



How Eastern Redcedar Encroachment Affects the Water Cycle of Oklahoma Rangelands

of soil disturbance and compaction associated with redcedar removal operations on infiltration capacity, overland flow and erosion, and future site productivity need proper study.

Current Studies in Oklahoma on the Effects of Redcedar on Water Resources

Oklahoma State University and the USGS Oklahoma Water Science Center are conducting a field-based, multiple-year collaborative research project to understand the effects of redcedar encroachment in the mesic grassland in the Cross Timber Experimental Range (CTER) near Stillwater. This work is supported by USGS/National Institutes of Water Research through its 104G Competitive Program (Grant G09AP00146). In this project, three grassland watersheds and three redcedar woodland watersheds with similar management history including moderate grazing were instrumented to quantify individual components of the water budget. Soil water storage, canopy interception, transpiration, and streamflow will be directly quantified for each watershed to understand the effect of encroachment in a mesic grassland.

Implications

1. Act early - While the effects of redcedar on watershed water budgets are likely to be large when tree canopy cover is high, treating sites with severe infestation is economically impractical (see Fact Sheet NREM-2876).
2. Not all regions will respond equally to redcedar encroachment and redcedar removal. Although streamflow might increase more following redcedar removal in eastern Oklahoma, a small increase in streamflow in western Oklahoma could be equally important both economically and environmentally.
3. Research has shown the linkage between removal of woody plants and increased water yield is stronger where water can move rapidly through the soil or parent materials to recharge springs or shallow aquifers.
4. If increased streamflow and groundwater recharge are a management objective, removal should be focused on those sites that have the greatest potential to increase streamflow and groundwater recharge. The removal activities must also cover an area large enough to produce a "useable" increase in streamflow and groundwater recharge. Besides the potential magnitude of increase in streamflow and groundwater recharge, the local water demand, ecological and economic assessments are critical for consideration to prioritize management plans.

These generalizations should only be used in guiding water resources management concerning redcedar encroachment in Oklahoma in principle. Site-specific research is timely needed in order to validate such deduction on the effects of redcedar encroachment on the water cycle across Oklahoma rangelands.

Glossary

Baseflow — The sustained flow between storm events in a stream that is not derived from surface run-off. Baseflow in perennial streams is derived from the release of groundwater from aquifers.

Evapotranspiration (ET) — Evaporation water losses from soils, plant surfaces, and water bodies, together with transpiration water losses through plant leaves, are considered collectively as evapotranspiration (ET).

Field Capacity — The maximum amount of water a given soil can retain against the force of gravity.

Groundwater Flow — The part of the discharge from a watershed or drainage basin that occurs from the release of groundwater.

Infiltration — The flow of water into the soil through pores or small openings.

Infiltration Rate — Rate of downward movement or flow of water from the surface into the soil.

Infiltration Capacity — the maximum rate at which water can infiltrate into the soil.

Overland Flow — (1) Surface runoff. (2) The flow of rainwater or snowmelt over the land surface towards a stream.

Percolation — The downward movement of water within a soil toward the water table without a definite channel.

Streamflow — The process of water discharging from watersheds through streams.

Subsurface Flow — Water which infiltrates the soil surface and moves laterally through the upper soil layers until it enters a channel. Subsurface flow is usually initiated by the formation of temporary or perched water tables in the soil.

Water Budget — An accounting of the inflows to, the outflows from, and the storage changes of water in a hydrologic unit or system.

Water Cycle — The cycle of evaporation and condensation that controls the distribution of the earth's water as it evaporates from bodies of water, condenses, precipitates, and returns to those bodies of water.

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The rapidly increasing acreage encroached by eastern redcedar (*Juniperus virginiana*) has recently attracted the attention of land owners, natural resource managers, water managers and policy makers because of the potential effect on streamflow and water supply. Numerous estimates of the amount of water used by redcedar trees have appeared in the media and other sources. From these numbers, streamflow reduction by redcedar encroachment or increases in streamflow following redcedar removal have been projected. However, simple extrapolations ignore the complex interactions among processes in the water budget and differences in watershed topography, geology, climate and soils that exist across Oklahoma. This fact sheet provides basic concepts about the linkages among climate, vegetation, and hydrological processes necessary to understand and evaluate the potential of redcedar encroachment to influence the water budget on Oklahoma rangelands.

Both redcedar and Ashe juniper (*J. ashei*) are present in Oklahoma rangeland. Because both species have similar canopy structure and other biological characteristics, we will focus on redcedar for simplicity.

The Water Cycle in Rangeland Watersheds

Water enters watersheds as precipitation, primarily rainfall in Oklahoma. A portion of the precipitation is captured by the vegetative canopy (redcedar or grass) and the litter layer and evaporates back into the atmosphere. The evaporative loss of water from the vegetative canopy or litter is called interception. The remaining water will either infiltrate into the soil or produce



Figure 1. Encroachment of redcedar in a mesic grassland at OSU's Cross Timber Experimental Range near Stillwater.

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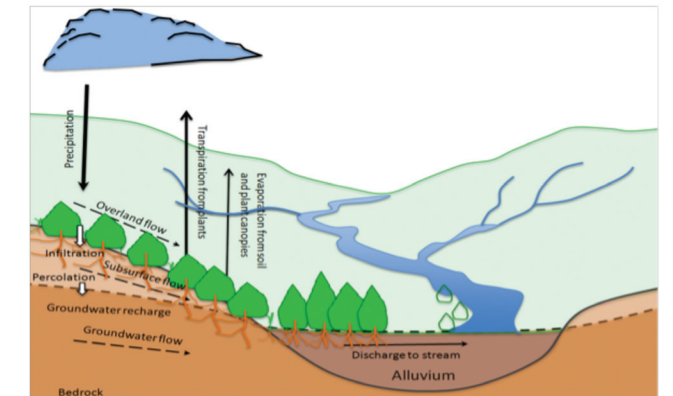


Figure 2. Illustration of the rangeland water budget with redcedar encroachment on upland and riparian area.

overland flow. For sites with deep soil and good infiltration, a large portion of percolated water will replenish soil water. Once soil water content is above field capacity, additional soil water inputs will produce subsurface flow and/or drain by gravity to percolate into deep soil and ultimately recharge groundwater. Overland flow, subsurface flow and a portion of groundwater flow will discharge to streams at different rates and times. The process of water discharging from watersheds through streams is called streamflow (Figure 2). Streamflow is the sum of water produced by surface, subsurface and groundwater flows. Water held in the soil can evaporate from the soil surface as soil evaporation or be extracted by plant roots as transpiration.

Water entering, stored and leaving watersheds by these processes must balance. A simple expression of this water balance is given by:

$$P = E + T + \Delta S + Q$$

Where:

P = Precipitation; E = Evaporation; T = Transpiration; ΔS = Change in the amount of water stored in soil and groundwater; and Q = Streamflow.

The amount of water available annually for use (water supply) is limited by available streamflow and groundwater storage. Groundwater storage is increased by recharge from the soil and rock above the water table. Additions and losses of water from soil water and groundwater storage balance over periods of years. As a result, water balance tells us that streamflow and groundwater recharge are primarily limited by water loss from evaporation and transpiration. The sum of evaporation and transpiration is called Evapotranspiration (ET). All other things being equal, replacing vegetation on a watershed that has a

low rate of ET with vegetation that has a high rate of ET, will accordingly, result in a decrease in streamflow or groundwater recharge or both. Numerous watershed experiments conducted around the world have confirmed this result. However, the magnitude and persistence of the change is highly variable.

If redcedar encroachment increases ET, it will reduce streamflow and water supply. Potential increases in ET could occur because, 1) redcedar might transpire more soil water than herbaceous plants because it is an evergreen plant that potentially transpires year-round and possesses a more extensive and deeper root system than herbaceous plants that can access a greater volume of soil water or perhaps the water table; and 2) evaporation might increase because rainfall intercepted by the redcedar tree crowns is greater than rainfall intercepted by herbaceous plants.

The extent to which redcedar encroachment might increase ET and reduce streamflow and groundwater recharge depends on numerous factors including amount of annual and seasonal precipitation, topography, soil type, soil depth, and extent of redcedar cover. Our understanding of the effects of woody plant encroachment on the rangeland water budget in Oklahoma is based primarily on research conducted in other regions such as the Edwards Plateau in Texas. However, using the water balance approach and applying knowledge of hydrologic processes, we can deduce how redcedar encroachment might affect streamflow and groundwater recharge in Oklahoma rangelands (Table 1).

How Changing from Grass to Redcedar Affects Streamflow and Groundwater Recharge

In general, the percentage of precipitation lost back to the atmosphere (also called the ET/P ratio) from watersheds

Table 1. Factors that influence watershed hydrologic processes and water budget as a result of redcedar encroachment.

<i>Water budget component</i>	<i>Effect of redcedar encroachment</i>	<i>Probable impact on component</i>
Evaporation (E)	Leaf area increases and is present year-round Grass cover decreases Litter cover increases/or decreases Bare soil decrease/or increase	increases
Transpiration (T)	Increase in total leaf area (combining redcedar and grass leaf areas) Year-round transpiration by redcedar	increases
Soil water and groundwater storage (ΔS)	Deeper rooting system of redcedar captures more water	decreases
Groundwater recharge	Deeper rooting system of redcedar captures more water	decreases
Streamflow (Q)		
Overland flow	Herbaceous cover decreases Litter cover, and infiltration rate likely reduced on semiarid sites Litter cover, and infiltration rate likely increase on mesic sites	increase on semiarid sites decrease on mesic sites
Subsurface flow	Increase in infiltration rate on mesic site Increase in macropores	increases
Baseflow	Deeper rooting system Access to groundwater on alluvial soils	decreases

is greater with woody vegetation than it is for grass at a given site and climate (Figure 3). The difference between woody vegetation and the grass ET/P ratios is a good estimate of the potential decrease in streamflow or groundwater recharge that could occur following redcedar encroachment. Conversely, the

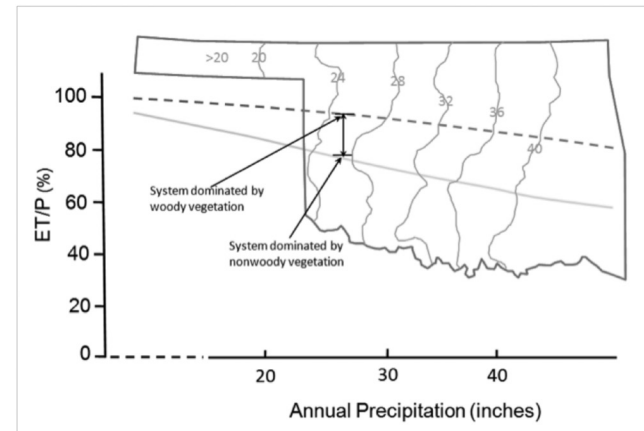


Figure 3. The general relationship between ET/P and annual precipitation developed for woody and non-woody (grass) plants from over 250 watersheds worldwide superimposed on the Oklahoma precipitation map. The two lines represent the percent of precipitation evaporated (also called the ET/P ratio) from watersheds for woody vegetation and grass cover at a given site and climate. The difference between the woody vegetation and grass lines represents a potential increase in ET that may occur following redcedar encroachment. A corresponding loss in streamflow and groundwater recharge may occur as a result if ET is higher.

difference in ET/P ratios also is a good estimate of the potential increase in streamflow and groundwater recharge following redcedar removal. The actual decrease in streamflow and groundwater recharge is also a function of site characteristics and annual rainfall. The ET/P ratios of grass and woody vegetation are almost equal in arid (P is less than 14 inches) lands of Oklahoma. In other words, evaporative demand is so high and rainfall so low in arid lands, it may make little difference for streamflow and groundwater recharge no matter what type of vegetation is present. On semi-arid lands of Oklahoma (P = 14 inches to 30 inches) the difference between the grass and woody vegetation ET/P ratios is greater than in arid lands, but not as great as in semi-humid (P is greater than 30 inches) lands (Figure 3). Therefore, the magnitude of the potential reduction in streamflow and groundwater recharge due to redcedar encroachment is greater on wetter regions of Oklahoma than in semi-arid regions.

In a relative sense, a small increase in ET on semi-arid lands resulting from redcedar encroachment represents a large percentage decrease in streamflow or groundwater recharge. For example, in western Oklahoma (area pointed to by arrows in Figure 3) on land that receives 26 inches average annual precipitation, a 7 percent increase in the ET/P (about 1/2 the difference between woody and grass ET/P lines) translates to a decrease of 1.2 inches in streamflow. This is equal to a 60 percent reduction in the current average annual streamflow (2 inches).

It should be noted the differences between ET/P between woody vegetation and grass shown in Figure 3 represent a maximum. In reality, it is likely the magnitude of increased ET resulting from redcedar encroachment will translate into a much lower magnitude decrease in streamflow and groundwater recharge due to other complicating factors.

Knowledge Limitations, Hydrologic Interactions, Climate and Other Complicating Factors

The simple water balance approach and the ET/P ratios discussed above provide a general concept of how much streamflow and groundwater recharge may decrease following redcedar encroachment or conversely, the increase in streamflow and groundwater recharge following redcedar removal. However, there are complicating factors that are not accounted for in these approaches that determine the magnitude and persistence of the effects of redcedar encroachment on streamflow and groundwater recharge for a particular watershed.

Extent and pattern of redcedar encroachment

Redcedar encroachment is patchy rather than spatially uniform across the landscape. This complicates quantifying the effect of redcedar on streamflow and groundwater recharge because watersheds may be partially encroached by redcedar with mixtures of different ages and canopy structures. The greatest effect of encroachment on streamflow and groundwater recharge would likely be in watersheds that are 100 percent covered by redcedar. This may occur on small watersheds (a few acres), but not throughout river basins.

Land Use: Past and current

The influence of redcedar encroachment on streamflow might be obscured by changes in land use and land cover. In Oklahoma, significant land-use change, especially cropland set-aside from the Conservation Reserve Program, concomitant to redcedar encroachment also might influence streamflow and groundwater recharge either positively or negatively.

Streamflow from watersheds that were highly degraded in the past may be dominated by overland flow. Overland flow

generates high quantities of streamflow, but at the expense of plant available soil water and groundwater recharge. As these watersheds recover, both redcedar and grass will improve infiltration capacity of soil, resulting in an increase in ET as more water enters the soil where it can be transpired. This may be a desirable outcome if the goal is to increase groundwater recharge in watersheds that have an important aquifer. Old terrace systems on go-back lands in Oklahoma can affect overland and subsurface flow and further complicate the effects of redcedar encroachment.

Climate

If redcedar encroachment has influenced Oklahoma's water resources, it has gone largely unnoticed. A complicating factor is that precipitation in the past 20 years to 30 years, which coincided with the rapid expansion of redcedar in Oklahoma rangeland, has for most years been above normal. The effect of redcedar encroachment may become more apparent and important under average and below-average precipitation that characterize projected climatic scenarios for the next 20 years to 100 years.

Vegetation characteristics and physiology

It might seem logical that redcedar is a water waster and uses (transpires) more water than grass (during the same time period). We have no supporting data indicating redcedar has a higher transpiration rate during the growing season than other tree species or grass. In fact, some preliminary studies showed that leaf level transpiration rate is much lower in redcedar than grass species. Actual ET is largely a function of available energy (solar), leaf area, and soil water. During periods of high evaporative demand and low soil water content both redcedar and grass will transpire at a low rate. Such conditions commonly occur across Oklahoma during the summer.

Soils, geology and topography

Soil affects many of the hydrologic processes that control the rates, quantities and timing of streamflow and groundwater recharge from watersheds. Soil texture determines in part the amount of plant-available water per unit depth available for transpiration. It also determines rates of infiltration and percolation. Coarse texture soils have low plant available water capacity per unit depth compared to fine texture soils.

Soil depth determines in part the total amount of water that is available for transpiration. In shallow soils, the roots of both grass and redcedar may occupy the entire soil profile. As a result, soils dry out quickly during the growing season and there may be little or no difference between water use by redcedar and grass. Some studies suggest the conversion of Ashe Juniper encroached watersheds in the Edwards Plateau of south-central Texas resulted in little or no increase in streamflow. In deep soils, redcedar may use more water if the deep root system can reach and utilize water that the shallow root system of some grasses cannot reach, but this might depend on grass species.

In situations where the water table is near the surface such as along the edges of wetland, ponds and streams, redcedar (and other trees) may use considerable quantities of water. The extensive root system of redcedar will be able to tap into shallow water tables that shallow-rooted grasses do not reach.

Lack of water budget and removal experiments at the watershed scale

Finally, perhaps our greatest limitation in understanding the effects of redcedar encroachment on the water budget and supply is a lack of data from water budget and removal experiments at the watershed scale in Oklahoma. The impact