Texas Section Society for Range Management

Position Statement Number 2

RANGELAND WATERSHED MANAGEMENT: THE POTENTIAL OF BRUSH MANAGEMENT TO ENHANCE WATER YIELD FROM RANGELANDS

July 7, 2017

SUMMARY

Meeting the increased needs for water throughout the state of Texas is a critically important aspect of natural resource management in the 21st century. All Texans have a stake in the need for a successful outcome of these efforts.

The removal of woody species (brush control) has the potential for substantially increasing water yield from some, but not all, rangelands in Texas. Water yield is the result of the interactions of multiple watershed processes and conditions. The responses of these processes vary across a landscape and many of the conditions vary both spatially and temporally. Consequently, no definitive statement can be scientifically justified as to whether or not brush control will universally result in enhanced water yield. Instead, watershed responses to brush control are site-specific and are likely to change over time as the site-specific conditions change.

It is extremely difficult, if not impossible, to assign a single scenario that fits all of Texas relative to water yield and conservation across the State. The following discussion 'fleshes out' the influence of brush management to enhance water yield from rangelands.

THE ISSUE

Water yield from Texas rangelands is a very complex issue. Very often the citizens of Texas want to suggest that the State could increase its water yield, decrease runoff, and increase soil and underground water storage by controlling the noxious brush and weeds that occur on our rangelands. The issue is much more complex than any one factor that influences water yield and conservation from Texas rangelands.

Some of the factors that must be taken into account when considering increasing water yield and conservation from Texas rangelands are as follows:

- History of Texas Water Law (ownership of water, right to capture, etc.);
- Site specific characteristics, including;
  - Geographical location (east Texas vs. west Texas, vs. south Texas vs. Panhandle, etc.);
  - Terrain, slope, soils (type, depth, surface characteristics, amount of organic carbon, compaction from improper grazing management), and geology (including especially, but not limited to, Karst geological formation), parent material;
  - Plant community (forest, grassland [type], shrubland, woodlands, desert, brush infested rangeland);
  - Dominant vegetation (tall, mid-grass, short grass, forbs [weeds], trees, or shrubs);
  - Canopy cover of woody vegetation;
  - Vegetative cover (species of grasses, sod grasses, bunchgrasses, bare ground, litter [or duff]);
  - Depth to water table (water stored in profile or percolates to water table);
  - Depth to hard pan or clay subsoil;
  - Species of non-desirable plants inhabiting specific sites, densities of non-desirable species, physical size of species;
  - Desirable species (that also ‘use’ large quantities of water) growing in association with of non-desirable species (e.g., switchgrass);
- Cultural practices (e.g. method of brush control [mechanical vs. chemical], reseeding, surface disturbance [ripping, grubbing, etc.]);
- Grazing management practices;

Fire suppression;

Degree of rangeland degradation vs. amount of rangeland in good to excellent condition;

Precipitation pattern and cycle (amount and form of precipitation, time precipitation occurs, intensity and duration of storm event, runoff, interception loss by overstory vegetation);

Infiltration capability of soil (rate, wet soil vs. dry soil at time of precipitation event, organic matter in surface soil); and

Evaporation: transpiration relationships to vegetation type;

Effect of precipitation in wet years vs. dry years; and;

Size of watershed and location of precipitation event within the watershed.

BASIC CONCEPTS

The basis for any evaluation of the potential for brush control to enhance water yields from rangelands is the fundamental watershed hydrologic cycle. This hydrologic cycle can be summarized by separating it into ten basic components: 1) precipitation, 2) interception, 3) surface runoff, 4) evaporation, 5) infiltration, 6) soil storage, 7) transpiration, 8) lateral movement, 9) recharge, and 10) groundwater uptake. These ten components are common to all watersheds, although specifics vary widely across a landscape and among locations.

The primary water input to rangeland watersheds is *precipitation*. The water received at a site during each precipitation event falls on various surfaces: plant canopies, surface litter, bare ground, rocks and other surface features, standing water (if present). The amount of water that remains on the plant canopies, surface litter, and rocks and other surface features is termed *interception*. This amount does not include the amount of water that runs off these surfaces onto the ground, but only the amount that remains on the surfaces at the end of the precipitation event. This interception water is then evaporated directly back into the atmosphere. The proportion of any precipitation event that is returned directly to the atmosphere because of interception varies by the type of precipitation (e.g., rain or snow), amount and intensity of the precipitation event, and amount and surface structure of the intercepting surface. Of particular importance is the amount and type of vegetation. Numerous studies have reported interception rates for different types of vegetation and these commonly range from 8-30%, with some values as high as 40-50%. Even at the same location, canopy interception can vary substantially depending on the vegetation mosaic. In the Edwards Plateau for example, shortgrass canopies may intercept 8% of annual precipitation, midgrass canopies 18%, and live oak mottes 25% (Thurow et al. 1987).

Precipitation that is not retained on other surfaces reaches the soil surface. Two pathways are then open to the movement of this water: *infiltration* into the soil and *surface runoff*. The rate at which water can infiltrate into the soil is dependent on a number of factors, especially the texture and bulk density of the surface soil, the presence of cracks in the soil surface, and root channels and animal burrows. Infiltration rates are typically high on sands and sandy loams and low on clays (unless surface cracks are present). If the rate of precipitation at the soil surface exceeds the infiltration rate, the excess water moves downslope as surface runoff. As surface runoff moves downslope, some may enter downslope soils while the remainder continues as surface runoff. The proportion that enters the soil is inversely related to the velocity of the water moving downslope. Obstacles at the surface (e.g, rocks, tree trunks, basal crowns of grasses, surface litter) that slow the water velocity result in increased infiltration. Consequently, changes in surface conditions (i.e., surface roughness) over time will result in shifts in surface runoff amounts.

Two examples illustrate the effects of different soils and different vegetation on surface runoff. In a study in South Texas, surface runoff was 9.6% of precipitation on bare soil, 2.6% on surfaces supporting shortgrasses, and 1.9% on sites supporting mesquite-shrub clusters (Weltz and Blackburn 1995). On a site in the Coastal Bend of Texas, surface runoff was 4.1% on sand prairie, compared to 1.1% on adjacent mesquite shrubland (Ockerman 2002). Precipitation rate and soil moisture conditions prior to the precipitation event also affect surface runoff. A 119-mm rainfall event under previously dry conditions resulted in 2.1% surface runoff on a sandy loam grassland site on the Texas Coast, while a similar rainfall event (106 mm) during a wet period produced 5.4% surface runoff at the same site (Ockerman 2002).

As vegetation changes, either from natural succession or from human-induced changes, there is a corresponding effect on infiltration and hence on surface runoff. On a site in the Edwards Plateau, infiltration rate was 199 mm/hour under live oak mottes, 162 mm/hour on midgrass sites, and 109 mm/hour on shortgrass sites (Thurow et al. 1987). Similarly, on clay loam soils in the Rolling Plains of Texas, infiltration rate was 103 mm/hour under mesquite, 66 mm/hour on midgrass sites, and 42 mm/hour on shortgrass sites (Brock et al. 1982).

Water that enters the soil moves downward through the soil profile. As the wetting front moves downward, some water remains in each soil layer and some continues to move downward. The amount that remains in a layer is known as the field capacity of that layer. It is the amount that can be held against the pull of gravity and the actual amount is a function of the texture and organic matter content of that layer. Any infiltrated water in excess of the field capacity drains (percolates) to the layers below until either all the infiltrated water is held or that in excess of the field capacity of the entire soil and substrate layers moves into groundwater. The total amount of water held in the soil at any particular time is the *soil storage* amount, and most of this is available to plants. *Recharge* water is the amount, if any, that is in excess of the soil storage capacity. Most soils contain layers of different soil textures and different soil densities, and therefore have variable percolation rates. When a more permeable layer overlays a less permeable layer, water will move more slowly into the less permeable layer and the more permeable layer may temporarily become saturated. If so, *lateral movement* of soil water can occur along a subsurface slope. This can also happen on a more permanent basis when the confining layer is relatively impervious (e.g., indurated caliche, dense clay layer), in which case the laterally moving water may emerge as a spring or seep.

Transpiration refers to water movement through plants along a water potential gradient, with the water eventually evaporating through stomatal openings. In many studies, transpiration is combined with evaporation (including interception and evaporation from the soil surface) and termed evapotranspiration (ET). Although this is a very convenient combination, the dynamics of the two components (E and T) can be very different. When plant cover is low, the contribution of soil evaporation (E) to ET is high (80-90%), whereas when plant cover is high, the contribution of transpiration (T) to ET is high (60-70%) (e.g., Mata-Gonzalez et al. 2014).

The amount of water transpired at a particular location is not constant. It varies as the supply of water, amount of vegetation, plant species, vegetation condition (e.g., dormant, new growth or regrowth, mature), and air temperature vary. Different species have different water-use efficiencies (WUE = amount of water required to produce or support one unit of plant biomass) and different potential productivities. Therefore, a stand of shortgrasses will not transpire the same amount of water as a stand of midgrasses or woody species. For example, in a comparative study over a three-year period (McGinnes and Arnold 1939) the shortgrass curly-mesquite (*Hilaria belangeri*) had a WUE of 500 (500 g of water to produce 1 g of aboveground dry biomass), compared to a WUE of 870 for the midgrass sideoats grama (*Bouteloua curtipendula*) and 2400 for the shrub catclaw (*Acacia greggii*). Annual production of the shortgrass will also be less than production by the midgrass. Assuming an annual aboveground production of 250 g/m^2 for curly-mesquite and 400 g/m^2 for sideoats, the resulting water use values would be 125 kg/m^2 for curly-mesquite and 348 kg/m^2 for sideoats, provided those amounts of water are available to the grasses.

Plant species also have different root architectures and therefore have varying access to soil moisture. Both maximum rooting depth and distribution of roots by depth are root architecture aspects that are important in determining effect of vegetation change on water use. Trees tend to have deeper roots than shrubs and shrubs generally have deeper roots than grasses. Most grasses have maximum rooting depths less than 3 m (10 feet) and maximum rooting depths of less than 2 m (6 feet) are most common. In contrast, many woody species root to 5-20 m (16-65 feet). As trees and shrubs increase on a site, the potential depth to which the vegetation can access soil water increases. As trees and shrubs are removed from a site, the potential depth to which the vegetation can access soil water decreases. Grasses not only have shallower root systems than most woody species but grasses also tend to have more of their roots concentrated in the upper portion of their rooting zone. Perennial grasses typically have 80-90% of their root biomass in the upper 15 cm (6 inches) of the soil, whereas tree species typically have less than 50% of their roots at that depth.

The depth to which a particular soil stores water is dependent on the amount of precipitation that infiltrates, the amount of soil moisture present in the soil prior to the precipitation event, and the amount of soil moisture extracted by the vegetation. Soil storage capacity (field capacity) of most soils and soil substrates is about 10-20% by volume. A 3-m soil depth (maximum rooting depth of most grasses; Canadell et al. 1996; Schenk and Jackson 2002) might have a maximum water storage capacity of about 45 cm (18 inches), assuming an average field capacity of 15%. The depth that water actually percolates to in a soil depends on, in part, the balance between 1) the amount and frequency of the infiltration events and 2) the rate at which the vegetation extracts the stored water (Cline et al. 1977; Cable 1980; Ehleringer et al. 1991; Weltz and Blackburn 1995). In mesic regions, there are periods when there is sufficient infiltration to move water to depths greater than the maximum rooting depth of grasses. This is especially true during the winter when most of the grasses are dormant. In arid and semiarid regions, these deep-percolation events occur less frequently, most often in particularly wet years (Yoder and Nowak 1999; Schwinning and Sala 2004; Seyfried et al. 2005). Even in years with average precipitation, soil water often percolates to deeper soil depths in arid and semiarid regions when the substrate materials are rocky and along cracks and root channels.

Soil water moving below a 3-m soil depth is largely protected from uptake by grasses. Subsequent heavy rainfall events or wet winters add to this deep soil storage, allowing the soil water to move deeper. Over time, field capacity is reached in these deep layers and then subsequent deep percolation events move water into the water table, thereby resulting in groundwater *recharge*, or the excess water moves laterally and emerges in seeps or springs. If the vegetation remains dominated by grasses, this process of deep percolation is not dependent on the deep layers being recharged each year because only the upper 2-3 m (6-10 feet) of the soil is potentially dewatered (Montana et al. 1995; Weltz and Blackburn 1995; Scott et al. 2000; Groom 2004). Therefore, only that upper zone requires replenishment on a regular basis. However, if the vegetation is composed of woody species, their greater rooting depths allows for the dewatering of the deeper layers. This largely eliminates groundwater recharge and spring flows except under very mesic conditions. In addition to largely eliminating recharge, deep-rooted woody species can also directly utilize *groundwater* if it is within their maximum rooting depth, thereby increasing the rate of groundwater depletion. For example, ashe juniper (*Juniperus ashei*) has a maximum rooting depth of at least 8 m (26 feet) and live oak (*Quercus virginiana*) and mesquite (*Prosopis glandulosa*) have maximum depths of over 20 m (65 feet).

POTENTIAL FOR ENHANCED WATER YIELD

There are some sites where brush control is not likely to result in enhanced water yield. These include areas where 1) the brush stands are sparse, 2) the brush species are relatively shallow-rooted, or at least not much deeper-rooted than the grasses that might replace them following brush control, 3) there are relatively impervious layers in the soil at shallow depths, 4) heavy precipitation events or wet periods are too infrequent to allow for deep percolation, and 5) the brush removal pattern allows substantial amounts of woody species to remain on the landscape, thereby allowing for rapid lateral expansion of the root systems of the remaining woody plants. In addition, thick fine-textured soils with high soil water storage capacity and slow percolation rates may result in recharge of the overlying soil profile following brush control occurring at such a slow rate as to be an impractical means of enhancing water yield.

However, in many other areas, brush control does provide a means for potential water enhancement. This is particularly true if the measurement of enhanced water yield is not restricted to surface runoff. In many cases, the replacement of woody species by grasses may actually reduce surface runoff because the grass stands tend to reduce runoff velocity, thereby allowing more water to infiltrate. Unless the other components of the water balance are considered, incorrect conclusions are likely to be reached at to the potential for brush control to enhance water yield from rangeland watersheds. In a ten-year study of the effects of brush control on water yields in the southeastern Edwards Plateau (Banta and Slattery 2011), removal of Ashe juniper resulted in no substantial increase in surface runoff (2% of annual rainfall) but ET decreased by 13% (85% of annual rainfall on the untreated area, 74% on the treated area) which resulted in an 85% increase in potential groundwater recharge (13% of annual rainfall on the untreated area, 24% on the treated area).

Spatial heterogeneity across a watershed is also an important factor influencing the effectiveness of brush control as a water enhancement technique. In support of the development of the watershed protection plan for the Upper Llano River watershed in the western Edwards Plateau (Broad et al. 2016), ecological simulation modeling was used to estimate potential enhanced water yield following brush control. Although these were modeling results and not field studies, the results were similar to those from the USGS field study (Banta and Slattery 2011). For example, ET on the untreated areas in the modeling study averaged 86% of annual rainfall compared to 85% on the USGS study. The modeling results indicated that of the 49 subwatersheds (11,000-40,000 acres each), brush control would be expected to increase on 12 and decrease on 37, but potential direct water enhancement (runoff + recharge – groundwater use) increased on 31 subwatersheds and decreased on 18. These results support conclusions from other studies that emphasize the need to prioritize areas subjected to brush control if a goal is enhancement of water yield (Fish and Rainwater 2007; McLendon 2013).

CONCLUSION

Removal of woody vegetation (brush control) can be an effective means of enhancing water yield from rangeland watersheds, but the degree to which it can be effective, or if it can be effective at all, is dependent on a number of site-specific conditions. In general, its effectiveness increases as 1) density of deep-rooted woody species increases, 2) soil conditions that favor deep percolation of infiltration water increase, 3) high precipitation events become more frequent, and 4) depth to groundwater decreases. Post-brush control management can also become an important factor, especially as to what type of vegetation replaces the removed woody species. Replacement of the brush by shallower-rooted shortgrasses will likely result in a greater increase in water yield than will replacement by deeper-rooted midgrasses.

Also of primary importance in the determination of enhanced water yield from brush control is how the potential water yield is calculated. If only surface runoff is included, there is less likely to be a significant enhancement from brush control. However, if all components of the water budget are included in the calculations, it is more likely that brush control will result in enhancement of water yield.

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