Rangeland Hydrology and Erosion Model guide for:
Post Oak Savana in central Texas

1 General background

Ecological Site for this example is a Deep Redlands 29-35” (R081CY358TX). This ecological site is located in MLRA 081C and is in the eastern part of the Edwards Plateau region of central Texas (Figure 1). The dominant vegetation is composed of post oak (*Quercus stellata*, Plateau oak (*Quercus fusiformis*) and Blackjack oak (*Quercus marilandica).* The dominant grass is little bluestem (*Schizachyrium scoparium*).

The eastern region of the Edwards Plateau is 98% rangeland and is composed of approximately 20 rangeland ecological sites across 8,060 square miles in central Texas. Limestone ridges and canyons (karst geology) with nearly level to gently sloping valley floors dominate the landscape. Average elevation is 900 feet, and the average annual precipitation in the area is 24 to 30 inches. Most of the rainfall occurs in spring and fall. The Reference plant community (Figure 2) is grassland and open savannah plains with tree or woody species found along rocky slopes and stream bottoms.

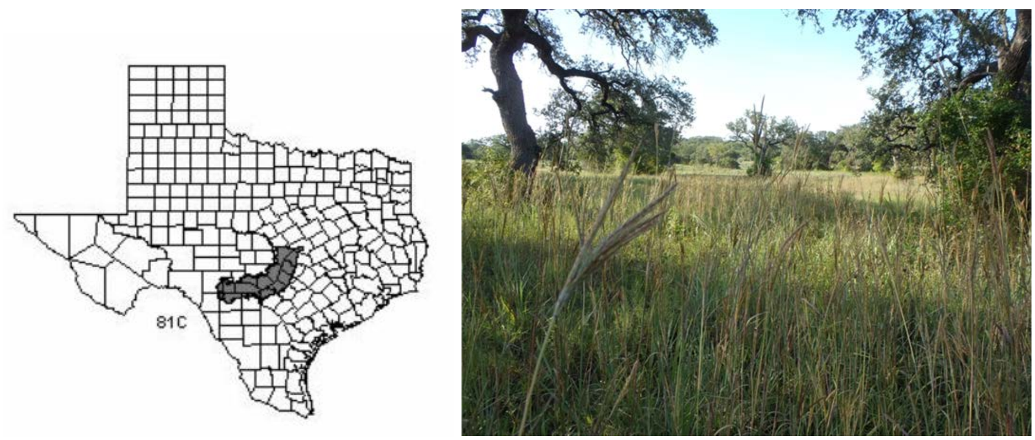
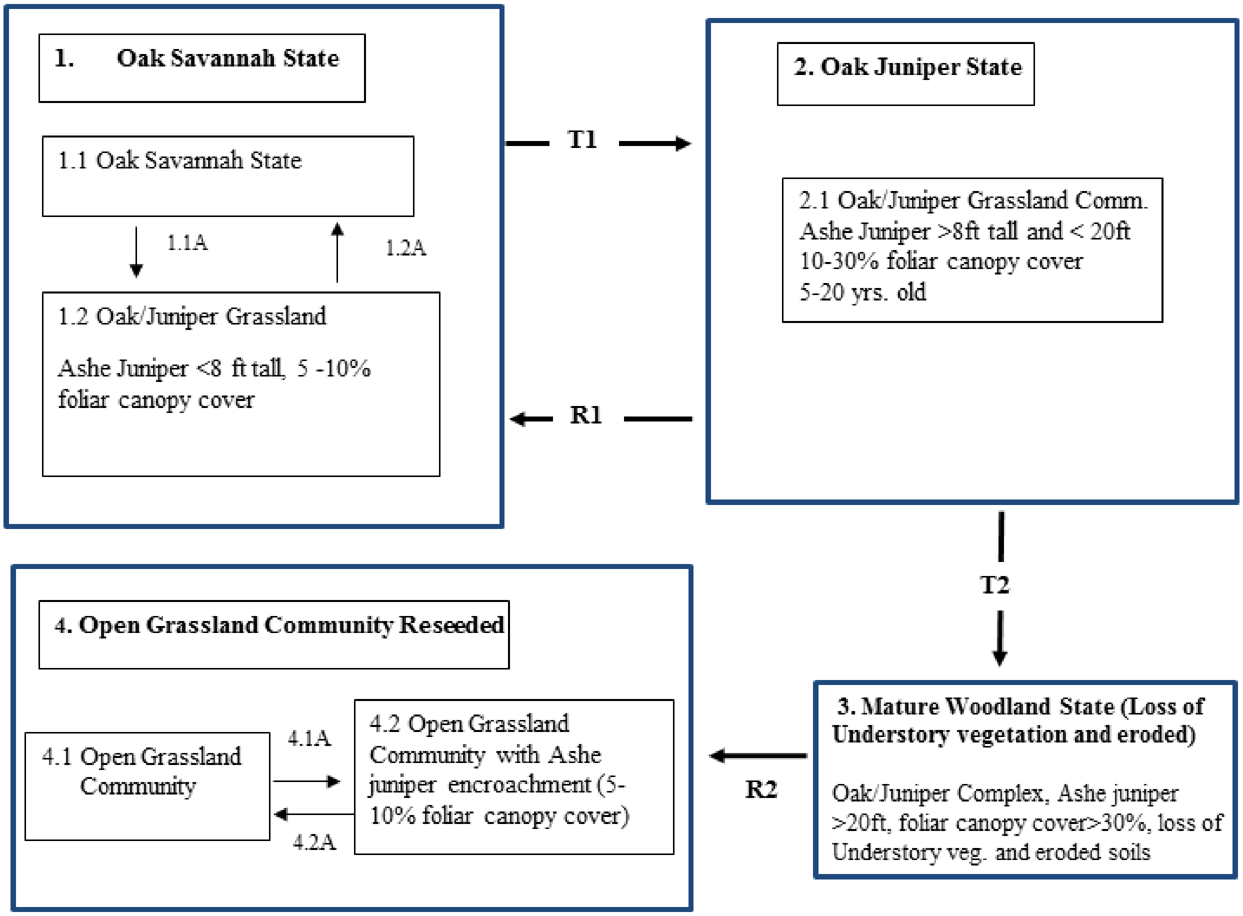


Figure 1. Location of Major Land Resource Area and example of Reference plant community.

2 Ecological Site Description

The Reference plant community (Figure 1) is grassland and open savannah plains with tree or woody species found along rocky slopes and stream bottoms. The Reference plant community for the Deep Redlands Ecological Site (State I, Figure 2) is an oak (*Quercus* spp.) savannah with native tall grasses [little bluestem (*Schizachyrium scoparium* (Michx.) Nash, big bluestem (*Andropogon gerardii* Vitman), Indiangrass (*Sorghastrum nutans* (L.) Nash), switchgrass (*Panicum virgatum* L.) and Eastern gamagrass (*Tripsacum dactyloides* (L.) L.)]. Average herbaceous foliar cover is > 75% with < 25% bare ground. Fire was an important factor in maintaining the original open prairie vegetation and plant community structure. Species such as Ashe juniper would invade the site, but would recede with periodic wildfire. Woody plant cover would vary in accordance with the type and frequency of disturbance and resulted in a mosaic of vegetation types within the same ecological site. The greatest abundance of Ashe juniper is found on the eastern and southern portions of the Edwards Plateau, but Ashe juniper also extends into the



Legend

Community Pathway succession/retrogression pathway ⟶

Transition —— T ⟶

Restoration Pathway —— R ⟶

1.1A	No Fire, Invasive Plants, No Brush Management
1.2 A	Prescribed grazing, Brush Management, Prescribed Fire
T1	Transition from State 1 to 2; Prescribed Grazing inconsistent, No Fire, Invasive Plants, No Brush Management
R1	Restoration from State2 to 1; Prescribed grazing, Prescribed Fire, Brush Management
T2	Intermediate-to-Long Term No Fire, Invasive Plants, No Brush Management, No Prescribed Grazing. Loss of understory vegetation and accelerated soil loss
R2	Restoration to State 4, Rangeland Seeding, Prescribed Grazing, Brush Management, Prescribed Fire
4.1A	No Fire, Invasive Plants, No Brush Management
4.2A	Prescribed grazing, Brush Management, Prescribed Fire

***Figure 2.** State and Transition Diagram for Deep Redlands Ecological Site in the Edwards Plateau near Johnson City, Texas illustrating State I (Reference plant community), possible alternative States II, III and IV, recovery pathways, and types of conservation practices that are needed to restore a degraded site to the Reference plant community (photos by NRCS).*

In the South Texas Plains and north into the Cross Timbers and Rolling Plains areas of the state several Ecological Sites in MLRA 81C (e.g., Steep Adobe) contain Ashe juniper as a native component (with 5-10% cover) and up to 10% of total average production based on current year's growth. Historically, Ashe juniper is believed to have been restricted to rocky outcrops and rocky, north-facing slopes where they were protected from intense grass fires. On the Deep Redlands Ecological Site, Ashe juniper is not listed as an allowable plant; however, juniper can readily invade this site.

On the Deep Redlands Ecological Site, Ashe juniper, because of its dense low growing foliage, has the ability to retard grass and forb growth. Grass and forb growth can become nonexistent and the diversity of native forbs and grasses dramatically reduced, while the presence of introduced and non-native species can increase rapidly. Where soil loss has not been significant in over grazed sites (State II), little bluestem and other native species will slowly return to the site with sound management and proactive conservation.

Figure 3. Stae II with young Juiper encroaching.

Historic overgrazing has brought about the reduction of these native grasses from a large portion of the area. Heavy grazing reduces fine fuels which help carry fire and facilitates rapid encroachment of Ashe juniper and associated woody species. In State III the loss of topsoil and soil organic matter cannot be replenished in a human management timeframe (decades); therefore, returning to the Reference state (State I) is not possible once the site has crossed this ecological and hydrologic threshold (canopy cover > 30%) and a eroded A horizon.

When Ashe juniper canopy cover > 30% (depending on slope, soil profile characteristics and other factors), biotic and hydrologic thresholds are often reached (State III). Ashe juniper canopy closure rapidly increases from this point forward. As the Ashe juniper canopy increases and closes in, understory grasses and forbs become depauperate and bare soil increases between mature junipers. On degraded and disturbed rangelands, an increase in runoff and soil loss with increasing land area is typical due to increased connectedness of bare soil patches that allow the formation of concentrated flow paths, which initiates accelerated soil loss, rills, and gullies. As Ashe juniper cover increases, the understory vegetation decreases, erosion processes are active, and substantial soil loss occurs as the site transitions to State III.

Figure 4. State IV where Juniper now dominates the site.

3 Soil

In a representative profile for the Deep Redland ecological site, the soils are reddish brown, moderately deep, non-calcareous clays, silt clays, clay loams or loams. They are underlain by slightly fractured indurated limestone bedrock at depths of 20 to 40 inches. Plant roots penetrate the crevices, which are usually filled with reddish brown clay. Limestone fragments, cherts, cobbles and stones sometimes occur on the surface and may make up as much as 15 percent of the soil by volume. When dry, the soils crack and take in water rapidly. When wet, the cracks close, and the soils become sticky and plastic and take in water very slowly. Light showers are ineffective on the site, which favors the growth of deep-rooted perennial plants. When plant residues are inadequate, soil condition deteriorates and heavy surface crusts develop. In this condition water intake is very slow, runoff is rapid, erosion is a hazard, and grass recovery is slow. These sites occur on more stable hillslopes on dissected plateaus and ridge side slopes.

Figure 5. Typical Map Unit for Deep Redland Ecological Site.

Due to the scale of mapping, there are inclusions of minor components of other soils within these mapping units. The representative soils map unit (Figure 3) associated with the Deep Redland ecological site are: Anhalt clay, 0 to 10 percent slopes; Crawford and Bexar stony soils; and Spires association on gently undulating landforms.

4 Climate

The climate is humid subtropical and is characterized by hot summers and relatively mild winters. The average first frost should occur around middle of November and the last freeze of the season should occur around the middle of March. The average relative humidity in mid-afternoon is 50 percent. Approximately two-thirds of annual rainfall occurs during the April to September period. Rainfall during this period generally falls during thunderstorms, and fairly large amounts of rain may fall in a short time. Hurricanes provide another source of extremely high rainfall in a short time period. A review of the rainfall records suggest that rainfall is below “normal” at least 60 percent of the time. Therefore, the erratic nature of the rainfall should be considered when developing any land management plans. The impact of droughts in the Edwards Plateau cannot be under-estimated. Droughts occur roughly every 20 years. A severe drought in 2012 coupled with extreme heat resulted in a die off of juniper over millions of acres as well as other native plants making the area vulnerable to accelerated soil erosion. Precipitation and runoff estimated by RHEM for this analysis is depicted in Figure 4.

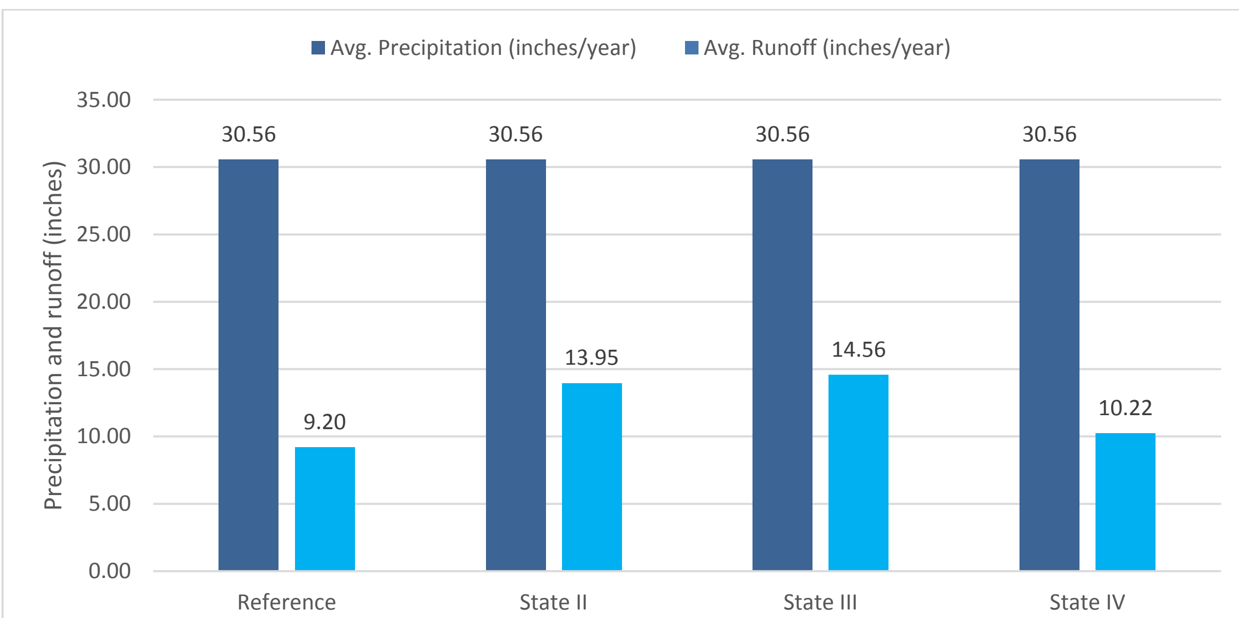


Figure 6. Rangeland Hydrology and Erosion Model estimated average annual precipitation and runoff for Deep Redland Ecological Site by ecological state near Johnson City, Texas.

Table 1. RHEM model inputs for evaluation of hydrologic impact of transitions from one ecological state to another ecological state for Deep Redlands 29-35 inch site (R081CY358TX). Soil Series is a Crawford with silty clay in the surface horizon and the landform is concave side slope on the shoulder of a ridge.

Input Parameter	**Reference (HPC) State I**	**Scenario 1 State II**	**Scenario 2 State III**	**Scenario 3 State IV**
Soil Texture	Silty clay	Silty clay	Silty clay	Silty clay
Soil Water Saturation (%)	25%	25%	25%	25%
Slope length (ft)	150	150	150	150
Slope Shape	Concave	Concave	Concave	Concave
Slope Steepness (%)	10%	10%	10%	10%
Foliar canopy cover (%)				
Bunch grass Foliar cover (%)	60%	15%	2%	50%
Forbs and/or Annual Grass Foliar cover (%)	5%	5%	3%	8%
Sodgrass Foliar cover (%)	0%	0%	0%	0%
Woody Foliar cover (%)	5%	25%	50%	0%
Ground surface cover %				
Basal Cover (%)	25%	15%	10%	20%
Rock cover (%)	5%	7%	10%	10
Litter Cover (%)	65%	20%	15%	60%
Cryptogam Cover (%)	0%	0%	0%	0%
Bare soil (%)	5%	48%	65%	10%

6 Modeling Results and Discussion

Figure 4 through 11 provide an overview of plant communities and summary of precipitation, runoff, sediment yield and soil loss rates for the 2, 5, 25, 50, and 100- year runoff recurrence interval. Based on the soil loss thresholds discussed in this risk assessment section States II and III are mostly likely unstainable and at risk of crossing an abiotic threshold that will permanently reduce net primary production and livestock carrying capacity.

Soil loss on many rangelands is not uniformly distributed, spatially or temporally across the landscape. Average annual soil loss rates cannot explain all soil loss in arid and semiarid rangelands because most soil loss occurs during high-intensity rainfall events that generate large amounts of runoff and that may occur only a few times in a decade. The RHEM return frequency output is based on yearly summations of runoff and erosion, which will take into account the occurrence of years that have these large events.

With reference to the Deep Redland ecological site (Figure 2), the oak savanna (Reference plant community – Historic plant community) is associated with maximum hydrologic function (State 1). The high degree of hydrologic function in State 1 is due to dominance of rhizomatous tall and mid grasses. When properly managed, these species provide adequate cover; however, one of the key factors affecting hydrologic function is the structure and morphology of the root system and other biotic and abiotic factors. During high rainfall periods, water will percolate beyond the immediate surface root zone via fractures in the predominantly limestone bedrock. When conditions are representative of tall-mid grass species (juniper canopy cover <5%) little runoff and soil loss occurs on an annual basis (0.89 ton/ac/year).

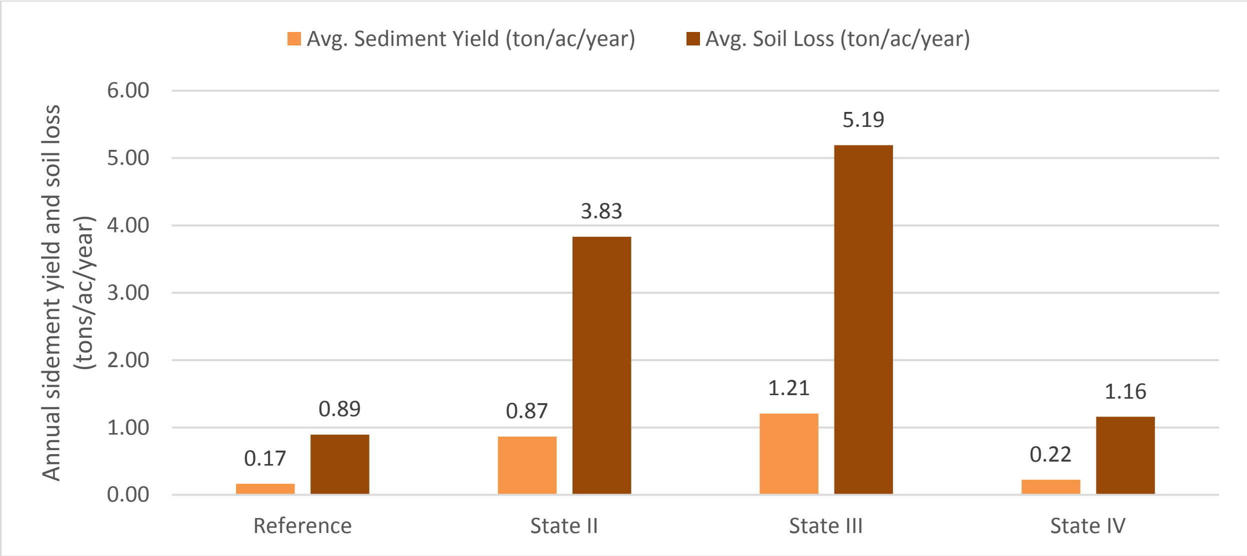


Figure 7. Rangeland Hydrology and Erosion Model estimated average annual sediment yield and soil loss for Deep Redland Ecological Site by ecological state near Johnson City, Texas.

Improper grazing management, lack of fire, and invasive species causes loss or reduction of the rhizomatous tall-mid grasses (State II). Prolonged improper grazing management, no brush management and/or prescribed fire, and the introduction of invasive species results in impaired hydrologic function. During the transition phase from State I to II, infiltration decreases, runoff increases, and soil loss may increase by nearly 4 fold to 3.83 ton/ac/year. This is because of shifts in grass density and litter cover (Figure 5 and Table 1)). Hydrologic conditions will continue to worsen if conservation is not applied.

In State III where Ashe juniper and associated woody species dominate the site (Figure 2 and Table 1), understory species become increasingly sparse and ground cover decreases due to shading and competition from woody plants. As Ashe juniper becomes mature (>8 ft tall) juniper density and bare ground increases. In State III, when the juniper is mature and > 30% canopy cover, soil loss can accelerate rapidly due to loss of understory vegetation to 5.19 ton/ac/year. The site can erode quickly, especially during rarer high-intensity climatic storm events.

If the site is allowed to deteriorate to a point where considerable soil loss has occurred, the site crosses an ecological threshold and can't be restored to its potential. If the site has not incurred significant soil loss, conservation treatments including a combination of practices (brush management, prescribed grazing, prescribed burning, and rangeland seeding) can help restore the natural hydrology of the site to some degree. For example, in the early stages of State III, where the erosive phase has not been significant, it may be possible to revert to State II. However, this window is "short lived" and often once the plant community reaches state III, conditions deteriorate rapidly limiting options for restoring to State I.

In State IV the plant community is a reconstructed seeded and managed pasture. If the site was converted to this state before excess soil loss occurred then the hydrologic and soil loss rates will be similar to the Reference state as indicated in this example. If State IV was converted to a pasture after significant soil loss had occurred then the site will have lower productivity, lower foliar canopy cover, more open exposed bare soil and rock outcrops. This will result in increased runoff and soil loss in comparison to the Reference

Figure 8. State IV a reconstructed and seeded pasture.

community in State I.

Figures 6 and 7 provide estimates of annual precipitation, runoff, soli loss and sediment yield. Figures 9 through 13 provide estimates of annual precipitation, runoff, soli loss and sediment yield by the 2-, 10-, 25-, 50-, and 100 year return period runoff events. As canopy and litter cover decreases with the encroachment of woody plants runoff, soil loss, and sediment yield increase in State II and State III.

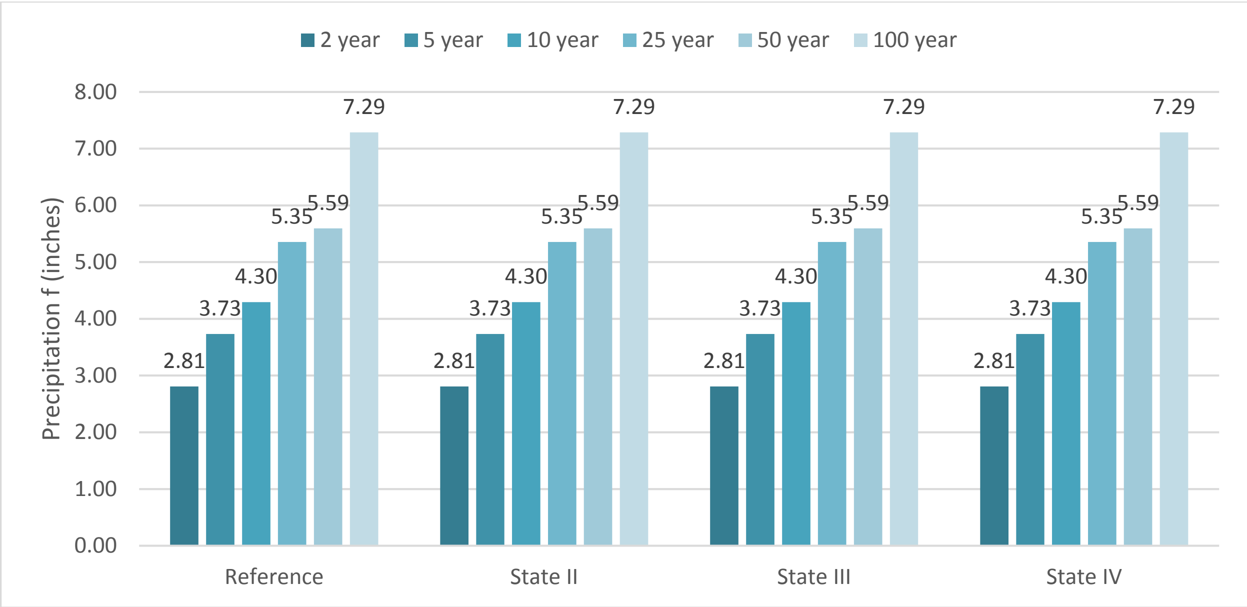


Figure 9. Rangeland Hydrology and Erosion Model estimated return period precipitation for Deep Redland Ecological Site by ecological state near Johnson City, Texas.

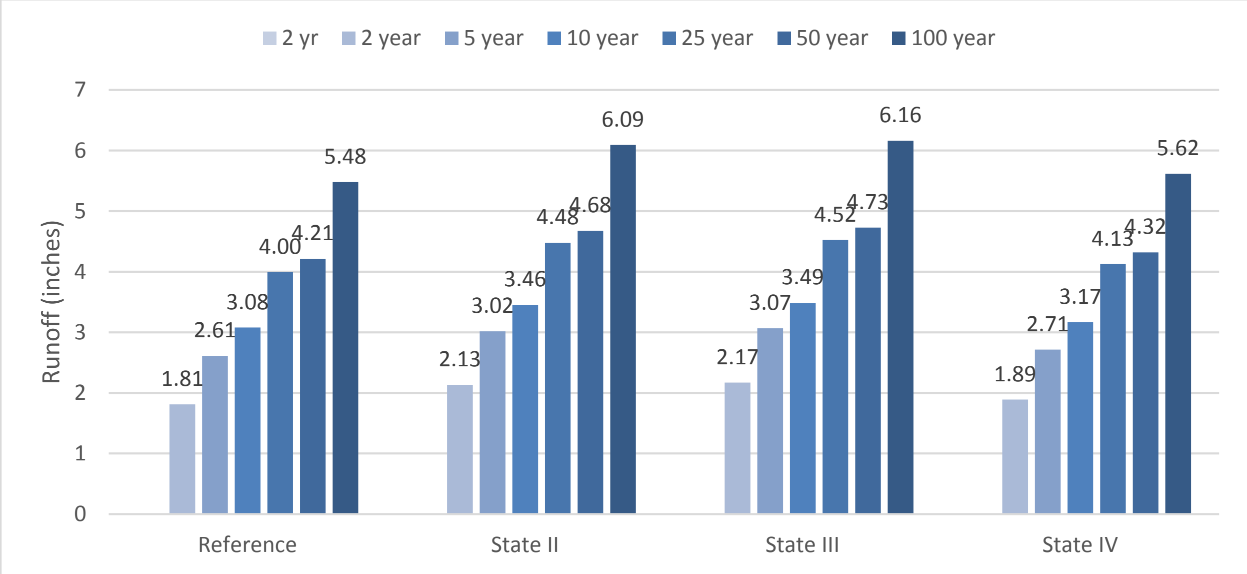


Figure 10. Rangeland Hydrology and Erosion Model estimated return period runoff for Deep Redland Ecological Site by ecological state near Johnson City, Texas.

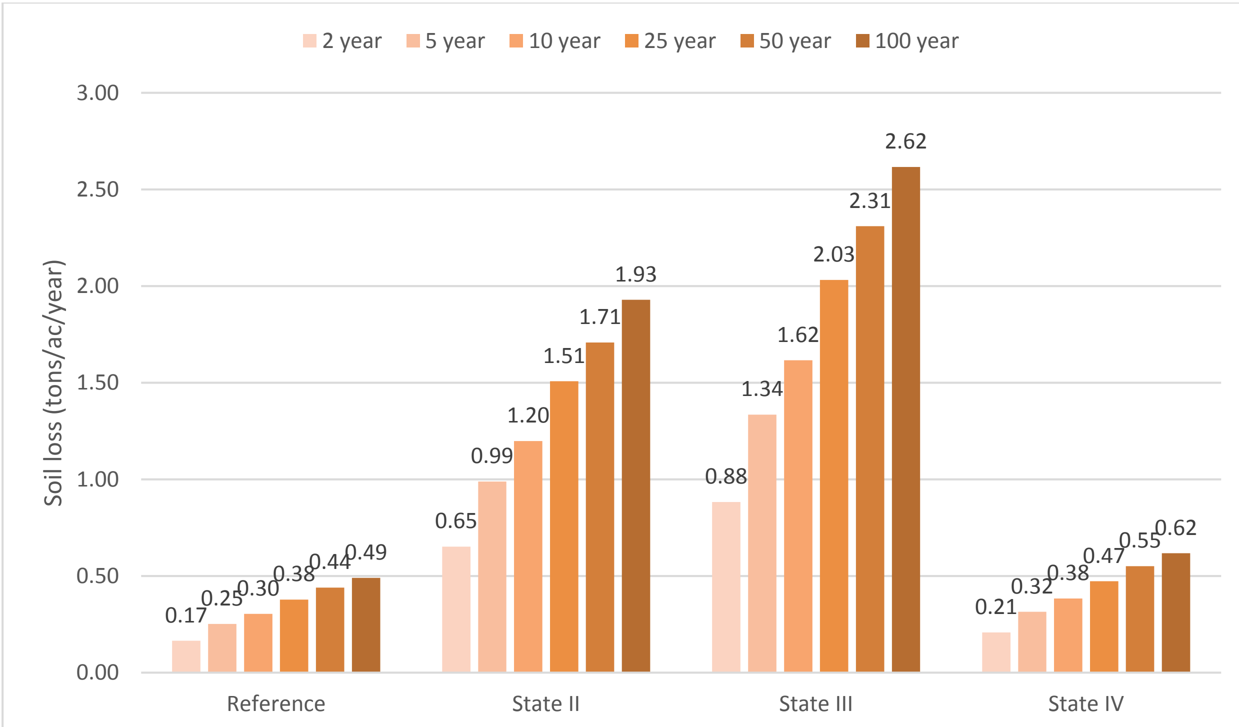


Figure 11. Rangeland Hydrology and Erosion Model estimated return period soil loss for Deep Redland Ecological Site by ecological state near Johnson City, Texas.

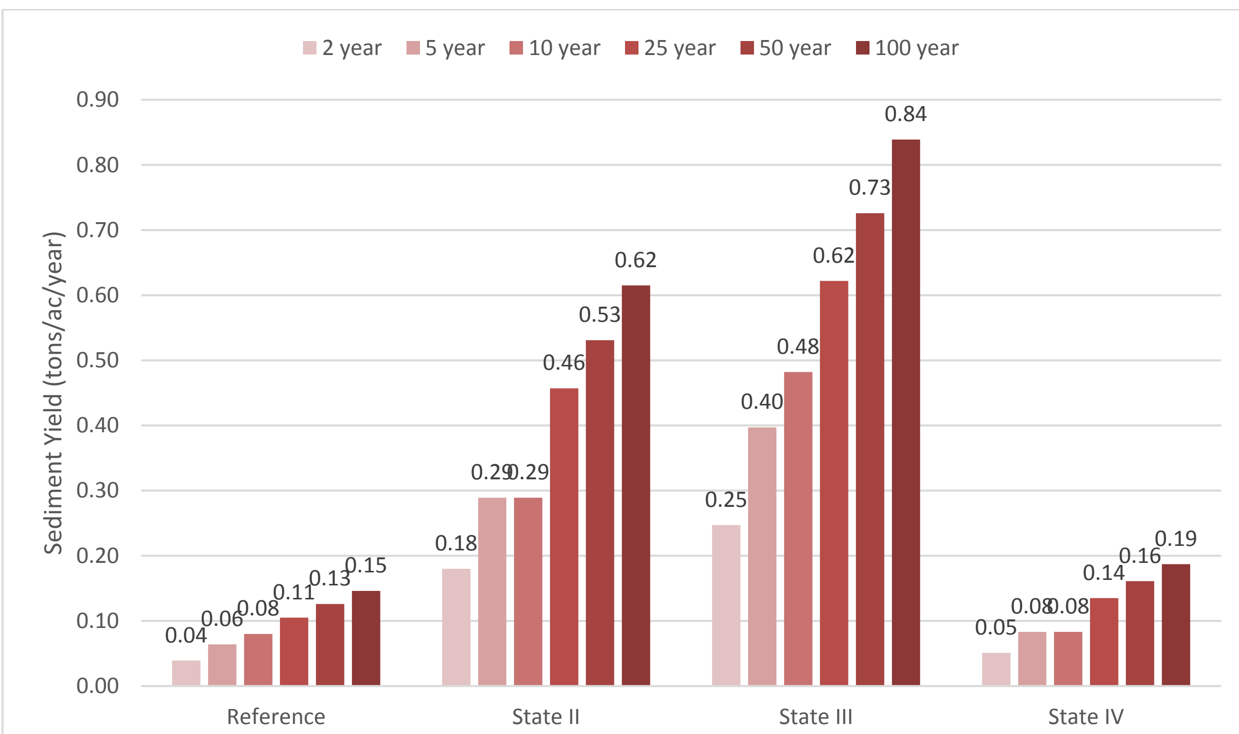


Figure 12. Rangeland Hydrology and Erosion Model estimated return period sediment yield for Deep Redland Ecological Site by ecological state near Johnson City, Texas.

7 Risk Assessment of Accelerated Soil Erosion

The mean annual soil losses for the Reference, State II, State II, and State IV are 0.89 (SD 0.30), 3.83 (SD 1.32), 5.19 (SD 1.78) and 1.6 (SD 1.05) ton/ac/year, respectively (Figure 5). In Table 2, the 50, 80, and 95 percentiles for yearly soil loss were determined [β1= 0.87, β2=1.172 and β3=1.42 (ton/ha/year)] from the Reference plant community soil from 300 year of simulated precipitation from Johnson City, Texas (Table 2). The soil loss (tons/ac/year) by return period runoff by decade for each state are presented in Table 3.

Table 2. Soil loss severity class for Deep Redlands ecological site.

Range of Annual Soil loss (ton/ac/year)		Probability	Reference (HPC)	State II	State III	State IV
Low	X < 0.87	0.50 ≤	0.50	0.00	0.00	0.26
Medium	0.87 =< X < 1.17	0.80 ≤	0.30	0.00	0.00	0.28
High	1.17 =< X < 1.42	0.95 ≤	0.15	0.01	0.00	0.20
Very High	X >= 1.42	1.00 ≤	0.05	0.99	1.00	0.27

Figure 10 represents the probability of occurrence of soil loss for any year for the Low, Medium, High, or Very High categories to occur based on soli loss of the Reference state. The baseline scenario for this analysis is the Reference state.

Table 3. Frequency analysis by annual soil loss (ton/ac/year) by return period for Deep Redlands 29-35 inch ecological site by decade.

Return Period (years)	Reference (HPC)	State II	State III	State IV
2	0.15	0.59	0.80	1.88
5	0.22	0.89	1.20	0.28
10	0.27	1.06	1.42	0.34
20	0.32	1.28	1.73	0.40
30	0.35	1.38	1.86	0.44
40	0.37	1.47	1.99	0.47
50	0.39	1.53	2.07	0.49
60	0.40	1.55	2.10	0.50
70	0.40	1.57	2.13	0.50
80	0.40	1.60	2.17	0.51
90	0.41	1.62	2.20	0.52
100	0.42	1.65	2.23	0.42

For example, in every baseline case it is considered that 5% (in purple) of the years for the baseline scenario are categorized as “Very High”. The purple parts of the bars in the other scenarios represent the fraction of years for those scenarios that also fall in that same range of yearly soil losses as defined by the greatest 5% of the baseline condition. For this example the baseline is the Reference plant community (State I).

Note that the output is reporting soil losses and not sediment yields, which will be different. Soil loss is defined as soil detached and moved by raindrop splash, sheetflow, and concentrated flow. Sediment yield is calculated as the amount of soil that is detached and transported off the slope. For uniform slopes all soil that is detached is considered mobile and transported off site. Therefore, soil loss and sediment are equal. When using convex or concave slope shapes the slope gradient is reduced at the toe of the slope allowing for potential deposition to occur. Therefore, sediment yield will be less than soil loss on convex or concaved slopes. Deposition can be calculated as the difference between soil loss and sediment yield.

Interpretive examples from Table 2, 3 and Figure 13 indicate:

- For Reference plant community (State I), there is a 50% annual probability of soil loss being equal to or lower than 0.87 tons/ac/year; likewise, there is a 5% chance of Very High erosion ≥ 1.42 tons/ac/year soil loss for any given year. The mean annual soil loss for the Reference state (0.89 tons/ha/year) falls in the moderate soil loss severity class.

- For State II, there is 0% chance that erosion will be in the low risk category. There is a 99% chance of Very High erosion being ≥ 1.42 tons/ac/year for any given year. The mean annual soil loss of State II (3.82 ton/ac/year) falls in the Very High soil loss severity class. This places this sites at risk of being unstainable and if no management actions are implemented the site will eventually cross an abiotic threshold that will result in permanent loss of productivity.

- For State III invaded state, there is a 0% chance that erosion will be Low (<0.87 tons/ac/year); likewise there is a 100% chance of Very High erosion ≥ 1.42 tons/ac/year. The mean annual soil loss of the Shrub invaded state (5.19 tons/ac/year) falls in the Very High soil loss severity class. This places this sites at risk of being unstainable and mostly likely if no management actions are implemented eventually crossing a biological threshold that will result in permanent loss of productivity.

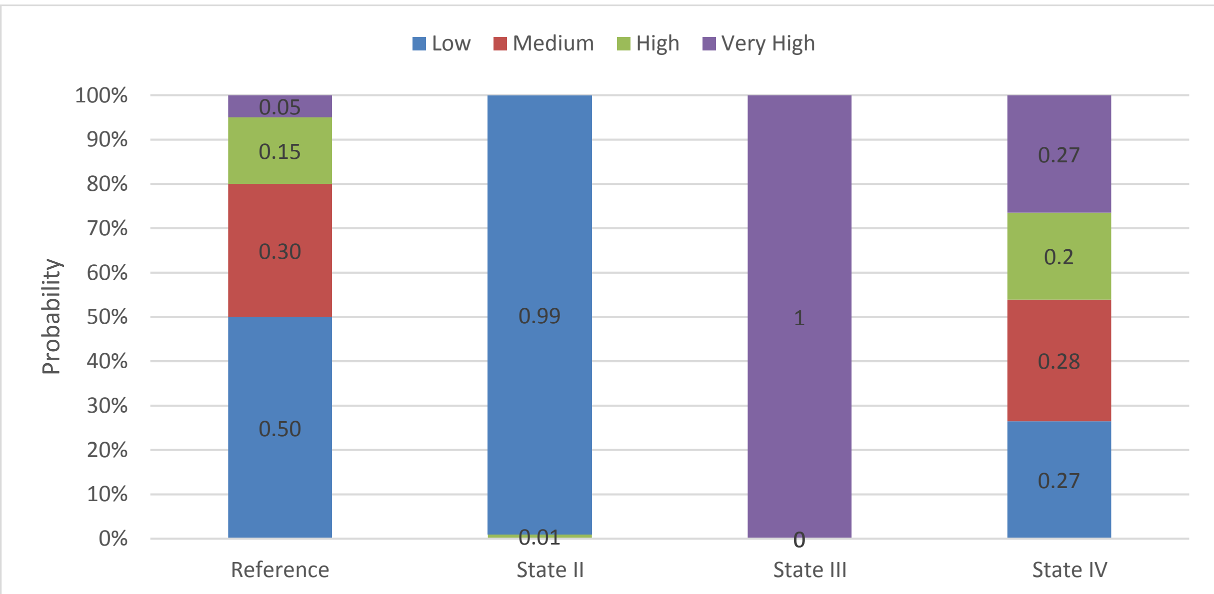


Figure 13. Probability of occurrence for yearly soil loss for all scenarios using erosion classes of Low (50%), Mediun (80%), High (95%), and Very High (>95%).

- For State IV, pasture state, there is a 26% chance that erosion will be Low <0.87 tons/ac/year. There is a 27% chance of Very High erosion ≥ 142 tons/ac/year soil loss for any given year. The mean annual soil loss of the pasture state (1.16 tons/ac/year), falls in the moderate soil loss severity class. Thus the pasture site would be evaluated as at risk in comparison to the Reference site. RHEM results indicate that there is a relatively uniform distribution of soil loss across all risk categories relative to the Reference state for this ecological site. It would be prudent to invest in proactive conservation to prevent this site from becoming unsustainable.

8 Summary

Analysis of the RHEM simulation runs on the Deep Redlands 29-35 inch ecological site provides a basis for interpreting the impacts of vegetative canopy cover, surface ground cover, and topography on dominant processes in controlling infiltration and runoff as well as sediment detachment, transport and deposition in overland flow at each state. Our results suggest that RHEM can predict runoff and erosion as a function of vegetation structure and behavior of different plant community phases and amount of cover for the different states.

The difference in estimated annual soil erosion rate between the State II when woody plant begin to encroach and the Reference state is 2.94 tons/ac/year. When the site is fully encroached by woody plants the difference in estimated soil loss is 4.30 tons/ac/year. The explanation for the difference in soil erosion rates can be related to the additional foliar canopy and ground cover protection present in the Reference state as shown in Table 1. The explanation for the difference in runoff and erosion between the Reference state and State II and State III the shrub encroached states can be related to differences in cover but also to the increased water storage associated with native bunchgrasses due to the formation of litter dams, intact soil A horizon, greater soil surface horizon depth, and greater soil organic matter content. The grass cover and litter on the Reference state cause water to pond behind small litter and debris dams as it moves downslope, which has the effect of backing up water and allowing more time for infiltration, increased tortuosity of the flow paths that results in reduced overland flow velocities as the water moves around the bunchgrasses.

The results from the risk assessment suggest that a shift from the Very High to Medium or low soil erosion severity class may be possible if management practices are implemented to remove woody plants, enhance mid-grasses reproduction, and promote litter production from State II to State I. This will reduce runoff and soil erosion. In contrast, based on the State and Transition Model and depending how long State III has been established the site may have lost so much soil it may have crossed a threshold and now have a different, less productive, potential plant community even if conservation is applied. These states are within the Very High soil erosion severity class and the probability of bringing them back to the Reference state maybe impossible due to loss of surface soil horizons that control water holding capacity and nutrient availability.