



# Science you can USE Bulletin

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## Our Forests in the [Water] Balance

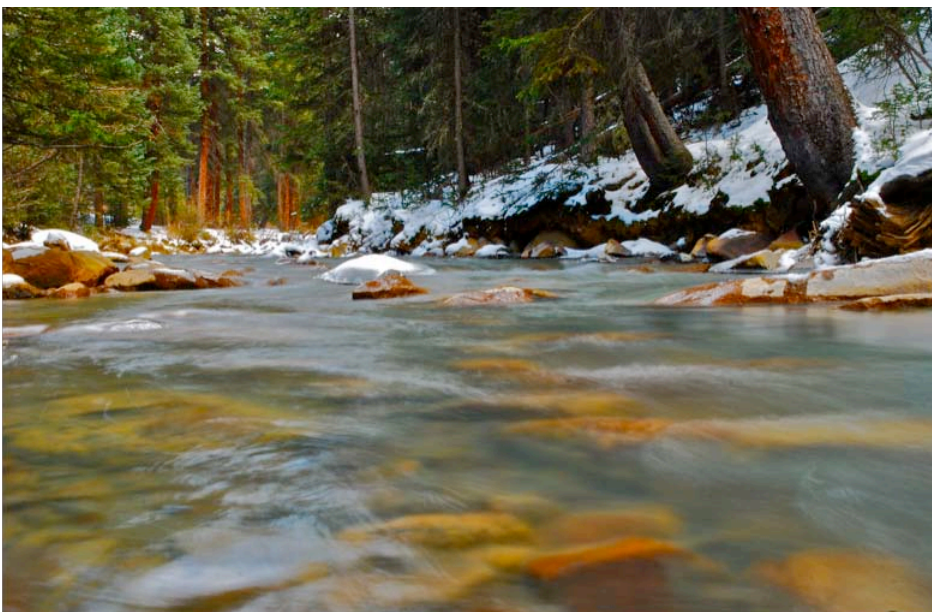
### Water: Brought by a forest near you

Water is a crucial and scarce resource in the West. It is important to humans for drinking water, irrigated agriculture, industry, energy, recreation, and the natural resources we manage and care about. While most citizens understand the basics of the water cycle, they are unaware of the leading role that forests play in delivering fresh water to streams and cities.

Where do you think water started its journey to your faucet after raining or

snowing to the ground? Many people might respond “a local reservoir or stream,” but in fact, almost 80 percent of the nation’s freshwater resources originate from forested areas. In the west, most forests occur in high-elevation areas where there’s enough snow and rainfall to support tree growth. The water that originates on these forests may then feed into the rivers, streams, and reservoirs that supply water to local communities.

Precipitation landing in a forest can experience several fates. Some water is captured by tree branches, where it



*Climate change is expected to increase the variability and unpredictability of precipitation across the West, which has implications for forest health as well as water levels in rivers and streams. This photo shows the Snake River near Keystone, Colorado in November of 2011. Photo by Bob Berwyn.*

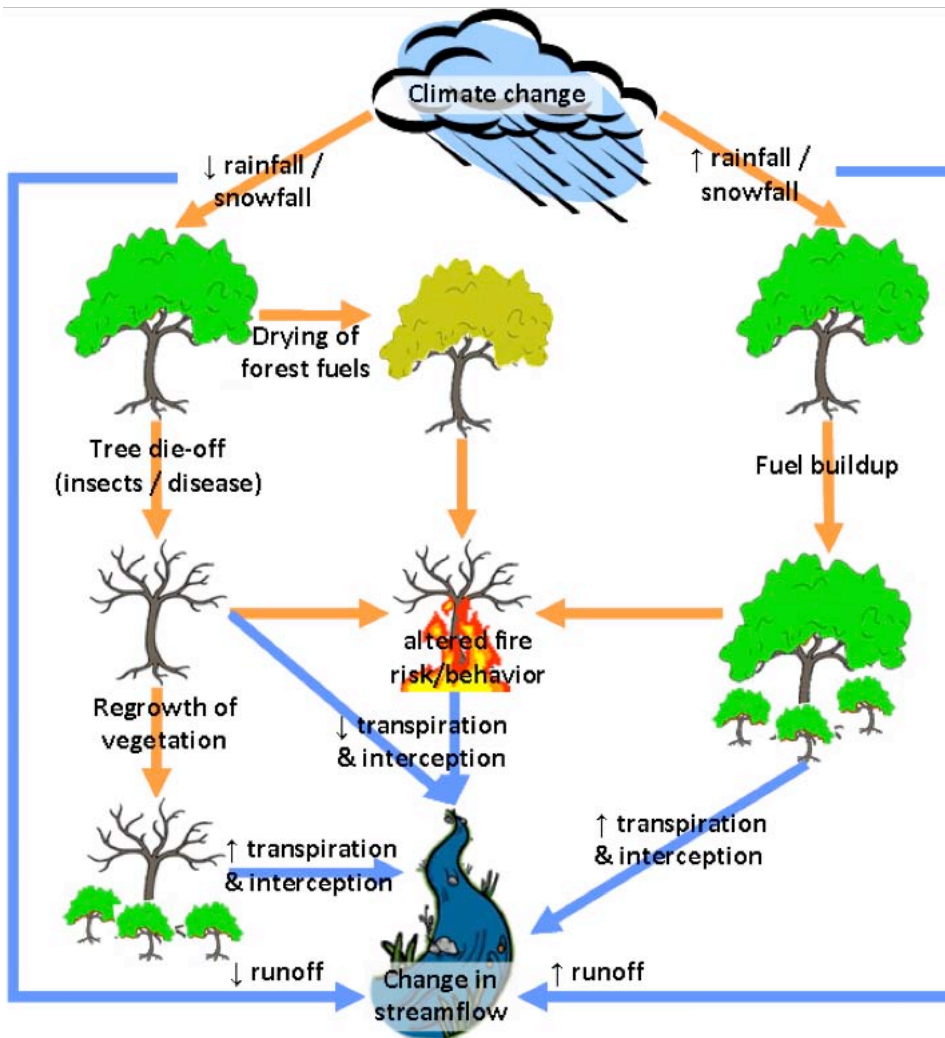
### SUMMARY

Climate change is not only causing temperatures to rise, it is also altering the amount and type of precipitation that falls across the western United States. Research shows a trend of increasingly dry “dry years,” meaning droughts are becoming more severe and streams are flowing lower during these periods.

Forests play an important role in delivering high quality water to streams, but climate change is affecting this role. Drought can cause tree mortality due to lack of water or reduced resistance to insects and disease. Dry fuels and stressed vegetation in forests also increases the potential for large wildfires. When many trees die in a forest fire or from disease or insect outbreaks, the amount of water entering nearby streams often increases. However, so does the delivery of sediment to these streams through erosion.

These changes call on resource managers and communities in the West to start conversations today about addressing water supplies in the future. In addition, silviculturists, fuel specialists, and aquatic ecologists can work together to maintain a holistic view of ecosystems that, above all, considers where forests fit in the water balance.





Annual precipitation is declining and will probably continue to decline across large portions of the West. Other areas might experience increased precipitation. These changes will impact the growth and mortality of trees, which will in turn affect the amount and dryness of fuels in forested areas. Changes in tree cover due to insects, diseases, or wildfires will alter how much water is used by forests and how much enters nearby streams. Diagram by Megan Matonis.

need to understand and appreciate these linkages if we are to enjoy forests, streams, and a supply of clean drinking water into the future.

**Climate change: It’s about more than just rising temperatures**

Over a century of data collection and research show that average temperatures are increasing across the globe. Minimum and maximum temperatures are also rising, increasing the amount of moisture sucked out of plants by the atmosphere. These changes are reducing the ability of some plant and animal species to persist in their current environments.

Many researchers and policymakers are focused on the temperature aspect of climate change, but according to Charlie Luce, research hydrologist with the Rocky Mountain Research Station, “The ecological effects of changing precipitation may well outweigh changes related to temperature. Ecosystems and economies are both very sensitive to precipitation, and they will go wherever the water takes them.”

Luce and fellow scientists with the Forest Service and University of Idaho published a comprehensive report in 2012 documenting many of the changes facing forests in the coming decades. Their report shows substantial declines in annual precipitation projected for the southwest United States, with estimates ranging anywhere from a 6 to 20 percent decline. Researchers are less certain about how precipitation will change in the Northern Rockies and Pacific Northwest. Some models predict as low as a 10 percent decline in average precipitation while others project as much as a 21 percent increase.

remains until evaporated by the sun or pulled to the forest floor by gravity. Water making it to forest floor hardly has time to rest. Much is evaporated from the soil surface or sucked up by plant roots. Plants retain some of this water to hydrate their cells, but they let most of it escape through their leaves and back into the atmosphere, a process called transpiration.

Water molecules that are not evaporated or transpired are dragged deeper into

the soil by gravity or they run across the soil surface into nearby streams. This “runoff” is then available as habitat for fish, nourishment for vegetation growing along the riverbank, and resources for human use.

The way we manage forests can greatly impact the balance between water entering and leaving a forest. However, the largest regulator of forest-water relationships will always be the climate. Resource managers and the general public

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Overall, climate projections for the West generally agree that precipitation will become more variable in the coming decades. Larger rainstorms could be punctuated by more severe droughts. Record snowfall one year could be followed the next by conditions that disappoint skiers for an entire season. Winter droughts will deepen the summer droughts much of the West is already experiencing due to warmer temperatures and earlier snowmelt.

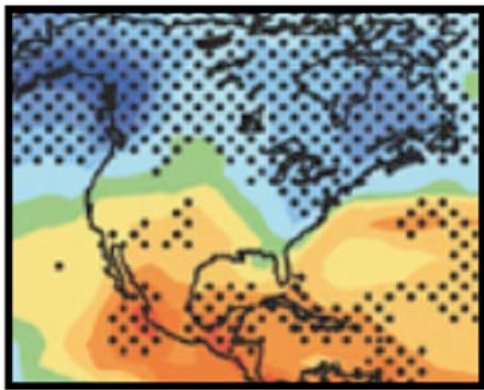
These changes in precipitation are not just looming in the future, some are already here today. Charlie Luce and Zack Holden, a researcher with

the Northern Region of the Forest Service, recently published an analysis of streamflow gages in the Pacific Northwest from 1948 to 2006. They noticed a consistent decrease in annual streamflow over this period, with flows decreasing as much as 20-50% during the driest of years. An increase in extreme conditions, especially the drying of dry years, is of great concern for forest and water managers. “Dry years test the trees—determine if they live,


die, or catch on fire. They test the fish. They also test the farmers and the water managers,” says Luce.

**Drought, forests, and wildfire**

When forests receive abundant precipitation, trees grow rapidly and excess water fills nearby streams. Periods of drought, on the other hand, slow tree growth and may result in tree mortality. Many trees have adaptations to cope with drought, such as closing the tiny pores on their leaves to reduce water loss from transpiration, but prolonged drought can cause starvation because trees cannot effectively photosynthesize when pores are closed. Severe drought can also cause hydraulic failure, which is when cells that transport water up tree trunks like a straw fill with air bubbles—generally an irreversible and fatal process.



Less precipitation      More precipitation

 = Areas of greater certainty

Models of future climates project less precipitation for the Southwest from 2080-2099 relative to 1980-1999. Changes for the Northwest are less certain, but may involve higher precipitation in some years.



Drought can kill trees directly or by reducing their ability to combat insects and diseases. Pictured here are dead and dying lodgepole pine and Douglas-fir trees near Salmon, ID, killed during recent outbreaks of mountain pine beetle and Douglas-fir beetle. Photo by Charlie Luce.

*“Dry years test the trees—determine if they live, die, or catch on fire. They test the fish. They also test the farmers and the water managers,” says research hydrologist Charlie Luce.*

*“Currently, we tend to put out fires when we can, causing most forests to burn only during droughts. Continuing this trend may have important consequences for tree mortality and post-fire erosion,” according to Forest Service researcher Zack Holden.*

A recent publication from researchers with the Forest Service, U.S. Geological Survey, and several universities across the West suggests several additional ways that drought can impact forests. For example, thirsty trees are also more vulnerable to insects and disease. The current mountain pine beetle epidemic started during some of the most extreme droughts observed in recent history. Trees could hardly grow given the dry soil conditions, and many were unable to produce the resin that can expel beetles. Droughts during the early 2000s are also implicated in the deaths of thousands of aspen trees across the West.

Prolonged and severe droughts set the stage for wildfires. Years of low annual streamflow in the Pacific Northwest also saw the greatest number of acres burned in wildfires from 1984 to 2005, according to new research by Holden, Luce, and their colleagues with the University of Idaho and The University of Arizona. Less annual precipitation leads to less runoff and it also leads to earlier snowmelt, simply because there is less snow to melt. These conditions dehydrate forests throughout the summer, with desiccated vegetation and dry fuels making perfect tinder for larger wildfires.

While it seems rather obvious that fires are more likely to ignite and grow large when things are dry, much less is known about how fire severity might change under a drying climate. Recent research suggests that fires burning under relatively dry conditions have a higher

probability of burning as stand-replacing wildfires. According to Holden, “These findings have important implications for how we manage fires in the West. Currently, we tend to put out fires when we can, causing most forests to burn only during droughts. Continuing this trend may have important consequences for tree mortality and post-fire erosion.”

At the same time, University of Idaho professor Penny Morgan cautions that we don’t want to always view increased acres burned as a bad thing. “Many forests, woodlands, and grasslands in the west are healthier when they have fire,” Penny explains, “fire that’s under controlled conditions and safe.”

### **Rivers and forest die-offs: Higher streamflow and erosion make for a muddy mix**

Streamflow can benefit from forest die-off. For example, annual water yield increased 15% following a spruce beetle outbreak in the 1940s on the White River Plateau of western Colorado. The beetles caused extensive mortality in Engelmann spruce and lodgepole pine, and it took over 25 years for the vegetation to recover and streamflow to decline back to pre-outbreak levels.

Findings from a research paper co-authored by Luce suggest that streamflow often increases when more than 20% of the trees die in a watershed and/or annual precipitation is greater than 20 inches (500 mm). When a large portion of trees die in a forest, there are fewer roots sucking up water and fewer branches capturing precipitation. This leaves more water in the soil that can eventually end up in streams.



*Erosion can wash woody debris from forests into nearby streams, creating habitat for fish like Chinook salmon. This group of salmon is breeding in a stream on the Boise National Forest, ID. Photo by Dan Isaak.*

*“We expect climate change to lead to higher streamflows and/or rates of erosion in some areas by inducing forest die-offs through drought stress, reduced resistance to insects and pathogens, or more extensive wildfires,” reports research hydrologist Charlie Luce.*

However, if annual precipitation is low, most of the excess water will be taken up by surviving vegetation or evaporated from the soil surface. This means that increased streamflow is less likely to follow extensive mortality in low-elevation forests. In fact, water yield from a piñon–juniper forest in northern New Mexico actually declined following substantial mortality of piñon trees due to drought. Researchers attribute the decline in water yield to thirsty grasses and forbs that sucked up the excess water to support rapid growth.

Not only does widespread tree mortality often increase streamflow, it can also increase rates of erosion. Erosion occurs when soils cannot resist the force of water running downhill. The death of trees and other deeply-rooted plants increases an area’s susceptibility to erosion by weakening the net of roots in the soil.

Wildfires can cause massive erosional events by denuding an area of vegetation. A publication by Luce and fellow Forest Service scientists Jaime Goode and John Buffington reports that high rates of erosion can even persist 10 years after severe fires. Heat from wildfires can also create water-repellent layers in soil. These layers temporarily change the water-absorbing capacity of soils from that of a sponges to that of a rain jackets, yielding rapid runoff over the soil surface. The amount of sediment

reaching streams during post-fire erosional events can be 100 times larger than long-term average values, and about 1000 times greater than the amount of erosion resulting from road construction.

Yet again, climate change inserts itself into the relationship between forests and water. “We expect climate change to lead to higher streamflows and/or rates of



*Severe drought during the early 2000s killed millions of aspen trees across the West, including these aspen on the Uncompahgre National Forest, CO. Severe drought and widespread tree deaths, likely exacerbated by climate change, are becoming more common. Photo by Megan Matonis.*

erosion in some areas by inducing forest die-offs through drought stress, reduced resistance to insects and pathogens, or more extensive wildfires,” reports Luce. Increased rates of erosion are even more likely in areas where the future climate includes more intense rainstorms.

A future with higher rates of erosion comes to most people as unwelcome tidings. Muddy rivers are displeasing to look at and cause problems for drinking water treatment. Sediment and debris also clog reservoirs, reducing how much water they can hold.

Negative connotations with erosion muddy the fact that this natural process also has beneficial impacts on fish and aquatic insects. Large woody debris often increases the abundance and diversity of fish habitat. Fine sediment can clog the gills of fish and increase mortality, but it also carries nutrients into streams and increases the productivity of algae and aquatic plants.

Stream ecosystems can handle a certain amount of sediment, but increased rates of erosion in the future could put some native fish species “up the creek without a paddle.” This is especially true as climate change raises stream temperatures and pushes cold-water species to their limits in smaller and smaller habitats.

While completely preventing the flow of sediment into streams is not feasible, there are ways that land managers can intervene to help stabilize the relationship between forested slopes and nearby streams. A great start is restoring riparian ecosystems and connecting



*Massive erosion following the Hot Creek Fire near Atlanta, ID, in 2003 caused damage to roadways and stream ecosystems along the Boise River. The fire burned about 27,000 acres and took three weeks to contain. Photo by Charlie Luce.*

aquatic habitats today. That way, stream ecosystems can recover should severe fires and massive erosion occur.

Intentionally putting large logs in streams can create deep pools and provide cover for fish, and planting vegetation along riparian areas can provide shade and decrease stream temperatures. Maintaining and even decommissioning roads can also go a long way towards restoring streams. Erosion rates following fires are magnitudes larger than erosion from roads, but roads deliver a consistent supply of sediment to streams over the long term. Removing these additional sources of sediment can put streams in a better position to handle debris from fires.

### Flowing with the changes

Researchers are confident that rainfall and snowfall patterns are changing and will continue to change and that these

changes will impact forest and water resources. We cannot predict exactly how much annual precipitation will decrease or increase in specific regions across the West, but the general trend is a drying of the dry years. This means less water to support tree growth. It means drier forests that more easily ignite and carry wildfire. It means less water to fill streams, provide

habitat for fish, and fill reservoirs for human use.

Humans have only a modest ability to change the amount and quality of water leaving forested areas. The biggest players are the amount and type of precipitation falling from the sky. This means that a crucial role for managers is monitoring changes, anticipating future conditions, and prioritizing when and where to intervene with actions such as fuel treatments, fire suppression, road reclamation, and riparian restoration.

Resource managers and communities in the West can start talking today about how to respond intelligently to major changes in ecosystems and water supplies in the future. Since there is uncertainty about how much and when changes in precipitation will happen, it helps to plan for “worst case” scenarios as well as more moderate conditions. Communication among diverse resource specialists is also crucial. When foresters, aquatic ecologists, and fuel specialists work together, it encourages holistic planning that keeps in mind the important role that forests play in the water balance.

### KEY FINDINGS

- Climate change is expected to increase the variability and unpredictability of precipitation across the West. This has the potential to cause forest die-off from drought, insect or pathogen outbreaks, and more wildfires.
- Drier years are growing drier. Over the past several decades, low-flow levels have declined in many streams across the Pacific Northwest.
- Years with less annual precipitation not only experience lower streamflows but also a greater number of acres burning in wildfires.
- Fires burning under relatively dry conditions tend to burn more severely.
- The death of more than 20% of trees in a watershed can result in greater streamflow, especially in areas that receive 20 inches or more of precipitation each year.
- Rain events following wildfires can cause rates of erosion that are several orders of magnitude larger than average conditions.

## MANAGEMENT IMPLICATIONS

- There are consequences to stream ecosystems when the forests don't receive enough precipitation. Silviculturists, fuel specialists, and aquatic ecologists can work together to maintain a holistic view of ecosystems and help prevent unintended consequences to nearby streams.
- Restoring aquatic ecosystems and maintaining riparian buffers can increase their resilience to future disturbances, such as post-fire erosion events.
- Forest and fire managers will play a critical role in influencing where and when wildfires burn, and to a certain degree, the ecological outcome of those fires.
- Managers may need to monitor and mitigate the impacts of erosion on streams, roads, and trails for 10 or more years following severe wildfires.
- Decommissioning forest roads presents the greatest opportunity for managers to offset erosion from wildfires and other forest die-offs. While sediment inputs from roads are small in comparison to inputs following wildfires, roads produce sustained input of sediment over long periods of time.
- Human communities across the West can improve their preparedness for prolonged droughts in the future by initiating conversations today about water allocation and water conservation.

## FURTHER READING

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## WRITER'S PROFILE

**Megan Matonis** is a PhD student with the Graduate Degree Program in Ecology at Colorado State University and a graduate student cooperator with the RMRS Science Application and Integration Staff. She earned a BS in natural resource management from CSU and a MS in forestry from Michigan State University. Megan can be reached at [mmatonis@fs.fed.us](mailto:mmatonis@fs.fed.us).

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## SCIENTIST PROFILES



**CHARLES LUCE** is a research hydrologist with the Rocky Mountain Research Station, working out of the Boise Aquatic Science Laboratory in Idaho. His current research centers on long-term trends in streamflow, linkages among hydrology, forests, and wildfire, and the impact of forest roads on rates of erosion. Charles holds a MS in forest hydrology from the University of Washington and a PhD in civil engineering from Utah State University.

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**ZACK HOLDEN** is a scientist with the Northern Region of the Forest Service. He is interested in mountain climatology, namely how fine-scale temperature and precipitation patterns influence mountain ecosystems. Zack also has a strong interest in the development of tools to help bridge the gap between research and management. He graduated with his PhD from the University of Idaho.

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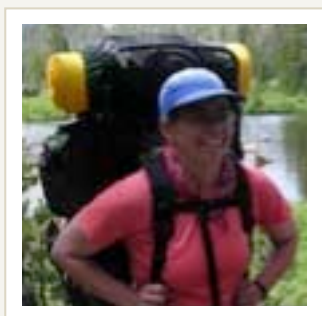
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**PENNY MORGAN** is a professor of fire sciences at the University of Idaho and director of the University's Wildland Fire Program. Her current research focuses on some of the broad challenges facing people in the West, such as the potential impacts of climate change on wildfire occurrence and severity. She also investigates the process of vegetation recovery following large fires, including the effects of post-fire management. Penny holds a PhD from the University of Idaho in fire ecology and management.



**EMILY HEYERDAHL** is a fire ecologist with the Rocky Mountain Research Station based out of the Missoula Fire Sciences Lab. Her research explores how climate, forest type, topography, and land use have affected spatial and temporal variation in fire regimes over the past several centuries. Emily's PhD is in forest ecology from the University of Washington.

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