rangeland issues

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WATER: A RENEWABLE RESOURCE FOR LIFE

Good hydrological management is good ranch management

RH™

RANGELAND ISSUES

A Publication Helping Landowners

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Rangeland Management Research Project
Mission: *Provide through publications and seminars timely research information to landowners*

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To preserve and interpret the history of ranching in North America and address contemporary ranching issues.

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WATER: A RENEWABLE RESOURCE FOR LIFE

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When I was much younger, I spent a summer on the farm with my uncle and his family. One day my younger cousin and I started a discussion that continued for several hours. We were determined to answer the question: "Which tractor part is the most important?" He argued in favor of the engine because it's the power source. What use, after all, is a tractor if it has no power? I took the position that the most important part is the hitch. If you can't harness the power and put it to use, then what good is power? Seeing my point but not willing to concede, my cousin pointed out that without a hitch he could still use the power take-off (PTO) to deliver power to an auger, a generator, or any number of useful tools. The reality is that both parts are important because most tractor parts serve some useful purpose that, if not performed, would reduce the tractor's utility.

As I look back on that day, two important lessons emerge: First, most parts in a complex system have an important purpose, so declaring one part supreme over all others doesn't often make sense. Second, the relative importance of a component depends, in part, on your goals. If you just want to turn an auger, the hitch isn't very important. The same lessons apply to the processes that compose the water cycle (also known as the hydrologic cycle). All are important, but the goals for that portion of the hydrosphere that we call the ranch may be different from the goals of an engineer trying to supply water to a city. Just as a tractor has independent parts that work together to make the tractor useful, the water cycle has four processes that work together to serve an important function *(Figure 1)*:

- Condensation and precipitation
- Interception, infiltration and runoff
- Storage and deep percolation
- Evapotranspiration

Nearly one-third of the total U.S. land area is used for grazing, according to a 2012 USDA Economic Research Service report. With almost two-thirds of this grazing land located in 17 western states, American ranchers and land managers play a vitally important role in a global water cycle driven by the sun's energy. Many of these hydrologic processes are outside man's control, but some are sensitive to man's actions at a scale important to achieving land management goals. Because these processes are most impacted by man's actions on the ground—the active surface—land managers need to better understand the hydrologic processes to better understand how their decisions can improve the utilization, quantity, quality, and regime of the nation's water resources.

Sustainable Rangeland Symposium

June 7-8, 2018 | National Ranching Heritage Center | Lubbock, TX
1 to 5 p.m. Thursday, 8 a.m. to 4 p.m. Friday
$75 RHA members | $95 Non-members | $25 Students
Registration includes three meals | Register at http://ranchingheritage.org/srs

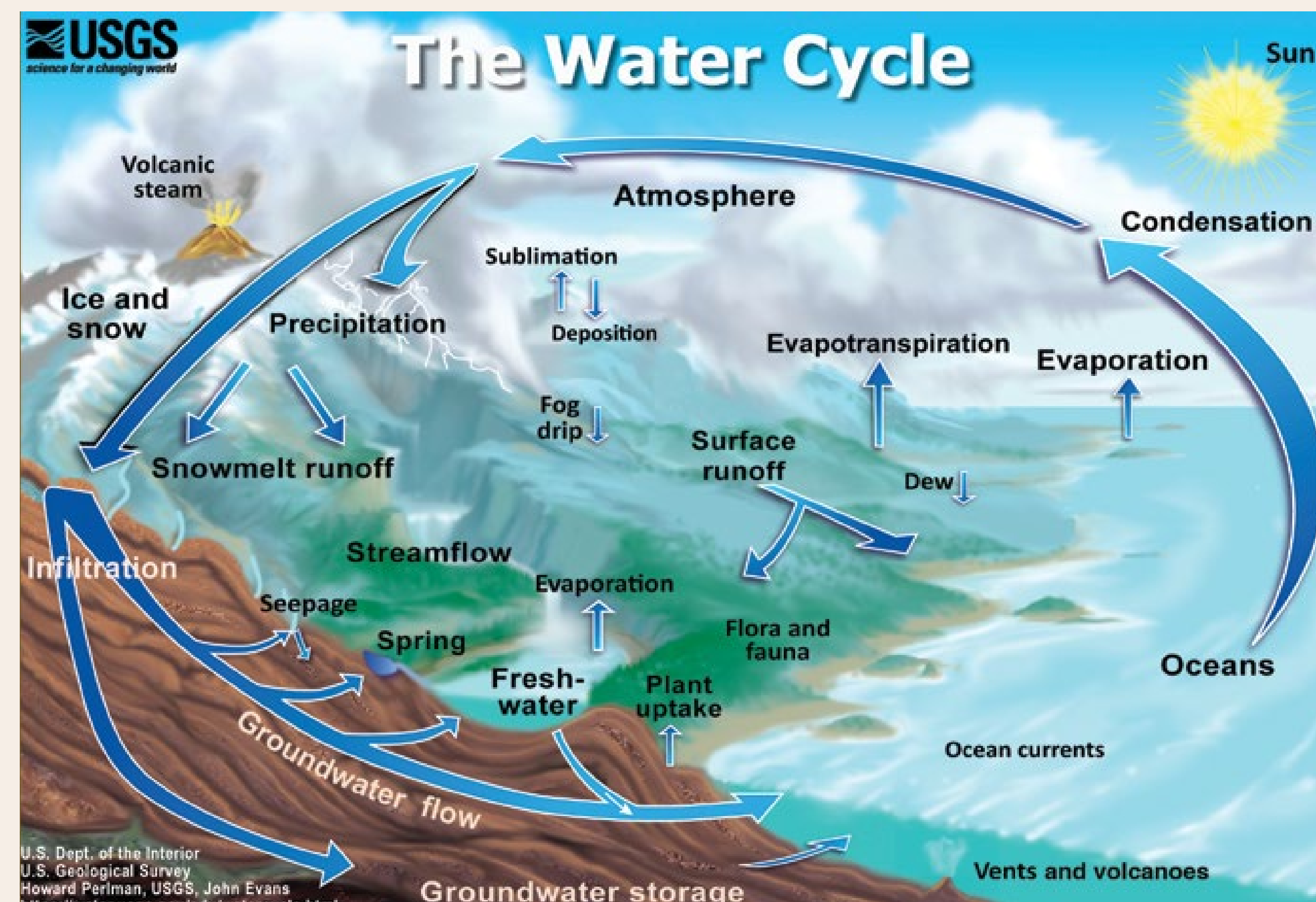
A Rancher's Hydrologic Goals

Ranchers are ultimately in the business of sustainably converting plants with little or no value for human consumption into high-quality protein that has great value for human consumption (food and/or fiber). In simple terms, the objective is to grow as much plant biomass—of a type livestock can and will use—and harvest that useable biomass without negatively impacting the plant's ability to produce in subsequent years. To be sustainable, this objective includes the idea that the vegetation on the ranch is composed of environmentally adapted plant species, such as those native to the region. Sustained use considers not only factors that directly impact the ranch and its bottom line, but also external factors such as the impact livestock has on native fauna and flora as well as runoff water quantity and quality. Plant use by livestock must be balanced with plant production, making allowance for other necessary uses of the plants.

In hydrologic terms, the rancher's object could be restated: Get as much precipitation as possible into the soil, store it, dissolve plant nutrients, and direct as much as possible the nutrient-rich soil water through preferred plants. During some precipitation events, not all the water will enter the soil. For the fraction that does not, the goal is to minimize the amount of soil and nutrients removed in the runoff. The details of how these goals can be achieved are site specific and best left to managers with site-specific knowledge; however, the principles are broadly applicable.

The Water Cycle

The supply of water on earth is vast, but according to U.S. Geological Survey figures, the majority of that water—greater than 97 percent—rests in the oceans. Another 2 percent is in glaciers and ice caps, .6 percent is groundwater, and less than .02 percent is surface freshwater. Water moves through the hydrosphere in a cycle known as the hydrologic cycle or water cycle (Figure 1) and the freshwater that has been used or has made its way to the oceans is eventually replaced. Because of this cycle, we consider fresh water to be a renewable resource. That is not to say, however, that all freshwater supplies are renewable resources. When the rate of water use exceeds the rate at which it's replenished, then the supply is not a renewable resource. An example of a non-renewable freshwater resource is the southern Ogallala Aquifer where groundwater extraction exceeds its recharge rate.



▲Figure 1: Earth's water is always in movement, and the natural water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above, and below the surface of the Earth.

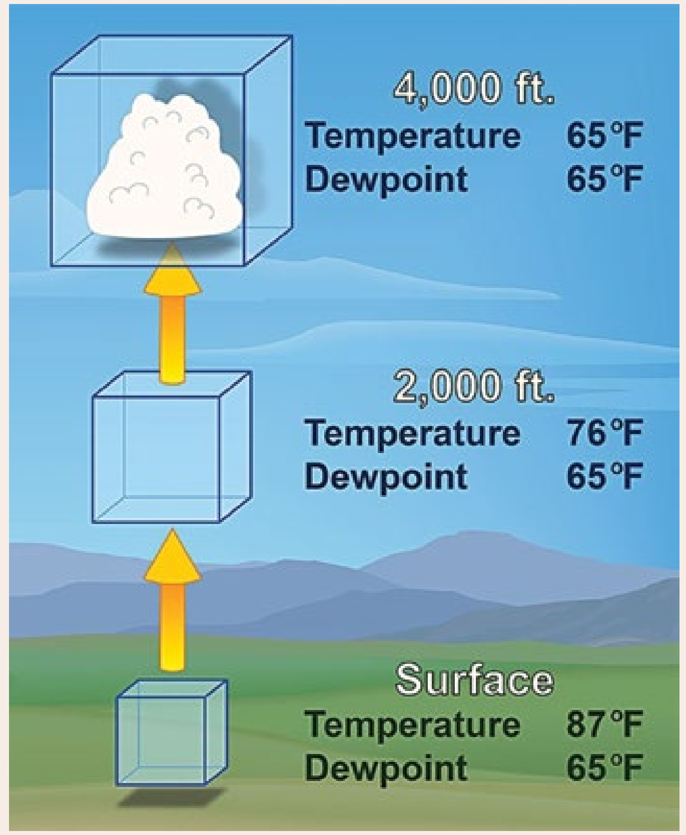
Condensation and Precipitation

The Science:

Perhaps the most tangible and well appreciated of all the hydrologic processes is *precipitation*, which is caused when water vapor condenses to a liquid or solid state and falls to the ground. Certain conditions must be met in the atmosphere before precipitation will form. The atmosphere must be saturated and the air must contain minute separate particles of matter on which vapor can condense. Vapor that has condensed directly on a plant, known as dew or frost, is best considered here with precipitation, but its contribution to the water balance is generally very small except for coastal regions where considerable moisture is brought inland each day.

The ratio of vapor content to saturation vapor content is known as *relative humidity*. Before water vapor will condense, the atmosphere must be at 100 percent relative humidity. This condition is called *saturated*. The atmosphere also must have condensation nuclei. Without these nuclei, the air can reach greater than 100 percent relative humidity, a condition known as *super saturation*. Condensation nuclei are very small particles that are abundant in the atmosphere, so super saturation does not occur naturally. Overly abundant nuclei, which can be caused with air pollution or by cloud seeding, can result in the condensed water having a small droplet size. These smaller droplets are more susceptible to being carried higher in the atmosphere where they freeze. This may be linked to more intense precipitation events.

Relative humidity is affected by vapor content as well as air temperature. Given a parcel of air with constant vapor content, relative humidity varies inversely with temperature. This relationship can inform our understanding of when and where precipitation occurs. When air descends, its pressure increases and causes the air parcel to contract and release energy that warms the air. Anyone who has operated a bicycle tire pump has felt the pump get hot and is familiar with this phenomenon. Conversely, the pressure and air temperature decrease when air ascends. When air temperature decreases, relative humidity increases to the point of becoming saturated and forming condensed droplets *(Figure 2)*.



▲Figure 2: Certain conditions must be met in the atmosphere before precipitation will form. When air ascends, pressure and air temperature decreases. When air temperature decreases, relative humidity increases to the point of becoming saturated and forming condensed droplets. (Source: NOAA)

Two rates of air temperature change with height: First, air with relative humidity less than 100 percent changes temperature at the dry adiabatic lapse rate, -5.4°F per 1000 ft. of ascent. Second, air at saturation changes temperature at the moist adiabatic lapse rate, typically around -2.7°F per 1000 ft. of ascent, though it strongly varies with temperature. The magnitude of the moist rate is less than the dry because energy is released as water condenses. The height at which lifted air becomes saturated and condensation begins is known as the *lifted condensation level*.

A number of factors can cause air to be lifted either from a mechanical lifting mechanism or when air is heated and becomes buoyant. An example of a mechanical lift is the orographic effect. When wind transports moist air over a mountain, the air on the windward side must rise to get over the mountain. When it reaches the lifting condensation level, clouds form and precipitation falls. When this air descends the mountain on the leeward side, the air will have lower relative humidity and higher temperature at every elevation compared with the relative humidity at corresponding elevations on the windward side. This is because the air on the windward side cools at the dry adiabatic rate part of the way and the wet adiabatic rate the remainder of the way, but on the leeward descent it warms the entire distance at the dry rate. This leeward air often results in hot desert conditions in the rain shadow of the mountain. Orographic effects are fixed by the topography and prevailing wind direction.

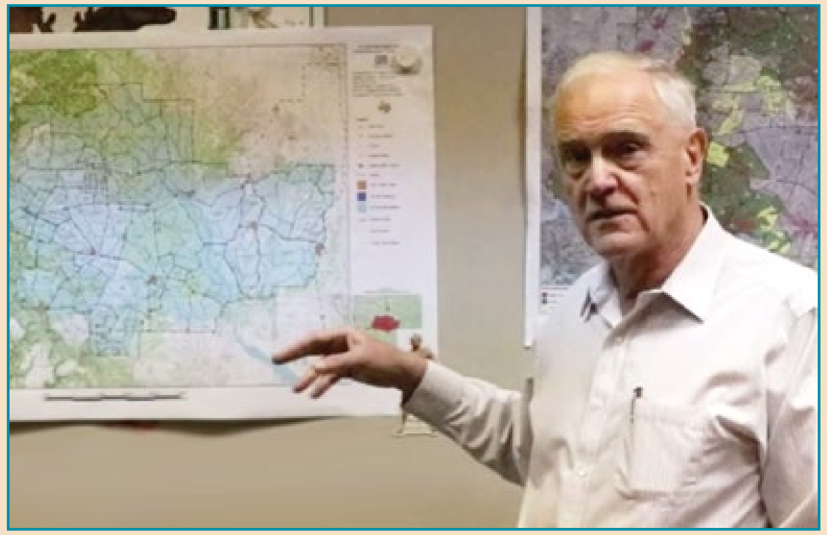
Air is also mechanically lifted when two air masses meet along a front. When cool dry air moves into a region occupied by warm moist air, the cold front lifts the warm air above the colder air along a steep incline to the lifting condensation level. Precipitation will occur over a long but relatively narrow zone. When warm air moves over a mass of cooler air, along a warm front, the warm air runs up over the cool air, but the incline is lower. When the air reaches the lifting condensation level, precipitation will occur with less intensity but be more widespread.

In summer, air heated near the ground will expand, causing it to become buoyant and rise. When the air in these convective cells rises to the convective condensation level, the cell can produce rain, sometimes very intense rain and hail. The area affected by these convective rain showers is generally more localized than is common with frontal showers, but there may be several cells that develop across a large area. Precipitation characteristics that are important when determining what happens next in the cycle include (1) amount, measured in terms of depth, (2) intensity or the amount per unit of time, and (3) precipitation type (e.g., rain, snow, hail, freezing rain).

A Rancher's Perspective: Condensation and Precipitation

Precipitation and the causes for where, when, and how it falls are complex with factors that span distance and time to extend well beyond any particular ranch. For the most part there is little to be done in terms of ranch management to affect precipitation except to consider the climatic reality of the ranch location in your management plans. These plans should be based on reasonable expectations for precipitation and should recognize and address the variable nature of precipitation. When developing your plans, consider the impacts this variability could have on your ranch and plan accordingly. For example, what is the least amount of forage you might produce in a single year due to drought? What about consecutive years? Do you maintain a reserve of standing forage or hay that would allow you to survive these low-forage production levels without removing too much cover or having to cut too deeply into your base herd? Are water developments dependable in dry years or would livestock have to forgo grazing a pasture for lack of drinking water even when forage was available? If destocking were required, have those contingencies been planned? Have timely destocking triggers been established or will action be delayed until even the best option is painful? Is early weaning an option? Would retaining yearlings in years with abundant forage allow you greater profitability and flexibility than keeping cows with the same forage requirements? Are records kept that would allow you to cull the least valuable cows first when cows need to be culled? Is your stocking rate appropriate or has it increased in recent years even while maintaining the same number of cows by unintentionally allowing cow size to increase? If stocking rate needs to be adjusted, is it more economical for you to reduce the number of cows and maintain their current size or reduce the number of cows now and begin working toward acquiring or selecting more but smaller cows? If snow is a risk, are pastures with the needed protection useable at times then the risk is greatest? If flooding is a potential problem, have contingencies for flood been developed?

Precipitation is what it is, but it's also only the first of several steps where the water cycle and your ranch interact. With respect to the precipitation you've received to date, you can only adapt. For the precipitation to come, you will still need to adapt, but through mitigation and management that allows you to make better use of the precipitation you receive, the need for adaptation can be reduced. As you make your plans, identify improvements to be made that would improve the effectiveness of the precipitation you receive and make your ranch more resistant to the impacts of too much, too little, or untimely precipitation. Finally, identify improvements to increase the resilience of your land to unfavorable precipitation conditions.



◀Pointing to a map of ranch pastures, Jay O'Brien stresses the importance of managing pastures according to the disparity in rainfall as opposed to a grazing system that moves cattle on a regular basis.

From the Grass Roots: Precipitation and Your Management Plan By Julie Hodges

Jay O'Brien manages several ranches in the Texas Panhandle where semi-arid conditions make precipitation, or the lack thereof, the forefront of his management plan.

"Our rainfall in the last 30 years has varied from 7 inches to 35," he said. "That means an average of somewhere around 22 inches. But we've only had something like 25 percent of those years that have been within 10 percent of the average. If you manage your ranch for the average, you are going to go broke and you are not going to be able to deal with this wide disparity."

O'Brien uses destocking as part of his regular management technique. "During times of stress from lack of water or lack of grass, we will destock," he said. "On these ranches, we try to utilize half the grass with cow/calf and half with stockers—cattle that we buy and grow to be yearlings. The reason we do that is because it is less painful economically to destock a ranch—to move cattle off—if they are yearlings than it is if they are cow/calves.

"Cows have a lifetime of 9 to 13 years. If you have to sell them in a time of drought, you can't amortize the original cost. Accepting that we are often in drought, we want to do our destocking with yearlings so that we can keep our cows and keep them profitable."

Because grass production "goes right with rainfall," O'Brien stresses the need to protect the crown of a grass plant (the part of the plant at soil level). "If we let that crown die or be injured, then it takes a lot longer for the land to recover from a drought," he said. "If we take care of it so that we don't graze off and do damage to the crown, then once we get any rain at all, the country comes back so fast you wouldn't believe it. The system is designed to recover from idiots like me. If you take care of the grass and don't overgraze, the land responds to less rain than country that's been overgrazed."

O'Brien believes it's important not to get caught up in grazing programs that assume the same amount of rainfall in every pasture. Disparity in rainfall means you have to manage each pasture differently by destocking country that doesn't get as much rain and putting more stock on pastures with more rainfall.

"There are grazing systems designed to move cattle on a regular basis and the theory is that you give country normal rest so it recovers in a healthy way," O'Brien said. "That would be fine if we were in control of the amount of rainfall that each pasture got and if it were dependable that we could get so much rain at a given, predictable time. But that is not how it works. These systems that are heavily grazed and then moved are destined to do damage to the country. As you move in a time of drought, sometimes you are moving into country that hasn't received any rainfall."

(This information was taken from an NRHC YouTube series called "From the Grass Roots" featuring landowners and producers who are putting their knowledge of rangeland sustainability into practice. To learn more, visit https://www.depts.ttu.edu/nrhc/Learn/grassroots.php)

Interception, Infiltration and Runoff

The Science:

The next step in the water cycle depends on surface and precipitation characteristics. At the active surface, water is partitioned among three processes. Water either infiltrates the soil, runs off or is intercepted. All three are necessary, but increasing the proportion that goes to infiltration is preferable for producing forage and keeping surface waters clean.

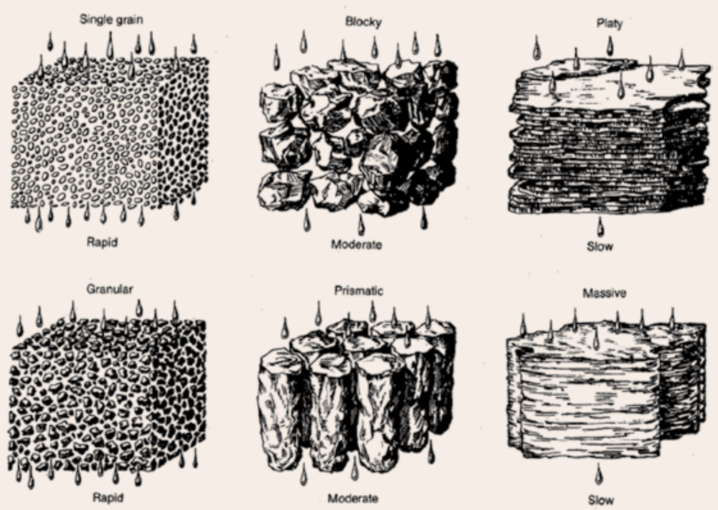
Interception temporarily halts water movement toward the soil. As precipitation comes to rest in vegetation, litter, or on other surfaces, it stops—at least for a short time. When precipitation is intercepted, its potentially damaging kinetic energy is absorbed by the intercepting surface. Intercepted drops coalesce with other drops and a portion of the intercepted water will make its way to the soil surface eventually. The water will move along plant leaves and stems to the soil near the plant base or it will move to a low point within the canopy where it drips to the ground. When it drips, it will regain a portion of its kinetic energy, the amount depending on its height and drop size. Another possible outcome for the intercepted water is that it just completes the water cycle, evaporating back into the atmosphere. The loss of this intercepted water contributes to keeping plants cool, shedding heat absorbed from the sun's rays. This temporarily reduces the plants transpiration requirement for thermoregulation. Different vegetation surfaces have different interception storage capacities and a certain amount of rain is needed to fill this storage. Small precipitation events that never fill the interception storage capacity have a greater fraction of their water intercepted than large events.

Plants with the right canopy architecture may favorably affect their water balance when intercepted water is redirected to the plant base, but for small precipitation events, a large fraction of the water will return to the atmosphere. Shrubs and trees tend to have greater interception losses than grasses and forbs. Large trees and shrubs, because of their large canopy area, can redistribute water effectively to their base and reduce the amount of water available in the outlying areas below their canopy. A study of oak mottes in south-central Texas showed that a zone within 3 feet of the trunk will receive the equivalent of two times the annual precipitation while the area under the canopy, outside this distance, will only receive about half. Juniper and other woody species with large canopies have similar effects on water redistribution. When intercepted rain freezes to stems or leaves, as in an ice storm, the interception storage capacity may be greatly exceeded and trees and shrubs may be severely damaged, breaking under the weight of the ice.

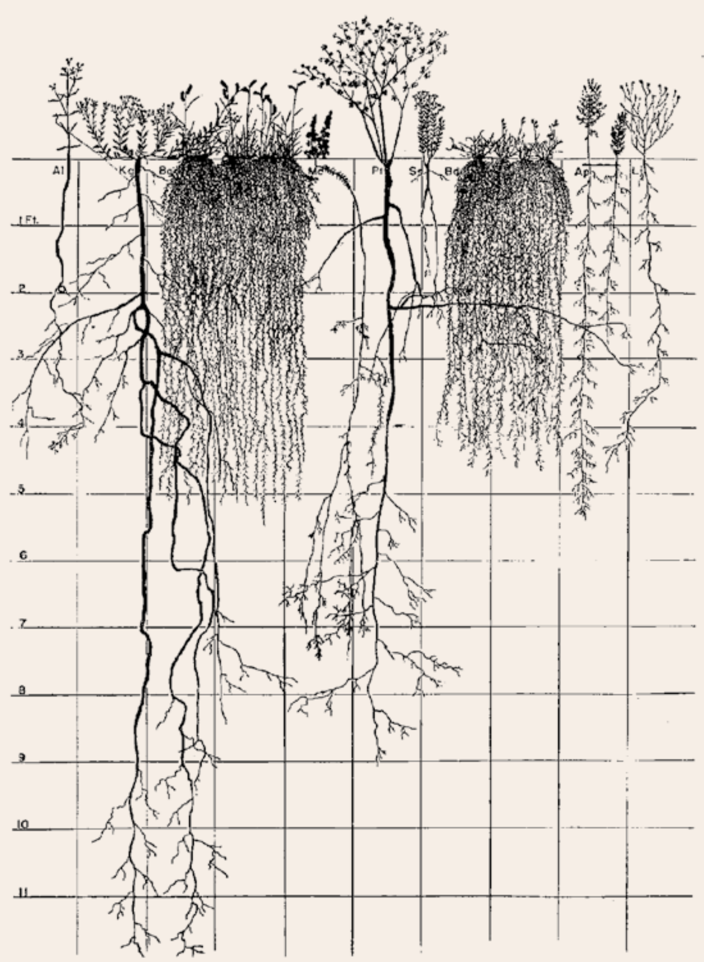
Infiltration is the process by which water enters the soil. For water in liquid form, infiltration begins as soon as the water encounters soil, but for snow and ice, infiltration won't begin until it melts. A soil's infiltration rate, or *infiltrability*, is a function of the size distribution of unfilled pores. Large pores are easy for the saturated water to move through but small pores contribute to the soils capillary forces which, along with gravity, pull the water into the soil during infiltration. The size distribution of unfilled pores is affected by soil and vegetation characteristics such as the amount of water already in the soil; soil texture; soil structure; whether the soil is frozen; the amount, type, size and turnover of roots; and the abundance, type and size of soil fauna. Infiltration rate also relates to how deeply the wetting front was reached during infiltration and the depth water ponded on the soil surface. For most uplands, however, water will not pond deeply before running off.

Sandy soils generally have high infiltration rates compared to other soil textures. The exception is when sands are dry and hydrophobic organic compounds are coating the sand particles, making the soil water repellent and reversing the capillary forces. In these conditions, water forms beads like those on the hood of a freshly waxed car. The soil may repel water for several minutes before the water finally wets the sand particles and infiltration begins. This phenomenon may be accentuated after a fire. The heat of the fire causes volatilization of organic compounds that condense in the soil when the fire cools. Large primary particles in sand are responsible for the large pores that give sand a high infiltrability. Unlike other soil textures, the infiltrability of sand is less affected by other factors such as structure and macroporosity.

For soil that is finer than sand or loamy sand, the abundance and continuity of macropores become much more important for achieving high infiltrability. Macropores occur where soil structural units meet and in the voids left by soil fauna and flora known as biopores. While soil texture is defined by the proportion of primary particles of different sizes, structure relates to the size, shape, and strength of secondary particles. Secondary particles are the clusters of primary particles that naturally form in the soil, called *peds (Figure 3).* Organic substances created by bacteria and fungi as they decompose organic matter combine with polymers and sugars secreted from plant roots to help create and maintain soil structure. This gives stability to the structure when wet. Granular structure has relatively small irregular- to spherical-shaped peds that confer high infiltrability. Strong granular structure is easy to dig, even by hand. Platy structure has peds that are like large sheets aligned horizontally. This horizontal alignment impedes downward flow. Massive is when the primary particles are bound but there are few natural breaks. The absence of structural macropores in this



▲Figure 3: Many factors affect the water infiltration rate of soil, including soil texture and clusters of primary particles called peds that naturally form in the soil. Granular structure, for instance, has relatively small irregular- to spherical-shaped peds that help high infiltration. Conversely, platy structure has horizontally aligned peds that impede downward flow. (Source: USDA/NRCS)



▲Figure 4: A diverse plant community is critical in maintaining a diverse soil fauna and leaving large macropores deep into the soil when the forbs turnover. Roots of some native plants extend to depths of 20 or more feet. A1, narrow-leafed 4-o'clock (Allionia linearis); Kg, prairie false boneset (Kuhnia gultinosa); Bg, blue grama (Bouteloua gracilis); Mc, globemallow (Malvastrum coccineum); Pt, a legume (Psoralea tenuiflora); Ss, Sideranthus spinulosis; Bd, buffalo grass (Buchloe dactyloides); Ap, western ragweed (Ambrosia psilostachya); and Li, skeleton weed (Lygodesmia juncea). (Source: USDA/Yearbook of Agriculture 1948)

structure impedes downward flow. Prismatic structure is more commonly associated with the subsoil but can occur at the surface, especially if the topsoil has been eroded. Strong blocky and prismatic structure can improve percolation rates. Structure is most effective at maintaining infiltrability when the peds are water stable. When the peds lack water stability, the peds disintegrate and the macropores close, reducing the conductivity of the soil. These peds will typically reform upon drying.

Another important source of macropores is the so-called biopores left by the activity of soil fauna (worms, insects, subterranean mammals) large enough to move soil particles and the flora through the turnover of roots. A diverse plant community is critical to maintaining a diverse soil faunal population. Many faunal species leave large, well-connected pores when they burrow through the soil. Diversity in the plant community is also important because of the variation in rooting habit among species. Grass species tend to be fine and fibrous, but many forbs have large taproots. When these forbs turnover, they leave large macropores that extend deep into the soil *(Figure 4)*.

Pore size distribution in soils with more than about 20 percent swelling clay may change when the soil becomes wet. When some clay minerals hydrate, they swell causing some larger pores to close. The abundance of soil pores may decrease when soil particles are detached and move with the water into the pore until it's plugged. This most likely occurs during intense rainfall when raindrops impact a bare unprotected soil. The swelling is an intrinsic characteristic of the soil, but it can be mitigated with better soil structure that keeps the soil loose with room for swelling. A good canopy and ground cover can protect the soil from raindrop impact and reduce detached particles plugging soil pores.

Persistent degradation of macro-porosity and soil structure may occur when (1) soils are compacted and soil cover is lost and (2) soil biota changes alter production of soil-binding organic matter and formation of biopores. On a ranch, compaction may occur when livestock trample soil excessively, especially when wet. Loss of cover and changes in soil biota may occur when grazing is excessive and too much biomass is trampled or consumed or a particular species is overused resulting in a shift in

▲Figure 5: A green dye was added to the runoff flow to emphasize creation of a concentrated flow path. Ground cover is important to slowing the movement of water to increase the opportunity for soil infiltration and decrease the risk of downstream flooding. (Source: USDA/ARS/Northwest Watershed Research Center)

species composition. These effects of overuse and excessive trampling may accrue slowly over time.

When soil is wet from the surface, nearly all the pore space above the wetting front is filled and additional water enters the soil only when the wetting front moves deeper. Water moves deeper in response to capillary and gravitational forces. The gravitational force increases as the depth of saturation increases but so does the wetted distance that increases the resistance to flow, thus keeping constant the hydraulic gradient due to gravity. Assuming soil characteristics below the wetting front are unchanged, the capillary force remains constant so its effect on the hydraulic gradient diminishes as the resistance increases. When soil is dry and has many small pores, the soil initially will have a very high infiltrability, but if it does not also have an abundance of well-connected macropores, its infiltrability will quickly decline.

When liquid water reaches the surface at a rate exceeding the soil's infiltration rate, the water accumulates and ponds on the surface. Then another process, runoff, becomes active. Runoff occurs when ponded water moves down slope across the soil surface. Runoff moves across the surface more quickly on sloping ground than on flat ground. Runoff occurs initially as sheet flow, a uniformly shallow flow of water on the soil surface, but as flow from different areas coalesce down the slope, runoff begins to move as a concentrated flow. In Figure 5, a green dye was added to the flow to emphasize the concentrated flow path. These concentrated flows are more efficient than sheet flow at removing surface water with greater flow velocity and energy. Eventually concentrated flows reach the bottom of the hillslope and move into ephemeral or perennial streams or into a pond. The better developed the network of concentrated flow paths, the more quickly the surface water is removed, thus shortening the concentration time and increasing the risk of downstream flooding with large runoff events.

After removing interception and infiltration, runoff is what's left of gross precipitation. Hydrologists and engineers refer to runoff as effective precipitation, whereas the rancher looks at the quantity of infiltrated water as effective precipitation. Because interception, infiltration and runoff are complementary, any factor that has an effect on interception or infiltration must also have an equal but opposite effect on runoff, all else being equal. One factor that bears mentioning with runoff is the effect of ground cover. Ground cover is the amount of soil surface covered with non-erodible features, including rocks, gravel, plant bases, litter in contact with the soil surface, and cryptogams. These features, like canopy cover, protect the soil from falling raindrops, but they also make the surface rough and impede water flow across the surface. When ground cover is abundant and thick, water ponds slightly deeper than it would if the cover were absent, slightly increasing water pressure and infiltration rate. More importantly, surface water movement is slowed. This keeps water on the hillslope longer after rain so infiltration can continue.

If flow is slower on sheet flow areas, it won't contribute water to concentrated flow paths as quickly, and the concentrated flow also will be slower with less energy. Holding roughness constant, flow velocity and energy increase with flow depth. Because of this, concentrated flow paths cut into deep, narrow channels called rills and remove water more efficiently than flow paths that aren't incised. A wide shallow flow with slow moving water needs a greater cross-sectional area to carry the same discharge than deep narrow flows.

A Rancher's Perspective: Interception, Infiltration and Runoff

From a rancher's perspective, we want to increase infiltration when precipitation reaches the ground. Interception loss is a necessary consequence of having abundant plant biomass and soil covering litter. The positive effects of abundant cover to infiltration outweigh the negative effects of water loss to interception. With respect to interception, management should aim to control undesirable plant species that redistribute intercepted water away from preferred

▲Figure 6: Although ground cover has a positive effect on infiltration, some undesirable plants such as juniper trees intercept the water needed for preferred plants. Fire is an especially effective method of controlling these invaders if the trees are small, widely scattered and surrounded by abundant grass. (Source: Oklahoma State University/The Prairie Project)

plants. Examples of these undesirable plants are invading woody plants, especially juniper species that have escaped the steep canyons and slopes they historically occupied when fire occurred in greater frequency on the landscape. Juniper is much easier to control when trees are just invading—still small and scattered (Figure 6). When juniper trees are less than 6 feet tall, widely scattered and surrounded by abundant grass, fire is an especially effective method of controlling these invaders. Having abundant grass—a highly combustible fuel for wildland fire—below the juniper and surrounding the juniper canopy will cause these small junipers to be consumed, leaving only a skeleton behind. Grass growth beneath large juniper canopies is minimal, significantly reducing the chance these junipers will catch fire under normal prescribed burn conditions and therefore reducing the efficacy of fire.

Managing for biodiversity and plant productivity assures the soils will have a diverse fauna and abundant protective cover that are conducive to maintaining and creating soil structure and large well-connected biopores. Diverse rangelands also have a good mix of grasses and forbs with differing rooting habits. When roots die and decompose, some may leave large biopores that reach deep into the soil *(Figure 4)*. Forbs, the broad-leafed herbaceous plants on rangelands, are important for their role in creating and maintaining large biopores. In an agronomic or pasture setting, we often view these plants as competing with the crop for resources and therefore see them as weeds that need to be controlled. While there are forbs that warrant control as they invade our rangelands, most of the native forb species have an important role in the ecosystem and should be maintained.

Persistently bare ground is subject to greater erosion risk. It likely has poor soil structure in the remaining topsoil, is prone to crusting, has few roots holding the soil in place and easily detaches during raindrop impact. These detached soil particles quickly plug large pores during rain. Ranchers should do what they can to minimize the amount of persistently bare ground. In an area where the ground has been bare a long time, reclaiming the ground for plant growth may be so difficult that reversing the damage is not feasible. Where bare ground has recently developed, the causes should be determined and managed to reverse the effect quickly. These conditions are prone to the development of rills that can alter, for a very long time, the efficiency with which water is shed from the hillslopes making it much more difficult for the site to recover.

Fire, whether it is wild or prescribed, causes severe and immediate canopy and ground cover removal. It is perhaps the most severe trauma well-managed rangelands ever experience, yet fire is a natural process in the evolution of these systems. Healthy rangelands have abundant roots throughout the topsoil that help hold soil in place until cover returns after fire. In grasslands, grass and forbs quickly emerge after a fire and begin the process of replacing canopy cover. Some shrubs and trees (e.g., sand sagebrush, Harvard oak—also known as shin or shinnery oak) have the ability to regenerate from their base and also may return quickly after fire. Bare ground declines with time after a fire. Canopy cover, in particular, is relatively quick to return, but ground cover returns much more slowly than canopy cover. For these reasons, the impact of an intense, short-term removal of cover by fire in the grasslands should not be compared with the proportionally greater impacts that persistent lack of cover has on rangelands. Some exceptions to this quick post-fire recovery that may warrant greater attention and management include the following:

(1) Sandy areas where soil cohesion is weak and roots are less abundant, especially if strong winds follow the fire.

(2) Sandy areas where the sand has become water repellent.

(3) Areas that converted from grassland to woodlands before the fire and significantly weakened the herbaceous species.

(4) Periods after or during severe drought when herbaceous plants may be weakened or periods with cold temperatures that impede rapid emergence and growth of herbaceous plants.

◀Delbert Trew's approach to rainwater infiltration has been successful at reviving springs, seeps and creeks in canyons that were once dry.

From the Grass Roots: Increasing Rainwater Infiltration By Julie Hodges

Delbert Trew of Alanreed, Texas, has made water conservation and rainwater harvesting a priority on the Trew Ranch. Two of his windmills went dry in 1992 after a neighbor drilled an irrigation well and pumped for a couple of months.

"Although occasional rain shortages and drought bring on dry dirt tanks and springs, there were always windmills for backup water supplies," Trew said. "When the water wells dry up, drastic measures are needed to service livestock or the land cannot be used."

Trew's "drastic measures" center around increasing rainwater infiltration through a five-point approach:

1. Locate and stop all erosion along creeks, roads and trails.
2. Construct catchments for capturing rainfall to recharge upper aquifers while building and maintaining flood water dams to capture excess runoff.
3. Monitor, aid, build and maintain all riparian areas.
4. Control all brush on upper-prairie areas, monitor brush and tree growth in canyon areas, and practice shade tree selection and brush sculpting for wildlife.
5. Limit grazing numbers to protect proper ground cover and grass growth.

After 35 years and two worn out bulldozers, Trew has single-handedly brought back springs, seeps and creeks. Despite increasing irrigation demands in the region, he now has live water on his place year-round.

Trew's water catchment basins are relatively small and simple. "People seeing these will think I do the ugliest dirt work there ever was," he said. In contrast to big flood control dams, Trew's catchments are specially designed to slow down and allow water flowing from the flats of his ranch to soak into lower lying areas. He leaves catchments rough and takes advantage of the seed bank already present in the soil. Most of Trew's catchments are hard to spot as they grass over quickly and become part of the surrounding landscape.

Dozens of catchments throughout Trew's property have resulted in fresh water for livestock and wildlife year-round. Describing one of his catchments, Trew said "It's not a very pretty dam because it doesn't need to be," he said, describing one of his catchments. "It just needs to be enough of a dam to hold just the overflow off the flat behind us. The water here goes into the aquifer and down. If you go down into the canyon below, there will be a stream of water running there. It will be running year-round and this is at a time when we have had no rain for nearly six months."

(This information was taken from an NRHC YouTube series called "From the Grass Roots" featuring landowners and producers who are putting their knowledge of rangeland sustainability into practice. To learn more, visit https://www.depts.ttu.edu/nrhc/Learn/grassroots.php)

Storage and Deep Percolation

The Science:

Water, after infiltrating the soil, continues to move down through the soil. This process, called *percolation*, may continue for several days after a rain until the forces acting on the water are balanced. When all the pore space in the soil is filled, the soil will become saturated and some water not held tightly by the soil will drain. The available small pores in drier soil below will fill. When the root zone has more water than it can hold, the excess water will pass out of the root zone. This is called *deep percolation*. This water is lost from the upland, but it may resurface at a later date in a seep or spring as base flow in a perennial stream as a lake, reservoir or ocean water. In the meantime, this deep percolated water may recharge an aquifer where it may be used as a source of groundwater.

Water that remains within the root zone is *soil water*. Factors that affect how much water can be stored usefully in the soil are the soil's depth and the available water-holding capacity. The entire soil pore volume can be water filled, but this capacity is not well related to the amount of water a soil can usefully store because some of that capacity is not held tightly and is easily drained. Some of that capacity is also so tightly held in the soil that plants can't use it. The concept of available water capacity incorporates these effects and is defined as the amount of water between two water potentials: (1) *field capacity* that approximates the water potential after a wet soil has drained for two or three days and (2) the *permanent wilting point* that approximates the water potential at which plants are unable to extract soil water, thus causing plants to wilt permanently.

The quantity of water held at these two water potentials—field capacity and permanent wilting point—depends on soil texture. Sand has large primary particles with large pores that can't hold water tightly. Much of the water will drain in the first several days after wetting. Little water will be held at field capacity and even less at the permanent wilting point. So, even wet sands are relatively dry. Unless sandy soils are quite deep, their low capacity for holding water limits the productivity of these soils in many climates. Clay particles, on the other hand, are very small and the small pores adjacent to these particles can hold much water at field capacity. The permanent wilting point of clay also has high water content, so the available water capacity is higher than sand but still relatively low. Silt has the highest available water capacity of the soil textural classes because it holds much water at field capacity and little water at the permanent wilting point. Most of the water it holds is plant available *(Table 1)*. Another factor that modifies the ability of soil to hold water is the soil organic matter content. The greatest reservoir of soil organic matter is in the topsoil—the upper several inches of soil. The more organic matter in the soil, the greater the available water-holding capacity.

A Rancher's Perspective: Storage and Deep Percolation

Soil depth and texture are affected very little by good management. Not much can be done by land managers to make a shallow soil appreciably deeper or cause a sandy soil to become a loam. Poor management on the other hand can alter these soil characteristics. Management that leads to excessive soil erosion can strip the hillslopes of soil and may even bury portions of the soil down slope. Erosion removes the organic matter in rich topsoil, but down slope where deposition may occur, soil particles are sorted. The coarser material such as fine gravel and sand is dropped from the flow and the finer silt and clay particles and important organic matter remain suspended and continue on to fill ponds, lakes and reservoirs. While good management has little impact on soil depth, deep percolation starts when water departs the root zone. Each plant has its own root zone and factors such as overuse of above ground biomass can cause root growth to stop, possibly leaving unreachable water deep in the soil.

The goals of management with respect to storage and deep percolation are to (1) maintain and improve the soil by protecting it from excessive erosion by promoting the creation and maintenance of soil organic matter and (2) make good use of the stored water between precipitation events by managing for preferred plants that will occupy the entire soil depth with roots and grow biomass that can be used by livestock. Managing for a diverse and productive plant community addresses all of these goals.

Evapotranspiration

The Science:

The return of water to the atmosphere through the process of evapotranspiration completes the cycle. *Evapotranspiration* is the sum of evaporation and transpiration. Evaporation is the process by which water transitions from liquid to gas. Transpiration is a special case of evaporation in which the liquid water transitions to gas within a plant's stomatal cavity after having entered the root and moved through the plant's vascular system to the leaf. For either to occur, air near the water must not be saturated with vapor. The air must have a vapor deficit, and an energy supply must exist. High air temperature, low vapor content, and high wind speed help to maintain a strong vapor deficit in the air above the liquid. Near the evaporating surface, temperatures in the air and water will decrease as they provide energy for the evaporation process. Solar radiation is needed to replenish the lost energy and keep evaporation rates high. Vapor content in the air near the water increases as water evaporates and will continue to do so until the air becomes saturated or the vapor is moved away from the liquid surface by diffusion or convection.

For evapotranspiration to occur, a source of liquid water obviously must be available. Evaporation of water from the surface of the soil reduces liquid water availability in that zone. The evaporated water must be replaced in the soil or evaporation will eventually stop. Soil drying lowers the water potential at the surface and causes water from deeper in the soil to move upward in a process known as *capillary action* or *wicking*. Fine textured soils can wick water from the soil more deeply than sands. All soils are dried more deeply when they're occupied by transpiring plants. In a healthy plant community, roots are abundant and extend deeply into the soil. The plant's vascular system connects roots with leaves and the water flows more easily through this low resistance conduit than it can through soil. Roots are generally found in a region of soil directly below the aerial portion of the plant. The soil water that is available to a plant is therefore near the plant base and extends as far into the soil as the roots. Plants must compete for soil water where the roots of several individual plants commingle. Once water is absorbed through the root, water is generally transported and used by that plant with little risk for loss to other plants. Hydraulic lift—a process whereby water is absorbed from deep in the soil, transported near the surface, and released back into the soil to be reabsorbed at a later time—occurs with some species. These plants may lose some of this water to other species.

Some plants, notably juniper, extend their roots well beyond the extent of their canopy and rob water from other plants in the zone between the tree canopies. Junipers not only rob plants of their precipitation by redirecting intercepted water to their base but also rob plants outside their canopies of soil water.

Litter cover on the soil surface can reduce evaporation by absorbing incident solar radiation and helping to maintain a weaker water vapor deficit in the air directly above the soil. Guard cells, which are located at the opening of stomata on plant leaves, open and close, thus helping to regulate the movement of vapor and other gasses, such as CO_2, in and out of the stomata and plant. When the stomata are closed, the vapor deficit between the liquid water and vapor inside the stomata weakens, causing a reduction in transpiration.

Most days during the growing season, transpiration by plants happens without much notice. Like good health or good housekeeping, its value is most apparent sometime after it ends. When transpiration slows or stops during the growing season due to a lack of soil water, this condition is known as drought. For many ranches in the Southern Plains and southwestern United States, precipitation is sporadic. In the course of most years, there will be periods of both plenty and scarcity *(Figures 7 and 8)*. In 2011, for example, one of the driest single-year droughts in recent history, cumulative precipitation at a location near Woodward, Okla., lagged behind median cumulative precipitation for the entire year *(Figure 7 top panel)*, but there were several periods within the growing season (i.e., early-August, late-September, and mid-October) when the 14-day precipitation rates were similar to the median 14-day rate *(Figure 7 bottom panel)*. In 2015, a wetter than normal year at this location, the area had somewhat greater precipitation than the median and from mid-April through mid-June the 14-day precipitation

Table 1. Soil characteristics for select soil textural classes*

Textural class	Total porosity (% v/v)	Water retained at field capacity (% v/v)	Water retained at permanent wilting point (% v/v)	Available water capacity (% v/v)
Sand	43.7	9.1	3.3	5.8
Sandy loam	45.3	20.7	9.5	11.2
Loam	46.3	27.0	11.7	15.3
Silt loam	50.1	33.0	13.3	19.7
Clay loam	46.4	31.8	19.7	12.1
Clay	47.5	39.6	27.2	12.4

* Adapted from Rawls et al., 1982

rates were much greater than median, except for a short period in early June. From the start of 2015 through mid-April, however, the precipitation was similar to 2011 and several periods from late-June through mid-November had significant dry periods. In areas where precipitation is sporadic, it's often difficult to recognize in the moment when drought has begun or ended.

During drought, when transpiration slows, plant water and dissolved plant nutrients do not move about the plant, and the plant is not able to regulate its temperature or shed the excess energy of solar radiation through evaporative cooling. With too much transpiration, plants can't remain turgid and will begin to wilt. When stomata are closed to conserve plant water, CO_2 exchange is impeded and productivity declines. Many perennial rangeland plants, especially those found in the Southern Plains and the Southwest, may enter a period of drought-induced dormancy that allows the plants to persist but will temporarily halt their ability to produce biomass. When soil water returns, a brief period of recovery will take place and the plant will soon return to being productive.

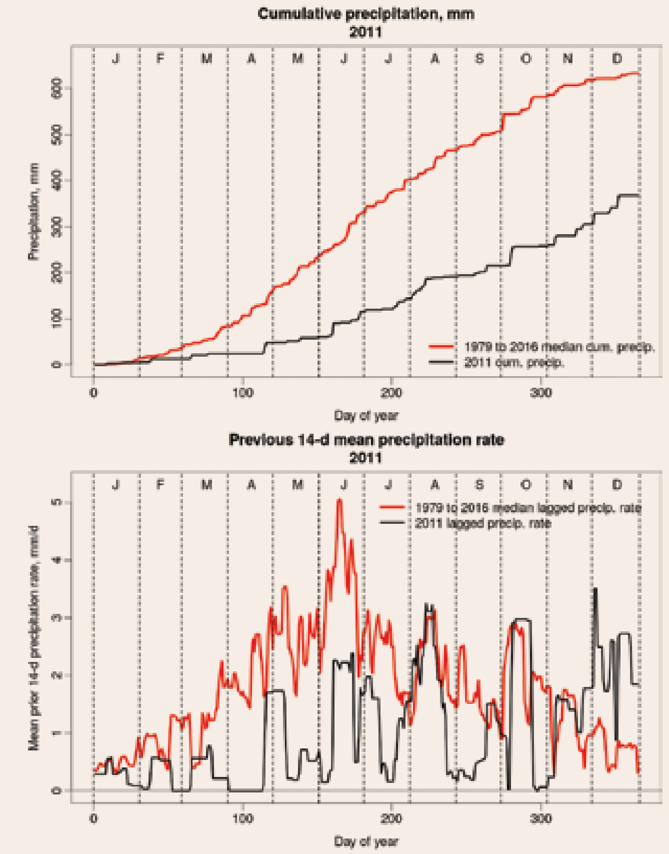
A Rancher's Perspective: Evapotranspiration

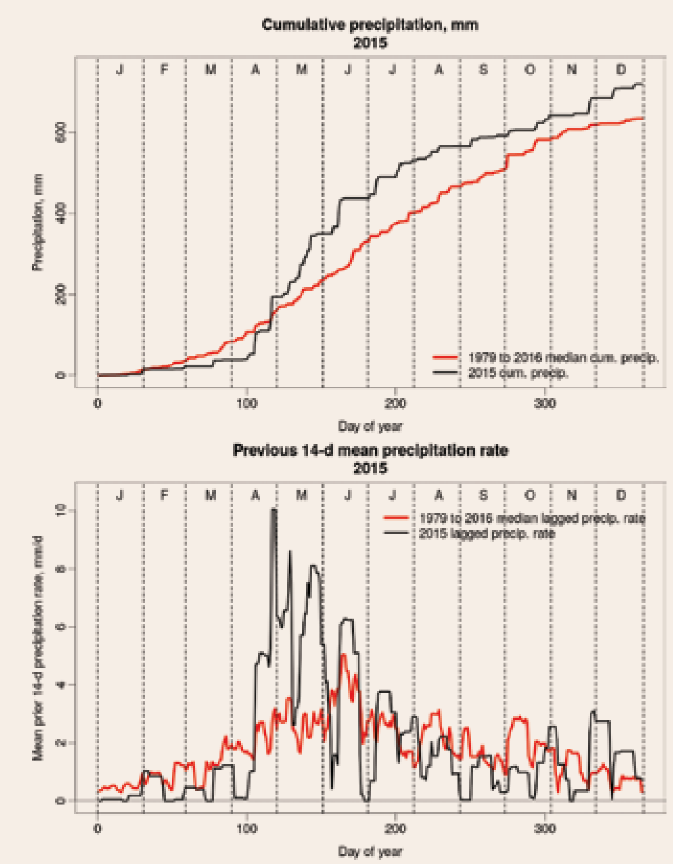
From a ranch management standpoint, precipitation is the engine that drives production. The importance of precipitation is easy to see, but transpiration receives little attention. Transpiration, however, is what engages the engine and PTO or hooks the hitch to the implement to accomplish the goals of the ranch. What can be done to increase transpiration by preferred species today? Nothing can be done. No switch or adjustment can be made to increase transpiration right now. Our understanding of the water cycle makes it clear: The moment for asking this question has passed, but a similar question addressing future transpiration has a more optimistic answer. The answer begs several other questions best addressed at other points in the cycle. Was as much water stored in the soil after the last precipitation event as might have been stored under different conditions? Did management maintain a robust root system of preferred plants throughout the soil, thus ensuring the soil could absorb the rain and minimize deep percolation loss? Did non-preferred plants rob water from preferred plants for lack of control? Has soil organic matter declined in the surface due to management thus reducing the available water-holding capacity? Was less water stored because too much bare ground reduced infiltration rates? Could management have influenced how quickly surface water left the hillslope through overland flow thus limiting the time for infiltration to occur? Did interception by non-preferred plants redistribute the rainfall away from preferred plants? By asking these questions today and making the right management decisions, ranchers can positively impact the amount of water transpired by preferred plants in the future and improve the quality of water leaving the hillslope as runoff.

Rangeland Soil Erosion

Accelerated soil erosion by water is both a cause and a consequence of poor hydrologic function on a hillslope. On a geological timescale, soil erosion is a self-limiting process, continually moving soil between high and low points in the landscape until the difference in height between these points becomes slight. On stable landscapes where erosion is at equilibrium with the soil-forming process, millennia may have passed to bring into balance topography, vegetation and soil conditions with the realities of the geologic parent material and the climate. Well-managed rangelands will mimic the characteristics of these stable landscapes. They do this by providing adequate canopy and ground cover to absorb the energy of raindrop impact and impede overland flow. They minimize runoff volume because high soil infiltration rates have been maintained with good soil texture and abundant macropores. The few exposed soil particles resist detachment because they are well aggregated. The factors responsible for accelerated soil erosion by water are (1) an abundant supply of easily detached soil particles combined with the energy in rain and flowing water to initiate the detaching, and (2) a supply of detached sediment suspended in the flow with an ample transport capacity in the flow.

When a raindrop strikes an exposed soil particle, the kinetic energy from that drop is absorbed by the particle. If that particle is loosely held to other soil particles, the kinetic energy absorbed may eject the particle along with splashed water. Detachment may also occur when flowing water exerts a sheer stress on an exposed soil particle but the stress is too great for the particle to resist. As a result, it is swept into the flowing water. When water flows over the surface of the earth, friction between the water and the surface slows the flow and the surface is under sheer stress. Anything that remains stationary in the water flow will share this stress. When there is no ground cover from plant bases, litter, or rock on the surface, stress is exerted on the soil. The more ground cover in the flow, the less sheer the soil must resist. If the sheer on a soil particle exceeds a critical sheer, the particle becomes detached.





▲Figures 7 and 8: These charts show cumulative precipitation at a location near Woodward, Okla. In the course of most years on ranches throughout the Southwest, periods of both plenty and scarcity make it difficult to recognize when drought has begun or ended. Even in 2011, which was one of the driest single-year droughts in recent history, a period existed in the growing season when precipitation rates were similar to the median. (Source: Derived by the author from the gridMET [University of Idaho] weather dataset)

The stress exerted by flowing water is a function of water depth and slope gradient. In general, flow depth is greater in concentrated flow than in sheet flow and detachment is more likely in these areas. Flow depth increases with distance down the slope as more and more water accumulates, thus concentrated flow detachment is more likely to occur near the bottom of a hillslope than at the top, all else being equal. Canopy and ground cover protect the soil from splash detachment but ground cover is critical for protecting the soil from flow detachment.

Once a particle has been detached, depending on its size, it can move in suspension with the flowing water. If there is no overland flow or the particle is too large and drops quickly out of suspension, the particle may move into a soil crack or pore which, when joined by other particles, eventually results in plugging macropores. Larger sand-sized particles fall out of suspension more quickly than silt and clay. If overland flow does occur, the suspended particle may move with the sheet flow and coalesce with other sheet flow until the flow is concentrated in deeper flow with a greater capacity to transport sediment.

Soil erosion by water is a surface phenomenon that removes the most biologically active and nutrient rich layers of soil near the surface. The effects of accelerated soil loss accrue over time and reduce the soil organic matter content, the concentration of soil nutrients and the soil's available water-holding capacity. The delivery of this detached soil is also a water quality issue in streams and lakes. The suspended sediment increases turbidity and the concentration of nitrogen, phosphorus, and dissolved solids in the water. When detachment occurs on rangeland soils and causes rills to form on the hillslope, these small channels may persist for years to come. Unlike farmlands, these are not—nor should they be—plowed up after they form. The consequence of persistent rills on the hillslope is that sheet flow will coalesce in these rills each time overland flow is generated. These channels will keep the flow more narrow and deeper, thus causing the flow to be more energetic and erosive than if it were slow, spread out and not confined.

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Summary

Grazing lands make up a large fraction of the active surface in the United States and an even larger fraction of the western states where the majority of grazing lands are rangeland. The active surface is where land management activity by mankind and in particular American ranchers have an opportunity to impact the utilization, quantity, quality, and regime of our nation's freshwater resources. While some questions are too specific to be answered in this publication (e.g., What's an acceptable species composition on this hillslope to best improve its hydrologic function?), the principles discussed here are widely applicable. Land managers should identify those things that are outside their control, such as the climate, geology and the topography. They should characterize the impacts of this reality and do their best to develop contingencies that will allow them to preserve their soils, plant communities, livestock genetics and economic well-being. Ranchers should identify the ranch characteristics that can be changed to improve hydrologic conditions and then focus on prioritizing the changes that will have the greatest positive effect for the effort. The greatest targets for improving hydrologic conditions are often woody species invasion, a mismatch between the current and potential species composition, excessive amounts of bare ground, and accelerated erosion. The mismatch in species composition may manifest as a reduction in the extent and intensity of rooting within the soil, a reduction in the mass of the fauna and flora supported in the soil, a reduction in the richness of soil fauna and flora, reduced pore-size distribution, poor soil structure, and reduced soil organic matter content. Good hydrological management is also good ranch management.