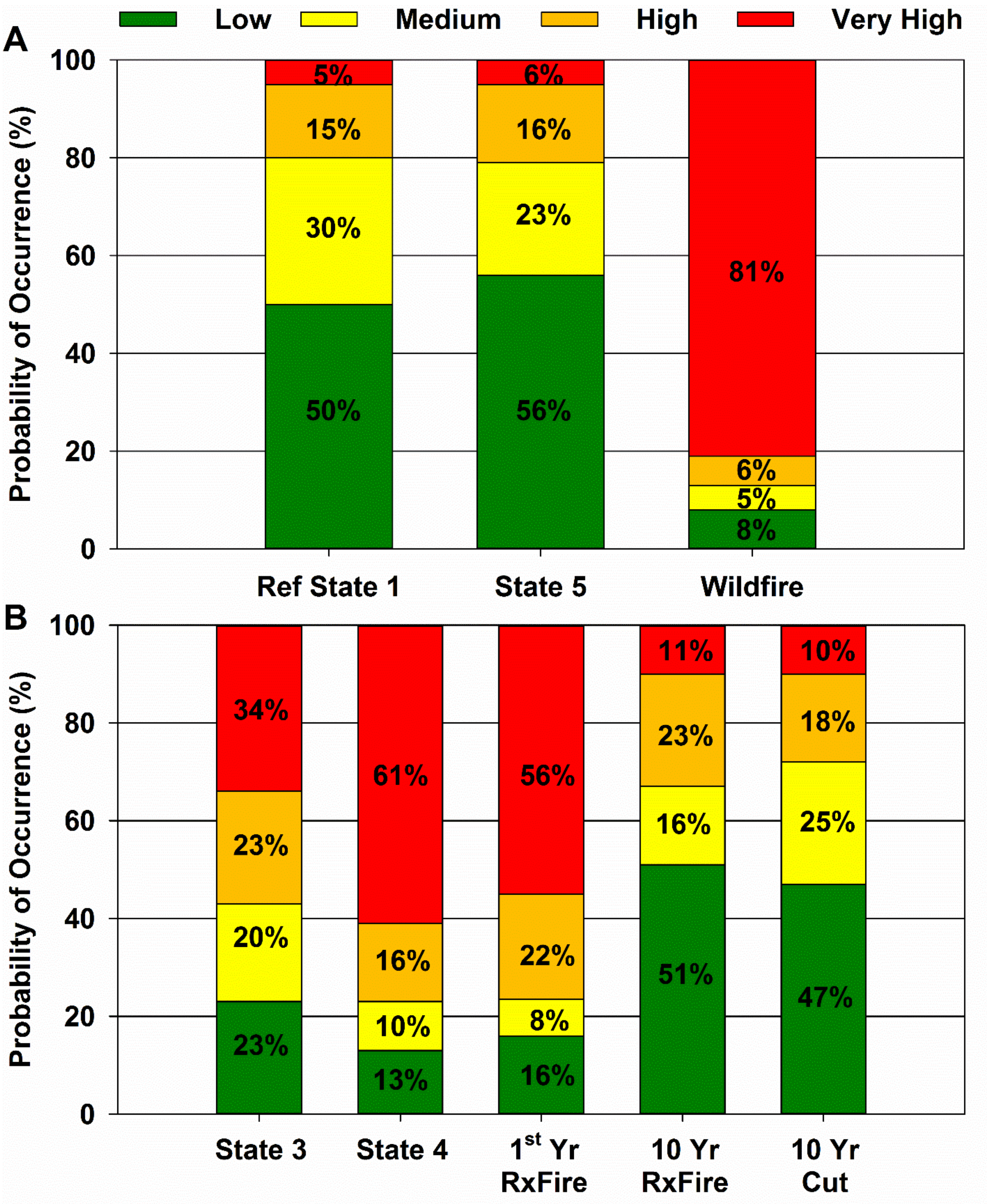

Figure 11. Probability (%) of occurrence of soil loss for any year for States 1 and 5 and conditions the 1st yr after wildfire for States 1, 2, and 5 (A); and for States 3 and 4, and following prescribed fire (Rx) and western juniper (Juniperus occidentails Hook.) cutting in State 3 (B) of the South Slopes 12-16 in PZ ecological site by erosion classes (Low, Medium, High, Very High, see Table 2 for respective values).

Figures 4-9 provide an overview of precipitation, runoff, soil loss, and sediment yield for the vegetation and ground cover conditions (Table 1) of the various ecological states of the South Slopes 12-16 in PZ site for the annual time scale (Figures 3 and 5) and for the 2, 5, 10, 25, 50, and 100 yr return interval runoff events (Figures 6-9) as predicted by the Rangeland Hydrology and Erosion Model (RHEM; Nearing et al., 2011; Al-Hamdan et al., 2015, Hernandez et al., 2017). RHEM predicted probability and amounts of annual soil loss for Low, Medium, High, and Very High soil loss severity classes are provided for each ecological state (Tables 2-3, Figure 10) and for conditions after burning States 1, 2, and 5 (Figure 11A) and after prescribed fire and tree cutting of State 3 (Figure 11B). Collectively, the RHEM results demonstrate the effects of vegetation change on hydrology and soil loss, the feedback of hydrologic and erosion processes on vegetation and state dynamics, and the effects of disturbances and varying management on state dynamics and associated hydrologic function for the South Slopes 12-16 in PZ site (Williams et al., 2016a, 2016b).

RHEM predicted runoff and soil loss are minimal for the Reference State except for extreme events (Figures 7-9). Dense vegetation and ground cover under Reference State conditions dissipate raindrop impact, trap and store water, increase time available for infiltration, and limit runoff and erosion (Pierson and Williams, 2016). Erosion for the reference condition occurs mainly in isolated bare patches, but downslope sediment delivery is limited due to deposition in and around plants and ground cover elements. The model results indicate the Reference State is indicative of good soil retention, with an 80% probability that annual soil loss will not exceed 0.289 tons/ac (Low to Medium soil loss risk; Table 2, Figure 10). Annual soil loss in excess of 0.5 ton/ac is generally considered unsustainable for sagebrush rangelands. RHEM predicted runoff and soil loss for State 2 is similar to that for the Reference State, although both runoff and soil loss slightly increase for 10- to 100-yr events. State 2 is generally considered less ecologically desirable than the Reference State due to encroachment by western juniper and trace cover of cheatgrass and other annual weeds, but vegetation and ground amounts in each phase of State 2 act to limit soil and water losses. Burning of the Reference State and State 2 increases short-term runoff and soil loss at the annual and event scales (by factors of 2-5 and 30-70, respectively, see Williams et al., 2016b) and increases the risk for Very High soil loss (Figure 11A). However, increases in runoff, sediment yield, and soil loss risk are likely short-lived (1 to 3 yr) due to the resilience of the states (Williams et al., 2016a, 2016b). Fire is necessary to limit western juniper cover and transition to State 3, and therefore acts to sustain the Reference State and State 2 (Figure 2).

States 3 and 4 respectively represent initial and potentially irreversible degraded state trajectories (Figure 2). Increased western juniper cover associated with fire exclusion enhances connectivity of bare ground (Figure 3C) and runoff sources and promotes formation of high velocity concentrated flow through bare intercanopy areas (Pierson et al., 2007; Williams et al., 2014a, 2016a, 2016c). Concentrated flow has greater sediment transport and detachment capacity than rainsplash and sheetflow (Pierson et al., 2008, 2009, 2010, 2011; Williams et al., 2014b; Pierson and Williams, 2016; Nouwakpo et al., 2016) and results in greater runoff and soil loss relative to conditions representative of the Reference State, particularly in State 4 (Figures 7-9). Increased bare ground following western juniper dominance increases soil water loss to evapotranspiration without beneficial intercanopy plant productivity, essentially isolating soil water and nutrients to tree islands (Miller et al., 2005). Western juniper encroachment may also affect timing and amount of soil water recharge and streamflow generation associated with tree effects on the distribution of snow (Kormos et al., 2017). These changes in water availability may impact vegetation productivity and thereby negatively affect sagebrush obligate wildlife habitat. RHEM predicted runoff and soil loss are greater for States 3 and 4 relative to the Reference State for nearly all return interval runoff events (Figures 7-9), but only soil loss is substantially greater. High erosion rates associated with transition from State 3 to State 4 indicate a likely shift beyond a soil conservation threshold to an irreversible degraded stable state (Williams et al., 2014a, 2016a; Figure 3D). The likelihood of annual soil loss to exceed 0.535 ton/ac (Very High category) is 34% for State 3 and more than 60% for State 4 (Figure 10). RHEM results suggest soil loss in States 3 and 4 is likely to exceed 0.5 ton/ac for the 25 yr, 50 yr, and 100 yr return-interval runoff events (Figure 9).

Juniper removal may re-establish sagebrush and perennial bunchgrass vegetation in States 2 and 3, and, thereby, reduce runoff and erosion risk (Pierson et al., 2007). Juniper removal by prescribed fire may increase runoff and soil loss in the first few years post-fire, but likely results in reduced soil erosion risk as vegetation and ground cover increase in the years post-treatment (Pierson et al., 2013, 2014; Williams et al., 2014a; Pierson et al., 2015; Pierson and Williams, 2016; Williams et al., 2016c). RHEM simulations of State 3 indicate that the likelihood of Very High levels of annual soil loss in any given year decreases from 34% without juniper removal to 11% within 10 yr after prescribed fire, while the likelihood of Low to Medium annual soil loss increases from 43% to 67% 10 yr after burning (Figure 11B). Similar results can be achieved through tree cutting without the initial erosion risk the first year or two post-fire (Figure 11B; Pierson et al., 2007). Either treatment in State 3, assuming favorable vegetation response, dramatically reduces long-term erosion risk relative to State 4 (Figure 11B). Burning initially increases erosion risk (Pierson et al., 2011; Pierson and Williams, 2016; Williams et al., 2014a, 2014b, 2016c), and sagebrush recovery following burning may take decades (Miller et al., 2013). Tree cutting without fire will retain the shrub component, but may increase wildfire risk due to increased downed woody fuels. Likewise, extensive downed trees may affect wildlife habitat and various land uses such as grazing. Mechanical treatments also commonly leave juvenile juniper that can later recolonize the respective site (Bates et al., 2005; Miller et al., 2013; Bates et al., 2017). Vegetation recruitment after tree removal by burning or cutting may require seeding in later stages of State 3. Prescribed burning and tree cutting are not commonly applied in State 4.

Assessing the ecohydrologic ramifications of transition to State 5 (cheatgrass) requires consideration of effects associated with frequent re-burning (Miller et al., 2011; Pierson et al., 2011; Wilcox et al., 2012; Balch et al., 2013; Williams et al., 2014b). The effects of cheatgrass on infiltration, runoff, and soils for unburned conditions are not well known (Wilcox et al., 2012). Fire removal of cover for any state increases the connectivity of runoff and erosion promoting bare ground and facilitates a temporary shift to concentrated flow as the dominant erosion process across the site (Pierson et al., 2008, 2009, 2013; Williams et al., 2014a, 2014b; Pierson et al., 2015; Pierson and Williams, 2016; Williams et al., 2016c). Post-fire vegetation and hydrologic recovery are generally more rapid for the Reference State and State 2 due to the presence of perennial grasses (Miller et al., 2013; Williams et al., 2016a). Frequent re-burning in the cheatgrass-dominated State 5 increases the frequency of bare ground exposure to erosion processes and likely results in long-term loss of nutrient rich surface soil due to repeated erosion by water and wind (Pierson et al., 2011; Wilcox et al., 2012; Williams et al., 2014b). The probability of Very High annual soil loss (> 0.535 ton/ac) is 81% for burned conditions in the Reference State and State 5 (Figure 11A). This condition will occur more frequently with extensive cheatgrass cover in State 5 (fire frequency ~ 10-fold less than States 1-2 [Miller et al., 2011]) relative to the Reference State and State 2, potentially increasing long-term soil loss and pushing the site beyond a soil conservation threshold. RHEM predicted soil loss for burned conditions in State 5 exceed that of unburned conditions in the Reference State and State 2 by 30- to more than 100-fold across the annual to 100-yr return interval runoff events, ranging from approximately 1 to 17 ton/ac for the simulated 5-100 yr return interval events and 3 ton/ac at the annual time scale.

6 Summary and Implications

Analysis of the RHEM simulations for the South Slopes 12-16 in PZ ecological site provides a framework for interpreting and predicting the effects of the state-specific vegetation and ground cover attributes on infiltration, runoff, and erosion processes that further affect site dynamics. The simulations also aid prediction of site ecohydrologic responses to disturbances and various land management actions. The simulations presented do not span the entire suite of available land treatments or disturbances possible on the select ecological site, but the overall framework demonstrates the application RHEM to evaluate and predict site specific ecohydrologic responses across a range of vegetation cover and surface conditions. Similar simulations could easily be developed and run for the South Slopes 12-16 in PZ site to evaluate the effects of management actions and disturbances not included in this analysis. The analysis presented indicates significant differences in estimated soil loss for the various ecological states of the South Slopes 12-16 in PZ ecological site. Substantial coverage of perennial grasses and shrubs in the Reference State and State 2 limit runoff and soil loss. A lack of fire associated with drought or improper grazing allows the site to transition to State 3 through extensive encroachment of western juniper. Encroaching trees in State 2, if not removed by fire, gradually outcompete sagebrush and perennial bunchgrasses for limited soil water and nutrients, facilitating the transition to State 3. Runoff and soil loss increase in State 3 as bare ground increases. Loss of surface soil and perpetual dominance by western juniper in State 3 promote transition to State 4, a juniper dominated eroded state. Juniper removal treatments, such cutting or prescribed fire, can effectively enhance sagebrush and perennial grasses in State 2 and in State 3 where shrub and native perennial grasses remain at least a minor component of the understory. However, re-establishment of sagebrush and native perennial grass cover is considered highly unlikely once a site transitions to State 4. Tree removal can improve infiltration and reduce runoff and erosion depending on the vegetation and ground cover response. Burning may increase runoff and soil loss risk in the first few years post-fire, but likely results in improved hydrologic function over time with increases in sagebrush-steppe vegetation and ground cover. Burning also potentially increases the risk of cheatgrass invasion and removes fire intolerant sagebrush plants. Sagebrush cover can take 30 yr to more than 50 yr to recover. Mechanical tree-removal treatments avoid the initial risk of elevated runoff and soil loss associated with burning and can likewise reduce runoff and erosion rates over time with favorable vegetation and ground cover recruitment. Mechanical applications also retain sagebrush and limit potential for cheatgrass increases associated with treatment. However, mechanical treatments commonly leave ample downed woody fuel and numerous residual juvenile western juniper that ultimately recolonize a site. Cheatgrass invasion of a site (transition to State 5) following prescribed burning or wildfire substantially changes site vegetation structure and increases the risk of wildfire. Runoff and soil loss in State 5 for unburned conditions are generally low. Burning of State 5 substantially increases the runoff and soil loss at the annual time scale and for most return-interval runoff events. Frequent re-burning in State 5 increases site spatial and temporal exposure to runoff generating storms over time and potentially increases long-term soil loss. Reversing the transition to State 5 is considered highly unlikely. Overall, the results from the RHEM simulations and the literature indicate retention of sagebrush, native perennial bunchgrasses, and near 50% ground cover are important in sustaining the water and soil conserving structure of sagebrush steppe and preventing transition to a degraded woodland- or cheatgrass-dominated state with elevated soil loss risk.

7 References and Further Reading

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