Western Confluence

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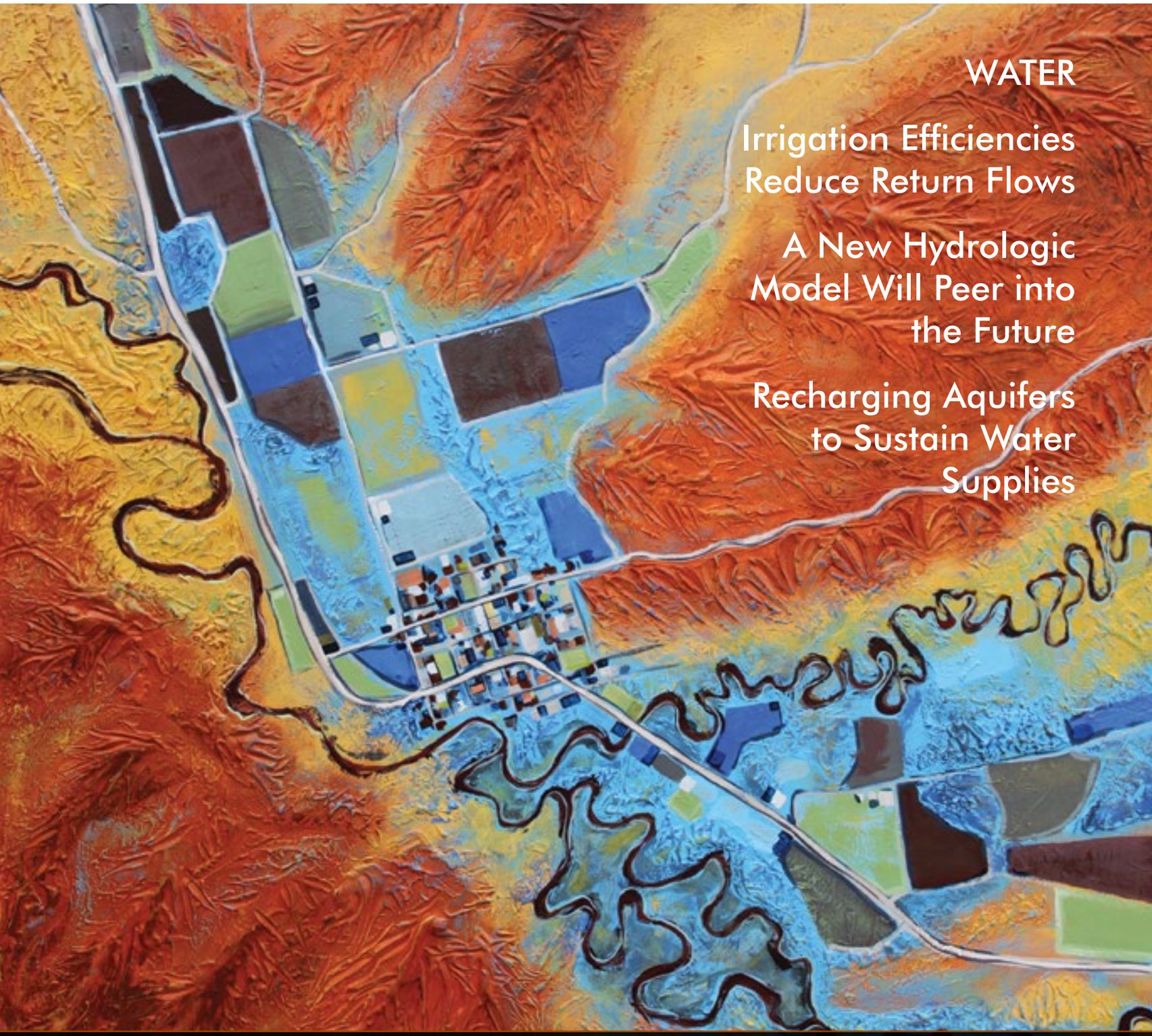
NATURAL RESOURCE SCIENCE AND MANAGEMENT IN THE WEST



WATER

Irrigation Efficiencies Reduce Return Flows

A New Hydrologic Model Will Peer into the Future

Recharging Aquifers to Sustain Water Supplies

A publication of the Ruckelshaus Institute, a division of the University of Wyoming's Haub School of Environment and Natural Resources

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Twice a year, *Western Confluence* magazine brings you on-the-ground, science-based stories about the research and policies shaping natural resource management and decisions in the West. *Western Confluence* tells clear, relevant stories of interdisciplinary, collaborative solutions to our toughest natural resource challenges.

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EDITOR'S NOTE

Water and humans: two powerful forces shaping our landscapes. Take a flight from Denver or Billings into some small western farming town to see the extent. From a few thousand feet up, one creek tendril builds around it a whole draw, and the draw makes up just one fringe in a frost-crystal fractal pattern of hills for miles across, say, the west edge of the Powder River Basin. From glaciated mountains to the driest desert basins, water leaves its mark in canyon scribbles, river bottom brush strokes, and pencil-line gullies.

And the airborne passenger can't miss the tidy grids of highways and gravel roads, the reservoir dams, or the straight-sided crop fields stippled over the land. From above, the marks of water and humans are sometimes indistinguishable, and always knitted together. Perhaps the most emblematic sign of the intersection between people and water is the perfect circles of center pivots. A delicately woven tapestry or a message spelled out in code?

Painter Virginia Moore's landscapes bring these aerial views to ground level. Her pieces reconfigure our planet's shapes and colors into bright abstractions. They also reveal our landscapes as they really are, not sentimentalized or pristine, but shaped by eons of water following gravity as well as decades of planning, labor, and construction. These images remind us of our power to alter the places we dwell, and of the smallness and fragility of our presence on this vast and ever-changing planet.

Starting with Virginia's view from above, this issue of *Western Confluence* examines a few of our many relationships to water. The articles look at how we use, rely on, and manipulate water, from the simplest dirt irrigation ditches to elaborate tunneling-pumping-piping-trading-filtering-recycling systems. And they question how sustainable our use of water is. You'll read about western cities trying to hold onto and make the most of a finite and infinitely valuable resource, as well as people who want to bring once-wild rivers back to life. It's impossible for one issue of a magazine to give comprehensive treatment to everything water means to us. Instead, I hope this collection of stories will provide a thought-provoking glimpse at how water shapes our landscapes and lives in order to trigger ongoing conversation.

And as you read through, flip back to the cover image from time to time. Virginia is a young artist who lives in Lander, Wyoming. Her fresh and honest interpretation of the place we all call home puts these stories into the right perspective. Water is everywhere, essential, and evasive.

Emilene Ostlind, Editor

On the cover: The painting Gathering *shows an isolated western town nestled into the surrounding topography. "The confluence of two rivers creates a valley sanctuary where we can raise cattle and crops and seek refuge in the shade of riparian trees," writes painter Virginia Moore.*

This page: Northeast Colorado crop circles cover a landscape kept productive by pumped groundwater in Virginia Moore's painting Cultivation Time. *"The soft, earthy colors reveal the pride and hope of feeding a growing population," she writes. "As an unsustainable practice, those fields will someday fade, and the image of crop circles will be remembered as 'the good old days.'"*

Both images printed with permission from the artist. See more of Virginia Moore's work at virginiamooreart.com.

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The West's Water

Words and photographs by Charlie Reinertsen

Water, or perhaps the absence of water, defines the Wyoming landscape and shapes the species that live on it. Big sagebrush (*Artemesia tridentata*) is one species particularly well adapted to Wyoming's arid climate. The shrub has two root systems. Shallow lateral roots absorb snowmelt and spring rain. A single long taproot extends straight underground to access deep water in late summer and fall. The plant's ephemeral leaves grow in the wet spring. In the dry summer months, these leaves fall off to conserve water. The smaller evergreen leaves stay on year round to turn sunlight into food for the plant without letting go of too much water. Thousands of years of adaptation help sagebrush make the most of scarce water in this arid landscape.

Humans, by contrast, have not had time to adapt to the Wyoming climate. Instead, we sculpt the landscape to make it habitable. We build dams, diversions, levies, and irrigation systems to control, store, distribute, and use water. Our success is measured in our towns and agricultural production. As the human population increases and the effects of climate change continue, demand for water will increase, placing more stress on the systems we have created. The changes are great and the time frame is short. We are in the middle of a massive experiment, and we are not sure what the outcome will be. How far will our technology carry us as water supplies change? As water resources are stretched thinner, can we mimic the sagebrush's strategy for making a livelihood in a spare environment?

WATER TODAY

One Irrigator's Waste is Another's Supply

Upstream Efficiencies Mean Less Water For Downstream Users in Nebraska's Panhandle

By Ariana Brocious, Platte Basin Timelapse

On a warm summer morning in western Nebraska, 77-year-old farmer Bob Busch stood next to a sugar beet field in a worn denim shirt, black suspenders and a mesh hat. At his feet, water coursed past in a concrete-lined irrigation ditch. A series of slender, curved pieces of aluminum pipe siphoned the water out of the ditch and onto the field.

This is one style of flood irrigation, a method that has been in use since the late 1800s when enterprising settlers began to divert water from the North Platte River to irrigate croplands and build an agricultural economy in western Nebraska. Busch lives in a jagged patch of verdant farmland on the western edge of the arid Nebraska panhandle, about 10 miles west of where the North Platte River flows through Scottsbluff. His farm, like many in the green patchwork around him, is completely dependent on irrigation from the North Platte River.

When Busch first started to irrigate, he said, it was pretty crude. Back then, there weren't even tubes to siphon the water, just cuts in the side of a dirt ditch. Pointing back to the ditch at his feet, Busch described how thirty-some years ago this canal "was all sod. It was a nightmare to irrigate out of." Concrete was available, so Busch started cementing his ditches.

Technically, Busch retired seven years ago. But he still works every day, helping his son take care of roughly 1,000 acres of sugar beets, dry beans, corn, and alfalfa, and irrigating from May through September. Through many decades of farming, he and farmers like him have struggled to make the most of a limited supply of water. Busch has seen, and contributed to, dramatic changes in irrigation technology and efficiency. Sealing canals with concrete is just one of those changes.

"I've seen a tremendous impact of going from sod ditches, dirt ditches to concrete ditches to gated pipe to plastic ditch. And then the pivots started going up," Busch said.

Water seeping through porous canals and ditches has always been an issue for irrigators, so districts and farmers alike have lined or sealed the waterways to reduce loss. "We can't afford to lose a whole lot of water out of the canal," Busch said, but "sealing a canal is a catch-22 because that water that comes out of them canals does replenish our groundwater system."

On a dusty road on the outskirts of Gering, Nebraska, not far from the local sugar beet processing plant, sits the main office of the Gering-Ft. Laramie Irrigation District. Inside, manager Rick Preston's office is a small museum to the history of irrigation. Big, detailed maps cover the tables and a bookshelf full of old surveying and irrigation equipment lines the back wall.

This is one of several irrigation districts in the Nebraska panhandle that deliver water diverted from the North Platte River to farmers. When he first started with the district 20 years ago, Preston said nearly all of the district's 55,000 acres used gravity flow, or flood, irrigation, including those owned by Busch. Now he estimates about half the district has converted to sprinkler systems including center pivots, which deliver precise amounts of water to the crops instead of flooding them. Through the years his district has put about half of its laterals—smaller ditches that divert water from the main canal to fields—into pipe.

Numerous factors have motivated irrigators to become more efficient in getting water from the river to their fields. In the late 1950s

Peter Steyn, Platte Valley Timelapse

Bob Busch is a third-generation farmer in the Nebraska panhandle.

and '60s, the government lent money to finance lining ditches and putting laterals into pipes to reduce seepage. More recently, finding and keeping good workers on the fields has become difficult, and center pivots require far less manual labor than flood irrigation.

"In agriculture it's a seven day a week job from when it's time to plant, up until it's time to harvest. A lot of individuals today do not want to have to give up their summers and weekends to do this type of work," Preston said, "so the work force has dwindled tremendously." Siphon tubes have to be moved by hand every day, whereas center pivots can be operated by the push of a button.

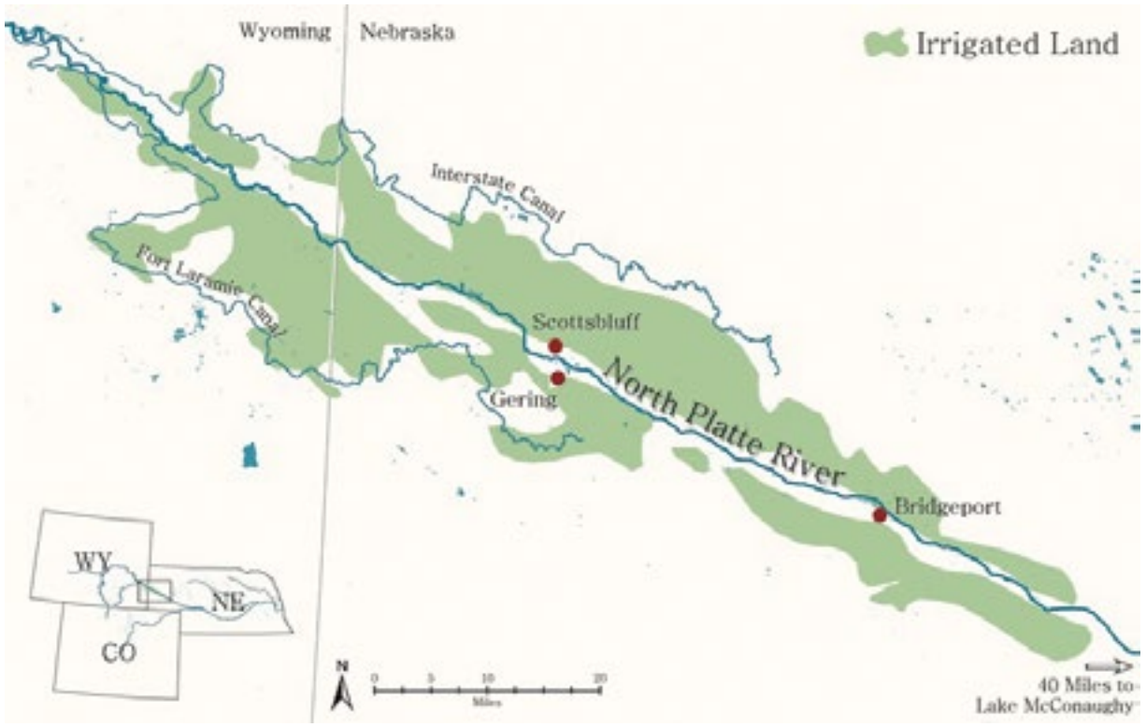
And there are other reasons to convert to sprinklers. Pivots reduce the need for tilling and help with erosion. Changing climate and weather patterns also play a role, because so much depends on how much moisture arrives in the mountain headwaters of the North Platte River and in the panhandle region itself, translating to soil, river and groundwater recharge. Drought, particularly during the last decade, often leads to irrigation water shortages, and makes the water that seeps away from unlined canals and ditches all the more valuable and worth trying to hold onto.

"From the late '60s to present day we more than doubled the ability to deliver water to the farm," Preston said. Now, much of the water that used to seep into the ground makes it to the fields, delivered through piped laterals or concrete ditches like the one on Busch's farm.

Kevin Adams, general manager of the nearby Farmers Irrigation District, is familiar with the system of water loss through unlined canals. His district's main earthen canal stretches 75 miles from the Tri-State Diversion Dam, just east of the Wyoming-Nebraska state line. Walking alongside it on a sunny afternoon just before the end of irrigation season, Adams pointed to the water gurgling under a bridge, and said the district loses about one-third of that water into the aquifer through seepage, about 1,000 acre feet per day.

But the water that seeps out of canals and ditches doesn't disappear for good.

"We lose it and it shows up in the creeks, in the river and going downstream," Adams said. "We supply the aquifers in western Nebraska."



Steven Speidler, Platte Basin Timelapse

Irrigation canals divert water from the North Platte River to soak crops in Nebraska's panhandle.

Nick Lapaseotes is a tall man, and his Greek heritage shows in the olive tone of his skin and bright eyes above the salt-and-pepper stubble across his chin. Over the years, he has adopted all the highest-tech solutions for getting water to his crops on his 10,000-acre farm. But he's still affected by diminishing water supplies, in his case, groundwater.

As he strode out to one of his sugar beet fields outside of Bridgeport, Nebraska, thirty miles down the North Platte River from Gering, he explained that until three years ago, he irrigated this field by gravity flow, using water pumped up from the aquifer. Now a long stretch of silver pipes spanned the field, sprinkling water down in a fine mist to the broad, green leaves of the beets below. That's been the case on many of his fields as Lapaseotes has converted more and more of his acreage to pivots.

Lapaseotes knows a lot about center pivots. The technology was refined in Nebraska, which remains their leading producer today. His father began investing in pivots and putting them on land he owned starting in the late 1960s, expanding year after year, Lapaseotes said. When he and his brother returned to the family land after school, they followed in their father's entrepreneurial footsteps, updating irrigation operations with the latest technology.

> The water that seeps out of canals and ditches doesn't disappear for good. "We lose it and it shows up in the creeks, in the river and going downstream. We supply the aquifers in western Nebraska."
>
> Kevin Adams, general manager, Farmers Irrigation District

He walked over to the pivot control box on the side of the field and showed off the panel inside. "We got a lot of these computerized panels now so we can control 'em from the office," Lapaseotes said. He demonstrated an hour later back in his office, turning the same pivot on and off with the click of a mouse.

On one field, he cut his water use by 20 percent using subsurface drip irrigation, which feeds water to plant roots through perforated plastic tubes laid under the dirt. That method has become more popular in recent years as farmers seek to make even more of the water they get, especially in dry years when water supplies are curtailed. Soil moisture probes on about a quarter of his fields measure precisely how much water crops need, and Lapaseotes can review the data from an iPad in the cab of his truck or miles away back in his office.

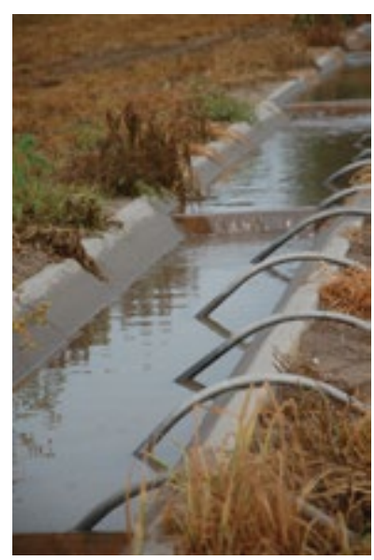
It might sound like all this new water delivery efficiency—concrete-lined ditches, piped laterals, sprinklers, drip irrigation—is helping irrigators make diminishing water supplies go further, but the truth is more complicated. As farmers use water more precisely, there's less flooding on fields, reducing what water users call "return flows." Return flows describe water that flows off a field back into an irrigation ditch, or goes back into creeks, streams, and the river where it is ready for use by other irrigators downstream. Some of it even seeps through leaky ditches, canals and fields back to the groundwater table, where it may contribute to river levels downstream weeks, months, or even years later.

"We operate this system on return flows," Preston said. His district, designed around the older system of flood irrigation, depends on that return water, particularly during years of water shortage.

In fact, farmers and water managers in the Nebraska panhandle are fond of saying that their water is used seven times before it meets the Missouri River on the state's eastern border. Adams cited this maxim too, but said things started to change in the early 1990s. He's worked for the Farmers Irrigation District for the past 35 years and has seen an even greater conversion from furrow irrigation to pivot than Preston has—nearly 70 percent of the district's 65,000 acres are now under pivots.

"When we were gravity flow irrigating our system we would get percolation return flows," Preston said, but the use of pivots has reduced that by about 50 percent.

Like many irrigators in the panhandle, Lapaseotes runs most of his pivots on groundwater. In the last



Ariana Brocious, Platte Valley Timelapse

Siphon tubes pull water from a concrete-lined irrigation ditch.

half-century, farmers have increasingly turned to groundwater to supplement surface water supplies. Adams said that adds another layer of complexity to the return flows equation.

Groundwater levels in Nebraska declined an unprecedented 2.5 feet on average from 2012 to 2013. A statewide report attributed the drop to increased groundwater pumping and decreased precipitation recharge, both exacerbated by drought in 2012. Excessive groundwater pumping can draw the underground water table below the levels of streams and rivers, further hampering the system of return flows that many users depend upon.

"Twenty-five years ago, you could pump unfettered if you wanted to," said John Berge, general manager of the North Platte Natural Resources District. "We don't allow that anymore."

In 1972, Nebraska put groundwater management in the hands of locally elected boards organized by river basins. The 23 Natural Resources Districts (NRDs), as they're called, work with surface water districts, municipalities, local and state government to monitor and regulate groundwater use and quality. The North Platte Natural Resources District covers about five and a half counties from the Wyoming state line down to the western end of Lake McConaughy, a huge reservoir built for irrigation and power generation in central Nebraska.

"We're one of a few NRDs in the state designated as over-appropriated," said Berge. As a result, his district monitors pumping on all existing groundwater wells to understand what that usage has done to static water levels. In 2002, the North Platte NRD put a moratorium on any new irrigation wells in the district. The district is also working on a groundwater recharge project—leasing surface water off a parcel of land and putting it into a pit to seep back into the ground.

"We're regulating the groundwater pretty heavily," Berge said. A 2004 law required NRDs in "over or fully appropriated" river basins to cut back on irrigated acreage and groundwater use. In response, the North Platte NRD limited acreage expansion and put limits on groundwater use from existing wells in the over-allocated part of the district. Most of Lapaseotes's groundwater wells are subject to limits and have been for the last decade.

Diminishing return flows—be it from more efficient measures on farms and irrigation districts, less snow and rain in the mountains and plains, cropping practices, drought, increased groundwater pumping, or other factors—affect water supplies beyond the panhandle itself. Return flows from the panhandle that eventually make it back to the North Platte River flow downstream to Lake McConaughy. Central Nebraska Public Power and Irrigation District, which runs the reservoir and supplies irrigation water to 223,000 acres in the center of the state, sees decreased return flows affecting its water supply. Lake inflows dropped by more than 30 percent between 1943 and 2013, which Central attributes to the 100-fold increase in groundwater wells in the panhandle during that time period.

Berge is aware of Central's assertion. "The overarching piece is simply that we have far too much consumptive use in this district," Berge said, referring to water that gets used by plants and never makes it back into the system.

There are three ways to reduce consumptive use, Berge said: provide less irrigation water to farmers, reduce the number of farmed acres, or convert to less thirsty crops like wheat. While none of these is popular, it's a matter of figuring out what strategy works best, Berge said. For example, some current irrigated lands could instead be used for wildlife habitat, hunting, or ranching. His district is looking at all these options to try to avoid "draconian measures" like further restrictions on irrigation water use, Berge said.

He's in a tricky spot, because even as farmers in his district and those upstream find new ways to maximize crop production from limited water supplies, they are further limiting water supplies.

"We hear about efficiency all the time," Berge said. And when it comes to water resources and quantity, "you

American Heritage Center

Water spreads to produce abundant grass where very little grew before in this 1941 University of Wyoming Cooperative Extension photo.

Peter Stegen, Platte Valley Timelapse

Flood irrigation on a field outside Gering, Nebraska.

want to make sure that that water is used as efficiently and effectively as possible." But "the inefficiencies in the surface water system can be helpful to the groundwater system," Berge said.

With farmers becoming more efficient, "the ultimate change is that we no longer have the recharge getting into our aquifer, which slows the timing back to the river, which diminishes the stream flow in the river, which is a significant part of our problem out here," Berge said.

By mid-September, early beet harvest was already underway in Scottsbluff. Sugar beets piled in giant mounds under the tall white silos of Western Sugar's plant, looking like huge piles of dirt from a distance. The air around the sugar processing plant smelled sour as harvesters and loaders worked late into the night. Irrigation season had just ended, and farmers picked up pipe and turned off pivots.

There's no easy answer to the paradox of competing and complementary surface and groundwater supplies.

"You know, we're not different than any part of the state. The population's growing. Municipalities. Factories. Water's being used," said Adams of the Farmers Irrigation District. "And over-appropriated, of course."

"With the increased demand for the produce, the increased demand for the livestock feeds, the increased amount for water, it's going to continue to get worse and more demanding as time goes on," Preston said.

Perhaps it's natural to feel disheartened after a career of such challenges. But John Berge, who's relatively new to the North Platte NRD, takes a different angle.

"You look at this ... and you can get really depressed and you can say, 'Oh my God, we're never gonna be able to fix this.' [But] ultimately, it's a pretty cool opportunity," Berge said.

We're at a new point in our agricultural history, he said. For decades, the overall policy was to plant as much as you possibly can, Berge said. "Now we're kind of pulling back and saying, let's do this the smart way."

***Ariana Brocious** is lead reporter for Platte Basin Timelapse, a multimedia documentary project that aims to increase understanding about water resources and build community throughout a watershed. Videos, interactive graphics, and more stories at plattebasintimelapse.com.*

Measuring

By Beatrice Gordon

As a child in northeastern Wyoming, I remember my summers as irrigation season. May meant the ceremonial ditch cleaning and the Sisyphean task of replacing broken gates along the lines of PVC pipe that delivered water to the fields. I spent June mornings setting orange tarps only to find that by evening the corners so carefully tucked in to the dirt had come loose. The irrigation ritual was predictable and comforting. Yet for all that is known about irrigation in Wyoming, critical pieces of the picture remain unexplored.

Although agriculture currently accounts for 90 percent of total water withdrawn from streams and aquifers in our state, the proportion of water actually consumed by crops remains uncertain. Water managers have an increasing interest in quantifying "return flow" or the portion of irrigation water that seeps through the ground and returns to local streams and aquifers. Now, as a graduate student at the University of Wyoming, I'm part of a team exploring new, more accurate ways to track and measure those return flows.

Flood irrigation delivers water to a field or a section of a field via pipes or ditches, saturating the upper portion of the soil profile. In Wyoming, the State Engineer's Office generally assumes that about half of flood irrigation water returns to a given stream. In reality, the amount and timing of return flow varies significantly depending on the soils, geology, and hydrology of a particular system. As irrigators switch from flood to more conservative irrigation methods like sprinklers, managers need to understand the role return flows play in recharging local streams and aquifers.

That's why I spent the summer of 2014 installing hydrologic and geophysical instruments in irrigated fields and along a stream in western Wyoming. Together with University of Wyoming professors Scott Miller and Ginger Paige, I am part of a research team studying water movement on a section of irrigated meadow managed by the Wyoming Game and Fish Department. Bear Creek, the targeted stream, lies between the Wiggins Fork and East Fork of the Wind River on the Spence Moriarty Wildlife Habitat Management Area, an elk feeding ground southeast of Dubois. Over the course of several years, our goal is to use geophysics in concert with more traditional

Return Flows

hydrological methods to get a handle on the timing and amount of return flow contributions to Bear Creek. Only one other published return flow study has ever been completed in Wyoming, back in 1989. We aim to broaden understanding of the role return flows play in a range of systems and to give managers across the state more tools to oversee water resources.

We are using a "water budget" approach to account for the various ways water enters and leaves the system. This approach will help us track the amount of water that returns to Bear Creek following irrigation. We are using several different hydrological, geophysical, and climatological instruments to establish the water budget. The short irrigation season from May until early August gives us a narrow timeframe to place our instruments and collect data. Much of this first year, we focused on installing instruments and developing and testing new field methods.

First, we installed seven submerged pressure transducers (SPTs) in Bear Creek and the nearby Fosher Ditch. SPTs are small cylindrical sensors that we submerge in stilling wells, PVC pipes set in the bank to dampen immediate fluctuations in water level while capturing water level rises and falls in the main channel. The SPTs record the stream's water level every 15 minutes. We also manually measured flow at several permanent monitoring locations along Bear Creek. These measurements allowed us to determine the volume of water flowing through each monitoring section in Bear Creek at that specific moment. We put together the data from both the transducers and the flow measurements to create a rating curve, an equation that approximates streamflow volume over the course of the season.

We also collected weather data from a small, extraterrestrial-looking meteorological station, which was of particular interest to the local elk and moose who ultimately pushed it over with the help of November snows. The "met" station recorded temperature, wind speed and direction, net solar radiation, net long wave radiation, and albedo throughout the summer. We use these measurements to calculate potential evapotranspiration. That lets us approximate how much water the vegetation in the irrigated meadow consumes over the course of a day.

In the traditional water budget approach, the water that enters the system as precipitation should equal the water that leaves the system as streamflow, subsurface storage, return flows, and evapotranspiration by vegetation. By analyzing our calculated values for streamflow and evapotranspiration along with precipitation data, we are able to determine how much water is neither consumed nor converted to surface runoff. That is the water that we expect is either stored

Beatrice Gordon

Survey equipment and stilling well at site along Bear Creek.

underground or returned to Bear Creek. This first year of hydrological data were further enhanced by preliminary geophysical experiments exploring subsurface hydrologic characteristics. Electrical Resistance Tomography uses a series of electrodes stuck into the ground across the field to monitor how soil conductivity, an indication of soil water, changes over time. Nuclear Magnetic Resonance measures magnetic fields to detect water molecules underground, which shows us how much water is in the soil and how deep it is. Coupling these two approaches, we hope to discover the timing and amount of return flows making it back to Bear Creek.

Our study is in its early stages. With additional summers of field work and data collection ahead of us, we have yet to determine how or if return flows work in this system. We do hope that isolating components of the water budget and tracking subsurface water movement with geophysical methods will allow us to quantify and describe return flow processes in Bear Creek. If we can refine return flow estimates in this system, it may help us improve understanding of return flow's larger role in the state.

Beatrice Gordon *is a Wyoming native and a first-year master of science student in water resources at the University of Wyoming.*

SUPERCOMPUTER-POWERED MODEL Improves Water Planning

A Hi-Resolution Hydrologic Model Peers into the Future of Western Water

By Stephanie Paige Ogburn

Inside the University of Wyoming's 3-D visualization cave, winter is coming. Through special glasses, a viewer watches winter snow pile up in the Wind River Mountains. The simulation shifts. Spring comes, and the snowpack begins to melt, waning gradually with warmth. Underfoot, the ground becomes translucent. Water accumulates and moves around, resurfacing as it feeds tributaries of the Green River, at times evaporating and returning further down the mountains as rainfall.

This holodeck-like experience of a year in water is just a glimpse into an incredibly detailed hydrologic model created by University of Wyoming engineering and environment and natural resources professor Fred Ogden. Called ADHydro, the model harnesses the power of supercomputing to create high-resolution, physics-based simulations of how water moves through very large watersheds. The project takes advantage of computing power at the new Cheyenne-based supercomputer facility the University of Wyoming shares with the National Center for Atmospheric Research.

"Right now we are simulating the Upper Green River basin in Wyoming," said Ogden, who has been working on the project for the last two years.

As climate change alters the way water falls on and flows through western landscapes, Ogden hopes his model can help water managers better understand how those changes play out, despite the uncertainties the future holds.

LOOKING TO THE PAST TO ESTIMATE THE FUTURE

The importance of the Colorado River is often summed up with the following facts: The river's basin touches seven Western states before reaching Mexico. It supplies life-giving water to 40 million people. It can generate 4,200 megawatts of hydroelectric power, and its water slakes the thirst of 5.5 million agricultural acres.

The Colorado is probably one of the most oft-studied and worried-over rivers in the country. Yet despite decades of efforts measuring and tracking the river's flows, every year when mountain snowpack begins to roll off rocky slopes, water managers still wrestle with many unknowns: How fast will the snow will melt? How much will get used up by trees? How much will evaporate before it gets into a stream? Until fairly recently, managers looked to weather from the past hundred years to try and find analogs that would help them plan for how the snow would behave.

"We really relied pretty dominantly on the historical records," said Jim Prairie, a hydrologic engineer with the Bureau of Reclamation's Upper Colorado Regional Office.

In the 2000s, though, as drought spread across the West, scientists and water managers realized they might need to look further back in time to understand was happening to the river. They turned

UW Photo

Wearing special goggles, a man interacts with a model in UW's 3-D visualization cave.

to tree rings, which tell a story of bigger floods and longer droughts in centuries past.

"That allowed us to get a much broader picture of how hydrology may be changing in the future," said Prairie. "What we have seen in the last 1,200 years is we could have higher and lower flows [than in the past 100]."

This knowledge gave water managers a better sense of what the snowpack, and the river, was capable of. Climate change, though, adds another wrinkle. The challenge, said Ken Nowak, the Bureau of Reclamation hydrologic engineer for the river's lower half, is that climate change means the next 100 years may not look like the last 100, or even the last 1,200.

"The past is no longer indicative of the future," said Nowak.

That's where models come in. To start, water managers get results from a set of climate model projections called the Coupled Model Intercomparison Project. These coupled models combine representations of the atmosphere and the oceans, as well as the ice sheets, sea ice, and the land surface, painting a fuller picture of the Earth's climate. For the purposes of predicting the future of Western water supplies, such models produce two key pieces of information: projected future temperatures and precipitation.

Of the two, changes in future temperatures are more predictable. The physics underlying what happens when carbon dioxide concentrations increase, as they have been since the Industrial Age, are pretty simple: add more CO_2, the atmosphere heats up. While the amount of warming won't be the same everywhere, the models show that the Rocky Mountains of the future will be warmer than they are now.

Precipitation is more fickle. Scientists know a warmer earth will hold more moisture in its atmosphere. But since there is not a direct relationship between temperature, CO_2, and precipitation, the question of where that moisture will go is more difficult to answer. Most researchers think wet areas, like the tropics, will tend to get wetter, and dry areas, like the desert Southwest, drier. The future of many places in between, like the Rocky Mountain region, is basically a toss-up at this point.

The coupled models run under a range of scenarios. One keeps the world on a high-emissions path, where carbon dioxide levels continue to increase rapidly. Others take a middle road. There is also a low-emissions option, to include the possibility of global action to drastically reduce emissions or capture carbon dioxide from the atmosphere. Each scenario results in different futures, some a

UW Photo

Inside the National Center for Atmospheric Research (NCAR) Wyoming Supercomputing Center.

degree or two warmer, others many degrees warmer, with corresponding changes to rain and snowfall regimes.

To get to the localized impacts of these climate changes on water, researchers plug the results of the climate models into hydrologic models representing all kinds of natural physical processes: Snowpack, how that water gets taken up by trees, whether it evaporates or soaks into soils, how fast it makes its way downstream.

HI-RESOLUTION HYDRO

Ogden's ADHydro effort represents a significant improvement over existing hydrologic models. Many past models, including one of Ogden's now used by the Army Corps of Engineers, use what's called a square mesh to represent a watershed. Essentially, the landscape and processes are divided up into small squares representing a given area. This gives you a standard resolution across the entire watershed.

That works well for smaller watersheds, said Ogden, but he's trying to represent something much larger—first, the Green River watershed, and later the entire Colorado River basin. So ADHydro uses a different approach.

"We are using an unstructured mesh, triangles, and they can change size," he said.

Since a whole lot of computing power is needed to run such models, this approach is more efficient. In the mountains, where a lot is going on in a small space, the model has tiny triangles, 50 meters on a side. It can represent processes like snowmelt, soil moisture, and groundwater recharge on a very detailed scale, where even subtle changes can have big effects downstream.

When a river gets to the plains, where not a lot is changing, that high resolution becomes superfluous. The ADHydro model then can bump its triangle mesh size up to 500 meters on a side, saving valuable computing resources for the areas that truly need it. Even with a supercomputer running the model, such high resolution uses a lot of processing power, so Ogden has tried to make it as efficient as possible. The model also represents processes in three dimensions, but saves resources by being "quasi-3-D," said Ogden.

"The models that we are trying to improve upon … tend to run at lower resolution. And because of that they don't really simulate feedbacks properly, particularly between groundwater and surface water," he said.

In contrast, the ADHydro model includes real world processes such as the effect of wind on sublimation, or snow evaporation. Other models can't represent this, so they do something called parameterization, "a fancy word for fudging it," said Ogden. And, in addition to simulating water, air, and soil, the new model includes layers like tree cover. Since trees use a lot of water, whether they are alive or dead, growing or not, can have a big impact on water availability.

Kristi Hansen, a water economist at the University of Wyoming, has been working with Ogden to create a layer for his model that will represent decisions water managers make about storing and releasing water. Management scenarios could include information about a city's rights to Colorado River diversions and its projections of future metropolitan growth. Such inputs allow researchers and policymakers to play around with different configurations of water use in the future. Say Las Vegas cuts its water use still further, but demand from a rapidly growing Phoenix jumps.

Hansen is excited about the model's improved resolution over existing ones, saying when there are shortfalls on the Colorado River, "the finer scale has the potential to tell us more about who is affected and by how much … a better, more detailed understanding of the hydrology can help us to make good decisions in the future."

Ogden imagines a case in Wyoming where the state might need to make a decision on a new pipeline to take water from the Green River to Colorado's Front Range. The State Engineer's Office could use his model to find out what granting approval for the withdrawal would mean.

"They [the engineers] could pull open the Web browser, say we are going to divert this amount under these rules, and then select a future climate scenario and maybe a future land use scenario, and then click 'run.' And then sometime later they would get an e-mail back with a report telling them what the effect of that was on, say, the water level of Lake Powell in the future."

By summer 2015, the model will be running simulations on the National Center for Atmospheric Research supercomputer, using output from coupled global climate models to model water behavior in large western watersheds, said Ogden.

FROM MODELS TO ACTION

No matter how good your model, moving from improvements in research models into improvements in the actual operation of a complex system of dams, diversions, and cities in the arid West is a monumental task. As a hydrologic model gets layered on different climate model outputs, each with its own assumptions, the view of the future actually becomes fuzzier, said Jeff Lukas, a senior research associate with the Western Water Assessment. That's because whenever multiple modeling steps are used, the range of possible outcomes broadens.

"The uncertainty increases because you have made these choices along the way," said Lukas.

Lukas points to local and regional efforts by utilities like Denver Water and others. With information from climate and hydrologic models, they are improving their flexibility to react to various circumstances, preparing for whatever the future brings.

Laurna Kaatz, the climate policy analyst for Denver Water, which serves a quarter of the state's population, thinks a lot about the future. She said climate models and hydrologic models give managers insights into how the region might change.

"They help us play out 'if' scenarios. If this happens, in the future, then this is what it could mean to the water system."

Even though models have uncertainty and do not predict the future, it's still "really valuable information," she said. "If we didn't have these than we would just be making assumptions about what the future could be."

Lukas agrees this is where models come in handy.

"Really, the important thing is not to be surprised," he said. "To have at least some ability to prepare for an event you haven't seen before."

"They help us play out 'if' scenarios. If this happens, in the future, then this is what it could mean to the water system." Even though models have uncertainty and do not predict the future, it's still "really valuable information. If we didn't have these than we would just be making assumptions about what the future could be."

Laurna Kaatz,
climate policy analyst, Denver Water

Ogden acknowledges that exactly predicting future flows "is almost impossible." But he says ADHydro is an improvement over current options. He notes a 2012 effort from the Bureau of Reclamation looking at the future of the Colorado River that painted a "pretty dire picture" of future Colorado River water availability. ADHydro could be used in similar sorts of research.

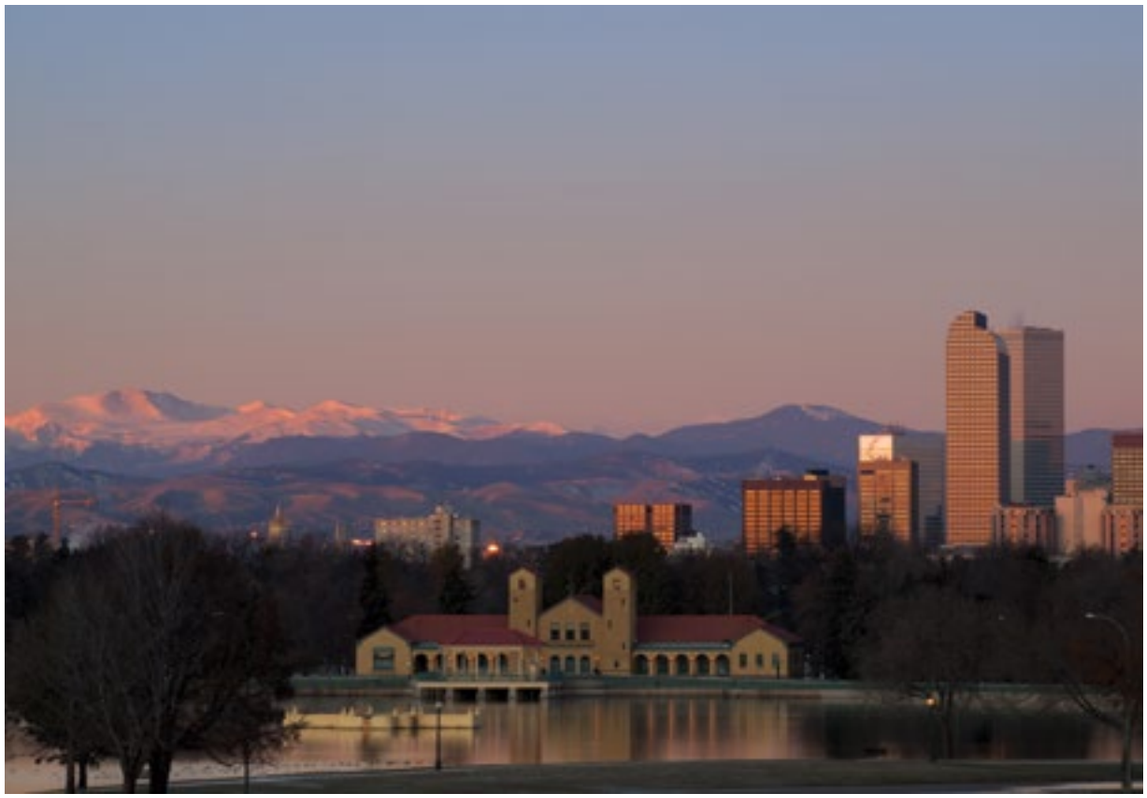
"What we hope to do would to be able to improve on those because we are including more feedback processes because of our higher resolution," Ogden said.

Denver Water's Kaatz agrees.

"Advancements in modeling are really important. Because it helps us better understand the system that we are trying to manage."

As snow coats mountaintops this winter, water users and water managers have begun their anxious watch, tallying inches and snow water equivalent, checking weather stations and SNOtel sites. No one knows what this winter, or the next, or the one 30 years from now, will bring. With models like ADHydro though, we may at least be better prepared for that uncertain future.

Stephanie Paige Ogburn *reports on science and environment in the West from Denver, Colorado. Find more of her work at stephaniepaigeogburn.com.*



Jeffrey Deems

DUST ON SNOW

A Dirty Mountain Snow Pack Affects Communities Downstream

By Kristen Pope

Some 40 million people rely on the Colorado River, and much of its water comes from snowmelt. So when something big changes in the watershed, like the timing of the spring melt, water managers and water users get nervous. Everyone has been hearing that warmer weather is leading to earlier spring runoff, but now researchers are studying another factor that has an even bigger effect than temperature on snowmelt timing: dust.

A dirty Rocky Mountain snow pack is more than just an eyesore. Dust-covered snow concentrates the sun's energy as the darker snow absorbs more solar radiation, leading to faster snow melt and a shorter runoff season. This can cause trouble for farms and cities that rely on a steady flow of water through the summer. Most of the dust that falls on snowfields feeding the Colorado River is stirred up by human activities like construction, ATV use, and ranching in the desert southwest.

Researchers are quantifying the effects of dust on snow. And, following the spring of 2009, which brought an order of magnitude increase in dust deposition to the mountains of the Upper Colorado River Basin over that observed in earlier years, they are trying to understand exactly where the dust comes from and to predict what kinds of dust events we might see in the coming years and decades. Finding solutions to the dust-on-snow problem will require sound science and continuing research.

Dr. Jeff Deems, Research Scientist at the Cooperative Institute for Research in the Environmental Sciences at the University of Colorado, Boulder, set out to study the dust-on-snow problem with colleagues. Earlier research indicated that dust-on-snow was disrupting normal runoff cycles. Deems' and his colleagues' newest work examines extreme dust conditions observed in 2009 and 2010. They are analyzing data from those years to help predict what future snowmelt seasons might look like if climate change and other factors make dust deposition worse.

To better understand how dust affects snowmelt, Deems and his colleagues skied for miles out to research sites high in the Colorado Rockies—above 13,000 feet in elevation—to measure the solar radiation the snow pack absorbs under different dust conditions. They faced challenging conditions, as they often skied in late spring on a fast-melting

snow pack, hauling packs full of research equipment and constantly assessing avalanche danger and weather conditions.

They conducted their research near meteorological instrumentation towers at several research sites, including one site in Colorado's San Juan Mountains called the Senator Beck Basin Study Area, maintained by the Center for Snow and Avalanche Studies. "These towers do something that's unique," Deems said. "They measure the complete snow surface energy balance, that is, all incoming and outgoing energy affecting the snow pack, including solar radiation, longwave radiation, air temperature, wind speed, and evaporation." By conducting their field observations next to these stations, the researchers were able to put their measurements in the context of the meteorological and energy data collected by the towers.

The towers automatically send their data to the Center for Snow and Avalanche Studies office in Silverton, Colorado. Deems and his colleagues dug snow pits to reveal the layers of dust sandwiched in the snow pack. And they used data from the towers to calculate the fraction of light reflected from the snow. Normally, fresh snow reflects about 90 percent of incoming energy. Springtime snow typically reflects 70 percent, as snow crystals naturally become coarser due to freeze-thaw cycles. However, dust on the snow can reduce this percentage dramatically, and measurements have shown that dusty snow can reflect as little as 30 percent of incoming energy, which is close to the reflectivity of plain old dirt.

Deems and his colleagues have determined that dusty snow melts three to seven weeks earlier than clean snow. Since snow pack provides the western U.S. with 80 percent of its water supply, the faster melting of the snow and the shorter runoff season is a critical problem. Earlier and faster runoff means all the water that would have been stored in the snow pack into summer instead rushes down the rivers too soon.

Reservoirs in the Upper Colorado River Basin, the part of the basin upstream from Lake Powell, can only hold so much water. Earlier runoff can mean they have to release excess water early and there may not be enough water stored for later in the season. Earlier melt also exposes bare ground up in the mountains where water is lost to evaporation and plant transpiration. That means less water makes it into the rivers overall, which exacerbates shortages in already over-allocated rivers downstream.

Agriculture, which uses 70-80 percent of the surface water runoff throughout the western U.S., will feel the brunt of these shortages. As water becomes scarcer and more valuable, there will be increasing pressure to divert it away from agriculture to cities. Wildlife could also suffer, including pikas and other alpine species that rely on a substantial snow pack. Fluctuating river volume and water temperatures could affect fish survival. White water recreationists and the businesses that rely on these rafters and kayakers could also face a shorter season. The diminished snow pack and shortened runoff could also lead to longer and more damaging fire seasons.

The dust settling on the snowy landscapes of Colorado and beyond comes from a variety of sources, and has increased significantly since the westward expansion of the U.S. in the mid-1800s. Much of the dust that falls in the Rocky Mountains comes from the desert southwest. "Dust shows up on the front edge of the storm and in most cases is immediately buried by fresh snow fall," Deems said. The southwest deserts are not naturally dusty, as long as the naturally occurring crust that anchors the soil is intact.

Jeffrey Deems

Researchers collect dust samples in Senator Beck Basin.

This biological crust, which includes colonies of moss, lichen, and cyanobacteria, makes the land resistant to wind erosion. However, grazing, oil and gas development, dry land farming, motorized and non-motorized recreation, and other disturbances over that last 165 years have damaged the crust, making it susceptible to erosion.

Abandoned croplands and cleared construction sites add to the dilemma, as they are often colonized by annual weeds that do not germinate in droughts, leaving the soil bare. Dirt roads also contribute. Southeastern Utah alone has over 6,000 miles of ATV tracks. The faster a vehicle drives, the more dust it sends into the air. Recent droughts and wind events are worsening erosion.

Controlling this problem would require stabilizing soils in southwestern deserts. "Keeping [off-road vehicle] speed down helps immensely," said Dr. Jayne Belnap, Research Ecologist for the U.S. Geological Survey Moab office. "We need to really start thinking about dust production when we do certain activities. We need to be smarter about what disturbance happens—where, when, and how much."

Many current policies focus only on replacing vegetation after a disturbance instead of evaluating soil stability as a whole.

Researchers found that reducing dust outputs could be an important part of climate adaption strategies in the region. Though a few government agencies and communities are taking steps to address these problems, dust erosion is likely to get worse.

The best remedy is prevention, according to Belnap. "We need to try hard to not disturb it in the first place, because we don't have very good ways to recover," Belnap said. "Recovery is not quick, so if we don't disturb it in the first place, we don't even have to go down this path. That's the real moral to this story."

Kristen Pope *is a freelance writer and editor who specializes in science and conservation topics and lives in Jackson, Wyoming. Find more of her work at kepope.com.*

FURTHER READING

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AQUIFER

UNDERGROUND STORAGE

By Emilene Ostlind

In 2009 Lytle Water Solutions, LLC, a geology consulting firm, constructed a small, rectangular basin in a groundwater well field outside of Cheyenne, Wyoming. Over the following six months nearly 110 acre feet of water—that's enough to fill about 54 Olympic swimming pools, or enough to supply about 193 Cheyenne homes for one year—quietly flowed into the straight-edged dirt pit and sank into the ground.

This was a test commissioned by the Cheyenne Board of Public Utilities in partnership with the Wyoming Water Development Commission to evaluate the potential for "aquifer storage and recovery," known as ASR. Cheyenne sits over the edge of the Ogallala Aquifer, a massive groundwater reservoir that stretches from central Texas to southern South Dakota. The Ogallala supplies almost a third of the groundwater that goes to irrigation in the US, plus water for homes, cities, and other uses. But it, like many aquifers around the country and world, is in trouble. For the last half century, water withdrawal from the aquifer has exceeded the amount of "recharge," or rainfall and seepage from streams and canals that flows back into the aquifer. Cheyenne has seen groundwater production from its wells decline as the aquifer water table has fallen. If current trends in agricultural expansion, population growth, and drought continue, farms over parts of the aquifer will start to lose access to groundwater all together, and water use from the aquifer will be unsustainable.

The Ogallala is not alone. Cities from Gillette to Juarez have had to drill deeper and deeper wells to draw water from declining water tables. Even as these water caches drain away, water managers race to secure water supplies for the future. Strategies include diversifying sources of water, recycling wastewater, incentivizing water conservation, and storing water on the surface and underground. Storage usually refers to building new reservoirs and expanding existing ones. But reservoirs have their shortcomings. They can only be placed in certain areas, namely constricted canyons or valleys with a supply of water.

"Permitting reservoirs is really tough in Colorado these days," says Bill Hahn, a professional geologist who has worked on several aquifer recharge projects and a proposed Two Forks Reservoir. "They worked on permitting for 10 years and spent millions and it got killed. New reservoirs are few and far between."

Once built reservoirs collect silt, slowly filling from the bottom up. And reservoirs' large surface areas evaporate off huge amounts of water. Lake Mead, the largest reservoir in the United States, evaporates 6 to 8 feet of water per year, which adds up to hundreds of thousands of acre-feet over the nearly 70-mile-long surface of the reservoir. ASR can avoid some of these problems. It has potential to offer a more sustainable alternative to reservoirs for future water storage. Water managers are tackling projects to test, study, and implement this technology.

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Several conditions need to line up for ASR to work. The process requires clean surplus water, an underground aquifer with space in it, and a nearby community in need of the water. Each

RECHARGE

COULD HELP CITIES SUSTAIN WATER SUPPLIES

project is different based on the source of the water, type and location of aquifer, and other factors.

The first requirement, excess water available for storage, could come from spring floodwaters, briny groundwater pumped up and cleaned, storm water runoff from cities, recycled municipal water, desalinated seawater, or other sources. In Cheyenne's case, the city proposed using excess surface water available in its reservoirs during spring runoff. El Paso, Texas, recharges its aquifer with treated storm water and city wastewater. The Arizona Water Banking Authority diverts water through canals from the Colorado River to store in aquifers near Phoenix and Tucson.

The water has to be clean enough to mix into a drinking water aquifer. Storm water runoff or saline groundwater requires extensive treatment. Most states require any injected water be cleaned enough that it won't contaminate the aquifer, usually to potable drinking water standards. Then the clean water has to be piped to the aquifer.

The two main methods for putting water into an aquifer are infiltration and injection. The Arizona Water Banking Authority uses spreading basins to infiltrate water into aquifers. These are big shallow ponds with permeable floors the water can soak through. The basins let a couple of feet of water per day filter into the aquifer. That water can be pumped out days, months, or even years later. These spreading basins do lose a small amount of water to evaporation, about 1 percent of the total volume placed in aquifer storage according to Bob Marley, technical specialist and hydrogeologist for Daniel B. Stephens and Associates, Inc., an Albuquerque-based company specializing in ASR. Spreading basins efficiently deliver water to the aquifer, eliminating the long-term evaporative losses associated with traditional surface reservoirs.

Infiltration works best for shallow aquifers. Infiltration basins are relatively low-tech, and thus less expensive and easier to maintain than some other methods. In addition, they clean the water as it soaks down through the soil layers. Chemicals in the water affix to minerals in the ground as the water seeps toward the aquifer. In some places, untreated river or canal water can safely be infiltrated into aquifers.

The other method for aquifer recharge uses injection wells, similar to wells that pump water out of aquifers. A motorized pump forces water down the injection well into the aquifer. Sometimes gravity of water falling down the pipe creates enough pressure for injection. Wells used to pump water out of aquifers can be retrofitted to work as injection wells. In fact, some injection systems use the exact same wells to put excess water into the aquifer in the spring as they do to withdraw the water later in the summer. Injection wells disturb only a small surface area. They can be placed anywhere, even in the middle of a city. They can also put water into aquifers too deep for infiltration basins.

A third option is vadose zone wells, sometimes called dry wells. The "vadose zone" is the area between the top of the aquifer and the ground surface. Hydrologists might dig a vertical tunnel partway to the aquifer, insert a perforated pipe, and fill around the pipe with something

permeable, like sand. Water will flow down the well and then soak the rest of the way to the aquifer. Vadose zone wells can collect surges of surface water, such as during a storm or flood, and ensure that water unable to soak down from the surface on its own reaches an aquifer. They also clean the water on the way, though not as thoroughly as infiltration basins.

"An above ground tank could store 5 million gallons. Aquifer recharge systems can put that much in the ground every day," says Marley. "If you have the right geology an aquifer can store water on the scale of a small reservoir. Not Lake Mead, but a midsize reservoir range—500 to 10,000 acre feet per year of water storage, up to 50,000 to 100,000 acre feet per year in other places."

In order for ASR to be viable for a community, the city needs a nearby aquifer with available space for added water, as well as a reliable surplus of clean water to infiltrate or inject into the aquifer. There must be sufficient water demand now or in the forecast to justify the cost of the studies and tests leading up to the ASR project and to develop the infrastructure and oversee the implementation, a process that can take years. Finally, the city needs to be sure it can control and effectively recover the water it puts into the aquifer.

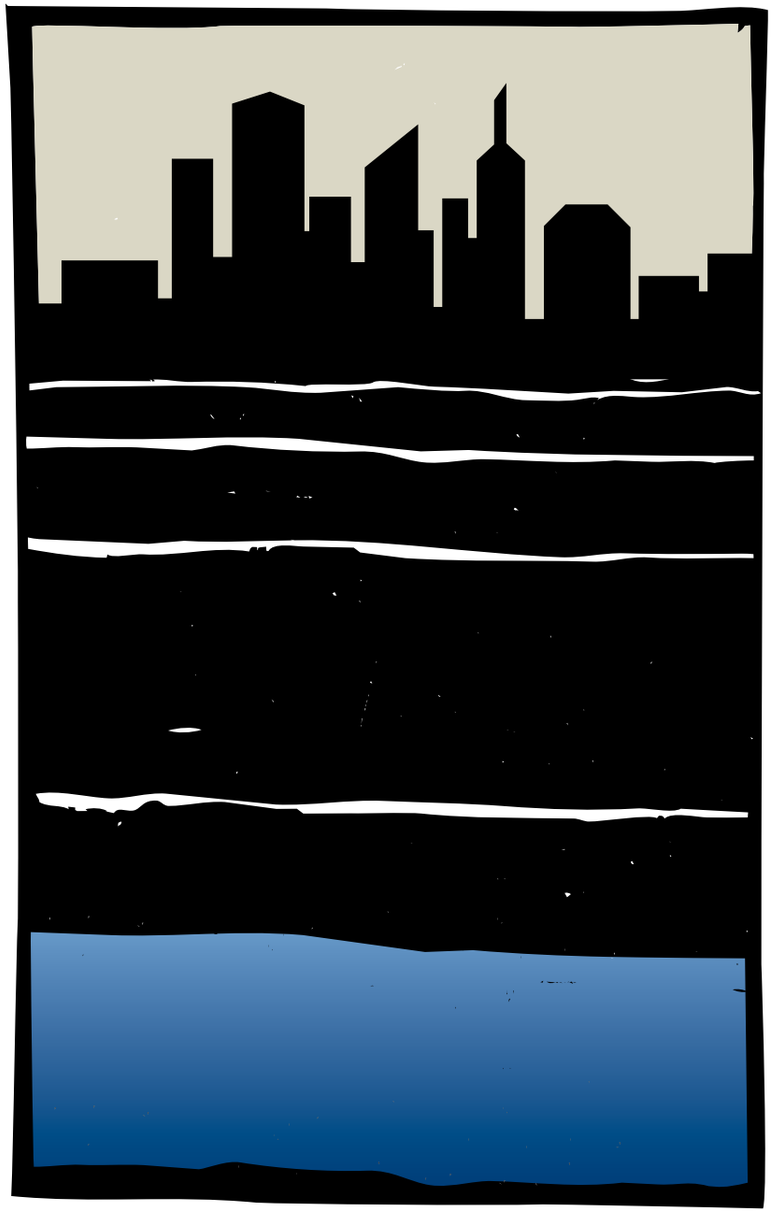
Cheyenne, Wyoming, is not the quintessence of an ASR-ready town, but the community does have the necessary surplus water, depleted aquifer, and thirsty population. The city's "Managed Aquifer Recharge, Storage, and Recovery Project" studied ASR's potential.

Geologists at Lytle Water Solutions (LWS), the Colorado-based company that conducted the study, found feasible test sites at two groundwater well fields west of the city. They first tested an infiltration basin approach. The water soaked into the ground like it was supposed to, but a 15-foot-thick layer of clay about 45 feet underground blocked the water from reaching the aquifer. Nearby monitoring wells did not detect any water increases in the aquifer. LWS suggested a vadose zone well penetrating the clay layer could solve the problem while letting the water infiltrate the remaining 75 or so feet to the aquifer. But the Wyoming Department of Environmental Quality denied the necessary permits because the agency feared a vadose zone well would let contaminants into the aquifer.

Following the infiltration basin study, LWS also tested an injection well. They retrofitted an existing municipal well so it could pump water both into and out of the aquifer. Over nearly three months LWS intermittently injected 93 acre-feet of water into the aquifer and pumped water back out to clean the well and test recovery. LWS determined that injecting water into Cheyenne's aquifer could be effective. However, the Cheyenne Board of Public Utilities was concerned about tracking the water's movement. They were not confident they would be able to recover their injected water. Following recent wet years, the city has not pursued the project any further.

Wyoming's governor appoints individuals to the Wyoming Water Development Commission to develop water projects funded by severance tax money. The group has explored several potential applications for ASR over the years. Usually the commission hires one consulting firm or another to conduct analyses and tests. Reports on these projects are posted to the Wyoming Water Resources Data System website.

Many ASR studies in Wyoming focused on the southeast corner of the state near Cheyenne. In the late



1980s, the commission investigated the potential for capturing spring floodwater to recharge a groundwater aquifer being depleted by irrigation. Floods were damaging roads and other infrastructure along the lower reaches of Crow Creek, downstream from Cheyenne. The report suggested installing spreader dikes in the stream to slow the floodwaters and let them soak into the aquifer, but more study was needed and the project was never carried out. In the early 2000s Laramie County also looked into recharging aquifers in the Lodgepole Creek Basin to help irrigators, but found it would be too expensive.

In the 2000s, the state began to look into ASR in the Green River Basin in western Wyoming. The geologists on the study determined the groundwater quality was too marginal for drinking or irrigation and the local aquifers lacked available space for injection. However, an idea arose to divert spring floodwaters into ponds near the river for infiltration. Then irrigators could either pump the water out of wells, or take it from the river as it soaked back to the main channel later in the summer. "Water banking via off-channel recharge could prove to be a valuable and effective

method of reducing or eliminating late season water shortages for several reaches in the Upper Green River Basin during dry years," the report concluded in 2001.

In the northeast corner of the state, the city of Gillette has also looked into groundwater storage. Gillette gets most of its drinking water from groundwater aquifers under the city and at the edge of the Black Hills near Devil's Tower 42 miles to the northeast. The city has had to deepen its in-town wells, from 400 feet in the 1970s to 700 feet in the 1980s. Then, in the late 90s, a coalbed methane boom started producing massive amounts of water of various qualities. In 2001 the city asked the Wyoming Water Development Commission to help it look into injecting produced coalbed methane water into the city's aquifer. This study found that the water was of too poor quality to use for drinking water. Furthermore, the city of Gillette had trouble coordinating with the coalbed methane producers to transfer the water. Finally, the only parts of the aquifer viable for ASR were too small to warrant the infrastructure required to bring the water to the city.

Wyoming has yet to find a suitable application for ASR, but some densely populated, thirsty Colorado cities are already recharging aquifers as a way to clean and store water for the future.

One of the most advanced ASR projects in Colorado is the Prairie Waters Project. The city of Aurora, a Denver suburb, created Prairie Waters to reclaim the city's effluent water. Prior to 2010, Aurora brought half of its water in from distant water basins to the south and west. The other half originated in the South Platte River Basin. Aurora was discharging treated water from its wastewater treatment plant into the South Platte River. Because half of that effluent was from water Aurora brought into the South Platte River Basin from elsewhere, the city still had a right to use it.

The Prairie Waters Project, which began delivering water in 2010, diverts water from the South Platte River downstream of the Aurora wastewater treatment plant and sends it through underground aquifers to both clean and temporarily store the water. The filtration provided by the sand and aquifer substrates underground removes pharmaceuticals and other contaminants. The city then uses wells to pump the cleaned water back out of the ground and pipes it 34 miles back to the city. The system added 10,000 acre feet of water to the Aurora City water system, about 20 percent of the city's supply, and will expand up to 50,000 acre feet by 2030.

The city of Denver and its utility, Denver Water, has historically relied almost entirely on surface water and now is investigating the potential to store water in a deep aquifer under the city limits. This would likely entail recharging excess surface water during spring runoff season and withdrawing that water later in the year during times of greater need. The Centennial Water and Sanitation District, which serves Highlands Ranch, Colorado, injects excess surface water that has been treated to drinking water quality through 19 wells into its aquifer to slow aquifer depletion. And Castle Rock south of Denver has historically relied exclusively on groundwater from several Denver Basin Aquifers, which do not naturally recharge from snowmelt or rain water. As the aquifer declines, the city is now lifting water from depths of as much as 1,400 feet, which requires heavy-duty pumps. In addition to diversifying its water supply with renewable surface water sources, the city is investigating potential to recharge its aquifer. In 2014 the city retrofitted some existing wells to test ASR.

Alongside their infrastructure projects, these Colorado communities have also emphasized water conservation. Most conservation measures focus on altering landscaping. Lawn care and other outdoor water uses account for more than half of all domestic water use. Conservation measures in Aurora reduced per capita daily water consumption from 175 gallons to around 135, a nearly 25 percent decrease, which saves millions of gallons per year the city would otherwise have to secure, treat, and transport.

Storing water in an aquifer, "extends the life of the resource," says Marley, the hydrogeologist in Albuquerque. "As a city, as soon as you discharge the water, there are no further benefits. If you can collect it, treat it, recycle it a few times, you get more bang for your buck."

Colorado's large and thirsty human population, diminishing aquifers, and lack of space for new reservoirs all converge to make ASR a viable option there. Unlike Colorado, Wyoming does have space for new reservoirs, but they also face hurdles related to environmental permitting, evaporative losses, and siltation. Meanwhile, Cheyenne's Aquifer Recharge, Storage, and Recovery Project is currently on hold.

"I think the technology has matured enough now that we have plenty of examples," says Marley of ASR. "It's now more common as a potential solution. But a project can stall out. The governing bodies and teams working on it have to be committed. They have to stay with it. It doesn't take as long as to build a reservoir, but it will be a multiyear event."

Kevin Boyce, project manager at the Wyoming Water Development Commission, has worked on several ASR tests and studies across Wyoming over the years. While he agrees that Wyoming needs to find sound methods for storing water into the future, our situation as a low-population headwaters state means we are not desperate enough for water storage at this time to invest the resources ASR requires. "We have some proactive studies, but nothing is off the ground," says Boyce.

Water storage will remain a primary concern for Wyoming water managers over the coming decades. Now that the state has tentatively explored aquifer recharge and found some promising ideas, when the time is right ASR will likely resurface.

Note: While this story was in production, the Laramie County Commissioners hired the Ruckelshaus Institute, publisher of this magazine, to facilitate meetings of a newly formed steering committee tasked with solving the aquifer depletion problem for irrigators downstream of Cheyenne, Wyoming.

RESOURCES

Find links to these reports at westernconfluence.org

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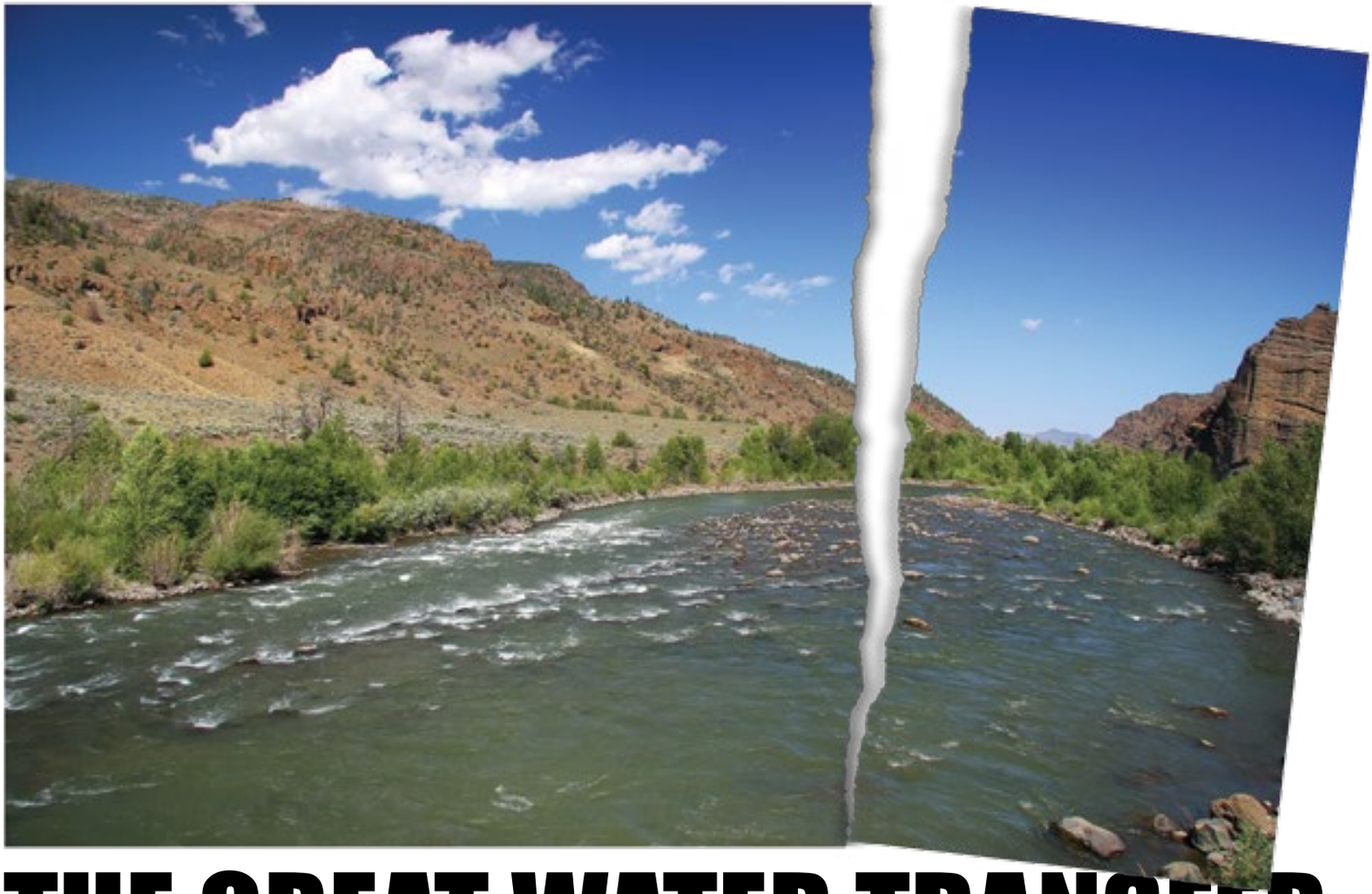

THE GREAT WATER TRANSFER

DIVERTING WATER FROM BASIN TO BASIN

By Erin Jones

In the summer of 1860, farmers in central Colorado found Left Hand Creek dry.[1] They started looking for replacement water. Just over the ridge, South St. Vrain Creek flowed wet, so they dug a ditch to divert its water back to Left Hand Creek. This solved their problem, but later in the summer St. Vrain Creek dried up downstream from the diversion. To take back their water, St. Vrain farmers ripped out part of the Left Hand Ditch.

The Left Hand farmers sued the St. Vrain farmers for destroying their diversion. When the case eventually reached the Colorado Supreme Court, judges ruled in favor of the Left Hand farmers. The court found that the Left Hand farmers had "priority of appropriation," meaning the water belonged to them because they were the first people to move it and put it to use, regardless of who owned the land adjacent to the waterway.

Thus began water diversion in Colorado. Colorado's biggest cities are built on water that's been moved from one side of the mountains to the other. As western communities plan for future growth, they may look for more opportunities to divert water from wet, low-population water basins to drier areas with more people.

Colorado's geography is ideal for water diversions. The Continental Divide twists along Colorado's middle like a spine. West of the Continental Divide the state's mountains collect snow through the winter. While most of the Colorado's water is west of the divide, 90 percent of the state's population plus most farms and industry are on the eastern foothills and plains. In the early part of the twentieth century, cities and counties on the Eastern Slope began to commission pipelines and ditches to bring them water from the Western Slope. And, because of legal precedent from the Left Hand case and others, the Eastern Slope has the right to Western Slope water. Today, most Front Range reservoirs hold Western Slope water, piped in through transbasin diversions.

One example is Turquoise Lake, part of the Frying Pan-Arkansas Project. The Frying Pan River starts as snowmelt at the crest of the Rockies near Aspen. Its water serves surrounding communities and ecosystems in the Colorado River headwaters.[2] About fifty years ago construction crews burrowed under the Continental Divide to build the Boustead Tunnel, which pipes Frying Pan water to Turquoise Lake near Leadville.[3] Shaped like a horseshoe, the tunnel has a ten-and-a-half foot diameter, big enough to drive a truck through. It would take strong headlights: the tunnel winds more than five miles under some of

[1] Caitlin Coleman, "Citizen's Guide to Colorado's Transbasin Diversions," Colorado Foundation for Water Education, 2014.

[2] Brent Gardner-Smith, "Pitkin County fighting city of Aurora over Fryingpan water," *Aspen Journalism*, January 25, 2013.

[3] US Department of the Interior Bureau of Reclamation, "Frying Pan-Arkansas Project," 2013.

the tallest mountains in the West. Boustead can carry 684,603 acre-feet per year. It's part of a larger network of ditches and tunnels called the Frying Pan-Arkansas Project.[4] Eventually, Frying Pan River water flows out of Turquoise Lake and makes it to the Arkansas River Basin where it serves Colorado Springs and Pueblo.

The Boustead Tunnel is just one of Colorado's 44 transbasin diversions, 27 of which cross the Continental Divide. Water that crosses the Divide effectively disappears from its original basin.

Colorado may be the poster child of water diversions, but such projects exist in other western states as well. Wyoming currently has one major transbasin diversion that moves water from the Little Snake River Basin west of the Continental Divide to the North Platte River Basin on the east. This is a complicated, multi-step diversion. The city of Cheyenne owns a water right in the Little Snake River, which it diverts over a mountain range to Hog Park Reservoir. From there, the water flows out of the reservoir, down Hog Park Creek, and into the North Platte River. In exchange for dumping its Little Snake River water into the North Platte, Cheyenne pipes water from another North Platte tributary, Douglas Creek, 75 miles from the Medicine Bow Mountains to the city. On average, this diversion moves 10,664 acre-feet of water every year.

Other diversions could one day join Cheyenne's elaborate system of trades and pipelines in Wyoming. In 2006, Fort Collins businessman Aaron Million proposed a 500-mile transbasin diversion from Flaming Gorge, in southwestern Wyoming, along I-80 to Cheyenne, and then south all the way to Pueblo, Colorado.[5] His goal was to move 250,000 acre-feet of water a year. Million's permit application was most recently rejected by the Federal Energy Regulatory Commission in 2012 because it didn't specify how he planned to gain approval for building across federal, state, county, local, and private lands.[6]

More recently, Governor Matt Mead explored transbasin diversion as a potential component of a water strategy for Wyoming.[7] He suggested Wyoming begin planning a pipeline to carry water from the Upper Green River to the North Platte River Basin near Cheyenne. However, following the public comment period for the strategy, this diversion was cut from the water strategy.

Some citizens in Wyoming, Utah, and Colorado strongly opposed these diversion proposals due to concerns about the ramifications to people and ecosystems in the water's original basins. They worried that taking water out of the Green River would hurt trout and salmon, dry up wetlands, spread cheatgrass, and otherwise damage the ecosystem. Also, they're concerned that decreasing Flaming Gorge Reservoir's water level could affect the local recreation economy and potentially force the government to spend money on construction of new recreation infrastructure.[8]

Meanwhile, if towns in Wyoming's North Platte River Basin grow at all in the future, they will be looking for more water. Like in Colorado, most of Wyoming's snowfall and major rivers are west of the Continental Divide, while the human population and agriculture is east of the divide. By some analyses, Wyoming is already using all the water it has a right to in the North Platte River, while there still remains unused water in Wyoming's allocation of the Green River, which is a tributary of the Colorado River. The 1922 Colorado River Compact allocated each of the states in the Colorado River Basin a certain amount of water. Depending on conditions, Wyoming gets roughly 1.04 million acre-feet, about 250,000 of which are currently not being used. As water supplies become more strained in the west, someone will figure out how store, use, or divert that water.

Despite the failure of recent Wyoming transbasin diversion proposals, it's likely that businesspeople and water managers will continue to explore them. As water becomes scarcer and people more plentiful in Wyoming, the tug-of-war over water will become more pronounced, and the population centers, like Casper and Cheyenne in Wyoming, may look west of the Continental Divide in their search for water. Transbasin diversions could reappear on Wyoming's water horizon in the future.

__Erin Jones__ is pursuing a master of fine arts in creative nonfiction writing and environment and natural resources at the University of Wyoming.

Find links to the resources cited in this story at westernconfluence.org

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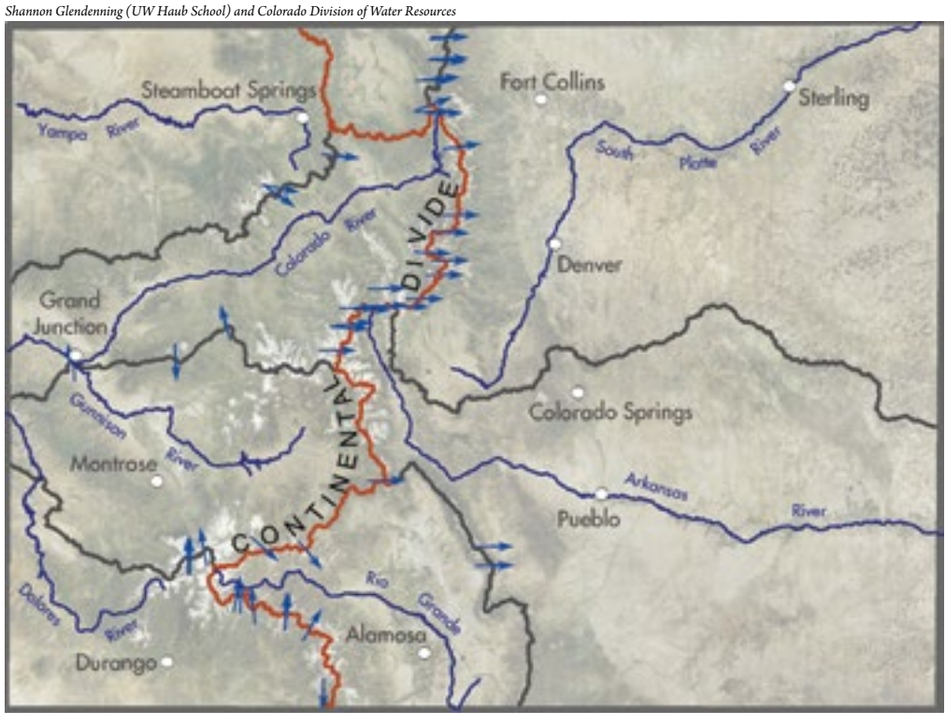
5 Shannon Love, "The Green River and Colorado's Water Future," *University of Denver Water Law Review*, August 27, 2013.

6 Hannah Northey, "FERC rejects major Wyo.-Colo. pipeline proposal," *Environment and Energy Publishing* (February 28, 2012).

7 Wyoming Governor's Office, "Wyoming Water Strategy Public Input Sessions Possible Initiatives Executive Summary," 2014.

8 It's Our Dam Water, "The Facts," 2014.

Shannon Glendenning (UW Haub School) and Colorado Division of Water Resources



Blue arrows show the 44 transbasin diversions in Colorado. Black lines show boundaries between major river watersheds.

No-Name

Asking Big Questions About Hydrology in One Little Watershed

By Elizabeth Nysson

Square solar panels congregate on weathered tree stumps in a small open area in the Medicine Bow National Forest. Filaments of sunlight stream through the dense pines and reflect off the photovoltaics. Under one tree sits a white metal rectangular box with a cable running from its base through the clearing. With trees entwined by electrical cords, the scene would likely puzzle any hiker who stumbled across this remote mountain area.

This is a study site in the No-Name Watershed, a little 300-acre (about half a square mile) drainage in the Medicine Bow Mountains of south central Wyoming. No-Name Creek starts as snow melt and trickles downhill for about one kilometer to Libby Creek, which eventually meets the Little Laramie River. Steep slopes cloaked in subalpine fir and Engelmann spruce characterize the No-Name Watershed, and a limestone escarpment marks one edge of this rugged area. On maps of the mountain range, it's just a tiny nameless thumbprint, but this little pocket of forest could hold answers to some of the most cutting-edge questions about subalpine hydrology.

The futuristic collection of equipment tucked into this clearing is part of an ambitious, multi-year, interdisciplinary research project being conducted by scientists and graduate students from the University of Wyoming. Roughly twenty researchers and students from seven departments are concentrating their research in the No-Name Watershed to learn how water moves through mountain environments. Growing demands on water throughout the West mean it is increasingly important to understand how water moves from high subalpine areas into the rivers and streams that support communities hundreds of miles downstream. But no single research discipline has all the tools needed to fully analyze subalpine hydrology. The only way to really comprehend the processes that control water in this system is through interdisciplinary collaboration, an idea that's a bit out-of-the-box for most university academics.

Crouched behind the solar panels in late June, geology and geophysics graduate student Drew Thayer is setting the controls on a fiber-optic Distributed Temperature Sensor. After he finishes, he and his research team unroll a thin black fiber-optic cable through the forest to No-Name Creek. Small boulders and bright green moss line the swift, narrow current. The team members weave the cable under fallen trees and limbs that crisscross the stream. The cable, which connects to a solar-powered computer housed inside the metal box back in the clearing, will collect water temperatures. These data will be paired with air and soil temperatures collected by other researchers to start to describe the watershed in minute, scientific detail. Like the little mountain creek flowing through this study site, the research here started as a trickle, and now rushes like spring snow melt.

Elizabeth Nysson

Drew Thayer gets ready to place a distributed temperature sensor cable into No-Name Creek.

In 2007, UW ecosystem scientists Ginger Paige and Scott Miller set out to look for a small watershed to use as a research site. After some investigation near the Snowy Range, Paige and Miller found this nameless little drainage at about 9,500 feet of elevation. A stream monitoring gauge had been installed in Libby Creek where the waters converge. At an appropriate size and with some historical data already available, the team decided No-Name would meet their needs.

Concentrating research in a small watershed is by design. "As you go out to a larger watershed you can no longer adequately describe how point-scale processes like snow melt and rainfall result in stream flow and groundwater recharge without a lot of uncertainty," says Miller. Focusing on No-Name allows researchers to more accurately answer questions about how and where water moves through the environment. These answers will inform understanding of larger watersheds.

In 2012, five years after Miller, Paige and a few other colleagues installed baseline hydrologic instrumentation and began to measure components of the water balance, No-Name research suddenly increased with an infusion of funds from the National Science Foundation through Wyoming's Experimental Program to Stimulate Competitive Research. This award, for which Miller is a principle investor, created the Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG), a multidisciplinary research center at the University of Wyoming.

One of the first students to develop a long-term project at No-

Name with WyCEHG funding was Alan Klatt, a field hydrology graduate student under Miller. Starting in the spring of 2012, he installed ten gauging stations to monitor water flow in No-Name Creek and has managed two meteorological stations that measure precipitation entering the watershed.

Over the next two years, research in No-Name Watershed quadrupled. A team of plant physiologists led by Professor Brent Ewers is measuring evapotranspiration to account for the water that escapes from trees and understory plants. Other researchers are calculating how trees take up water, modeling future forest conditions, mapping vegetation, and surveying trees killed by bark beetles. A group of geophysics students and faculty are using electrical resistivity to generate a two-dimensional image of water underground. Still more studies are looking at weather and atmospheric conditions, such as air temperature and humidity. During the winter, Assistant Professor Noriaki Ohara is modeling snow pack dynamics and joining other researchers working to better understand snowmelt. There is an array of studies related to surface water conditions in which teams are investigating surface water flow, analyzing how water flows through soils, and understanding the chemistry of water. Klatt explains, "The water cycle has many complex components and requires an interdisciplinary group of experts working together to understand the whole system."

Even without a name, researchers hope this little watershed will lead to big discoveries. As the project continues, WyCEHG researchers will piece together the most thorough picture of subalpine hydrology ever produced by science. This research will not only build knowledge within the scientific community, but also inform managers in the West and give students like Klatt and Thayer experience to be leaders in water-science fields in the future.

Elizabeth Nysson *is the education, outreach, and diversity coordinator for Wyoming's Experimental Program to Stimulate Competitive Research (EPSCoR) at the University of Wyoming.*

Elizabeth Nysson

Instruments measure surface water characteristics.

Elizabeth Nysson

Alan Klatt wades into Libby Creek.

Finding Teton Glacier

By Manasseh Franklin

My partner Matt and I left the Lupine Meadows parking lot in Grand Teton National Park at sunrise, his long stride covering miles quickly, my short stride moving fast to keep up. We paused at Amphitheater Lake for handfuls of trail mix and then, at the direction of the park ranger we'd spoken to the evening before, began to hunt for a faint trail that would lead us up the ridge east of the high alpine lake. In the basin beyond that ridge, we'd been told, sat a glacier.

We found the path in a cluster of boulders and followed it away from the lake. The steep incline required scrambling with all fours past scrubby pine trees. When we finally reached the ridge, we were disappointed: there was no glacier in sight.

Instead we saw piles of house- and car-sized boulders strewn along a valley floor. Beyond towered a horseshoe-shaped wall of debris. Rocks, silt, and boulders once carried by a glacier and then left behind, this moraine offered a clue. Maybe behind it we would find what we were looking for.

I was searching for Teton Glacier just as I'd been searching for glaciers all summer to gather material for my master of fine arts writing thesis at the University of Wyoming. My journey began in Alaska where I'd traveled by foot, floatplane, pack raft, and ski to glaciers in the Southeast and the Kenai Range. Next Matt and I visited a series of glaciers that became notably smaller as we moved south through Alberta, British Columbia, Montana, and, finally, Wyoming. I traveled to the glaciers not to measure them or to mourn the loss of ice, but simply to experience them and to record that experience for others.

I am a writer and a scientifically curious person. I'm drawn to glaciers because I feel most alive in hard, cold spaces, and have a fierce desire to tell a story not often told. Much of what the public knows about glaciers comes through media stories about climate change, rising sea levels, or how glaciated regions of the world are melting fast. But there is more to glaciers. Their decline shifts climate. Their decline changes ecosystems. And their decline also means the loss of incredibly bizarre and inspiring spaces on earth that few humans will ever experience first hand. My goal is to share the story—the ecological, climactic, and personal story—of these places.

Which is how I ended up picking my way down the steep slope into the valley alongside Matt, searching for one of the few glaciers still standing in the Teton range. We reached the boulder field and worked our way across it, pressing our feet and hands between car-sized granite chunks and scattered shreds of malachite. Water gurgled beneath us, unseen, hidden by a cluttered rock mess.

The boulder field steepened. Boulders gave way to sandy scree and rocks. The fluted moraine glittered in pale sunlight that cut through clouds above. We tipped our heads back to see the top of it 100 feet above us, hunched our shoulders and continued climbing. Rocks shifted beneath our boots with each slow, steady step. Occasionally we slid back as far as we'd moved forward.

Once atop the moraine ridge, we still couldn't see the glacier, but we stood where it had once been. Before us a steep loose pitch slanted down to a large snow patch. We glissaded down the moraine and followed the snow to a sheer rock pillar. We rounded the pillar and an amphitheater opened before us.

Manasseh Franklin

Matt approaches Teton Glacier.

I stopped and put my hand on Matt's arm. The glacier sat tightly nestled against the lower reaches of the Grand Teton, Mount Owen, and Mount Teewinot. It filled a small corner of the amphitheater and spread 2000 feet or so to where we stood. Its bergschrund—a wide seam that forms where moving ice has pulled away from rock wall—sat high above the rest of the ice, a large slit pressed against the rock behind. The seam gave way to a miniature icefall, and to the right of the icefall, a small band of crevasses etched into dirty snow like ribs.

The glacier had all of the form and texture of a typical glacier, but in miniature.

Down slope from the icefall and the cracks, water trickled through soft ice studded with multicolored rock and punctuated the air with muffled, steady rhythms. The water slid beneath the debris horseshoe that stretched across the opening of the amphitheater, and far down slope, met a creek that gurgled and splashed through Glacier Gulch to the glittering, rich turquoise surface of Delta Lake.

I gazed up at the glacier and down to the lake and imagined ice filling the space as it did during the last Ice Age. This glacier, along with others in North America, is a remnant of the ice sheets that once stretched across the continent. As the climate shifted over the last 12,000 years, the ice sheets shrunk to glaciers and left mountain peaks and valleys in their wake. Some of the remaining glaciers still grow, most are declining, and some, like the Teton Glacier maintain their small mass thanks to northerly aspects, and protective cirque walls.

I come to these places to experience the earth as it was and to experience it as it is. Glaciers—especially these hidden ones burrowed in the Rocky Mountain West—illustrate the ever-changing nature of these landscapes. They are a living history, and someday—perhaps sooner than later—their presence and current shapes will exist only in text and photos on the pages of books. All we will know and experience of them is what they leave behind.

I smiled at Matt and squeezed his hand. He smiled back. We turned back toward the moraine and slowly began the climb out.

Manasseh Franklin *is pursuing a master of fine arts in creative nonfiction writing and environment and natural resources at the University of Wyoming. She has reported for magazines including* Afar, Rock and Ice, Trail Runner, *and others.*

Beaver Dreams

The Rancher Who Wished for a Beaver

By Erin Jones

"They're really beneficial, to get the shrubs in, get the water up."

Clyde Woolery, a rancher near Kinnear, Wyoming, wishes he had more beavers. In 2011, he called the Wyoming Game and Fish Department and asked if they could live trap a beaver and transplant it to his ranch.

Many landowners fight with beavers. Like humans, beavers manufacture a landscape to suit their needs. Take this scenario, for example. A rancher installs a culvert under a road leading to a pasture. A beaver dams the culvert to make a pond, flooding the road. The rancher dynamites the dam. The beaver rebuilds. And so on. Many ranchers see a beaver as a headache, but for landowners like Woolery who have no beavers, that sentiment is changing.

Since beavers reached near extinction around the turn of the twentieth century, trapping limits have helped beaver populations recover, but not to the levels they used to exist in Wyoming. That's why organizations like Wyoming Wetlands Society, with cooperation from the Wyoming Game and Fish Department, have been moving live beavers to places they won't come into conflict with human structures, and educating landowners about the benefits beavers provide.

Bill Long, the program director of Wyoming Wetlands Society, says that beavers can establish new wetlands and make existing wetlands work better. "Cleaner, colder water comes out of beaver dams," he says. "They're a keystone species." Beaver dams raise the water table and increase water quality by slowing down the flow and filtering the water, Long says. That helps establish willows and other shrubs, which are good habitat and browsing for animals including livestock.

After all, "it's been said many times before, they're nature's engineer." He says wetlands benefit ecosystem health and even boost biodiversity. "They're doing good things. Whether it be for cutthroat trout or for cattle, they're good for the system."

When a landowner has a problem beaver, Long's group live traps it and moves it to public land, usually national forests. Wyoming Wetlands Society has been moving dozens of beavers each year since 2004. Game and Fish reacts to isolated phone calls, also moving troublesome beavers to public and sometimes private lands.

And, meanwhile, ranchers like Clyde Woolery wish for a beaver. In a state looking for ways to store water in an arid landscape, beavers could help. A program for landowners to request beavers could be one step toward healthier wetlands for people, livestock, fish, and ecosystems.

Woolery believes he's not alone in his dreams of bringing beavers back to his ranch. If Game and Fish streamlined a way for landowners to get on a beaver request list, Woolery thinks there would be demand. He says Game and Fish agreed to bring him a beaver once he could get willow established closer to his creek. "The coyotes get them, if they have to go too far for willow," Woolery explains. He's on beaver hold until then.

Wyoming Conservation Exchange

New Marketplace Will Reward Wyoming Ranchers for Conserving Sage Grouse Habitat

By Sara Brodnax, Kristi Hansen, Jen Lamb, and Melanie Purcell

The Upper Green River Basin of Wyoming, at the headwaters of the Colorado River, is laced with clear running streams and fosters abundant habitat and some of the most robust greater sage grouse, mule deer, and pronghorn populations in the world. With steady projected population growth for Pinedale, the seat of Sublette County in the heart of the basin, and some of the country's most significant natural gas fields, the area needs solutions that keep working lands productive while protecting at-risk habitats. That's where a "conservation exchange" comes in.

One at-risk species in the basin is the greater sage grouse. The U.S. Fish and Wildlife Service (the Service) must decide whether the greater sage grouse warrants listing under the Endangered Species Act. Across the West, land management agencies, wildlife agencies, private landowners, and others are racing against the clock to get regulatory structures and on-the-ground conservation in place. Their hope is to convince the Service that the sage grouse can thrive under current management and does not need the additional protection that would come with being listed as a threatened or endangered species. A listing could impede some activities in sage grouse habitat including agriculture and energy development.

Many sage grouse conservation efforts have focused on breeding areas known as leks, most often found in dry upland areas, 80 percent of which are on public land. However, after breeding, sage grouse move to wetter areas to raise their broods through the summer. Private lands in the West are often found along rivers and streams, as homesteaders put down stakes where they had ready access to water. These areas are also critically important to wildlife. A recent study by the Sage Grouse Initiative, a public-private partnership of ranchers, agencies, universities, non-profit groups, and businesses launched by the Natural Resources Conservation Service, found that more than 80 percent of these essential wet habitats are on private lands. So while sage grouse conservation on state and federal lands is very important, private land conservation cannot be ignored.

Wyoming, home to nearly half of the greater sage grouse's remaining habitat, is critical to the species' recovery. A full 40 percent of the bird's habitat in Wyoming is on private lands, so ranchers and other private landowners are looking for ways to conserve these habitats.

A few years back, landowners in the Upper Green River Basin in Wyoming stepped up to find ways to put a value on the benefits provided by their lands. To this end, the Sublette County Conservation District, the University of Wyoming, The Nature Conservancy, and the Environmental Defense Fund teamed up to support landowners in their efforts to develop the Upper Green River Conservation Exchange. Together, this group began designing a marketplace that would establish an economic value for healthy, intact wildlife habitat and water resources on private lands.

The basic idea of the conservation exchange is that ranchers who conserve good habitat and other natural resources can sell those values, in the form of credits, to energy companies or other developers seeking to offset unavoidable impacts of development. For example, if an energy company plans to drill a well in sage grouse habitat in one part of the Green River Basin, it would first try to avoid or minimize impacts to grouse to the fullest extent possible, such as by modifying the projec. To offset unavoidable impacts, the energy company could then buy credits from a rancher who voluntarily agrees to maintain and enhance sage grouse habitat nearby in the basin. The amount of habitat protected should more than offset the direct and indirect impacts on the bird and its habitat. This would help the energy company protect wildlife, and reward the landowner for providing sage grouse habitat. In addition to benefitting both landowners and developers, the exchange would support the wildlife and open landscapes that characterize the basin. Conservation investors interested in supporting sage grouse habitat, such as sportsmen or non-profits, could also purchase credits in the exchange.

In early 2014, the participants in the Upper Green River Conservation Exchange recognized the opportunity to scale up to a statewide Wyoming Conservation Exchange to generate additional conservation for greater sage grouse. Critically, a statewide

exchange would allow landowners throughout the state to participate in mitigation efforts in close proximity to proposed land disturbances. As this effort has evolved to a statewide platform, it has attracted additional involvement and support from stakeholders like the Wyoming Stock Growers Association and the Wyoming Association of Conservation Districts.

The tools and standards of the Wyoming Conservation Exchange are modeled after conservation banking, which is used to protect lands and offset adverse impacts to threatened or endangered species. The exchange will have programmatic features and standards like a Habitat Quantification Tool used to measure and assess sage grouse habitat, placing the highest value on healthy, unfragmented habitat. Eventually, the Wyoming Conservation Exchange can expand to protect more than just sage grouse habitat. Tools are in development for mule deer habitat and hydrologic services as well. The Habitat Quantification Tool uses a set of measurements and methods to evaluate vegetation and environmental conditions related to habitat quality and quantity. Energy companies and other developers that need to mitigate the unavoidable impacts of their projects can use the tool to calculate pre- and post-conditions on both development sites (debits) and habitat improvement sites (credits).

In the coming months, the Exchange partners will hire an Exchange Administrator and establish pilot projects. Much work is need to get the program off the ground, but if all goes as planned, a pilot version of the Wyoming Conservation Exchange will open for business in 2015.

The Wyoming Conservation Exchange will complement ongoing state and federal efforts to protect sage grouse. For example, Wyoming's "Core Area Strategy" supports grouse protection on key habitat areas and concentrates development elsewhere. And the Bureau of Land Management is incorporating sage grouse regulatory mechanisms in its revised Resource Management Plans. The Wyoming Conservation Exchange will complement these strategies by rewarding landowners for bolstering habitat on private lands. The Exchange can also be used to complement the measures required by the Core Areas Strategy and the Resource Management Plans by offsetting any unavoidable impacts that remain after onsite mitigation efforts. Because offsetting or "compensatory mitigation" generally requires that offsite habitat improvements are greater in value than the onsite habitat destruction, the Wyoming Conservation Exchange in theory has the potential to actually increase the overall extent of sage grouse habitat.

As the Service reviews whether to list the sage grouse as a threatened or endangered species, it will be evaluating whether states have adopted regulatory mechanisms adequate to ensure the grouse's survival. In its recent "Greater Sage-Grouse Range-Wide Mitigation Framework," the Service emphasized how important it is for states to develop robust mitigation programs that provide for no net loss and even net gain of sage grouse habitat. In the Mitigation Framework, the Service specifically recognized how conservation exchanges can help address these needs.

The Service, along with the Wyoming Department of Game and Fish, Wyoming Office of State Lands, Wyoming Department of Environmental Quality, Bureau of Land Management, and Natural Resources Conservation Service, is currently reviewing the Wyoming Conservation Exchange proposal. If the application is approved, the Service and any other approving agencies will formally recognize sage grouse habitat conservation undertaken through the Exchange.

"By using tools that encourage collaboration and forward thinking like conservation exchanges, everyone—including the greater sage grouse—wins," says Eric Peterson, the District Manager of the Sublette County Conservation District. "That's a great outcome for ranchers, industry, and Wyoming."

***Sara Brodnax**, the Habitat Markets Manager for the Environmental Defense Fund, works to develop incentives for conservation and stewardship of working farms and ranches. She is based out of Washington, DC, and spent summer and fall 2014 in Wyoming.*

***Kristi Hansen** is Assistant Professor and Extension Water Resource Economist in the Department of Agricultural and Applied Economics at the University of Wyoming. Her research focus includes environmental markets and payment for ecosystem services programs.*

***Jen Lamb** is the Southwest Wyoming Program Director for The Nature Conservancy in Wyoming. She works with landowners, agencies and other partners to conserve healthy working landscapes.*

***Melanie Purcell** is Wildlife and Habitat Program Manager and Payment for Ecosystem Services Specialist for the Sublette County Conservation District. Her local knowledge of biology and socio-economics helps to inform ecosystem service opportunities.*

FURTHER READING

Wyoming Conservation Exchange – wyomingconservationexchange.org

Habitat Exchanges – thehabitatexchange.org

Find links to the following reports at westernconfluence.org:

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Sagebrush Recovers at Oil and Gas Wells

Other Species Do Not

By Emilene Ostlind

"The most important questions have to do with the long-term behavior of systems," says Indy Burke, University of Wyoming ecologist. The system she's talking about, in this case, is western landscapes. And their behavior has to do with how the sagebrush and other vegetation recovers after disturbance. She, botanist Bill Lauenroth, and their graduate students have a paper coming out in the journal *Ecosphere*. The paper describes their study designed to learn how sagebrush grows back at abandoned oil and gas wells, but the most surprising finding was about another family of vegetation.

The researchers used a "chronosequence" to look at well pad sites 30, 60, and even 90 years after abandonment. History is part of their experimental design. Instead of setting up a study and waiting for the site to age three to nine decades, they went to the Wyoming Oil and Gas Conservation Commission records and found oil and gas wells that had been abandoned 30 to 90 years ago.

"We had difficulty getting these papers published," Burke says. The reviewers wanted to see controls and an experiment that could be replicated. "We don't have any of that." A controlled study would have required clearing a well pad, abandoning it, and monitoring it and the surrounding area for 90 years to see what happened.

Instead, the team identified 29 old, abandoned oil and gas wells in two areas of south central Wyoming. When they visited the sites, they found metal posts at the center of each pad bearing information that allowed them to identify the well and connect it to information stored in the Wyoming Oil and Gas Conservation Commission database.

The wells were abandoned between 1923 and 1980 and showed no sign of reclamation. They averaged about 40 yards in diameter. All were situated in a landscape dominated by Wyoming big sagebrush, with other shrubs, grasses, and wildflowers present. At each well pad site, the researchers measured the sagebrush height, cover, and density. They also recorded cover and density of three other categories of vegetation: non-sagebrush shrubs, grasses, and forbs. In addition, they recorded the same information for adjacent areas never disturbed by oil and gas development.

Sagebrush once covered an estimated 232,000 square miles across western North America, an area almost two and half times the size of Wyoming. Today, as much as half of that ecosystem has been lost due to invasive weeds and land use changes. Several iconic western species such as mule deer, pronghorn, Rocky Mountain elk, and pygmy rabbits, as well as birds including sage grouse, sage thrasher, and sage sparrow depend on sagebrush for habitat. Energy development is one of the primary causes of land disturbance in the sagebrush ecosystem, so understanding the long-term effects of such activities on the vegetation matters as we try to manage for those sagebrush-dependent species.

The findings from the study startled the researchers. "Sagebrush recovers but it takes 60-80 years," says Burke. "Grasses recover fully very quickly," she adds. But the forbs did not recover even after 90 years.

This last part was unexpected. Forbs include wildflowers and other small leafy, flowering, non-woody plants. Even though forbs don't account for a very high percentage of vegetation in these sagebrush landscapes, they account for the most species and are a critical part of the ecosystem. Sage grouse, for example, need at least 10 percent forb cover for shelter and forage.

"If you're patient the sagebrush will come back," says Burke. "The forbs will take much longer."

Because this research was designed to ask questions about sagebrush and the finding about wildflowers was incidental, Burke and her team are now returning to the well sites to survey individual forb species. They will also look for seeds in the soil to begin to understand whether forbs have trouble because their seeds don't persist on abandoned well pads or if something else, like soil disturbance and compaction, is preventing their recovery. The results could help improve reclamation requirements to return old energy development sites to suitable habitat.

Emilene Ostlind *edits* Western Confluence *magazine.*

Indy Burke *directs the Haub School of Environment and Natural Resources at the University of Wyoming, home to the Ruckelshaus Institute, which publishes this magazine.*

FURTHER READING

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SOLUTIONS

Healing Sick Rivers

Encampment River Case Study

By Charlie Reinertsen

A front loader picks up massive boulders as if they are pebbles. A bulldozer shoves rocks into a mound. High-pitched beeps ebb and flow as the machinery works back and forth. Everything about this construction site is typical, with one exception: the equipment is in the middle of the Encampment River. The front loader bucket dips into the water, scrapes along the riverbed, and scoops up cobbles and sediment. Water streams over the edges as the bucket lifts and swivels towards the stream bank. With one deft movement, the heavy machinery dumps the cobbles and sediment. The rocks crash and boom to the riverbank. River reconstruction is under way.

Many rivers today are not the same wild waterways they once were. Throughout human history, civilizations have struggled to transport, store, use, and control water, and these actions have restructured our watersheds. In some cases, manipulation has resulted in sick rivers—straightened, widened, and degraded until they no longer provide critical ecosystem services such as efficiently moving sediment and water. Across the West, conservation groups, private landowners, federal and state agencies, and construction companies are working together to enhance river function.

To see an example of river enhancement, I drove to Riverside, Wyoming, to meet Christina Barrineau, an aquatic habitat biologist with the Wyoming Game and Fish Department. Wearing hiking boots, a fleece pullover, and large black sunglasses, she greeted me with a smile and a firm handshake at the Bear Trap Restaurant, where I climbed into her pickup truck. Barrineau restores and enhances watersheds throughout Wyoming, and has most recently been overseeing work on the Encampment River. As we drove to the first site, Barrineau told me the river's story.

Like many western rivers, the Encampment is, in Barrineau's words, "well-used." During construction of the transcontinental railroad in the nineteenth century, workers harvested trees along the upper Encampment River, cut them into railroad ties, and floated them down the river. The ties filled the entire channel, scouring the bottom of the river. In 1897, prospectors built a diversion dam in the Encampment River to supply water to a copper smelter. Sediment built up above the diversion dam, and downstream water from the smelter rushed out of a pipeline and degraded the stream banks.

Diversions for agriculture also damaged the river. Cobble push-up dams, built to force water into irrigation ditches, restricted the river's flow and prevented fish from moving upstream. The push-up dams couldn't withstand spring floods, so every year workers bulldozed the riverbed back up. Another agricultural use, cattle grazing, has reduced streamside vegetation, leading to bank erosion.

The combined historic uses of the watershed have created a stream unable to heal itself. In one section of the river, the bank eroded forty feet in one year, cutting into an adjacent pasture. Private landowners along the Encampment River have tried to reduce bank erosion to save their property. One landowner cabled hundreds of tires to the riverbank, while others threw rocks, trees, and car bodies in the water to break up and slow the powerful current. These structures have not held up. Over time, they have fallen apart while erosion has put private property at risk and the river channel sprawls and becomes shallower. Barrineau's description of the river as "well-used" is an understatement.

A front loader moves sediment out of the Encampment River.

As the truck approached the first construction site, Barrineau explained that a river has two roles: to move water and to move sediment. A "healthy" river has deep channels with fast-moving current broken up by eddies and pools. The channels meander and even shift paths or directions over time. Intact riparian habitat, the vegetation on the banks of a river, filters run-off and provides stability to the riverbanks. Spring floods move sediment through the system, maintaining the deep channels. A healthy river runs wild.

The Encampment River running through Riverside does not paint the picture of a healthy river. The channel is shallow and wide. Native vegetation is missing from large stretches of the banks, and the banks crumble into the water. Undercut banks loom over the river, waiting to fall and add more sediment to the already shallow channel. Levies, dams, irrigation ditches, and droughts prevent spring floods from sweeping the river clean. Without regular floods, the river cannot carve deeper channels or move sediment from the streambed to the flood plain. This shallow, wide, eroding river is not just "well-used"; it is painfully sick.

In an attempt to tame rambunctious waters, humans have removed many rivers' ability to heal themselves, requiring even more management to engineer river

Charlie Rattersten

A rock cross-van diverts water to an irrigation ditch while allowing fish to move upstream.

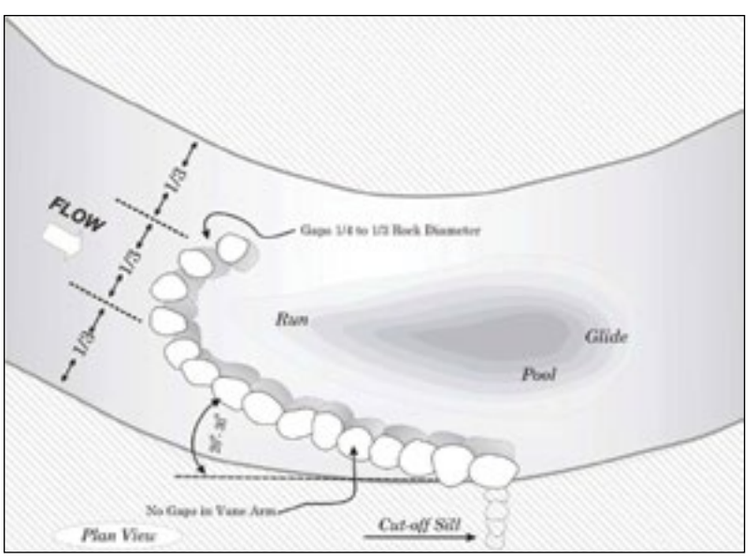
recovery. Early "hard" engineering methods disregarded a river's natural function and ecology. These engineers straightened and widened streams to gain complete control over the waters. A shift in river management occurred in the 1950s when hard engineering gave way to fluvial geomorphology, or the study of a river's natural function to inform ecological restoration.

One fluvial geomorphologist, Dave Rosgen, has heavily influenced river enhancement throughout the country. Rosgen recieved a PhD in geomorphology and hydrology and started his career as a hydrologist for the Forest Service. After working for the Forest Service, Rosgen started a river restoration consulting firm and developed a straightforward river enhancement method called Natural Channel Design. Natural Channel Design studies unimpaired rivers and applies ideas from fluvial geomorphology to restore function to impaired rivers. Over the past twenty-five years, Rosgen has honed Natural Channel Design by developing and testing the techniques on hundreds of river restoration projects. He also developed a four-part course and certification program, and has taught over 17,000 people Natural Channel Design theory and methodology.

On the Encampment River, since 2011 Barrineau has been overseeing contractors trained in Natural Channel Design methods. The work doesn't come for free. This enhancement project is a collaborative effort between the Wyoming Wildlife and Natural Resource Trust, the Wyoming Game and Fish Department, the Saratoga-Encampment-Rawlins Conservation District, Trout Unlimited, the Natural Resource Conservation Service, the US Fish and Wildlife Service, the US Forest Service Resource Advisory Committee, the Wyoming Governor's Big Game License Coalition, the Wyoming Landscape Conservation Initiative, private landowners, the Encampment School, and volunteers. Together, these groups have been restoring two contiguous river segments spanning nearly 6,000 feet at the cost of roughly $200 per liner foot, or $1.2 million.

When Barrineau's truck pulls up, the bulldozer and front loader are working in the river, beeping as they move cobbles from the streambed to the bank, repairing structures damaged by unusually high spring floods. A curve of massive boulders in the riverbed extends upstream from one bank and curls around to the opposite bank, creating rapids and a deep channel downstream. Barrineau explains it is a J-hook designed to centralize flows and keep the river from gnawing at the banks.

Rosgen designed structures such as the J-hook to help maintain or create the dimension (the depth and width of the river), pattern (the extent of meandering), and profile (the slope) of a river. Natural Channel Design includes a classification system that can be used to describe different types of rivers. Restoration work on an impaired river is then modeled after an unimpaired river of the same classification.



Design plan for a J-hook from a Wildland Hydrology manual.

After classifying a river, a Natural Channel Design project would involve measuring bank erosion rates and other factors to describe the river impairment. After that, the next step is to define the objectives of the project, which may include improving fisheries or aesthetic appearance, reducing land loss and erosion, or increasing sediment transport. On the Encampment River, the primary objectives were to transport sediment and reduce land loss from erosion, and a secondary goal was fishery improvement. The last step is for workers to reconstruct a channel by selecting structures to create the dimension, pattern, and profile to meet the objectives.

The J-hook we're looking at was one of the first structures built here. Barrineau is critical of her early work, warning me, "Don't take notes here. You will see better examples later today." River enhancement projects are a "learning process," she says. She explains that this particular structure is too prominent and creates a large drop-off downriver. Further downstream newer J-hooks are built lower in the water to create a more gradual grade.

Even though the structure is not up to Barrineau's standards, the J-hook is centralizing the flow, reducing bank erosion, and creating a deep trout pool. And new structures have benefited from the lessons learned here. As we walk upstream, Barrineau points out another Natural Channel Design structure called toe wood. From the edge of the river, we can see stacks of dead cottonwoods buried in cobble on the outside bank of a curve. In a shift from earlier river engineering, which relied on cement or other durable, unnatural

substances, Natural Channel Design builds out of local, native materials. The logs are layered on top of one another with their tops stuck into the riverbank and the roots jutting out into the river to create a rough edge that breaks up the water's energy. Layers of cobbles hold the trees five feet or more underwater, providing structure and stability to help the bank resist erosion. The submerged wood will not rot, and properly installed toe wood will provide bank stability until natural vegetation is reestablished. In addition, an untrained eye would not even know the toe wood is there.

Natural Channel Design goes beyond engineering to include ecology. Structures are one component, but Rosgen argues that without restoring streamside vegetation, the river will not function. Barrineau smiles as she points out an army of blue and green tubes sticking out of the cobble. Inside each one is a native shrub or tree—river hawthorn, water birch, thinleaf alder, redosier dogwood, chokecherry, woods rose, golden current, and four willow species—all painstakingly planted in the cobble riverbank. The tubes protect the young plants from browsing and trap heat to help them grow. The toe wood and in-stream structures help guide the flow of the stream today, but healthy riparian habitat will maintain the future of the stream indefinitely.

Further up the river, two front loaders are digging out the middle of the river to create a berm channel. This will deepen the river to help move sediment during spring run-off. Berm channels, combined with cross-vane structures such as J-hooks, temporarily fix the stream profile, pattern, and dimension while the vegetation grows back. Barrineau explains these in-stream structures buy time for the plants to establish. Once the riparian ecosystem is restored, the river will no longer need human intervention to remain healthy. As we walk, I begin to see structures before Barrineau points them out: toe wood, berm channels,

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Vegetation transplanted into cobbles will eventually stabilize the bank and reduce erosion.

transplanted willow clumps, and the sculpted riverbanks. What seemed like a perfectly natural landscape is actually carefully constructed. I begin to understand something Barrineau mentioned in the beginning of our tour: "Every little elevation out here is designed for some purpose." With these reconstruction projects complete, Barrineau will oversee monitoring to measure how these structures perform over time.

Natural Channel Design includes before and after monitoring to quantify how rivers improve. Despite such thoroughness, not everyone is onboard with these methods. In fact, the dispute over this program has become so vehement as to earn the title the "Rosgen Wars." On one side are Rosgen and other proponents of Natural Channel Design who claim that after restoration, rivers move water and sediment more efficiently. On the other side are academic and scientific experts who argue that Natural Channel Design courses are inadequate preparation for effective stream restoration and that Rosgen's ideas are easily misused.

Natural Channel Design's popularity comes from its simple 40-step certification program, much easier to learn and apply than a PhD in hydrology. But critics argue the program has oversimplified extremely complex systems. Especially when people take only the first of the four certification courses or when they lack a comprehensive understanding of the philosophy, foundations, and implementation of Natural Channel Design, yet they launch into practice. This can lead to ineffective work. Perhaps the more unsettling criticism of Natural Channel Design is that peer-reviewed studies have not been able to measure its effectiveness against other methods. Even after decades of implementation, scientists have not confirmed that the work restores river ecology. Still, river restoration projects are in high demand, and many have accepted Natural Channel Design as the best available option. Until river engineers, hydrologists, and ecologists determine a better way to restore natural function to our rivers or develop a new certification process, perhaps a nationwide standard informed by the latest science, restoration projects will continue to turn to Natural Channel Design.

Around the next bend we come to a structure we haven't seen before. It resembles a modified J-hook. Barrineau tells me this project, in the making since the early 2000's, is the result of a collaboration with the local landowner. An irrigation ditch runs from the river to a nearby property. To direct the river into the ditch, the rancher maintained a push-up dam, which required annual maintenance after flooding. As a replacement for the push-up dam, Barrineau's team built a rock cross-vane, which diverts water to the ditch even in low-flows while allowing fish to move upstream. Although Natural Channel Design focuses on restoring the natural function of a stream, it also takes into account human uses of the water.

The future of the Encampment River is promising. Barrineau and her team have assessed fifteen miles of the river, and identified several projects with potential to improve stability, fish habitat, and water delivery in the system. Barrineau hopes to continue enhancement work on the Encampment, but she recognizes the challenges. "We have huge plans. But you just have to get people to sign up and say, 'Yeah, come out, come do this,' because the funding is not a limiting factor anymore." The Wyoming Wildlife and Natural Resource Trust and other organizations are eager to help fund enhancement projects as long as landowners agree to participate.

As Barrineau's truck pulls away from the last construction site, I can't shake the feeling that putting bulldozers and front loaders in rivers is exactly how we created sick rivers in the first place. These enhancement and restoration projects claim to be reviving our watersheds, and many believe in their power. Such projects may be healing sick waterways, but Rosgen warns, stream reconstruction is not the best option. Instead, we need better water and land management practices to avoid the damage in the first place. If we graze livestock differently or manage stream flow differently, rivers will take care of themselves. Perhaps preventing the degradation, rather than elaborate reconstruction, will be the future for river restoration and enhancement.

Public Opinion on Natural Resource Conservation in Wyoming

By Kit Freedman

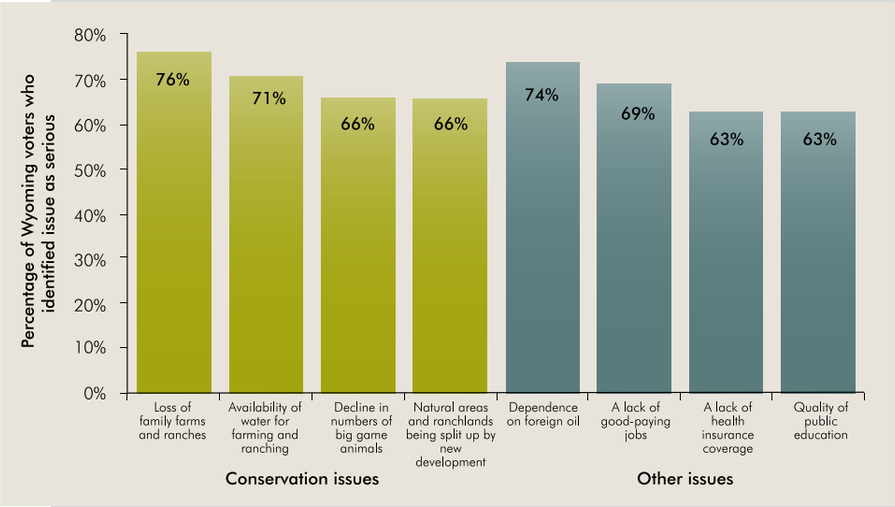
A recent statewide poll of Wyoming voters documented a strong interest in conservation and support for dedicating additional state funds to protect land, air, water, wildlife habitat, and ranchlands in the state. As part of its Wyoming Open Spaces Initiative at the University of Wyoming, the William D. Ruckelshaus Institute partnered with the Wyoming Stock Growers Association, the Wyoming Stock Growers Land Trust, and The Nature Conservancy in Wyoming to commission the poll. The groups contracted a bipartisan research team from two independent polling firms to conduct 500 telephone interviews with randomly-selected registered voters across Wyoming.

Among the questions presented, pollsters read a list of seventeen issues facing Wyoming and asked respondents to identify them as extremely serious, very serious, somewhat serious, or not a problem. The issues ranged from lack of health insurance coverage and dependence on foreign oil to loss of habitat for fish and wildlife and the impact of oil and gas drilling on land, air, and water. Respondents were also asked whether they would favor or oppose a small increase in local taxes to obtain matching funds to protect water, wildlife habitat, and ranchlands, as well as other questions about willingness to dedicate additional state funding to conservation.

Overall, the poll found that Wyoming voters:

- View the loss of family farms and ranches, availability of water for farming and ranching, and the decline in numbers of big game animals as the top three most serious conservation issues facing the state.
- Support state funding of many conservation projects, including protecting water resources, agriculture, tourism, family farms, and ranches.
- Support dedicating existing revenues to conservation, including fully funding the Wyoming Wildlife and Natural Resources Trust at the maximum level of $200 million.
- Favor setting aside more state money to protect land, air, water, wildlife habitat, and ranchlands, and half favor a small increase in local taxes to obtain matching state funds to protect these resources in their communities.

View the full report on the poll at uwyo.edu/haub/ruckelshaus-institute.



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Ba'a — Water is Life

By Baptiste Weed

I was fortunate to grow up on the banks of Trout Creek, one of the many streams winding its way out of the Wind River Mountains onto mile-high flatlands and eventually to the lower elevations of the Big Wind River, if you consider 4,000 to 5,000 feet to be low. This part of the country, about 200 miles south of Yellowstone National Park, shares the same mountain range, wildlife, climate, biology, and ecology with that famous area. The Wind River Indian Reservation even has one or two thermal hot springs.

Trout Creek starts as a brook a foot wide, high up in the Wind Rivers, but as it reaches the Little Wind River (tributary to the Big Wind River) it widens to 20 feet or more thanks to the many underground springs that flow to it. These springs make for vibrant trout habitat. The subsurface springs feeding the creek always fascinated me as a youth, because they expanded the life-sustaining source of water beyond the stream and its aquatic inhabitants to reach into the riparian areas and wetlands and their inhabitants.

My parents, both of whom were subject to government boarding schools and lived through the Depression, spoke Shoshone as their first language. It was told to them by their elders and relayed to me, my siblings and our children on cool summer or cold winter nights over hot cups of coffee. My parents' stories gave me a glimpse of what life may have been like centuries ago. Listening to them, I gathered that surviving day to day was not easy when existence depended on the abundance or lack of wildlife, berries, vegetables, and plants—all totally dependent on the life-giving element of water.

I often imagined, while roaming or fishing this lush riparian area and encountering the many crawly critters—fowl to moose and everything in between—what life for my Shoshone ancestors was like decades or even eons ago. This region where the sagebrush plains begin and water-dependent vegetation ends is clearly distinct. Looking out to the dusty plains from the lush foothills with their shrubs, berries and water-guzzling cottonwoods, one thing was always apparent: water is essential for all life to exist.

The thirsty cottonwoods, used as the center pole in a round Sun Dance lodge, symbolize extending the gift of life, of water. Many of the religions practiced today by the Shoshone, Arapaho, and other tribes in the surrounding states share in common water as their focal point. The Sun Dance participants, after days of fasting, gain a whole new respect for water. At the culmination of this ceremony, water is blessed and praised for its life-giving qualities. The sweat lodge, a purification rite, depends on the scorching steam produced by water poured over hot rocks. The Native American church ceremonies also end with praises, blessings, and reverences to the life-giving qualities of water. With water as the focal point, these ceremonies are performed in concert and orientation with an equally important element: the sun. At sunrise, a woman brings water in to be blessed. She and the water are both bearers of life, as is the sun. These are not random acts, but there is a purpose and meaning rooted over the many hundreds of years in each ceremony.

Today the agricultural use of water stretches the boundaries of this arid region. Limited only by dollars to construct new irrigation infrastructure and laws governing the use of the water, the arid land produces. We take for granted our water, much less the fact that we owe our existence to it. We consider any water service disruption or overabundance an inconvenience. Whether you believe that global warming is human caused or not, local droughts are intensifying. How do we plan for more intense and frequent erratic weather and rising global temperatures? The impact on the local climate will be anyone's guess. With such uncertainty, our attitudes will have to follow those of the early inhabitants who instilled in their ceremonies the idea that water is not a right that should be taken for granted. Instead, it is a precious gift given and received with humble gratitude and no guarantees for how long it will remain.

***Baptiste Weed** was born and raised on the Wind River Indian Reservation, where he has worked on water issues for twenty-five years. He is currently the Deputy Tribal Water Engineer.*

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