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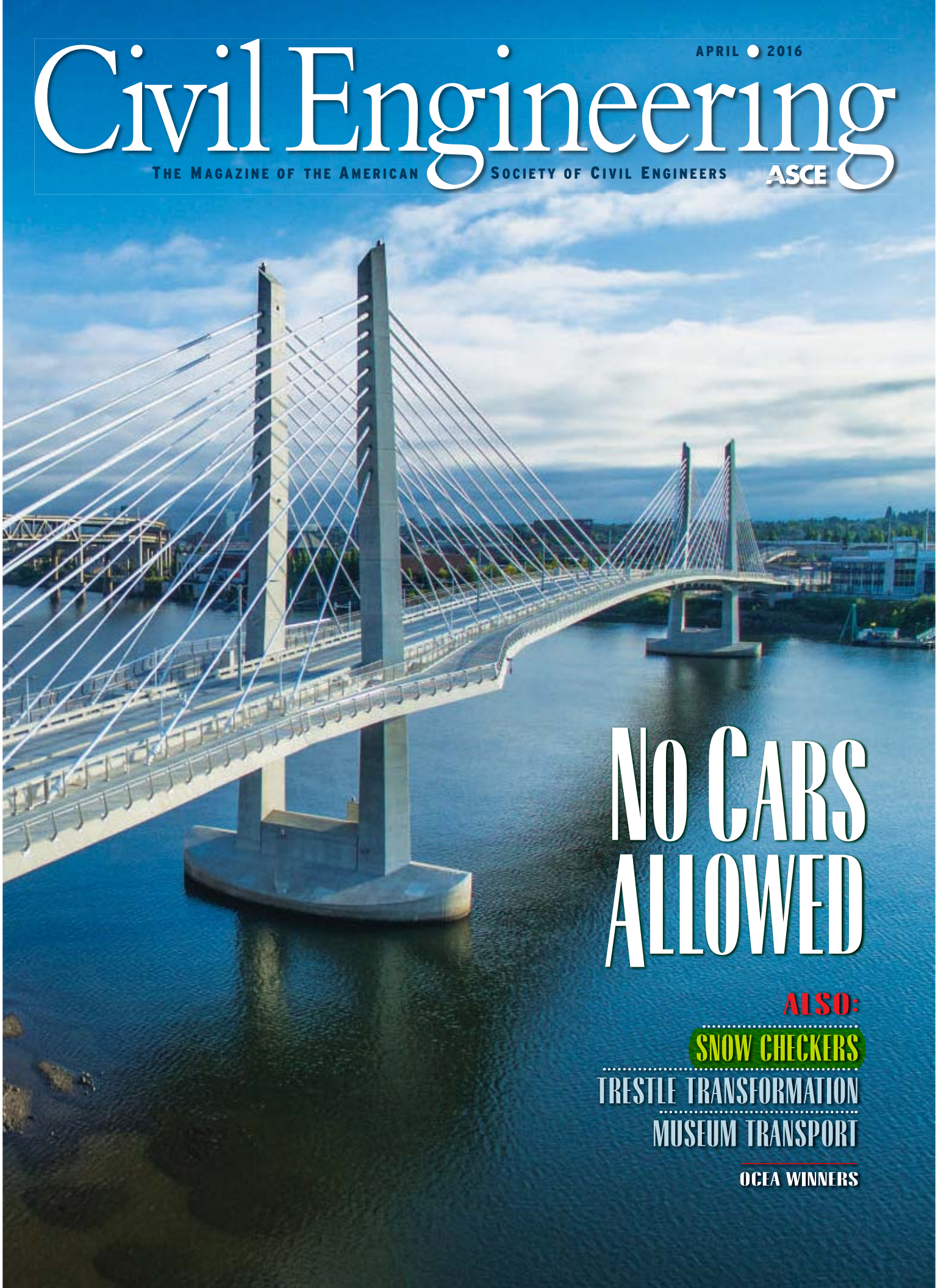

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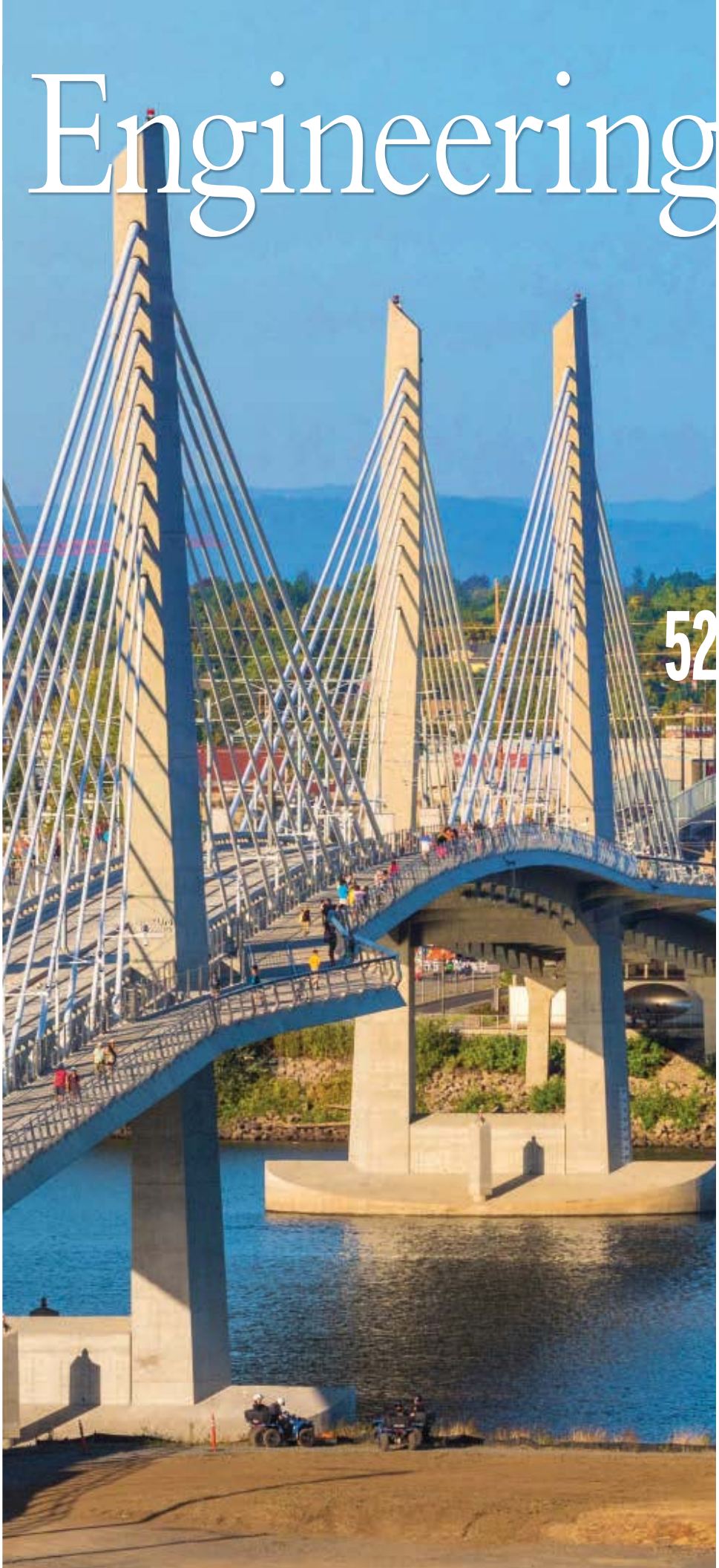
ON THE COVER: The deck of the Tilikum Crossing is 100 ft above the river surface, and its tower heights were limited to 180 ft above water. Light-rail trains travel along the center while cyclists and pedestrians use the outer lanes. (Photograph © Bob Cronk Photography. See page 52.)



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The massive (2-acre) roof of a new student services building at California Polytechnic State University at Pomona is designed to mimic the rolling hills and mountains of the region.

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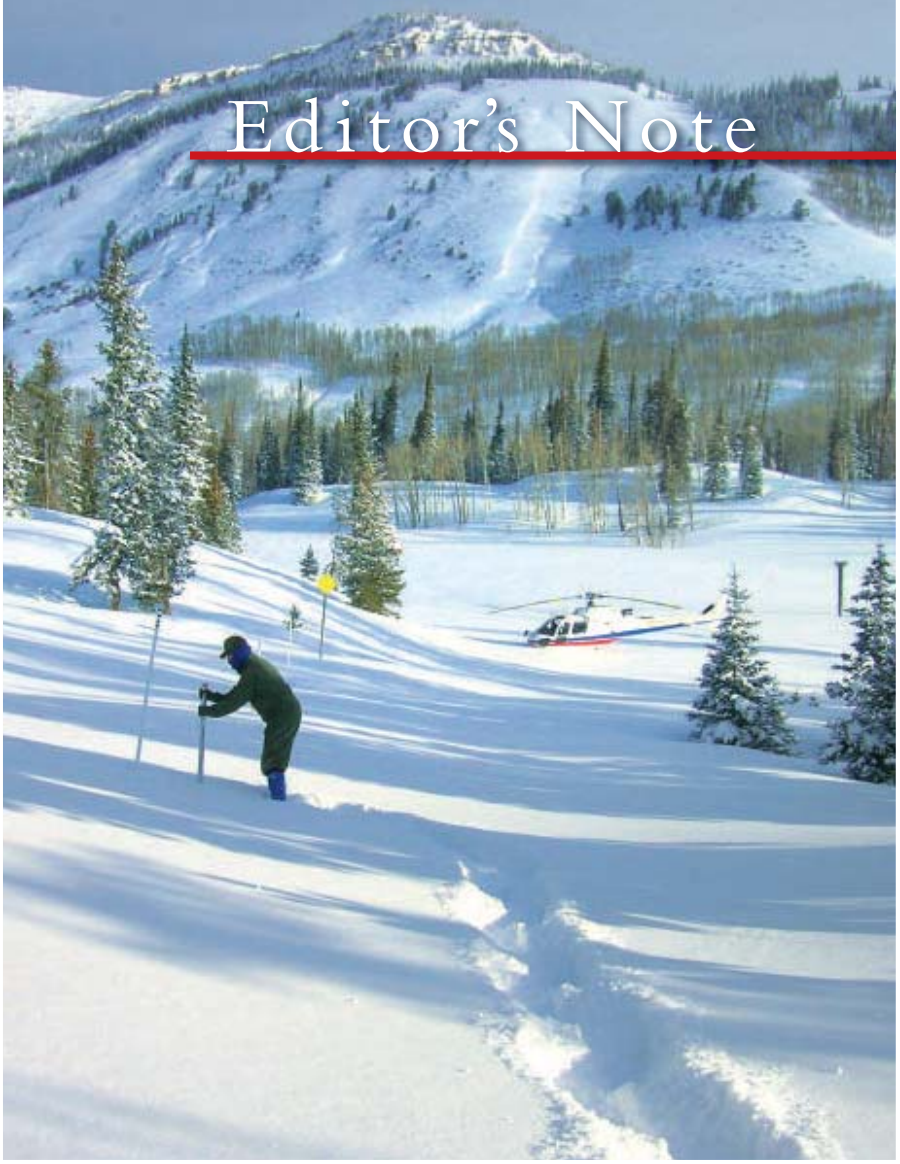
The Arizona Department of Transportation has finalized a $916-million contract for the design, construction, and long-term maintenance of a freeway that will complete Loop 202 in Phoenix.

SAVVY SECTOR
The U.S. water industry could benefit from some of the changes that have been made in the electricity sector, a recent report states.

Editor's Note



RANDY JULANDER COURTESY OF THE USDA NATURAL RESOURCES CONSERVATION SERVICE

Snow survey sites are often located in remote settings that are best accessed by helicopter and skis.

IT'S CERTAINLY NOT your typical civil engineering endeavor: equipped with snowshoes or skis and sometimes delivered to remote locations by helicopter, civil engineers who conduct snow surveys constitute an exclusive group. As the magazine's senior editor, Robert L. Reid, writes in his article "Snow Bound," which begins on page 60, "Civil engineers who conduct snow surveys help water managers and other stakeholders in western states predict the annual snowmelt runoff that is so vital to agriculture, recreation, and flood and reservoir management. They also help keep alive an engineering tradition and maintain a climate record that extends back more than a century."

And there is really no such thing as a "routine" snow survey. In California, for example, the snow survey program run by the U.S. Department of Agriculture's Natural Resources Conservation Service focuses largely on snowmelt runoff that begins on the eastern side of the Sierra Nevada in California but actually drains to watersheds outside of California. So the majority of snow survey efforts within the state of California are actually performed independently of the Natural Resources Conservation Service as part of the California Cooperative Snow Surveys Program, which falls under the purview of the state's Department of Water Resources.

Given the remote locations of survey sites and the depths of the snow involved, safety is always of paramount concern. Snow survey teams involve at least two people—physically fit people—who at times must take turns "breaking the trail" by pushing their way through the snow single file.

Snow survey work is invaluable because there are so many users of the data. For instance, the National Weather Service uses the data to forecast streamflows, and farmers use the information to make decisions regarding growing crops. Water managers use the forecasts to plan reservoir storage, while building managers use the Natural Resources Conservation Service data to determine the anticipated snow loads on roofs.

And while experimental efforts are under way to conduct snow surveys from the air via lidar, most experts in the field say that human surveyors are not likely to disappear because it remains important to obtain "ground truth" for assessing the accuracy of automated equipment. And thus, civil engineers with a love of the outdoors and a true sense of adventure can continue this essential work for the foreseeable future.

Anne Elizabeth Powell

ANNE ELIZABETH POWELL
Editor in Chief

Snow Bound

Civil engineers who conduct snow surveys help water managers and other stakeholders in western states predict the annual snowmelt runoff that is so vital to agriculture, recreation, and flood and reservoir management. They also help keep alive an engineering tradition and maintain a climate record that extends back more than a century.

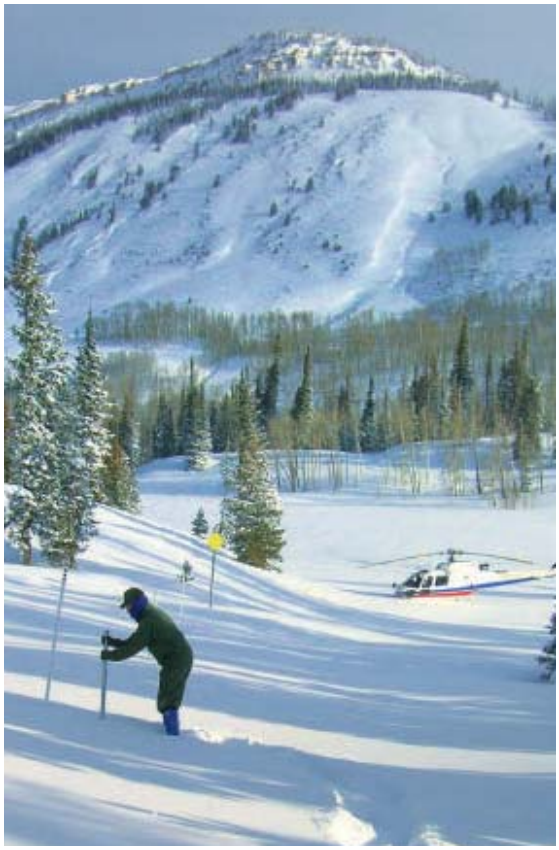
By Robert L. Reid

THE WORK OF CIVIL ENGINEERS has long involved getting out of the office and into the field, although typically these outdoors efforts are in some way tied to an existing part of the built environment. The excursions may be to, say, inspect a bridge or visit a construction site for a building, road, pipeline, or other infrastructure project. Or they at least involve a location that will eventually become part of the nation's infrastructure, even if the construction of the actual structure has not yet commenced. But there are also civil engineers who trek to places in the wilderness on which nothing substantial will ever be constructed, to locations that are so remote or at such high altitudes—upwards of 11,000 ft and higher—that the only way to access them is by snowmobiles, snowcats, or all-terrain vehicles. Snowshoes or skis are often indispensable, and the trips are sometimes made on horseback or by mule team or helicopter.

These are the engineers who perform snow surveys, a highly specialized line of work that involves visiting these isolated sites, mostly located throughout the mountains of the western United States, usually during the winter and early spring. They go to measure the depth of snow at those locations and the water content of that snow in order to forecast the expected runoff when the snow eventually melts. These runoff forecasts are vital for water managers, reservoir operators, and other stakeholders throughout the western states, where an estimated 50 to 80 percent or more of the region's water supply originates in the mountain snowpack, according to information from the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS). In addition to other activities, the NRCS runs the Snow Survey and Water Supply Forecasting Programs through its National Water and Climate Center, which is based in Portland, Oregon. The snow survey program encompasses 12 states in the continental United States: Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

In California the NRCS snow survey program largely focuses on snowmelt runoff that begins on the eastern side of the Sierra Nevada in the Golden State but actually drains to watersheds outside of California, notes Greg Norris, P.E., a civil engineer and the assistant state conservation engineer for the NRCS's office in Davis, California. The majority of snow survey efforts within California are performed independently of the NRCS as part of the California Cooperative Snow Surveys Program, which is overseen by the state's Department of Water Resources (DWR). This program collects snowpack data using its own staff, as well as staff members from dozens of public agencies and public utilities, private organizations, municipalities, state agencies, and federal agencies, including the U.S. Army Corps of Engineers.

Snow surveys are also conducted elsewhere in the United States and in various countries around the world. New York State, for instance, has its own program independent of the NRCS effort, and Canada works with the NRCS program. And interest in America's snow measurement techniques has been expressed by officials in Afghanistan, Bhutan, India, and Nepal, notes Frank Gehrke,



Snow survey sites are often located in remote settings that are best accessed by helicopter and skis.

PHOTO COURTESY OF USDA NATURAL RESOURCES CONSERVATION SERVICE, PHOTOGRAPHY BY RANDY JULANDER, *LEFT;* BEAU URIONA, NRCS UTAH, *RIGHT*

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Beau Uriona, P.E., who conducts snow surveys for the Natural Resources Conservation Service program in Utah, visits the state's Mount Baldy SNOTEL site at an elevation of more than 9,400 ft.

P.E., the chief of the California Cooperative Snow Surveys Program.

The importance of the snow survey work "is that it's a fairly small program, but the return on investment is just incredible because there are so many users of the data," says Claudia Hoeft, P.E., F.ASCE, who as the NRCS's national hydraulic engineer oversaw the snow survey program from 2005 to 2010. As explained in the NRCS document "How Snow Survey Data and Products Are Used," the data about the "frozen liquid gold" that the snowpack represents help the National Weather Service forecast streamflows and enable farmers to make decisions about growing crops. Water managers use the forecasts to plan their reservoir storage and water releases, information that is also vital to dam operators and hydropower producers, and building managers and brewers use the NRCS data to determine respectively the expected snow loads on roofs and the barley and hops outlook. Even Boy Scout leaders use the data to help determine water flows on rivers on which they've planned rafting trips.

The civil engineers involved in the snow survey programs work alongside hydrographers, hydrologists, and others with a background in watershed and snow sciences or other disciplines. Often, these civil engineers spend much of their time in more traditional engineering pursuits, conducting snow surveys and related work only during certain periods each year. For instance, Dale Gooby, P.E., a field office civil engineer based in the Salmon, Idaho, office of the NRCS, spends most of his time designing irrigation structures and systems for other NRCS programs, since the conservation service primarily works with private landowners "to develop conservation plans, create and restore wetlands and wildlife habitat, ensure healthy and productive soils, and manage animal and nutrient waste," explains the agency's website.

Thus, Gooby spends only about the equivalent of two weeks each year on snow survey work. He does this on various days during the winter months, visiting the "snow course" sites. These long transects in snow-covered areas are inspected manually via instruments that enable snow surveyors to measure both the depth of the snow and its water content at multiple sampling points. Gooby also performs maintenance on the increasingly automated snow survey sites, which in the NRCS program are referred to as SNOTEL (snowpack telemetry) sites.

Likewise, Brian Murphy, P.E., a water resources engineer in the Flood Maintenance Office of the DWR's Division of Flood Management, routinely works to help maintain the levee system around Sacramento, and Derick Louie, P.E., a water resources engineer, works in the DWR's Reservoir Operations Section. But both will don their parkas and skis several times each year to conduct manual snow surveys, heading out to the remote and undeveloped backcountry where the snow can reach above their knees or higher.

Snow survey teams almost always involve at least two people for safety reasons, and sometimes more, especially when the snow is so deep that the survey members must take turns "breaking the trail" by pushing their way through the snow single file, explains Gehrke.

Gehrke is a civil engineer who works full-time in the DWR snow survey program. Other full-time civil engineers are Brian Domonkos of the NRCS and John J. King, P.E., M.ASCE, a water resources engineer in the DWR's Sacramento office. Domonkos, for example, is a snow survey supervisor and data collection officer in the NRCS's Denver office, which is responsible for 95 manual snow courses within Colorado as well as more than 180 SNOTEL sites in Colorado, New Mexico, Arizona, and southern Wyoming. Domonkos personally visits between 20 and 30 snow course or SNOTEL sites each year, conducting the manual surveys in the winter months and performing maintenance on SNOTEL sites, mostly during the summer because the SNOTEL locations are often even more remote than the snow course sites and can be extremely difficult to access during the winter, he explains.

During the summer months Domonkos also works on the snow-related data, creating reports and spreadsheets and providing analyses. He holds a civil engineering degree from the University of Maryland, and it is in these aspects of his job that his engineering background has been most helpful, especially the classes he took that involved statistics, applied mathematics, and "problem solving" in general, he notes.

King conducts snow surveys and assists with managing all the snow survey data collected by the DWR surveyors in the winter. The DWR team uses the data to forecast water supply for most rivers in California. Summer months are spent working with data, comparing what was forecast with the actual observed runoff, and constructing better forecasting models. King explains that the DWR's existing statistical models "tell us what the runoff is at a particular section that we're forecasting, but new physical models will allow us to actually drill down and look at a particular watershed to see how much water is retained in the aquifers and how much water is in the snowpack."

And while he spends much of his time in the office, King also sees his time in the field as invaluable because the details he can observe at the snow course sites can be critical. Besides measuring the water content and the depth and height of snow in the field, the field work can determine when the snow will melt to become river flow. This includes such factors as snowpack density, soil conditions, sun exposure, and weather trends. These factors give forecasters guidance for adjusting water supply forecasts to reflect an early or late snowmelt.

Beau Uriona, P.E., who holds bachelor's and master's degrees in civil engineering disciplines from the University of Utah, is a hydrologist in the NRCS's Salt Lake City office, which covers sites in Utah, Nevada, and portions of California. He credits his civil engineering education with helping him develop the drafting skills he has used to communicate with fabricators about the designs of new snow survey equipment. It has also given him experience with geographic information systems, which are increasingly important in the maps the NRCS produces. Although his office includes geologists and soils experts, Uriona sees a critical role for civil engineers. "I'd say that having a civil engineer on staff in any snow survey office would be a great benefit," he explains, because of the data-intensive nature of the work, the water quality and water resources issues, and the computer modeling that comes into play.

"I love this job because it lets me get out in the field and get my hands dirty," Uriona says. "But I also really love it

Frank Gehrke, P.E., right, the chief of the California Cooperative Snow Surveys Program, works with Michael Jarred, a staff member for the California State Assembly's Committee on Natural Resources, at a snow course site near Lake Tahoe.

CALIFORNIA DEPARTMENT OF WATER RESOURCES

because I'm able to come back to the office and use the skills I learned, especially in graduate school, when I really got into the data side of things."

The data that are collected by the snow surveyors in both the DWR and the NRCS programs are used to help produce monthly reports, which generally are issued from December through May, on the depth of the snowpack and the snow water equivalent (which measures the amount of water in the snow). These reports also contain stream runoff forecasts, along with both the monthly snow course data and the data derived every day at 15-minute intervals from the SNOTEL sites.

The April report is especially significant because that forecast usually represents the peak snowfall each year, notes King, who adds that the DWR program monitors all 250 of its snow courses for the April report but generally collects data from fewer courses for each of the other reports. The importance of these snowpack data to the region's water supplies means that the results are closely followed by the local media, whose reporters and camera crews are generally brought to locations that can be easily accessed by road, explains Gehrke, a regular "star" at such press events.

But the snowpack can vary greatly from year to year. In recent years, for instance, the drought conditions throughout the American West have reduced the California snowpack to historically low levels. In 2015, for example, Gehrke visited one snow course site with Governor Edmund G. Brown, Jr., that was completely devoid of snow by April, providing a greenish brown background to the governor's imposition of mandatory water restrictions. Roughly a year later, however, the same site was buried beneath a rolling field of white snow. And as recently as 2011, there had been such heavy snowfall that the snow surveys continued into June, adds King.

The history of snow surveys in the United States is now 110 years old, dating to the 1906 efforts by James E. Church, Ph.D., a professor of classics at the University of Nevada and a mountain climbing enthusiast, to establish a weather station observatory and shelter on Nevada's Mount Rose, near Lake Tahoe. The shelter was designed so that researchers could stay overnight on the mountain, something that "would greatly facilitate the work including the study of the distribution of snow, which evolved into snow surveying," according to *The History of Snow Survey and Water Supply Forecasting: Interviews with U.S. Department of Agriculture Pioneers,* edited by Douglas Helms, Steven E. Phillips, and Paul F. Reich (Washington, D.C.: U.S. Department of Agriculture, 2008).

By 1909 Church had determined that merely measuring the depth of snow was not sufficient for forecasting snowmelt runoff because the actual water content of the snow could vary. Because of this, he developed one of the first snow samplers. The long metal tube was inserted deep into the snowpack to collect a column of snow having a small diameter. The water content of the sample was then determined by comparing the weight of the empty tube with the weight of the tube and its snow core. An instrument similar to Church's Mount Rose snow sampler is still in use. Sometime around 1909—the sources differ on the exact date—Church also established the first snow course site on Mount Rose. It's a location that has been continually surveyed for more than a century, explained Maurice Roos, the DWR's chief hydrologist, in his paper "California's Cooperative Snow Surveys Program," which he presented in 2004 in New South Wales, Australia, at a regional conference organized by the International Commission on Irrigation and Drainage.

Other snow courses that followed this early effort also have

a long-standing record, which many find inspiring. As Murphy explains, "I enjoy just knowing that I'm measuring on these courses that historically have been measured for over a hundred years." The history is also important because of the insight that a continuous data record can provide into climate studies and how the climate may have changed over time, says Michael L. Strobel, Ph.D., the director of the NRCS's National Water and Climate Center and the agency's program manager of snow survey and water supply forecasting.

The data collected from Mount Rose actually helped settle the "water war" that was waged over Lake Tahoe. In that dispute, "irrigation and power interests wanted to keep the lake as high as possible," but the melting snow sometimes raised the lake so high that it threatened lakeside homes, Roos explained in his paper. Church's pioneering snow survey methodology "provided much better estimates of the lake's spring rise from snowmelt and set a precedent for cooperation amongst interested parties," Roos concluded.

As a result of Church's work, Nevada and other western states began snow survey programs that were eventually consolidated under the Department of Agriculture's Bureau of Agricultural Engineering, a precursor to the NRCS. A key proponent of coordinating these efforts was Walter Wesley McLaughlin, the chief of the Department of Agriculture's Division of Irrigation, who had earned a degree in civil engineering from Utah Agricultural College (later Utah State Agricultural College and today Utah State University). Among those who helped McLaughlin design the federal snow survey program were Church and George D. Clyde, A.M.ASCE, the dean of engineering at the school when it was known as Utah State Agricultural College. Clyde authored the article "Forecasting Stream Flow from Snow Surveys," which appeared in the September 1939 issue of *Civil Engineering.*

California officially began its snow survey program in 1929, hardly an auspicious time to launch a publicly funded effort given the onset of the Great Depression, explained Gehrke and Dave Hart, then the field activities coordinator of the California program, in their paper "Status of the California Cooperative Snow Surveys Program," which they presented in Sacramento at the 1990 Western Snow Conference. But even though there were times in the early 1930s when no money was allocated to the program, the staff and many cooperating agencies continued to gather snow data on their own, "maintaining records that allowed the Program to rebound vigorously when allocations were resumed" later that decade, Gehrke and Hart wrote.

By the 1960s automated sites were in use for both the DWR and the NRCS program, and by the 1970s these SNOTEL sites were actually starting to replace some of the existing manual snow courses, notes Strobel. There are currently more than 1,000 manual snow courses throughout the western states and more than 850 SNOTEL sites, which actually cost more to establish than a manual course because of the expensive equipment involved, says Strobel.

The automated sites feature a snow "pillow." This is a bladder filled with antifreeze and connected to manometer tubes and a pressure transducer that is located in a nearby shelter. When snow falls on the pillow, the weight pushes the fluid into the tubes, and the pressure transducer records the weight, which determines the water content. The SNOTEL sites also typically feature rain gauge equipment and solar radiation sensors; batteries or solar power systems; towers that elevate temperature, wind speed, and humidity sensors; and sonic systems to measure snow depth. The site's communication system transmits data via meteor burst technology—that is, by reflecting VHF radio signals off the "ever-present band of ionized meteors" that exists approximately 50 to 75 mi above the earth—to a master station site that can be 1,200 mi away, according to information on the NRCS website.

The SNOTEL sites in Alaska use a satellite phone system to transmit data because the cost of upgrading the state's master station was too high, says Brett Nelson, P.E., the state conservation engineer in the NRCS's Palmer, Alaska, office.

An increasing number of SNOTEL sites have also added soil moisture sensors, which "tell us a lot about what will be the fate of the snowmelt," notes Strobel. In particular, will the water actually run off because

In April 2012, the rain gauge, sensor tower, and other equipment at the SNOTEL site on Mount Eyak, Alaska, lay half buried beneath more than 10 ft of snow.

PHOTO COURTESY OF USDA NATURAL RESOURCES CONSERVATION SERVICE, PHOTOGRAPHY BY DANIEL FISHER

The Natural Resources Conservation Service offers an annual "snow school" at various sites, teaching snow safety and snow sampling techniques. Lucas Zukiewicz, of the service's Montana program, conducts an exercise during the 2016 school in Bend, Oregon.

NRCS OREGON

the soil is frozen, or will it just permeate into the local soils that are warm and dry? "Knowing those kinds of things is very valuable," Strobel says. "In the office we try to interpret those conditions and use that information to make the most accurate forecast we can."

The SNOTEL shelters are essentially tall, narrow wooden shacks designed to protect the sensitive electronic equipment from the elements, and they can be anywhere from 10 to 30 ft tall, depending on how deep the surrounding snow tends to be, Strobel says. The side of the shelter can feature a ladder leading to an upper-level door. During heavy snowfalls most of the shelter will be buried, and that upper door will be the only way to access the equipment inside, Strobel explains.

The sampler used at the manual snow survey courses typically involves a series of aluminum tubes with a cutting head diameter of 1.484 in., which "equates one inch of depth of water to one ounce of weight," says Domonkos. The tubes are each 30 in. long and are screwed together end to end to form a longer tool on the basis of the expected snow depth. The NRCS's *Snow Survey Sampling Guide* indicates that most surveys will require three or more sections of tubing, but if necessary the tool can reach a length of 20 ft.

Although the aluminum tubes are standard, in Alaska a fiberglass version is sometimes preferred for sampling the dry and powdery snow often found at survey sites in the state's interior, says Nelson. Unfortunately, the fiberglass tubes were manufactured only once about 30 years ago, he explains, and cannot be replaced.

To collect the samples, which often involve 5 to 10 locations per snow course, each designated by special markers, the sampler is pushed down through the snow until it reaches the ground surface. The end of the tube at the bottom features a cutting edge to help pierce the frozen layers. Once the sample has been collected, the tube and its core are weighed on a spring scale system with a specific constant to determine the water equivalent, Domonkos explains. The snow depth and the water equivalent are the two parameters that establish the snowpack density, he adds.

Although the process may sound simple, the DWR's manual for snow surveys runs to 28 pages and contains samples of surveys illustrating the correct way to make notations. Likewise, the NRCS's *Snow Survey Sampling Guide* lists a 20-step process that covers everything from who should carry what equipment on the sampling team to the importance of checking the sampling tube for cleanliness before and after taking the sample. It also points out that any debris is to be tossed at least 15 ft away from the sampling point to avoid the formation of "melt holes" at the sampling points. In addition to other details, the guide notes that surveyors should always wear gloves so that the warmth of their hands does not affect the tube, that they should point the tube into the wind while weighing the sample to record a more accurate weight, and that they should periodically reweigh the empty tube "because small particles of water or snow often cling to the inside and outside of the tube."

The data are recorded by hand on paper documents called field notes, the depth of snow and the sample length read to the nearest half-inch. The snow surveyors also calculate the snow density by dividing the water content by the depth or by using the NRCS-provided density determination chart, and they produce an average sample depth.

Supplementing the equipment-filled shelters at SNOTEL sites is another type of shelter associated with snow surveys. These are the fairly rustic cabins located throughout the wilderness areas in many western states. Stocked and maintained during the summer and fall by the DWR, the NRCS, the U.S. Department of the Interior's Bureau of Land Management, the U.S. Forest Service, the National Park Service, and other groups, these cabins provide a safe place for snow surveyors to spend the night when they are out on an extended survey trip or when, say, an unexpected snowstorm makes it unsafe to try to return from a remote site. In some cases constructed for snow surveyors and in others for ranchers and other users, the cabins might offer little more than an enclosed space against the wind and cold, perhaps a lantern and a wood stove, and some canned or packaged food.

But they do offer a sense of history, notes the DWR's Louie, who has stayed at cabins that date to the 1940s and 1950s and feature what is essentially graffiti, in this case snowfall measurements and other comments by previous inhabitants that were written on the interior walls or even carved into them. Louie recalls seeing "some scribblings about people being snowed in, and they weren't sure when they were going to get out or if they were going to survive."

The DWR's King spent about a week or more one fall with representatives of one of the groups participating in the California Cooperative Snow Surveys Program taking food and other supplies to three cabins on horseback and via mule team. Even though it was not yet winter, "at one site we had to lay up because a snowstorm came in, and so that night we just cut a bunch of wood for the winter and we did that with handsaws—two-man handsaws."

Although a chain saw would have been easier, since the cabin was in a protected wilderness area, no gas-powered vehicles were permitted, and the restriction also covered equipment. Such restrictions by the National Park Service or the U.S. Forest Service can complicate the work of snow survey teams, says Dave Rizzardo, P.E., the DWR's chief of snow surveys and water supply forecasting. But he realizes that different stakeholders in the West have different missions to accomplish. So while his engineers might need the snow survey data for flood protection efforts, the National Park Service and U.S. Forest Service people also need to maintain the pristine wilderness areas they are charged with protecting and preserving.

"We do our best to educate [the National Park Service and U.S. Forest Service personnel] on how the information we collect can be used to their benefit," Rizzardo explains, "and it falls on us then to understand and respect their rules and what they need to do."

To initially prepare for snow surveying or as a periodic refresher, the civil engineers and others involved in this work often attend a "snow school." The instruction generally covers two main topics: proper snow sampling techniques and the safest ways to reach the sample sites, obtain the samples, and return to civilization. Even experienced snow surveyors need to avoid certain bad habits when collecting their samples, explains Tony Tolsdorf, a hydrologist and the principal instructor at the NRCS's Westwide Snow Survey Training School. The school offers a five-day course each January at various locations, and organizers hope that plenty of snow will be available so that the students can practice.

For example, surveyors can easily overlook the importance of weighing the empty snow sampler tube, believing that they already know the weight from previous surveys. But in fact different tubes can vary in weight by several ounces, and since each ounce represents a potential inch of water in the snowpack, the discrepancy can be considerable, Tolsdorf warns. Snow surveyors also need to be wary of avalanche dangers, and for this reason they must study the slope and terrain visually and monitor wind conditions. They are even encouraged to dig test pits to evaluate the different layers of snow and search for potentially weak layers that could cause a massive slide, Tolsdorf says.

Safe operation of snowmobiles and all-terrain vehicles also is taught, as are basic first aid and wilderness survival techniques. What is more, students learn how to climb towers safely to perform maintenance at SNOTEL sites. Perhaps most important of all, they learn how to construct an emergency shelter, for example, a snow cave or a shelter fashioned from tree boughs, in case they find themselves trapped outdoors overnight. This knowledge is so critical that the students are required to construct an emergency shelter and spend one night in it during the snow school itself, Tolsdorf explains.

Fortunately for the snow survey programs, the participants tend to be outdoor winter enthusiasts who enjoy skiing, snowmobiling, or snow camping. Both the DWR's Louie and the DWR's Murphy consider their time out of the office on snow survey trips to be perks. And Gehrke says, "You wonder why you're getting paid to do this, because you're enjoying it so much." But he adds that the strenuous physical work and often difficult conditions under which that work is performed can distinguish those who are cut out for snow surveying from those who are not. "Most of the people who get into this work are in it because they like to be in the backcountry," explains Gehrke, who, as mentioned above, heads the California Cooperative Snow Surveys Program. "If you don't, you're probably not going to stick with it that long."

But much as the snow surveyors might enjoy the snow, reaching the survey sites often presents a formidable challenge. Although some sites are located in reasonably accessible spots, for example, near a ski resort, others are several miles from the nearest road. The distances must be crossed with skis or snowshoes, and if the sites are more remote, snowmobiles or tracked vehicles may be required. And given that this is winter, the weather and the snow conditions can be unpredictable, even though snow surveyors carefully check the weather forecasts before heading out.

Brant Dallas, a civil engineering technician in the NRCS's Palmer, Alaska, office, recalls one snow survey that he undertook with Nelson. The trip began with more than five hours of driving on roads, followed by a 60 mi ride across open snow on snowmobiles to reach the survey site. This effort was followed by an overnight stay in a wilderness cabin, and the temperature dropped to –40°F. "The next morning we had to wait until the sun got up and warmed things up to about 25 below before we took off," Dallas says.

On many occasions, snow surveyors cannot actually reach the survey sites on their first try. Dallas recalls one survey trip to a site near Denali (formerly Mount McKinley) that was called off "because the snow was three feet deep of fresh powder and kept coming over the hoods" of the snowmobiles. They "had to turn around," he says, because they faced 10 mi of "whiteout conditions." Likewise, the NRCS's Uriona notes that "there are so many days in my job when the best course of action is to turn around and go home." Fortunately, there is about a 10-day window during which each survey can be conducted, says King, who adds that the snow conditions can vary widely during that period.

On one recent survey trip to multiple sites, the NRCS's Gooby faced a series of challenges ranging from a trail that was blocked by a fallen tree to a sampler tube on which the cutter edge came off, forcing him to "dig through 50 inches of snow

to retrieve it," Gooby told *Civil Engineering* in an email. He also faced an obstinate moose and its calf that kept getting in his way.

Such animals as moose and caribou can definitely create headaches for snow surveyors, especially when "every now and then you'll go in to do measurements, and the entire site will be absolutely trampled because a herd of a hundred caribou spent three days lounging there," notes Nelson. But bears present problems on a more regular basis, from chewing up the snow pillows at SNOTEL sites to breaking into the wilderness cabins. And while bears do tend to hibernate for most of the winter, during the summers, when maintenance is performed at snow survey sites, bears can pose such a threat that surveyors in Alaska carry shotguns for their own protection, says Dallas, who is also the state's firearms coordinator.

When snow surveyors are "dropped off" at sites by helicopter, the term sometimes has an all-too-literal meaning. Both Uriona and Gehrke recall times when their helicopters could not land because of uncertain conditions on the ground. They had to drop their equipment into the snow and jump into the snow themselves while the helicopter hovered a few feet in the air. In Gehrke's case, he and the other surveyors on that trip then spent the next hour stomping down the snow with their skis to create a flat space for the helicopter to land on so it could pick them up once they had completed the survey.

Brian Domonkos, of the Natural Resources Conservation Service's Denver office, inserts a sampler at a now-discontinued site in Montana and then weighs the sample to help determine the amount of water in the snow.

BRIAN DOMONKOS, NRCS COLORADO

Murphy experienced an even more dramatic example of the adventure that snow surveying can entail when he broke his leg on a survey in December 2014. It was a year with a snowpack lower than normal, he explains, so his ski caught on a root or something else on the ground, and he went down. At first he thought he had just sprained his ankle, and he, King, and a third surveyor discussed various options, including leaving him behind while the others went for help or making a snow shelter for the night. Ultimately they fashioned a makeshift sled for him out of skis, backpacks, and other equipment they had on hand and decided to try to make it out over the snow. "Harsh conditions were starting to creep up on us," Murphy recalls, and there was no place for a rescue helicopter to land.

The sled was even more uncomfortable than trying to walk, Murphy says, so in the end he decided to "hobble my way out," supported by his colleagues. It took roughly two hours for him to walk the roughly 1 mi that remained to reach their vehicle, as opposed to just 15 minutes if he'd been on skis. Fortunately, the low snowpack meant the truck was much closer than it would have been in a year with a deeper snowpack, when the distance to the vehicle might have been as much as 5 mi. Murphy later learned that he had actually broken his fibula, which fortunately for him is not a weight-supporting bone. Thus he was able "to hike out by limping along," he explains.

Although the SNOTEL sites are gradually replacing the manual snow courses in some locations and experimental efforts are under way to conduct snow surveys from the air via lidar, most of the engineers and officials contacted for this article express confidence that the human element in snow surveying is unlikely to disappear. For one thing, even when an automated system is installed at a snow course site, manual surveys are continued for several years to obtain "ground truth" for assessing the accuracy of the automated equipment and "to make sure there's a continuous record," explains Strobel.

This is especially critical in terms of "changes in climate and how that might impact water management," notes the DWR's Rizzardo. "So you have to stop and look back—how do we assess climate change? You have to use historical data to compare against what's happening now or what you predict will happen in the future."

Given that there are "snow course data dating back to the early 1900s in some cases and an even larger amount of snow course data that are at least 50 to 70 years old, you start to realize that one of the best climate records we have in the state is the snow courses," Rizzardo concludes. "So we're likely to keep on with manual data gathering." **CE**

Reid

Robert L. Reid is the senior editor of Civil Engineering.