COLORADO SOIL HEALTH FUNDAMENTALS

PRIMER 2: DROUGHT MITIGATION

PRIMER 2 SUMMARY

The goal of the Colorado Soil Health Primer series is to demonstrate the core principles related to soil health management as practiced and researched within the boundaries of the State of Colorado. Colorado scientists studying the effects of management practices and the state's farmers and ranchers implementing and measuring the changes on the land participated in this project.

This series is not about instructing the exact tactics a farmer or rancher would need to improve soil health. The individual tactics and strategies must change from property to property — or even field to field — depending on the goals of the land manager, and the available natural and financial resources. This series will give readers the resources to understand and evaluate practical and proven ideas to explore and adapt into a new or existing operation.

This primer is focused on Drought Management and Soil Health, and will share strategies to build soil carbon and biology that can help producers better manage their operations in an era of increased stresses on water availability and quality.

The Colorado STAR program supports soil health practices designed to build systems that create soil armor, minimize soil disturbance, increase plant diversity, ensure continual live plants and roots, and, when appropriate, integrate livestock. These practices, along with a focus on measuring and managing soil biology, carbon and other key elements that hold and store water in the soil, will help producers in the state ensure both their resilience and their continued economic viability as development and population pressure causes increased demands on the available water.

"The push in Colorado is to increase the size of the bucket of water being stored in soils," said Jim Ippolito, a soil scientist at Colorado State University. "That's the soil health spin. We live in an area of prolonged drought. We want to make every drop of water go a little bit farther."

Trends suggest Colorado's resident population will double over the next 3 decades, reaching about 8.6 million to 10 million people by 2050, and it has been estimated that the state will need approximately 600,000- to 1-million more acre-feet of water per year to meet demands. This wouldn't be a problem at the state level, but the conflict inherent in our state water supply is concentrated around where people live, where we farm, and where the snow falls. This statistic tells it all: Eighty percent of our state population and the majority of irrigation needs are east of the Continental divide, while 80 percent of the surface water resources flow to the west.

▲ *Source: Colorado Department of Agriculture and Flip Dalfonso*

COMMON TERMS

Cover Crops: The act of keeping the ground covered and maintaining living roots are two principles of soil management, and cover crops are a key tool to help farmers transition and measure the gains.

Pasture: Fields for grazing, wildlife passage or soil remediation are common across the state of Colorado.

Soil Biology: The life in the soil, from the smallest microbes to earthworms and dung beetles. The biology is responsible for helping break down organic matter and turning it into available nutrients for your crops.

Soil Chemistry: The ratios of elements in the soil are important and go beyond N-P-K.

Soil Health: The concept of maximizing an ecosystem's ability to feed soil microorganisms, leading to efficient nutrient cycling and turnover, which creates more nutrient availability for plants, increases soil water storage, and improves ecosystem sustainability and resiliency.

Soil Testing: The process of quantifying certain attributes of soil, including macro- and micro-nutrients, soil organic matter, cation exchange capacity, soil biology, water and/or air.

NRCS: The Natural Resources Conservation Service.

Source: Jim Ippolito & Megan Machmuller, Colorado State University

USDA-NRCS Soil Management Principles

1. Limit disturbance
2. Keep soil covered
3. Strive for biodiversity
4. Maintain living roots
5. Integrate animals

▲ One of the primary goals of Colorado's STAR system is to help farmers and ranchers find management tactics for naturally storing water and avoiding unnecessary evaporation or runoff. *Source: Colorado Department of Agriculture and Jill Yarberry*

Agriculture, including watering crops and livestock, account for approximately 80 percent of Colorado's annual water usage from surface streams, and 20 percent of the withdrawal from groundwater.

According to Colorado State University, agriculture in the state uses about 4.7-million acre feet of the state's 5.3-million acre feet of total consumption. A certain percentage of groundwater and surface water withdrawal returns to surface water flows, and some water returns to the local watershed. The type of water use that returns water back into the hydrological cycle is called non-consumptive. Uses that permanently remove water from the system are called consumptive. Current Colorado water usage practices allow 8.4-million acre feet of water to flow out of the state through Compact obligation to other states.

The question then becomes, how to divvy up that water. Andy Mueller, general manager of the Colorado River Water Conservation District, explains: the state doesn't regulate water rights based on type of use. In other words, it doesn't state a preference for agricultural use over municipal use, or vice versa. Changing the use of a water right requires a long, legal process, and a water market in the state helps dictate the value and sales volume for water rights each year. That said, there are limitations on how many agricultural water rights can be sold each year, Mueller said. He added that conservation planning needed to become standard in all areas, rural and urban. He suggested more urban incentives like land-use codes and lawn restrictions, along with agricultural conservation practices.

As urban areas expand outward into suburbs, bedroom communities, and satellite towns, irrigated acres are expected to decline by 15 to 20 percent by 2050. In the semi-arid landscape of Colorado, irrigation has seemed a necessity for farmers looking to produce a certain yield. These developments will put more pressure on farmers to find new grow systems for capturing and storing water as it becomes more expensive, and as more of it is diverted to municipalities.

Water Management in Practice

On agricultural lands, a farmer or rancher's production goals drive the amount of water use, especially if an operation is multifaceted, or as Jared Kerst a fifth-generation farmer puts it, "blessed."

Kerst owns and operates Rivendell Farms, a regenerative sod farm, and Plus Lazy K, a holistically managed beef operation in the Spring Valley of Glenwood Springs, which lies near the confluence of the Colorado River and the Roaring Fork River along the Interstate 70 corridor. His operation primarily uses groundwater for irrigation and crop watering, and as Kerst put it, "Our farm is blessed with an amazingly stable artesian spring." That base of water provides a majority of the farm's water and helps shield the operation from the drought's most severe impacts.

"Despite this advantage, it is always a challenge to effectively manage the water cycle, especially with depleted soils,"Kerst said. "Much of our irrigation is facilitated by diesel-powered pumps along a ditch and pond system that is very much in focus as a potential area for efficiency improvements."

Whether an operation utilizes groundwater or snowpack melt, the tactics these farmers and ranchers are using to manage their soil are directly connected to their goals of managing scarce water resources. Drought mitigation strategies are a key element of the Colorado Department of Agriculture's goals for the Saving Tomorrow's Agriculture Resources (STAR) program, which encourages farmers and ranchers to volunteer to receive incentives for specific, conservation-minded practices.

Megan Machmuller, a soil scientist at Colorado State University, is helping develop testing systems that track water-retention results in the STAR program.

"With our data, we can then say with the implementation of this practice, we see X amount of savings in irrigation water, and reduction in water, and X percent increase in water-holding capacity," Machmuller said. "Even if you're not irrigating, your soil can hang onto water this much longer. It can hold X gallons more than the usual business scenario."

Nathan Raymer and his family farm have seen the results from employing some of those tactics, like decreasing tillage. They grow about 5,000 acres of wheat, millet, and milo in the New Raymer area, which is situated in the northeastern plains. He says in his experience, he's seen tillage decrease moisture, so he shies away from using it.

"You lose between a quarter to half an inch of moisture between each tillage pass," he said. "We do it if need be, depending on the situation, but that's kind of a last ditch effort."

The dry stretch of 2021, when the state saw very little precipitation between July and December, hit hard on the Raymer farm.

"Our production was basically cut in half this year from what it typically is," he reported about his wheat fields. "We're just kind of rolling with the punches. In a really good year we have 60- to 70-bushel potential, or even higher, but that's seldom. Year in, year out, with decent rainfall, we can expect 50-bushel wheat consistently. On the millet side of things, it's essentially birdseed, in good years we can raise 50- to 60-bushel with the millet; in recent years with the drought we've been raising a lot of 20-bushel millet."

Daniel and Hana Fullmer run the Tiera Vida Farm, a two-acre diversified operation in the Mountain Region near the Florida River, between Durango and Bayfield in the southwest corner of the state. Their soil management systems are helping maximize the benefits of an irrigation ditch connected to the Florida River system, a 62-mile long tributary of the Animas River that flows from Lillie Lake in the 500,000-acre Weminuche Wilderness.

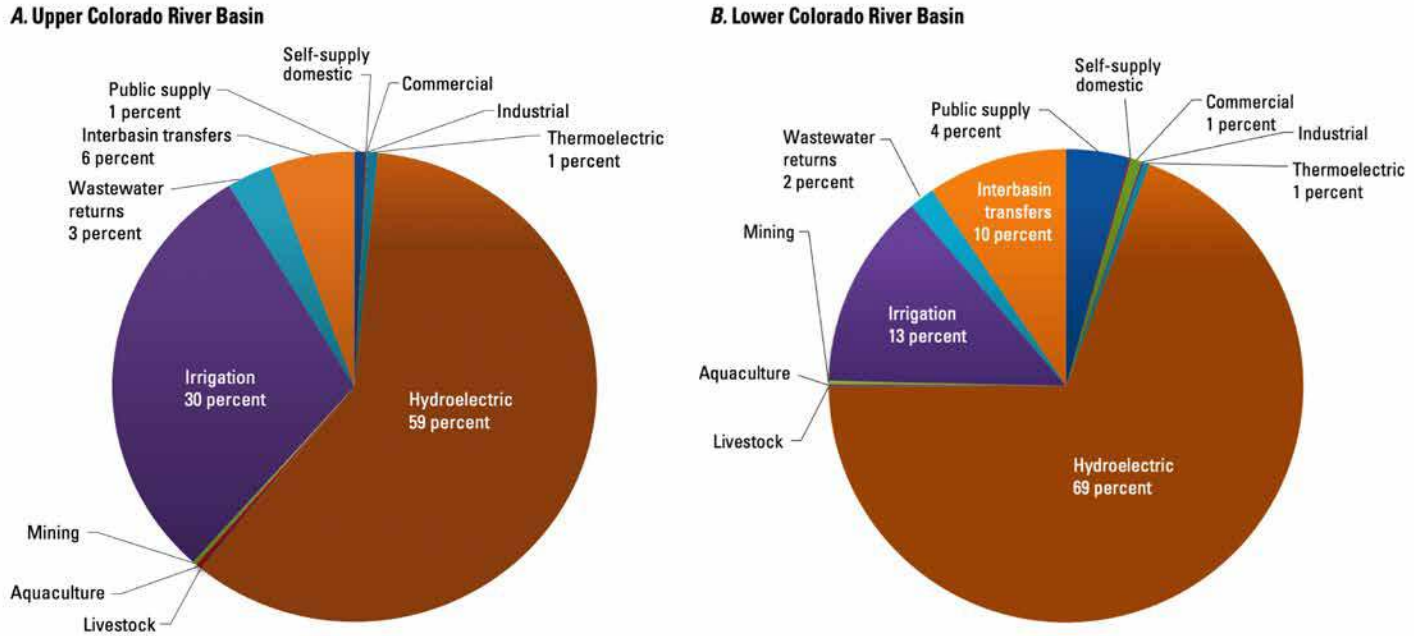
Since 2015, they have been building soil on their farm from the ground up using regenerative methods, including these five essential growing practices, namely:

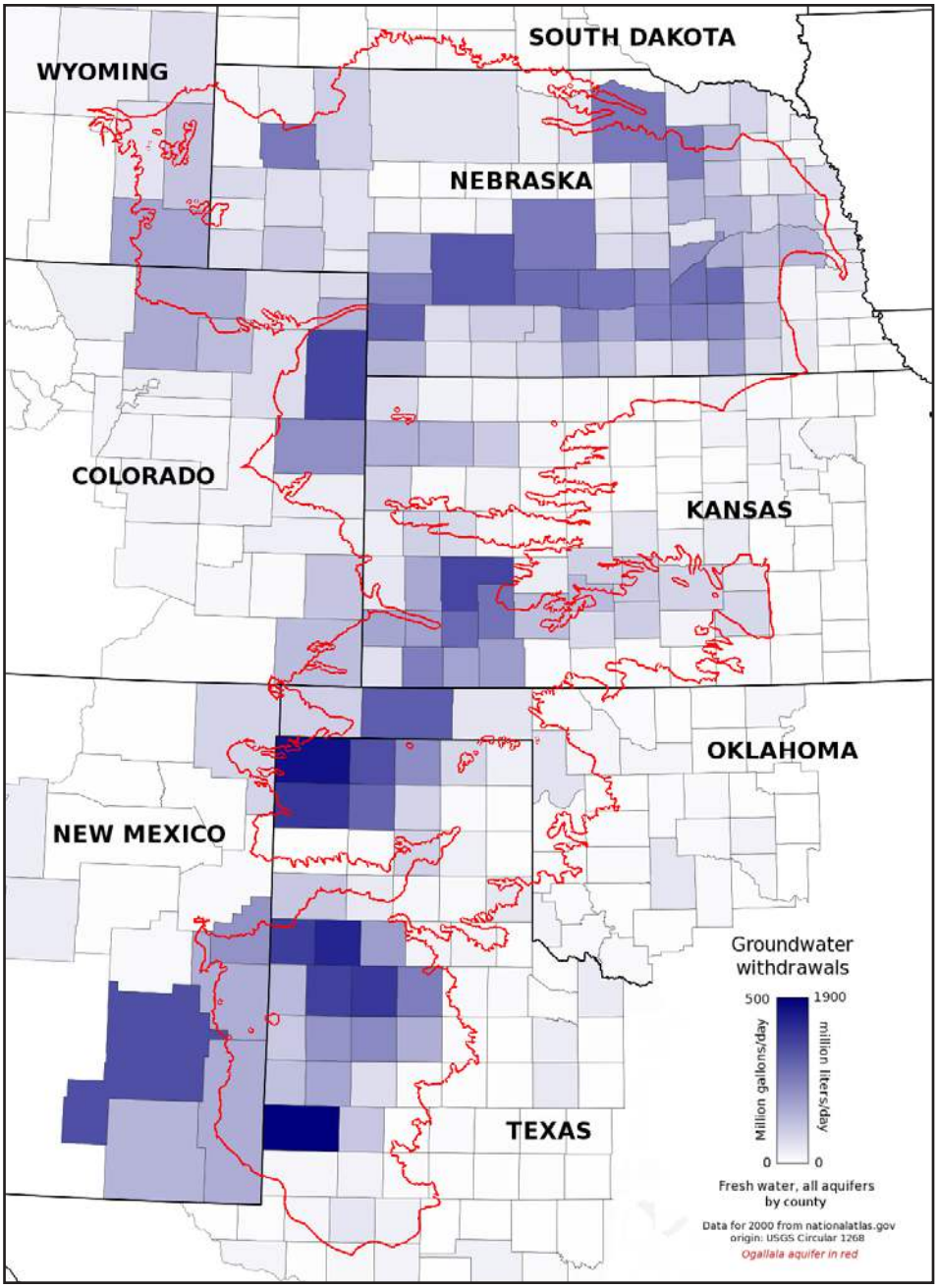
- Minimize soil disturbance;
- Cover the soil;
- Diversify their crops;
- Maximize photosynthesis/maintain plant roots, and
- Integrate animals.

"Our irrigation ditch fills a pond that we rely on to make it through a farming season," Fullmer said, adding, "The vegetable production area is small enough that we can always manage, but in the drier years establishing a cover crop later in the season can be difficult without the river water."

While crops can be grown using the area's 20 or so inches of annual precipitation, Fullmer noted that, "When we use less water, we get less soil and plant performance. An uneven rye and vetch crop germination in the fall due to insufficient water results in more exposed ground — and less feed for and impact from chickens in the spring. The reduced root development

▼ Percentage of total estimated water withdrawals by category, interbasin transfers, hydroelectric power use, and wastewater returns for the upper (A) and lower (B) Colorado River Basin, Southwestern United States, 2010.





▲ The most recent data available showing use of the Ogalalla Aquifer, which supplies the eastern part of Colorado water for agriculture. *Source: Wikipedia Commons*

and chicken fertilizer provides less soil `building, less water retention, and lower cash crop yields."

Fullmer thinks that the wise use of water resources is a crucial aspect to both production and conservation on any landscape.

"In my experience being able to use more water in our system would create better results for conservation," he said. "More water allows for more root growth, more animal impact, creating better plant growth which covers the soil, improves infiltration, retention, and cycling of water. This is a virtuous cycle that is either sped up or inhibited based on water availability."

Many farmers in eastern Colorado depend on the Ogalalla Aquifer for irrigation, which underlies some of eastern Colorado and much of the other High Plains states. Unfortunately, as irrigation pumping rates have increased, this critical resource has declined significantly.

According to the United States Geological Survey (USGS), in some areas of Colorado the Ogalalla Aquifer has dropped 50 to 150 feet, while areas east and south in Kansas and Texas have seen decreases of more than 150 feet. The USGS reports that the average drop for the resource as a whole is around 15 feet. This aquifer is crucial to the region for both agricultural and residential use. For producers, reduced water resources can lead to thirsty crops which can then be crowded out by more vigorous and tenacious weeds.

Practices that Increase Drought Resilience

The first principle of the STAR program is " Limit Soil Disturbance," using NRCS practices that reduce tillage. When farmers till, they turn up the soil and create temporary soil deserts, even if only for a few days or weeks. Surface water and wind can erode these temporary deserts. Moisture is lost from the surface in evaporation, and drops into the aquifer if there are no plants to keep the moisture at the surface.

The increased salinization of cropland is a big issue in arid regions. To understand why, it is helpful to remember that the saline content of the world's oceans is contributed in part by millions of years of stream erosion. This erosion contributed toward the accumulation and deposition of minerals and salts eroded from river rocks by collected rainwater (which is slightly acidic), carried along by rivers in solution as ions. These ions mostly consist of sodium and chloride, which together make sodium chloride, or table salt. The accumulation of these ions in floodplains or fields can lead to salinization of the soil.

In climates where there are high annual evaporation rates and low annual precipitation rates (as well as restricted soil drainage), lowland fields accumulate these salts. This is a common occurrence in Colorado and other states with similar geographic

features, like California. For example, an estimated 250,000 acres have been removed from production because of high salinity soils in the San Joaquin valley of California, along with a further 1.5-million acres that are potentially salt impaired.

The second principle of the STAR program is "Keep Soil Covered." The use of cover crops is a strategic step producers can take to improve soil health. Which cover crops to introduce will vary by location as well as a range of individual factors, from equipment and labor availability to market opportunities. For a detailed discussion of the use of cover crops, please refer to Primer #3 in this series, Cover Cropping.

The third STAR principle is "Strive for Plant Diversity." In our modern agricultural systems, farmers are trained or taught to utilize only a handful of species in their crop rotations. One often-overlooked feature of using a multi-species mix is the multiple soil horizons that various species' roots access, and the water that these species pump back up to the surface or help hold in suspension in the interstitial matrix of the soil crumb.

The fourth principle is "Maintain Living Roots." As already noted, living plants and roots are two of the primary reservoirs of moisture in an arid or semi-arid climate. Plants are essentially water pumps that very slowly move water from the ground into the air via the process called "evapotranspiration." The water that is trapped via surface tension in the soil is the main source of water for plants, and the areas around their roots become fertile ground for the proliferation of fungi, bacteria, microorganisms, nematodes, protozoa, and the larger invertebrates, such as worms and spiders. When water is trapped on the surface through compaction or poor soil management, the rate of evaporation skyrockets and becomes unavailable to the plants and soil life.

These fertile zones accumulate soil organic matter (SOM), which is composed of small organic molecules like bacteria, fungi and other plant exudates that can stick to the surface of clay particles. In this way soil aggregates are formed, and are the active agents that store water and sequester carbon. These soil aggregate particles form a film, which allows water to enter the soil around them, and holds it there to make it more available for our crops. When management practices destroy this organic matter and biological systems with tillage or heavy use of inputs, the ability to trap and store water decreases. Although the numbers are debatable, scientists estimate that a 1 percent increase in soil organic matter can help soil hold an increase of around ~27,000 gallons of water per acre. While this may not be perfectly accurate, the basic concept holds true: more soil organic matter, more chance for water storage.

"Carbon is the driver, and carbon is the energy source for microorganisms," Ippolito said. But they need energy to do it — they get energy from carbon and you have to feed them."

Soil organic matter can provide between 20 to 80 percent of a soil's cation exchange capacity — or potential energy — depending on the soil type.

The fifth principle is "Integrate Animals." While modern farming techniques tend to rely heavily on synthetic weed control and fertilization, livestock can play an effective and harmonious role in these efforts as well.

On Daniel Fullmer's farm, they consider their flock of chickens to be an essential component of their weed elimination and fertilizer integration system; they see it as a unified whole.

Livestock trample vegetation, creating micro-pockets of living mulch that help keep dust down and reduce erosion. The trampling of vegetation is a livestock benefit to grasslands, and can help reduce wind and water erosion while applying fertilizer in the form of nitrogen rich manure to the landscape.

Many if not all of these principles

▲ Water is money in the West, and wasted water from a soil's poor drainage quality can cost the farmer. *Source: Colorado Department of Agriculture and Shelby Chesnut*

can be applied through the practices of agroforestry, silvopasture, or alley-cropping.

Many producers also implement other strategies to improve "Soil Armor," which involves using NRCS conservation practices that protect soil from wind and water erosion, and evaporation from high temperatures. Erosion continually moves soil particles downhill or across a field, and so makes it difficult for plants to take root. Any protection from erosion — the armor — is better than nothing. This includes perennial and annual strips of vegetation such as windbreaks, alley-cropping, and contour farming.

A system of perennial crop rows planted on contour, such as elderberry, cherry trees, hazelnut bushes, or other fruit or nut tree or shrub, provide a continuously growing perennial crop that can be used in a production system or by livestock. Within those rows of continuous ground cover via trees or shrubs, a producer can grow other perennial or annual crops and/or graze animals, depending on the goals of the producer. This, in a nutshell, is the perennial system of agriculture that nonprofits like the Savory Institute in Boulder help institute around the world.

Grasses and grazing play a large role in the highlands of the state. Managing grass requires planning and goal setting on a continual basis, largely based on water and grazing pressure. Jared Kerst operates his farm with livestock integration systems and has goals to be completely regenerative with his operation.

By implementing some of these innovative practices that draw on the inherent water-conserving biology of perennial plants, producers in Colorado can better weather changes to the future availability of water for agriculture.

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The Colorado Water System

The three major rivers in Colorado are the Rio Grande River, the Colorado River, and the Arkansas River. The 1,450-mile long Colorado River is arguably the most important river in the state. It begins high in the central Rocky Mountains and flows across the Colorado Plateau before it leaves the state and travels through the Grand Canyon and several southwestern states, ultimately finding its way to the Gulf of California and emptying into the Pacific Ocean. The Colorado River basin provides 40 million people with a source of water — about 12 percent of the U.S. population — including about five million residents of Colorado.

The Colorado River begins at La Poudre Pass Lake near the Grand Continental Divide in the Rocky Mountain National Park. Due to its steep gradient and large flow, this river has been heavily dammed to generate hydroelectricity, and is a major source of water for reservoirs and aqueducts. Even near its source, this water resource has been diverted via the Grand Ditch east through the La Poudre Pass in order to irrigate farmlands.

The Colorado River and the surface waters that flow through the semi-arid climate of Colorado are highly regulated. These regulations began during the California Gold Rush of 1848, when miners began to dig drainage ditches and appropriate river flows for gold mining. These practices migrated from California northeast into Colorado and surged during the gold rush of 1859. An intricate system of surface water regulation in the state became known as the Doctrine of Prior Appropriation, or the Colorado Doctrine.

Water rights in Colorado are established dependent on when they are first put to beneficial use, i.e. the seniority of their origination. These rights are based on the date, location, and amount of water withdrawn from the resource, as well as the use of the water. Water is considered to be the private property of the right's holder. If a senior water rights holder puts out a "call" for a certain amount of water, an upstream junior holder of rights must forfeit their allocation until the senior holder's allocation is met. Any water project in the state must go through a lengthy and complex process of regulation and paperwork in order to establish that there is unappropriated water available for use.

In Colorado, most major streams are considered to be over-appropriated, meaning that in wet years every drop of water that runs through the state's rivers has been appropriated, while in dry years only senior rights holders have the ability to withdraw and use water.

As an example, Xcel Energy's Shoshone hydroelectric dam on the Colorado River holds a senior water right to a certain allocation of water, and when they put in a "call" to the state water engineers, junior water holder upstream are required to let the water that flows in their ditches to pass through until Xcel's allotment is fulfilled.

Agriculture in Colorado depends in large part upon these water rights and consumes about 80% of the available surface water resources. The state's producers rely on precipitation in the form of snow for the majority of these surface waters.

The Colorado River and its tributaries supply the largest portion of surface water in the state. "... the state only consumes between 1.5 and 2.5 MAF [million acre feet] of Colorado River water total for all water user sectors annually," said Andy Mueller, general manager of the Colorado River District. "That being said, agricultural users in many basins in the state consume water from the Colorado and/or its tributaries. Specifically, the Yampa, White, Green, mainstem Colorado, Gunnison, San Juan, and Delores are all tributaries of the Colorado River and have significant agricultural operations. Agricultural users in the South Platte, the Arkansas, and, to a lesser degree, in the Rio Blanco River all utilize Colorado River water for their agricultural production."

The 1922 Colorado River Compact allotted half of the approximately 15-million acre feet of the river's flow to the upper states of Colorado, Utah, New Mexico, and Wyoming, and half to the lower states of California, Arizona, and Nevada. Later revisions increased the lower basin allotment by another million-acre feet to 8.5 million acre feet, and set aside 1.5 million acre feet for Mexico. The assumption was that the Colorado River would flow with an average of 18-million acre feet a year.

However, even in the early 20th century, William L. Siebert, who was chairman of the Colorado River Board in 1928, noted that, rather than the presumed 18-million acre feet, the river probably flowed between 10 and 14.5 million acre feet in an average year. And in fact, water scarcity in the Colorado River Basin became apparent very early on after the Compact was signed.

This and other water negotiations also neglected to include the thirty or so Native American tribes that held rights to the water as well. The states eventually acknowledged the tribes' water rights, and the tribes essentially now hold the balance of whatever water rights remain unallocated.

Climate Change

A recent study in the Proceedings of the National Academy of Sciences notes that climate change will make predicting water resources for the region more difficult. Lead author William Wieder, a scientist at the National Center for Atmospheric Research, says that "Water managers will be at the whim of individual precipitation events instead of having four-to-six months lead time to anticipate snowmelt and runoff."

The drought that began at the turn of the 21st century is still ongoing. The lines of supply and demand of the Colorado River crossed paths in 2000. A 2013 report from the U.S. Bureau of Reclamation notes "the Colorado River Basin faces a range of potential future imbalances between supply and demand. Addressing such imbalances will require diligent planning and cannot be resolved through any single approach or option."

One of those important approaches to water conservation is through agriculture, the single largest consumer of water in the region.

Allan Andales, professor and extension irrigation and water science specialist at Colorado State University, said that even agricultural use may be reduced under severe drought.

"Because many farms and ranches in

eastern Colorado were among the first to beneficially use water, many of them have senior water rights," Andales said. "During drought, senior water rights holders are given priority in water allocations. Junior water rights get reduced water allocations or none, depending on current water supply. However, even senior water right holders can get reduced water allocations under severe drought conditions."

Andales goes on to note that development along the Front Range can impact water use: "Growing cities along the Front Range see farms and ranches as reliable sources of water, so there is a trend of decreasing irrigated farming as a result of 'buy and dry' transactions. To sustain irrigated agriculture and minimize 'buy and dry', Colorado has been exploring and piloting alternative transfer methods."

Agriculture in the Colorado region has historically been dependent on the water resources provided by snowpack, which are the dense layers of snow that accumulate over the winter and melt slowly throughout the spring and summer, nourishing rivers like the Colorado with their water.

Scientists say that by the end of the century - as long as greenhouse gas emissions stay high - there may be as many as 45 more snow-free days in the northern hemisphere each year. Agricultural producers rely on this snowpack for livestock and crop production, so implementing the soil health strategies outlined in this primer can help increase future resilience as this already maxed out resource is stretched even thinner.

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The STAR program was originally developed by Champaign County Soil and Water Conservation District (CCSWCD) in Illinois and is now also administered in four other states: Colorado, Indiana, Iowa, and Missouri. The Colorado STAR Plus program grew out of a stakeholder process launched by the Colorado Department of Agriculture and other partners in 2019 that was facilitated by the Colorado Collaborative for Healthy Soils, involved more than 250 stakeholders and resulted in passage of HB21-1181 and SB21-235, which authorized and funded the launch of a state soil health program based around STAR. This state stimulus funding and additional grant funding received from the Gates Family Foundation, Colorado Department of Public Health and the Environment, Colorado Water Conservation Board, NFWF, and NRCS have enabled the launch of the first round of the STAR Plus program.

Getting Involved with Colorado STAR

In the summer of 2021, legislation was passed in the Colorado House of Representatives funding the Agricultural Soil Health Program for 2022. The Colorado Soil Health Program is built around the framework of an Illinois program called STAR, which stands for Saving Tomorrow's Agriculture Resources. STAR was developed to be a free resource for farmers and ranchers, helping them evaluate their current land practices, and particularly focusing on nutrient and soil loss. The STAR program encourages best soil health practices, and rewards producers with recognition, a high rating, and a field sign. While the STAR rating system is a useful metric for farmers to measure their own conservation efforts, it is also a tool for consumers interested in a farmer's soil health practices.

The program was originally created in the Champaign County Soil & Water Conservation District in 2017, with the assistance of the Illinois Department of Agriculture, as a means to facilitate specific environmental and agricultural goals that were outlined in the state's Nutrient Loss Reduction Strategy. Colorado, as well as Iowa and Missouri, have adopted this program framework.

Best management practices for agricultural land use have been developed since the 1930s by the United States Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS). The STAR program utilizes these best practices, and also relies on a panel of experts, including university researchers and scientists, to establish appropriate ranking systems based on different resource factors. STAR Plus is an additional level of producer support that "facilitates capacity building by providing matching state funds towards the cost of these projects and activities within each district". This means that the state provides technical and financial assistance to producers over the course of three years, through grants and services like soil testing that are facilitated through the state's conservation districts.

Any farmer or rancher can visit the STAR website and fill out these forms in order to receive this rating. The first 100 participants in a year also receive a free soil test.

To participate, the only requirement is that the farmer or rancher fill out a form to the best of their knowledge, describing their farm practices in detail for a specific field chosen by the producer. The forms include questions about cropping practices, tillage regimes, fertilizer and nutrient applications, and other management practice information. The producer then receives a STAR rating from 1-5 that demonstrates their incorporation of the five principles of STAR: Soil Armor, Minimize Soil Disturbance, Plant Diversity, Continual Live Plant/Root, and Livestock Integration in their cropping system. Earning five stars in a field means that a farmer or rancher is implementing all five soil health principles on that field, while earning one star means that they are following only one.

COLORADO Department of Agriculture Conservation Services Division

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SAVING TOMORROW'S S.T.A.R. AGRICULTURE RESOURCES