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SCIENCE

Sierra Nevada Snow Won't End California's Thirst

By HENRY FOUNTAIN APRIL 11, 2016

YOSEMITE NATIONAL PARK, Calif. — Thanks in part to El Niño, snowpack in the Sierra Nevada is greater than it has been in years. With the winter snowfall season winding down, California officials said that the pack peaked two weeks ago at 87 percent of the long-term average.

That's far better than last year, when it was just 5 percent of normal and Gov. Jerry Brown announced restrictions on water use after four years of severe drought. But the drought is still far from over, especially in Southern California, where El Niño did not bring many major storms.

Despite the better news this year, there are plenty of worrying signs about the Sierra snowpack, which provides about 30 percent of the water Californians use after it melts and flows into rivers and reservoirs, according to the state Department of Water Resources.

Many of those concerns stem from the effects of climate change and the structure of Sierra forests, which can influence how the snowpack accumulates and melts. Because the snow, in effect, serves as a reservoir that is released over time, any changes can affect how much water is available for people, industry and agriculture, and when.

"We'll be getting more rain and less snow here," said Roger C. Bales, a professor at the University of California, Merced, and a principal investigator with the Southern Sierra Critical Zone Observatory, which studies snowpack and other water-related issues. "That means less snowpack storage and faster runoff."

Dr. Bales was standing on a snowy slope in Yosemite last Thursday, at about 7,000 feet elevation, just off a 19th-century wagon road that is used by hikers and snowshoers. Nearby, amid car-size granite boulders and close to a soaring Ponderosa pine, were instruments that he and his fellow researchers use to obtain detailed information about the snowpack in several spots throughout the southern Sierra.

The effects of warmer temperatures can already be seen here, Dr. Bales said.

"Historically, this has been the reliable snow zone, where it accumulates till late March or early April and then melts," he said. But now the snowpack here is more like that at lower elevations, "where it will accumulate, melt, accumulate, melt," he said.

Proof was close at hand, as well. Until the last quarter-mile of a two-mile hike here from 6,300 feet, snowshoes were not needed. What snow remained was in small patches.

Similar effects of climate change have been seen throughout the Sierra, including at the Central Sierra Snow Laboratory, which is operated by the University of California at Berkeley near the Donner Pass, about 120 miles to the north. Researchers there still make some measurements the way they have since the lab started in the 1940s, by inserting special metal tubes into the snow.

"We are seeing an ever-increasing percentage of annual and winter precipitation in liquid rather than solid form," said Randall Osterhuber, who spends winters at the lab. The altitude above which snow accumulates is becoming higher as temperatures warm. "That change in elevation means a lot less terrain is covered in snow."

Climate change is also expected to increase precipitation in some areas, because warmer air can hold more moisture. But it is not yet clear if that will be the case in the Sierra Nevada.

Snowpack is measured in "snow water equivalent," or how much water would result if the snow were melted. When snow first falls in the Sierra, it is usually dry and powdery, with about 10 to 12 percent moisture by volume, but as it accumulates and compresses, the moisture content rises to about 40 percent. So 30 inches of snow on March 30 would be equivalent to about 12 inches of water.

The data from Dr. Bales's instruments will not be downloaded until later in the spring, but just up the slope, other instruments set up by the Department of Water Resources send data continuously to state offices in Sacramento. Last Thursday, they recorded a water equivalent of 18.36 inches. With warm spring temperatures, the snowpack here was past its peak, with the water equivalent declining by more than three inches in less than two weeks.

The Department of Water Resources instruments are set up in a relatively open part of the forest. The observatory's instruments, by contrast, are near the Ponderosa pine, and there are three of them: one next to the trunk, one a little farther away where water drips from the tips of the branches, and one in the open, about 20 feet away. Other sensors, which are buried, detect how much water is in the ground.

The goal is to gather a complete picture of the snowpack, which is far from a uniform blanket of white. A tree, for example can affect snow cover in several ways, Dr. Bales said. Some snow is caught by the branches and turns directly to vapor. Other flakes melt and the water drips to the ground. The tree trunk itself absorbs sunlight and re-emits it as heat, melting the snow around it. Boulders do the same thing. Even the tiniest pieces of forest litter — needles or bits of pine cones — can heat up in the sunlight and cause melting.

"We're strategically sampling the landscape," Dr. Bales said. "We pretty much know what topographic features affect snowpack." That will give water managers a truer understanding of how much water the snowpack will generate.

Trees also affect the amount of water stored in the mountains simply by growing, sucking up water from the ground. Some of it is used in photosynthesis, but much of it is lost through evaporation and transpiration through the leaves and stems. Dr. Bales and his colleagues study this, too, with instruments atop towers that measure the flow of water vapor from the tree canopy.

The scientists learned that a lot of water was lost through the trees — more than was even thought to be there in some cases. “That told us the precipitation estimates that people had for higher elevations were just plain wrong,” Dr. Bales said.

Warmer temperatures also mean that trees grow faster, and don’t necessarily shut down for the winter. Thus they use more of the melting snow, and over a longer period. That leaves less water to flow into streams and down to reservoirs.

Less snow, earlier melting and faster growth mean that more trees are running out of water in the summer. Mohammad Safeeq, a colleague of Dr. Bales at the university, said that, in general, water was flowing off the mountains two weeks earlier than in the past. “Two weeks in a three-month summer window is significant,” he said.

Water-stressed trees are more susceptible to pests and disease, so one result of the changes is more tree deaths. This is readily apparent at Yosemite in the drive from the valley floor, where the green hillsides are dotted — in some cases in large numbers — with the brown of dead pines and firs.

Contributing to the problem is the fact that there are many more trees here than there used to be. A century ago, Dr. Safeeq said, Yosemite had perhaps 20 trees an acre; now the number is closer to 100. That means more of the melting snowpack never gets off the mountain to the valley below, he said. The greater number of trees is due in part to years of forest agency policies under which small natural fires were quickly extinguished to protect homes and other property in the mountains.

But smaller, less intense fires are nature’s way of thinning the forest, culling trees that are less fire-resistant, said Martha H. Conklin, a Merced professor and another principal investigator with the observatory. Paradoxically, because fire suppression leaves so much timber on the mountains, it can lead to much bigger and hotter fires, like the Rim Fire that burned 250,000 acres in and around Yosemite and destroyed more than 100 structures in 2013.

Fire suppression is a controversial subject in California. But thinning the forest by letting small fires run their course would increase snowpack because more of the snow would reach the ground, and less of the water would be taken up by the trees. That could be, in effect, like adding an entire new reservoir of water in the mountains, rather than building a new billion-dollar reservoir down in the valley.

If small fires were allowed to burn, Dr. Conklin said, "you'd have a forest of a very different structure." Even the types of trees would eventually change, she said, as species that are better able to resist fire replaced others. "I don't know if we can ever go back to a forest that has a natural fire regime," Dr. Conklin said. "It's very difficult to let a fire burn if you have houses dispersed in the forest."

But with climate change affecting how much water is available from the mountains, she added, "we have to think about how we're going to manage these forests."

Correction: April 14, 2016

An article on Tuesday about the effects of climate change on California's mountain snowpack paraphrased incorrectly from comments by Mohammad Safeeq, a researcher at the University of California, Merced, about the density of trees in the Sierra Nevada now compared with a century ago. Sierra forests now average about 100 trees an acre, not 250, he said; and a century ago they had about 20 trees an acre, not 80.

A version of this article appears in print on April 12, 2016, on page D1 of the New York edition with the headline: Uncertainty in the Sierra.

Losing snow in a changing climate

What global warming means for our water supplies

Story by Ian James and photographs by Jay Calderon, The Desert Sun | April 14, 2016

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Among firs and cedars high in the Sierra Nevada, scientists are using an array of instruments to monitor the health of the forest, measure the snowpack and track the water that melts and seeps into the soil.

As they collect data, they're taking snapshots of a landscape in the midst of major changes.

When Erin Stacy checked the instruments last month at one of the research stations she manages in the Sierra National Forest, her boots crunched through snow that blanketed meadows and lay in patches among the trees. But the snow was melting early near the end of a record-warm winter. And in the future, there's likely to be much less snow, if any, on the ground here.

Already, as the winters have grown warmer, the snow has been melting earlier after storms pass. It's just the beginning of a shift that is projected to dramatically shrink the snowpack in the mountains as global warming intensifies.

"We're going to get a smaller snowpack. It's going to melt out earlier and it might melt out more times during the winter, and that has some pretty big implications for people downstream – all of our water users downstream," Stacy said, standing beside a sensor that measures snow depth. "The snowpack acts as a reservoir for us, and if we don't have that reservoir, then we need to find some way to store more water or to use less water."

Across the continental United States, measurements from sensors since the 1950s show that the average snowpack has been decreasing in most areas as temperatures have risen. Precipitation that used to fall as snow is increasingly falling as rain. Snowlines in the mountains have begun creeping upward. And scientists have estimated that for each 1 degree Fahrenheit of warming in mountain regions, the snowpack could retreat upslope by a distance of roughly 300 feet in elevation.

The impacts are expected to vary by location. But across the mountains of the West, the snowpack is already melting about a week earlier on average as compared to the mid-20th century.

The decreases in snow and the earlier runoff pose especially critical challenges for western states, where many areas rely heavily on snowmelt for water supplies and where the demands of growing populations, agriculture and industries are already draining rivers and depleting aquifers.

As the planet heats up, the changing climate is projected not only to shrink the snow and melt the glaciers, but also to unleash more extreme weather ranging from floods to longer-lasting and more intense droughts. The severe drought that has ravaged California for more than four years has coincided with record heat, and it appears to offer a preview of what the hotter droughts of the future will look like.

“It’s pretty dire. I think we need to start moving pretty quickly, whether that’s water conservation or even just more conversations about it,” said Stacy, a scientist with the Sierra Nevada Research Institute at the University of California, Merced. “We’re going to have to figure out how to deal with water downstream differently.”

Just how radically water supplies are altered will depend in part on whether the world takes significant steps to slow emissions of carbon dioxide and other planet-warming pollutants. But even if the world successfully limits warming to the goal of 2 degrees Celsius set last year in Paris – a target that appears increasingly difficult to achieve – snowpack-dependent regions from the Pacific Northwest to the Colorado River basin could still be hit hard.

Play Video

As the planet warms, the average snowpack is shrinking in the mountains. That poses challenges for water supplies downstream.

Jay Calderon/The Desert Sun

In order to face that threat, there have been growing calls by academics, conservation advocates and policymakers to rethink how water is used and managed, and to adopt a lineup of strategies to prepare and adapt.

The list of ideas is long: capturing more stormwater during floods; using more surface water to recharge depleted aquifers; treating and reusing more wastewater; cleaning up contaminated groundwater; improving efficiency on farms and in cities; and adopting policies that encourage conservation, among other things.

No single strategy is likely to be enough on its own. Many government officials in charge of water management in places from California to Washington, D.C., have lined up behind what they've called an "all-of-the-above" approach. They say that making water systems more resilient is achievable with intelligent planning, and that steps are underway to adapt.

Questions about how global warming will affect water supplies have become an active focus of scientific research. Many scientists agree that the scale of the water challenges, especially in the West, is monumental, and that each area will need to develop its own local solutions to stretch water supplies further.

In a 2014 study, researchers at the University of Idaho examined likely shifts in the rain-snow transition zone across the western United States. They projected declines in the areas where snow falls in the wintertime of between 24 percent and 53 percent by mid-century.

The changes in the timing of runoff are projected to be drastic. And as temperatures rise, more of the snow and rain that falls will evaporate instead of running off. Scientists expect those changes to shrink the average flows of streams and rivers.

At the research site in the Sierra Nevada, located more than 6,000 feet up in the mountains northeast of Fresno, Stacy was at work along with doctoral student Melissa Thaw, who was collecting water samples from the soil beneath a large incense cedar.

Her research involves using isotope "signatures" in the water to track how it moves through the soil and where trees and shrubs are taking up water. Thaw is interested in learning more about how climate change will affect the water and the ecology of the forest, and she is focusing on the transition zone between rainfall and snow.

As the climate warms, it will push this transition zone higher into the mountains, moving the snowline upslope. Thaw said that points to a need to anticipate the effects on water supplies, while also taking steps to slow global warming.

"The mountains are the world's water towers, so when the water can be held up in the Sierra Nevada later in the year, we have a longer amount of time where we have runoff coming down into the reservoirs," she said, standing among boulders and snow-covered manzanita bushes.

"I think being aware that these water resources are changing pretty fast and that they're limited is important," she said. As for the scale of the threats posed by climate change, she said: "It's super important, and I don't think people are doing enough."

Where the runoff goes

The snow that melts in this rugged stretch of the Sierra collects in Providence Creek and flows into Big Creek, snaking down through forests of brown, dry ponderosa pines that have been killed by infestations of bark beetles during the drought. The creek eventually reaches the Kings River, which flows into Pine Flat Reservoir.

Much of the water flows through canals to the farms of the Central Valley, which produce a large share of the nation's fruits, vegetables and nuts.

During the drought, the levels of Pine Flat Reservoir have fallen far below average levels. But in times of flooding, the Kings River can also unleash huge pulses of water.

Farmer Don Cameron has been preparing for those times. He is the general manager of Terranova Ranch, and in 2010 his farm received a $75,000 grant from the U.S. Department of Agriculture's Natural Resources Conservation Service to help pay for an experimental project that involved flooding 1,100 acres of farmland in order to replenish the aquifer.

When the floodwaters poured in during 2011, the inflows helped boost groundwater levels, which have been declining for decades in this area and across the Central Valley.

Cameron said the project worked well, and now the farm has obtained a larger $5 million grant from the California Department of Water Resources to spread larger quantities of floodwater on its fields in the future. The farm is contributing $2 million in matching funds for the project.

"For the long-term viability of the area, we need to do this," said Cameron, who manages more than 7,000 acres of farmland growing two dozen crops ranging from tomatoes and carrots to onions, wine grapes and kale.

The grant from the state will be used to pay for upgrades to canals, pipelines and other infrastructure. The state will also buy an easement to be able to permanently use a portion of the ranch's lands to deliver floodwaters to fields. The project will involve spreading water over 6,000 acres on Terranova Ranch and neighboring farms to replenish the aquifer. In subsequent phases, the plan calls for spreading water over a total of 16,000 acres.

Cameron sees it as an important strategy to prepare for the effects of warming. The farm, which relies on groundwater, has also converted many of its fields from flood irrigation to drip irrigation.

"When I look long-term at climate change, I look at a probably less reliable water supply as a grower," Cameron said, standing above a dry canal. "I think growers are going to be the ones that are going to see the real net effect before anyone else."

He ticked off examples of the changes that are already occurring: The seasons have begun to shift, changing the times of plantings. Last year, the pistachio crop was a disaster due to the warm winter.

"I think we're going to see growers having to adapt to change crops possibly and to be more cognizant of the water that they use. They're going to have to capture floodwater when it comes by," Cameron said. "We need to be proactive. We need to put in systems. We need to use the systems that we already have in place to be able to use this water when it is here and save it for times when we don't have it available."

The city of Fresno is taking a similar approach in trying to boost its underground water supply. When surface water from reservoirs is available, some is diverted through canals to a series of spreading ponds at a 203-acre city facility called Leaky Acres, where the water seeps down into the soil to the aquifer.

The water shimmers in pools encircled by a freeway and busy avenues, attracting birds that float on the surface.

“We put the water into the ponds and let nature take its course,” said Ken Heard, chief of water operations for the city’s public utilities department.

Lately, about 15 million gallons a day have been flowing into the ponds. It’s still not enough, though. The average groundwater levels around Fresno have fallen more than 100 feet in the last 80 years, and the levels are still declining, Heard said. As the water table continues to recede, pumping costs for the city’s wells gradually increase.

With climate change, Heard said, that supply of groundwater is going to become even more precious.

“From Fresno’s perspective, one of the biggest impacts of limited or no snowpack is it’s going to limit our ability to offset our groundwater pumping with treated surface water,” he said. Fresno recently began building a plant that will treat surface water from reservoirs to relieve pressure on the aquifer.

“Now with the prospect of prolonged or more frequent droughts, we may not be able to do that as much, which means we’ll have to continue using the wells,” Heard said. “And as long as we keep using the wells faster than the water is being replenished – whether artificially or naturally – that’s going to be a losing battle.”

He said that makes conservation all the more important. People in Fresno have reduced water use by about 25 percent in response to the state’s emergency drought regulations, building on previous reductions.

“I think these levels that we’re seeing that we’re calling reductions are going to need to just become our normal,” Heard said. “It’s definitely going to take a change in thinking for pretty much the whole state.”

Other water managers express confidence that the Kings River basin is relatively well prepared. Steve Haugen, the watermaster of the Kings River Water Association, said the area has already grown accustomed to highly variable natural swings in runoff. The amounts of water in the Kings River in a record wet year can be on the order of 10 times larger than a dry year, he said.

“At least in this area, most of the basin I think is well set and prepared,” Haugen said. “Unless we get into these 20- or 30-year droughts, there are some challenges there, and that’ll have to be responded to as we see those develop.”

Across California, the state government has received reports of more than 3,000 households out of water since the summer of 2014, many of them with dry wells – and most of them in small communities around Central Valley farms that have been pumping groundwater heavily during the drought.

As for the future, Haugen said the mountains above the Kings River are so high and steep that even a rise of 1,000 feet in the snowline – which scientists say is likely with 2 degrees Celsius of warming – should have a “fairly minimal impact” on the total amount of water.

But in other areas of California, such as the watersheds that feed the Feather River and the American River, he said the same rise in snowlines would change snow to rain over large areas. And that would unleash much bigger impacts.

Dwindling snow

Using data from snow sensors across the country, scientists have tracked significant declines in the average snowpack throughout much of the continental United States as the climate has begun to heat up.

Some stations at the highest elevations, including parts of the southern Sierra Nevada and the southern Rocky Mountains, have been the exception and have seen increases in snowfall with that initial warming. But that's because at those heights a little extra warmth can make the atmosphere more conducive to generating snow – and scientists expect that will last for only a limited time.

Once the atmosphere warms up enough, then snow is projected to decrease at those high-elevation sites, too, said Sarah Kapnick, a research physical scientist at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey.

The snow is melting earlier at all of the monitoring stations in the western U.S., Kapnick said, "and that's why you don't have as high of a peak within the season."

She and colleague Alex Hall of the University of California, Los Angeles, estimated in a 2012 study that across the West, snow has been melting on average one day earlier per decade since 1950 – about a week earlier than it used to melt. In Northern California and the Northern Rockies, they found the melt has moved up even more – by about two weeks over that same period.

Stream gauges have also shown earlier spring runoff from snowmelt than in the past.

Trends in western snowpack
Projected changes in snowfall

Projected changes in average annual snowfall due to global warming

The map illustrates projected snowfall changes as a result of human-caused global warming, based on a scenario in which carbon dioxide is doubled from 1990 levels. This information was calculated by researchers at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory. The scientists used a global climate model named CM2.5 to calculate snowfall in a constant climate (with 1990 carbon dioxide levels held constant) and compared that against a climate with carbon dioxide doubled.
SOURCE: Sarah B. Kapnick and Thomas L. Delworth, NOAA Geophysical Fluid Dynamics Laboratory
MAP: Robert Hopwood, The Desert Sun
Those shifts are just the beginning of the more pronounced changes that scientists expect. Kapnick has estimated in her research that if the quantity of carbon dioxide in the atmosphere is doubled from 1990 levels, the average amounts of snowfall are likely to decline by 50 percent or more in coastal regions of the lower 48

states, and by amounts ranging from 10 percent to 40 percent on inland mountains.

As the amounts of snowfall gradually decrease with warming, Kapnick said, “it takes us closer to drought conditions on an average basis.”

In fact, the drought in Oregon and parts of Northern California during 2014 and 2015 had a lot to do with the very warm winter, said Philip Mote, a climate scientist at Oregon State University.

“Here we had pretty close to average precipitation in the previous winter, but only about 10 percent of average snow in much of Oregon and the northern counties of California,” Mote said. “So that was an illustration of what happens if it’s just a lot warmer.”

Scientists concluded in one study last year that global warming has exacerbated the drought in California by drawing moisture from the soil and plants into the air.

California, Oregon and Washington rely to a large extent on spring snowmelt to sustain water supplies through the summers, and that natural reservoir is shrinking.

“So if you imagine a big reservoir like Shasta in Northern California or Lake Mead or Lake Powell, and every year we’re sort of cutting another foot off the top of the dam, reducing the amount of water that we can store,” Mote said. “That’s sort of effectively what’s happening, because as we raise the snowline, we’re reducing the area over which snow can accumulate.”

One team of scientists recently studied how declines in snowpack will likely affect the water supplies of different regions around the world based on the projections of climate models. And what they found was striking. Of 421 drainage basins in the Northern Hemisphere, they identified 97 regions as being “snow-sensitive” and dependent on snowmelt to help meet water demands. Those regions are home to about 2 billion people.

The scientists’ results, laid out on a map, show that much of the western U.S. – from California to the Colorado River basin to the Rio Grande – is shaded in red and maroon. That indicates those regions are particularly vulnerable and face high risks of having less water available during spring and summer months due to decreases in snowpack.

“What we’re really quantifying in that study is, what’s the potential of the climate of tomorrow to supply the water needs of today?” said Justin Mankin, a climate scientist at Columbia University’s Lamont-Doherty Earth Observatory who co-authored the study.

NOTE: Analysis does not take into account pumping of groundwater or transfers of water between river basins.
SOURCE: Justin S. Mankin, et al., Environmental Research Letters
MAP: Robert Hopwood, The Desert Sun

Declining snowpack puts water supplies at risk

This map shows scientists’ calculations of how declines in snowpack are likely to affect the water supplies of different regions of the United States. Using climate models, researchers found that much of the western United States is especially vulnerable and faces high risks of having less water available during spring and summer months.

In regions that pop up as red across the western U.S., Mankin said, “according to our measure, the climate of tomorrow will not be in a position to supply the water demands of today.”

Mankin, who is also affiliated with the NASA Goddard Institute for Space Studies, said the findings point to a need for a “management response.” He said how policymakers should respond differs for each river basin. “But in general, what a measure like this is telling us is that our historical reliance on snow is untenable in a future climate.”

The challenges for the Southwest appear especially daunting. Over the past few decades, the region has grown drier. Using climate models, scientists have projected that increasing emissions of greenhouse gases make for higher chances of a decades-long “megadrought” by the end of the century.

Even without such an extreme event, many scientific studies forecast significant declines in the flow of the Colorado River, which together with its tributaries provides water for nearly 40 million people and more than 5 million acres of farmland.

Researchers have estimated that warmer temperatures and the resulting declines in runoff could reduce the river’s flow by between 5 percent and 35 percent by the middle of the century. That will add to the enormous pressures on a river that is already heavily over-allocated and rarely reaches the Sea of Cortez anymore.

Federal officials who manage dams for the U.S. Bureau of Reclamation have recently calculated that the chances of Lake Mead reaching shortage levels in 2018 have risen to 59 percent.

If a shortage is declared, that would trigger cutbacks in the amounts of water delivered to Arizona and Nevada. Those sorts of impacts could grow more severe if continued decreases in the flow of the river collide with the existing framework of water allocations, which was drawn up during wetter times over the past century. Even California, which under the law of the river would be the last in line to have its water deliveries reduced, could face growing pressures to accept cutbacks.

With warming, demands for water also will tend to increase in the Southwest as the same amount of irrigated acreage will grow thirstier, and as more water will evaporate off the landscape.

“The Colorado system is really vulnerable to climate warming,” said Dan Cayan, a climate researcher with the Scripps Institution of Oceanography and the U.S. Geological Survey. He pointed to recent research indicating that for every 1 degree Celsius of warming, the Colorado River could lose somewhere between 5 percent and 10 percent of its flow.

While the pressures grow on the river’s limited supply, potential remedies are constrained by the legal framework laid out under the 1922 Colorado River Compact and subsequent water agreements.

Some researchers have compared the river to a pie that’s being cut up to share: The problem now, they say, is that the pie is still being divided in the same way as it has been for a long time, even though we’re finding the pie is actually much smaller than we once thought it was.

“The management of the river is going to have to dramatically change,” said Gary Wockner of the environmental group Save the Colorado.

“There’s going to have to be more conservation. There’s going to have to be more water transferred from farms to cities. And it is increasingly unlikely that there’s going to be enough water,” Wockner said. “So something has to change.”

Adapting to water changes

Aside from the scandal over lead-contaminated water in Flint, Michigan, water issues haven’t come up during the U.S. presidential race. Candidates have barely discussed climate change, much less the impact of warming on water supplies.

But some people argue the United States is long overdue to move toward a comprehensive national water policy, especially with the effects of climate change looming.

“We’re in a water transition from what I would say is a 20th century way of managing water to what I think will be a much more sustainable way of managing water, and it’s a transition,” said Peter Gleick, president of the Pacific Institute, a think tank that focuses on water issues. “Inevitably, our water system will be much more sustainable. Ultimately the question is how quickly and with how little pain we can get there.”

He and others say adapting will require a host of strategies, from preparing for more severe droughts to adopting new “rule curves,” or sets of guidelines for managing water levels in reservoirs, based on patterns of runoff that are shifting away from historical norms. Adapting will also require investments in infrastructure, better water data and science-based policymaking to address vulnerabilities.

While all of those steps may sound relatively simple, efforts to make the nation’s water systems more sustainably face a host of barriers. Just fixing old, leaky infrastructure could save vast quantities of water, but doing that would require substantial investments by local and state governments. Budgets for new infrastructure projects are limited in many areas, and private investments in new water-saving technologies have also remained small when compared with the rapid growth in investments in renewable energy.

Many areas could recycle and reuse much more treated wastewater if there were enough investment by public agencies. Other barriers include a lack of sufficient monitoring and measurement of groundwater use; antiquated and rigid water rights systems; and in some places, pricing systems that don’t go far enough in encouraging conservation. With management responsibilities fragmented among many local and state entities, some agencies appear to be taking forward-looking steps while others are constrained by bureaucratic inertia, pursuing the same old approaches even as the climate changes.

Questions about preparedness for climate change need to be answered at the local level, area by area, said Mote, the climate scientist at Oregon State.

“I think there’s no better test than a drought like we’ve just had,” Mote said. “Whatever can be done now to figure out a better way to manage that situation will probably stand us in good stead for the next time it happens."

With the snow holding less water, that seasonal water-storing capacity will need to be replaced elsewhere. But that doesn't necessarily have to involve building more dams.

"There are multiple ways to get storage," said Roger Bales, a professor and director of the Sierra Nevada Research Institute at UC Merced. "Before we ask the public to pay for an expensive dam, we'd better make sure that's the best option, that we need to exhaust local options such as groundwater storage and recharge."

Researchers have also found that investments in thinning overgrown forests could help. By removing vegetation and carrying out prescribed burns, those sorts of projects can make forests healthier and reduce the risks of wildfires, while also increasing runoff from the mountains – which could give a boost to water supplies downstream.

"We need to prioritize where investments in forest restoration will actually make a difference, both for fire and water," Bales said.

Preparing for a hotter climate will involve not only counting on less snowmelt, scientists say, but also getting ready for changes in the timing and intensity of storms, and more extreme downpours. Among other things, warming can raise the odds of events in which rain falls on top of snow. By rapidly melting the snowpack, that can trigger floods.

"What we have to think about is, how are we going to manage the infrastructure that is not adapted to the new regime which we'll be operating under?" said Noah Molotch, director of the Center for Water Earth Science and Technology at the University of Colorado, Boulder. "That really is the challenge, I think, for society."

Many managers of local water districts as well as state and federal officials have been emphasizing a need to use water more efficiently and stretch local supplies further.

"If you just do what we do now over the next 30 years, we will definitely face challenges," said David Groves, co-director of the RAND Water and Climate Resilience Center. "The region is not prepared for growth in certain areas, as well as superimposing climate warming."

He and other experts see enormous potential for California and other states to recycle more wastewater, "bank" water in aquifers, and capture more stormwater instead of letting it run off city streets into the sea.

When California's Natural Resources Agency recently issued a report outlining the state's efforts to prepare for climate change, it focused on objectives such as preparing for floods, managing groundwater, diversifying local water supplies and improving efficiency, among other things.

The Obama administration has also launched several initiatives aimed at encouraging more investments in water infrastructure, improving water data and boosting technologies that can help shrink the country's water footprint. When the White House held its first-ever national water summit in March, much of the discussion focused on efforts to help address the threats posed by climate change.

Coinciding with the event, the Interior Department released a report detailing projections of climate change impacts on the regional water supplies of 17 western states. In the report, the department said average temperatures will likely rise by 5-7 degrees Fahrenheit by the end of the century, bringing reductions in stream flows of between 7 percent and 27 percent from April through July in several river basins, including the San Joaquin River, the Rio Grande and the Colorado River.

Deputy Interior Secretary Mike Connor said recently that some of the White House's key goals include encouraging more wastewater recycling and promoting investments in water treatment and desalination technologies.

"There's great potential across the West to increase what we're doing in the area of water reuse," Connor said. "There's very significant opportunities for targeted desalination facilities, brackish groundwater desalination. We're already seeing that in some areas. That can add to the water supply from previously unusable supplies. That can help relieve the stress on existing potable water supplies."

Some California water districts have begun investing heavily in plans to prepare for longer and more intense droughts, as well as for the wetter times.

The Santa Ana Watershed Project Authority, for instance, is backing a $100 million project that involves developing four large groundwater basins to store imported water from Northern California when it is available. Celeste Cantú, the authority's general manager, said the strategy is to "capture the flashy wet years."

Several agencies are pooling their resources and participating jointly in the project.

"You have four basins that are going to be managed for the greater good of the watershed," Cantú said. She called it a big step toward becoming more climate-resilient.

A number of California agencies are taking significant steps to become less dependent on imported water supplies, said Frances Spivy-Weber, vice chair of the State Water Resources Control Board. She pointed out some water districts are projecting they will need less water in two decades than they do now, and she said that's cause for optimism. Growing numbers of water districts have also switched to tiered pricing systems that reward those who conserve and penalize those who don't.

"Climate adaptation definitely is achievable with conservation and portfolio of water supplies," Spivy-Weber said. "We're going to be able to ride out the droughts – even if they last for 10 years or 20 years."

The drought in California, now in its fifth year, has been a harbinger of the hotter droughts expected under climate change.

Last year was the planet's warmest year since records began in 1880, surpassing a record set the previous year.

This past winter also brought record-breaking warmth, partly influenced by El Niño. In the continental U.S., the average temperature in the three months from December through February was 4.6 degrees Fahrenheit warmer than the 20th century average.

Stacy and other scientists who are doing research in the Sierra Nevada have been seeing the effects of the abnormal heat all around them, even as this winter brought a larger snowpack that peaked at 88 percent of average in late March.

Stacy works at five research sites as field manager for a project called the Southern Sierra Critical Zone Observatory. Over the past couple of years, she and other researchers have watched mid-elevation forests of ponderosa pines turn brown and die.

Warm winters have enabled bark beetles to flourish in the drought-stressed forests, and the insects have left the mountains covered with millions of dead trees.

At the beginning of last summer, Thaw began studying one lower elevation site and marked trees to take samples over the following months.

“I came back later in the summer and they were dead,” Thaw said, “so I had to change my research plan.”

At research sites where several years ago Stacy trekked in using snowshoes or skis, she’s now often able to park nearby and walk on exposed ground.

“Sometimes it makes our work a little bit easier up here, but it’s really noticeable when we’re out here doing research that the snow isn’t there,” Stacy said.

She slipped on a safety harness and climbed up a 160-foot tower to replace air filters on instruments that monitor water vapor and carbon dioxide in the air. She explained that the measurements enable her team to “observe the forest breathing” as the trees conduct photosynthesis.

Then she went to check a snow sensor. As she walked across a white meadow, she skirted holes in the snow where sheets of water were flowing beneath and shimmering in the sun. The water streamed off onto patches of bare ground.

“It’s been melting pretty quickly over the past couple of weeks,” she said, “because it’s been so warm.”

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More information: