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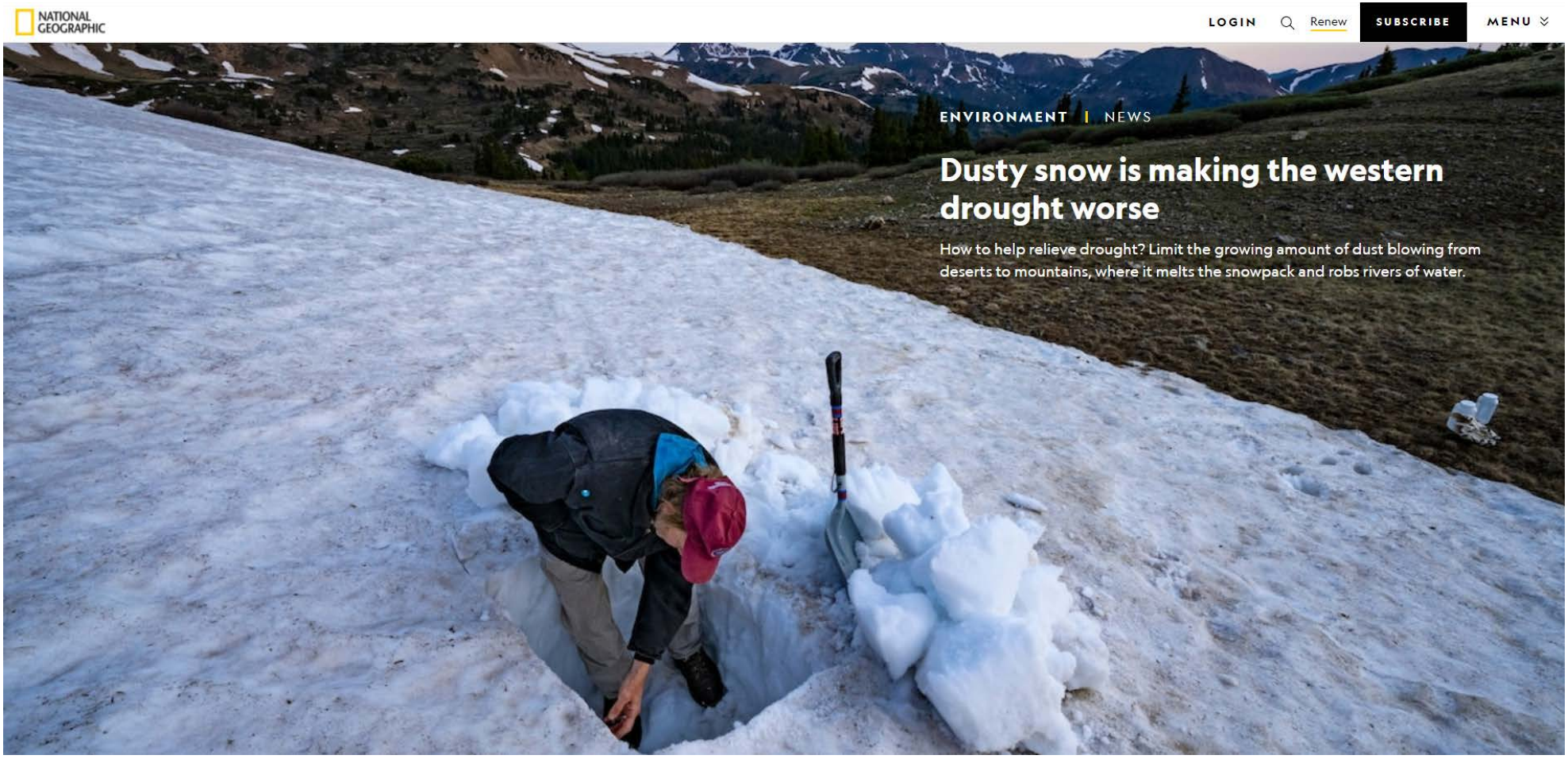

At about 12,000 feet on Colorado's Loveland Pass, dirty snow patches melt into the river water. Jeff Derry, with the Center for Snow and Avalanche Studies, takes samples of dust on snow.
PHOTOGRAPH BY PETE MCBRIDE

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LOVELAND PASS, COLORADO — Hydrologist Jeff Derry thrusts a shovel into one of the season's last snowfields on the jagged granite flank of the Continental Divide. He's looking for something specific: dust.

Standing thigh deep in an icy pit at 11,000 feet above sea level, Derry scrapes his square blade across the dirty snow and dumps its contents into a 1.5-gallon plastic jug. Geologists will analyze the dust to determine its mineral content and pinpoint where it came from—in this case Mexico's Chihuahuan Desert, carried by a historic blizzard a few months earlier.

Aerial images taken from 14,000 feet show dirty snow across the Elk Mountains, part of the Colorado River system that supplies water to 40 million Americans.

Left: This hydroclimate station collects a variety of snow data that helps scientists determine how much water the dusty snow will produce, like barometric pressure and snow depth.

Right: The rare instruments—until recently there were just three in Colorado—measure incoming and reflected solar radiation.

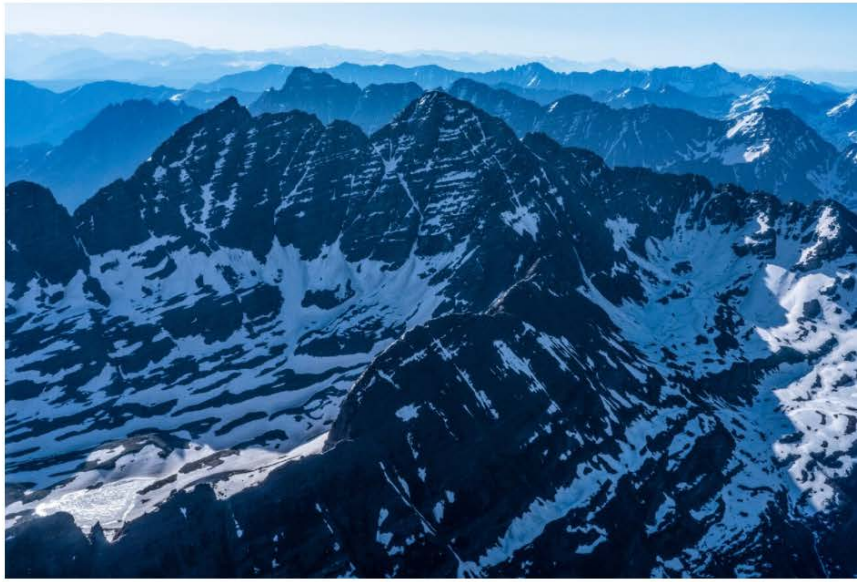
"I'm the snow guy who finds himself talking about the desert a lot," says Derry, who directs the largest high-elevation network of dust-on-snow monitoring sites in North America, headquartered about 300 miles southwest of where he stands. "There aren't many things we can do to tweak the supply side of our water, but one of them is mitigating dust to keep snow around on the surface longer."

Worsening drought in the West's deserts contributed to a heavy dust season on Colorado's Loveland Pass this year, and the tea-colored snow shows it. Soil intermingled with ice crystals fell here on four occasions this spring. Subsequent storms buried each layer of dust particles under new snow. As the air warmed and the days grew longer, the snow melted and by June, the layers had combined at the surface.

Snowfields covered in dust across the Rockies don't just mar scenic views. The dirt acts like a blanket; the snowpack, no longer white, absorbs heat from the sun, melting more quickly and up to six weeks earlier than it would if there were no dust. Forty million people in the Colorado River Basin rely on sustained snowpack for drinking water and to irrigate 5.5 million acres of agricultural land through the hot, dry summer.

Evaporation from early runoff also robs the Colorado of 250 billion gallons of water each year—enough to supply the Los Angeles region for more than 12 months. This situation represents a tantalizing opportunity for scientists like Derry: figure out how to get rid of the dust and add water back into a river system staring down its first-ever shortage, which means less water for communities in the river's lower basin states, including Arizona and Nevada.

Reading the snowmelt



Left: The dust deposits, carried onto the mountains with snowstorms, speed up the snowmelt and reduce the Colorado River's flow.

Right: A layer of wildfire smoke from early-season wildfires lingers across the Elk Mountains.

Derry takes samples of dusty layers from a snowpit.

Water managers along the 1,400-mile Colorado River system turn to Derry for accurate forecasts of when water will come gushing out of the mountains in the spring and how much will be available to fill reservoirs.

His work at the Center for Snow & Avalanche Studies, in Silverton in southwest Colorado, is drawing attention as the American West endures the twenty-second year of the worst drought in about 500 years. The intense and widespread dry spell defies historical records and leaves meteorologists and water managers at a loss for how to predict the future. Scientists argue that the West is now experiencing "aridification"—a

Scientists argue that the West is now experiencing "aridification"—a permanent transition to an "increasingly water scarce environment."

Water managers in the Colorado River's lower basin, among the last in line to receive snowmelt, are eager for more precise information about how dust affects water availability.

"Every indication is next year we will go into a first year of shortage in the Colorado River," says Mohammed Mahmoud, a senior policy analyst at the Central Arizona Project, which supplies water to 80 percent of the state's residents.

"When our system is so close to thresholds that affect how much water is delivered, things like dust on snow absolutely become a big deal," he adds.

The western United States is becoming steadily more arid as climate change extends droughts, and that is preventing deserts from recovering from oil and gas development, grazing, and off-road vehicle use that destroys soil crusts and plants that anchor dirt. All those things intensify

destroys soil crusts and plants that anchor dirt. All those things intensify erosion and led to a 60 percent increase in dust storms in the last two decades to 48 per year. Some storms drop dust from the Great Basin and the Colorado Plateau on snow in the Rockies, coloring it red, pink, or brown.

Water managers are donating funds to Derry's efforts to quantify the impacts of dust on snow. They hope to shore up a precious resource in a Colorado River system that faces "an impending water supply crisis," according to the Center for Colorado River Studies.

"This is an urgent problem," says Jeffrey Deems, a research scientist at the University of Colorado, Boulder and co-founder of Airborne Snow Observatories, Inc., which uses instruments mounted in aircraft to inventory snow depth, water contained in snow, and how dust affects snowmelt.

"We had plenty of dust this year and the early snowmelt could have been delayed if the dust wasn't present," adds Deems. "That can make or break some water systems— we're already looking at the Dolores River [a tributary of the Colorado River] running dry."

The Rockies aren't the only place where dust impacts water availability, causing economic and ecological ripple effects that include less water for farmers, as well as endangered fish. Particles blowing off the fast-drying Great Salt Lake accelerated snowmelt in Utah's Wasatch Mountains by about 25 percent in 2017, imperiling the state's $1.4-billion ski industry and Salt Lake City's water supply, scientists found. Dust from the Saharan desert last May turned snow in the European Alps orange.

In Colorado, Derry's nonprofit studies how a changing climate affects snow systems. As part of this work, he and his staff visit 11 high-elevation sites around the state at least three times between mid-March and May, when most dust events occur. At each location, they dig deep snowpits all the way to the bare earth. They measure the amount of water in the snow, mark dust layers that punctuate the pits, and incorporate data from weather forecasts to predict how dust is likely to influence snowmelt timing and rates during the runoff season.

Dust likely forced snow to melt early at the center's Grizzly Peak site, down the hill from the Loveland Pass snowfield, according to Derry. Standing in an alpine meadow here surrounded by wildflowers, Derry removes his faded red ball cap and rubs his head as he explains how he correlates data from his sites with information from nearby Snow Telemetry, or Snotel, stations operated by the U.S. Department of Agriculture's Natural Resources Conservation Service.

Dangers of early runoff

Downstream from where Derry stands in above-the-ankle leather boots, the Snake River burbles through heavy shrubbery. The icy waterway feeds Dillon Reservoir, part of a system operated by Denver Water that serves 1.5 million people. Nathan Elder, the system's water supply manager, uses NRCS's information and Derry's snowpit observations to make decisions with long-term consequences.

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"If you get an early runoff because of a high dust-on-snow year, you have to capture that water sooner and that means you will start draining your reservoir sooner and you will go into the following year with less water," Elder said, referring to runoff historically seen in late May or June, now coming in April or May.

Outside Las Vegas, Lake Mead, the nation's largest reservoir, now sits at a record low 35 percent full, or 1,068 feet above sea level. A shortage will be declared in the lower Colorado if water levels in Lake Mead dip below 1,075 feet above sea level. Laws governing Colorado River use require mandatory cutbacks in Arizona, Nevada, and Mexico if such a deficit is forecast in August for January 1.

For farmers in the arid Southwest, earlier runoff caused in part by dust blanketing snow means reduced crop productivity because little to no water is left in rivers during hot summer months.

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"The dust on snow complicates our lack of supply," says Cleave Simpson, a fourth-generation farmer in southern Colorado and general manager of the Rio Grande Water Conservation District. "We're getting less from irrigated hay meadows we're using to put up hay to feed cows through the winter—if they don't produce, we have to buy hay, which is expensive because most of the West is in a drought."

Two hundred miles to the northwest, scientists who conduct experiments in Derry's most intensively used site, the Senator Beck Basin above Silverton, are working to answer the many unknowns about how dust affects water availability. What they find at the 12,180-foot study area will have worldwide implications.

In snowpits at the 720-acre site in the San Juan Mountains, researchers are trying to better measure the amount of water contained in snowpack and to understand what particles are contained in dust and how they absorb solar radiation to speed snow melt. Ultimately, they hope to incorporate such measurements into hydrologic models to better predict the timing and rate of snowmelt.

Mitigating the dust

"It is totally detective work," says Rich Reynolds, a senior scientist emeritus at the United States Geological Survey, who analyzes Derry's samples in an effort to link dust to the region's deserts based on grain size and mineral content.

"The thing that stunned me in looking at some of these data recently are the variations in dust composition from year to year and place to place," he adds.

Scientists are trying to discern what causes this variability. Using satellite data, they surmise dust coating Colorado's mountain ranges frequently originates on the Colorado Plateau, south and west of the Rockies. The Four Corners region, where Utah, Arizona, New Mexico, and Colorado meet, is the epicenter of the current drought.

Deserts like the plateau are not naturally dusty. Most of the area is owned by the federal government, which is required to allow multiple uses like drilling, grazing, and recreation. Soil scientists are working to quantify which activities produce the most dust.

"There is an opportunity to reduce dust coming off the Four Corners, but it's going to be very challenging, it's a very large problem," says Mike Duniway, a research ecologist with the USGS's Southwest Biological Science Center. "I don't think analogies to the Dust Bowl are overblown; it's a similar combination of people and land use activities and weather resulting in large-scale erosion."

Scientists are “on the cusp” of developing models land managers can use to estimate how much earth new development might stir up. This information would be incorporated into environmental studies prior to allowing such uses on federal land.

Duniway and Derry agreed that as scientists try to better understand how to mitigate dust, people who live, work, and play in the desert can make a difference in the amount of soil that ends up on the snowpack each winter. They can do so particularly by sticking to existing roads and curbing their use of all-terrain vehicles and dirt bikes off road in highly sensitive arid areas.

“Tourism in desert areas has really skyrocketed—the highest dust flux ever measured was from an off-road vehicle area near Hanksville, Utah,” said Duniway. “There’s definitely a parallel between how people drive, and where they drive, and dust on snow.”