

INSIDE

Flows Run Deep .....2  
A Warmer Outlook .....3  
Nothing to Lose .....3  
Where Will the Water Come From? The  
National Forests .....5

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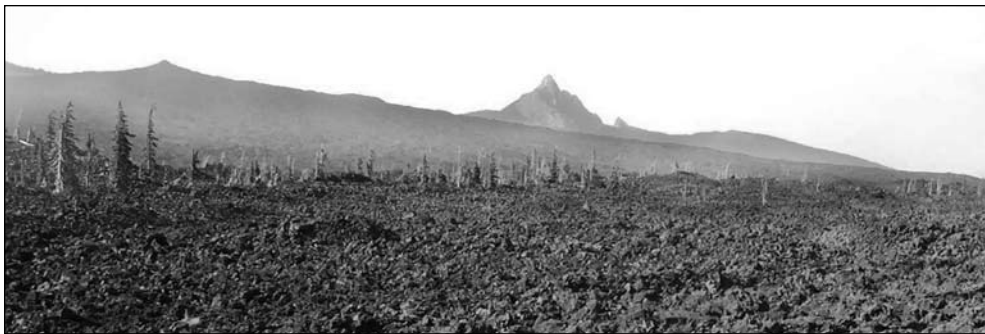
# Science

FINDINGS

*“Science affects the way we think together.”*

Lewis Thomas

## RUNNING DRY: WHERE WILL THE WEST GET ITS WATER?



G. Grant

Young lava flows at McKenzie Pass are an entrance into the deep aquifers that supply summer flows to rivers in the Cascade Range.

*“Between earth and earth’s atmosphere, the amount of water remains constant, there is never a drop more, never a drop less. This is a story of circular infinity, of a planet birthing itself.”*

—Linda Hogan

Now, as ever, the West faces a hydrological conundrum: winter months bring rain and snow but summer is when we need water most. Whether for drinking, agriculture, recreation, or ecosystems, water demands in the West are greatest in late summer—smack in the middle of the annual drought. Storage, it seems, is the only solution.

Mountain snowpacks are recognized as one of the largest stores of winter precipitation. Rivers and streams continue flowing into the summer so long as there is snow melting above. Not surprisingly, global warming is fast diminishing the proportion of mountain precipitation falling as snow, as opposed to rain. What’s more, the snow that does accumulate is melting earlier in the year. This trend is observable throughout the West, and there is every reason to believe that, as temperatures continue to rise, snowpacks will be smaller and less reliable as a store of water to

carry us through the dry months. In fact, recent climate studies predict future snowpack reductions as much as 55 percent over the next 50 years in the Pacific Northwest.

Where will the West get its summer water? Gordon Grant, a research hydrologist with the PNW Research Station in Corvallis, Oregon, studies this very question. He believes that, in part, the answer lies below ground. “New research is revealing that the source of late summer water in western and central Oregon and northern California is almost exclusively due to immense groundwater storage in the Cascade Range. In fact, the volume of water stored below ground in the Cascade Range totally eclipses the water stored as snowmelt. Understanding the future of water in these landscapes requires an understanding of geology,” he explains.

The High Cascades Province has massive groundwater storage capacity because it has young, permeable volcanoes—the youngest are only a few thousand years old. They are layer-cakes of voluminous lava flows—tremendously porous and miles deep. “You could stand on McKenzie Pass with a fire hose on full blast all day—day after day—and you’d barely make a puddle, the water would just pour into the

### IN SUMMARY

Late summer streamflow in western and central Oregon and northern California is almost exclusively due to immense groundwater storage in the Cascade Range. The volume of water stored in permeable lava flows in the Cascades is seven times that stored as snow. Nonetheless, until recently, virtually all examinations of streamflow trends under future climates in the West have focused on the anticipated loss of snowpack. This has painted an incomplete picture of the looming water resource crisis that is expected because of global warming.

Researchers at the PNW Research Station have recently completed an analysis showing that variation in geology across the West is going to influence regional sensitivity to global warming. Regions sourced by groundwater will continue to have streamflow, in contrast to areas sourced exclusively by snowpack. Paradoxically, regions sourced from groundwater will lose a greater total amount of late summer water, simply because they have more water available to lose. Under future climates, high-elevation Forest Service lands will be critical sources of freshwater, though not all forests will be equally affected. The Willamette, Deschutes, Umpqua, and Lassen National Forests will provide the most significant water resources.

ground,” explains Grant. “These landscapes are hydrologic sponges.”

According to Grant, there is more water underneath the Cascade Range than there is in the Great Salt Lake. And these stores of groundwater are the reason large rivers such as the Willamette, Deschutes, and Sacramento continue to have relatively high flows late into the summer.

In contrast, the Sierra Nevada is a huge block of uplifted granite, which has no capacity for groundwater storage whatsoever. Once the snow melts in the Sierra, the only opportunity for summer water storage is behind a dam.

There is one obvious question then: Will groundwater storage buffer the Cascade Range from the effects of climate change? The answer is less obvious than you might think, and it requires a bit of nuanced understanding.



## KEY FINDINGS



- Contrary to the commonly accepted view that snowpack storage is the dominant source of late summer water, new research is revealing that the source of late summer water in western and central Oregon and northern California is almost exclusively immense groundwater storage in the Cascade Range. The volume of water stored as groundwater in permeable lava flows in the Cascade Range is seven times that stored as snow.
- Regions of the West sourced by groundwater, such as the Oregon and northern California Cascade Range, will continue to have streamflow under climate warming, in contrast to areas sourced exclusively by snowpack, such as the Sierras in California. Paradoxically, however, these same groundwater regions will lose a greater volume of water than those without deep groundwater.
- The effect of climate warming on streamflows will be higher winter flows, diminished spring snowmelt, and markedly reduced late summer flows. This is because of two factors: an earlier peak for maximum snowmelt, and the geologically mediated rate at which water drains from the landscape.

### High Cascade (spring-fed)



S. Hayes

### Western Cascade (surface flow)



S. Hayes

*Groundwater-fed streams, such as those in the High Cascades Province, tend to have stable, moss-covered wood and boulders and no floodplain. In contrast, streams that are dependent on surface flow, such as those in the Western Cascades Province, tend to have mobile wood, gravel bars, and coarse boulder floodplain.*

## FLOWS RUN DEEP

Until recently, most research predicting water resources under a changing climate has focused on annual snowpack as the primary storage component. Accordingly, predicted warming temperatures lead to decrease in storage and virtually zero streamflow late in the summer. This, according to Grant, has painted an incomplete picture of the problem.

“When I first considered the issue of decreased snowpack, I thought: ‘The High Cascades have nothing to worry about. Either way, whether the precipitation comes as rain or snow, it will end up in the ground, thereby minimizing the impact of warmer temperatures,’” says Grant. “But my early perspective didn’t account for the full hydrologic pathway.”

You can think of the subsurface hydrology in the High Cascades as analogous to your garden hose. When you turn on the valve at your house, water instantly comes out the end of the hose—but, of course, it’s not the same water. It takes time to push out the warm water residing in the hose before the cold water from the house appears. The High Cascades are the same way. When precipitation enters the groundwater aquifer, it increases the subsurface pressure and pushes out a roughly equivalent amount of water lower in the system, usually as streamflow. A drop of water falling in the High Cascades takes an average of 7 years, and as much as several decades, to work its way through a groundwater flowpath—the proverbial garden hose.

If the High Cascades Province is at one end of a geological gradient of subsurface drainage, then the Western Cascades Province is at the other. The Western Cascades, like the Sierra Nevada mentioned earlier, have shallow, comparably insignificant subsurface flows. In these systems, precipitation quickly moves downslope, downstream, and out of the watershed, unless it is stored as snow. Consequently, Western Cascade streams are typically flashier, with higher winter peaks and lower summer flows.

“If you were to look at a hydrograph of streamflow volume throughout the year, the Western Cascades would show sharp, high peaks

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throughout the winter and spring corresponding to rain events, and another muted peak in the late spring, during peak snow melt. By mid to late summer, the graph would be flat and near zero,” explains Grant. “A hydrograph for the High Cascades also has peaks in the winter and spring, and another related to

snowmelt, but these would be relatively muted and the flow would subside slowly throughout the summer, never quite reaching zero.”

It’s clear that the variation in geology across the West is going to influence regional sensitivity to global warming.

## A WARMER OUTLOOK

Grant and his colleague Christina Tague, from the University of California at Santa Barbara, capitalized on the hydrologic differences between the High and Western Cascades to explore the importance of geologic-based distinctions in subsurface flows in mediating the impact of climate warming.

Long-term streamflow records from 1958 to 2003 were coupled with climate data and fed into a hydrologic simulation model, which was needed to disentangle the effects of snowmelt from groundwater.

“At an annual timescale, the streamflow statistics from the two watersheds are remarkably similar,” says Grant. “During the summer, however, there are clearly distinctive flow regimes. The High Cascade watershed maintains significantly higher August streamflow—roughly 6 percent of total annual streamflow—while in the Western Cascades it is less than 1 percent.”

To assess how these differences would play out during a warmer climate, Grant and his colleagues simulated the expected flow patterns in both watersheds while assuming no change in the amount of precipitation but an increase in average temperature. In addition,

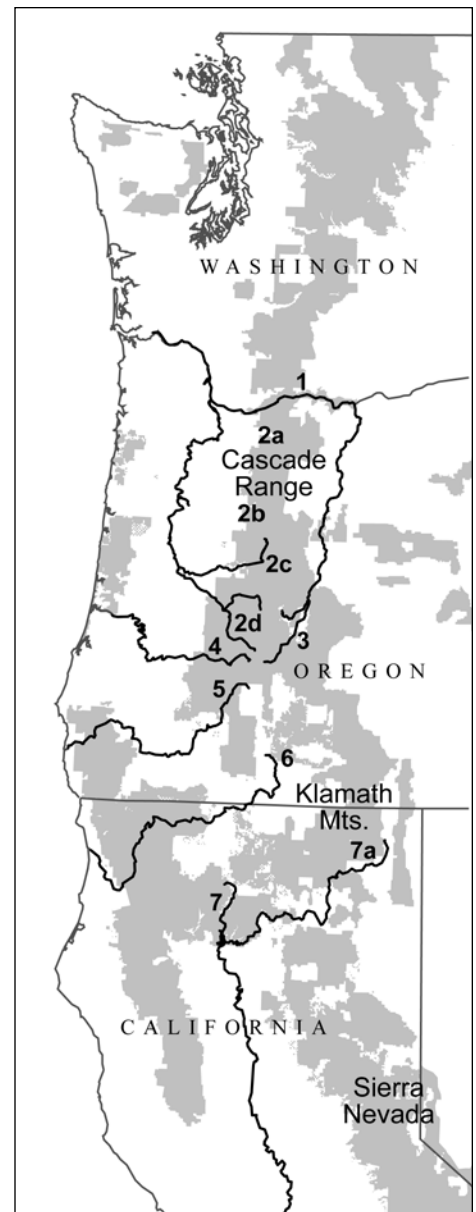
they simulated a hypothetical watershed that was just like the High Cascades site in every way, except that it had no deep groundwater flow. This allowed them to explicitly measure the influence of the unique geology.

“The simulated impact of warmer temperatures revealed a significant loss in snow accumulation and an increase in rates of snowmelt,” says Grant. “This corresponded to increases in winter flows and reductions in spring and summer flows. These findings are consistent with overall predictions made by other climate studies in the Western U.S.”

The effect of diminished snowpacks played out quite differently in the three modeled watersheds. “Because the High Cascades and hypothetical sites are higher in elevation than the Western Cascades site, the increase in temperature had a greater influence on the snowpack and melt rates,” says Grant. “However, the resulting streamflow response was quite different between the two high-elevation sites, emphasizing the importance of groundwater.”

“Because snow is the primary source of storage for the Western Cascades, loss of winter snowpack will likely result in permanent streams becoming more intermittent and ephemeral, resulting in an overall contraction of the late summer drainage network. High Cascade streams, in contrast, will continue to flow year-round because of their ground-water component, but with reduced volumes,” explains Grant.

In terms of percentage of reduction in late summer streamflow, their simulations showed the importance of groundwater storage in mediating the effects of climate change.



Groundwater-fed rivers of the Pacific Northwest will continue to have late summer flows, even after an increase in global temperatures. Some of the most important rivers will be: 1. White Salmon; tributaries to the Willamette, 2a. Clackamas, 2b. North Santiam, 2c. McKenzie, 2d. Middle Fork Willamette; 3. Deschutes; 4. North Umpqua; 5. Upper Rogue; 6. Upper Klamath; 7. Sacramento; and 7a. Pitt. Gray shading indicates Forest Service lands.

### Purpose of PNW Science Findings

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## NOTHING TO LOSE

Although the Western Cascades showed the highest percentage of reductions, the highest total loss of late summer streamflow was in the High Cascades. But wait; aren’t the High Cascades buffered by their unique geology? As it turns out, not when it comes to total reductions of streamflow in late summer.

“Understanding why the groundwater-dominated system has a greater reduction in summer flow volumes requires considering how they translate the recharge signal (precipitation or snowmelt) into streamflow,” explains Grant.

This takes us back to our garden hose. The water begins exiting the hose the moment we turn on the valve—i.e., when we increase the

pressure. Similarly, in groundwater-dominated streams, the flow volume is regulated by the timing of precipitation and snowmelt. If more water enters the system in the winter as rain, then more will exit into the streams during winter. Likewise, if the snowmelt peak is earlier in the summer, the streamflow peak will also be earlier in the summer.

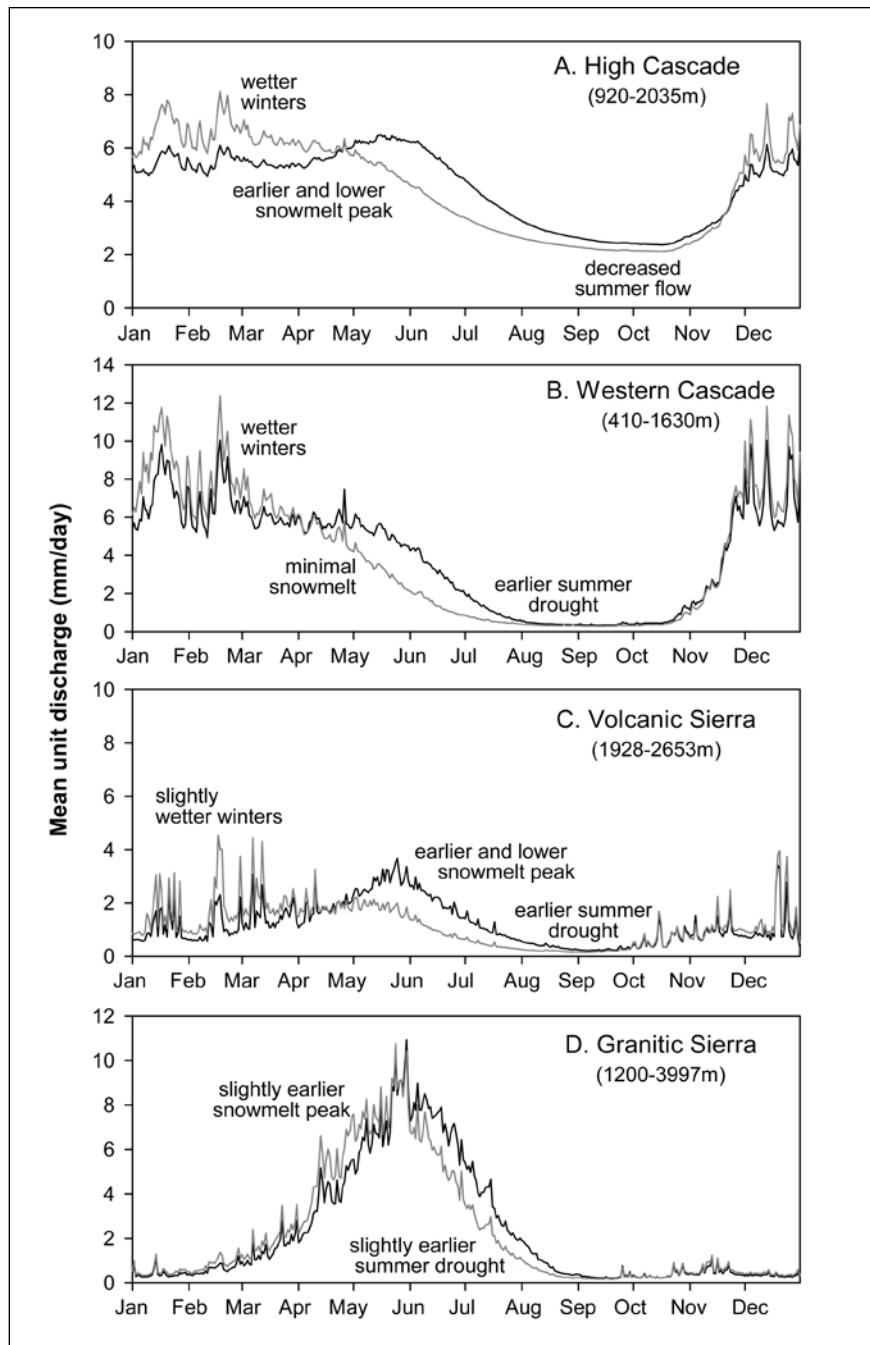
“That’s what I was missing when I first started thinking about climate warming effects in groundwater-dominated watersheds,” he says. “The whole system is going to come online earlier.”

This does not change the fact that groundwater-dominated systems will have more streamflow in the late summer than those with little subsurface flow. The essential fact is streams with no groundwater don’t have much late summer flow to begin with. They simply don’t have much to lose, which explains the seemingly contradictory results in terms of percentage loss versus absolute loss.

“Remember the gradually declining line on the hydrograph of High Cascades streamflow? It begins sloping downward after peak snowmelt in June and continues its slow decline until the rains come in October. In a warmer climate, that line will start sloping downward earlier in the year, and it will start its decline from a lower point,” says Grant.

Grant and his colleagues have recently expanded their analysis to include two additional watersheds in California. Together these four study sites represent a range of snowpack, elevation, and subsurface geologic conditions. Their analyses have led them to a simple conceptual mathematical formula to predict the influence of geology on streamflow in a warming climate.

Grant hopes that application of their formula will entice future researchers to explicitly include geological variation in future streamflow predictions. To date, geology has been largely ignored.



A 1.5 degree Celsius warming results in less precipitation falling as snow as well as earlier snow melt. In these graphs, stream discharges under the current climate are shown with black lines, and flows under a projected 1.5 degree Celsius warming are shown with gray lines (Tague and Grant, in review).



## LAND MANAGEMENT IMPLICATIONS



- It is likely that the deep groundwater systems of the Cascade Range will provide an increasingly greater proportion of water, both to the Pacific Northwest and to the greater Western region.
- Under future climates, most Western water will be sourced from high-elevation Forest Service lands in the Cascade Range. In fact, water is likely to be the most valuable commodity produced from national forest lands.
- Not all national forests will be equally affected. Underlying geology will be a primary determinant of where water will come from. Top-tier water-producing forests will be the Willamette, Deschutes, Umpqua, and Lassen; second tier will be the Mount Hood, Rogue River, Shasta, Klamath, and Gifford-Pinchot National Forests.

# WHERE WILL WATER COME FROM? THE NATIONAL FORESTS

Grant's findings have significant implications for how rivers, dams, and water supplies are managed in the future throughout the West. "In a nutshell, it is likely that the deep groundwater systems of the Cascade Range, even in their diminished state, will provide an increasingly greater proportion of water, both to the Pacific Northwest and to California," he says.

Under future climates, the high-elevation forest lands, managed by the Forest Service, will be the most important sources of water. "In fact," says Grant, "I'm willing to go on record and say, in the not-so-distant future, clean water will be the single most important

commodity produced from national forest lands. It will totally eclipse timber."

"Not all national forests will be equally affected. And the underlying geology will be a primary determinant of where water will come from," he explains. "Top-tier water-producing forests now and in the future will be the Willamette, Deschutes, Umpqua, and Lassen; second tier will be Mount Hood, Rogue River, Shasta, Klamath, and Gifford-Pinchot."

As Grant points out, relying on the Forest Service for clean water is not a new idea. The 1897 Organic Act creating the new agency

cites "securing favorable conditions of water flows" as one of three missions for the forests. In the future, it seems, that objective will be more important than ever.

*"When the well's dry, we know the worth of water."*

—Benjamin Franklin

## FOR FURTHER READING

Gregory J.M.; Wolock D.M. 1999. *General-circulation-model simulations of future snowpack in the Western United States*. Journal of the American Water Resources Association. 35(6): 1473–1484.

Jefferson, A.; Grant, G.F.; Lewis, S.L. [In press]. *A river runs underneath it: geological control of spring and channel systems and management implications, Cascade Range, Oregon*. In: Furniss, M.J.; Clifton, D.F.; Ronnenberg, K.L., eds. *Advancing the fundamental sciences: proceedings of the forest service national earth sciences conference*. PNW-GTR-689. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

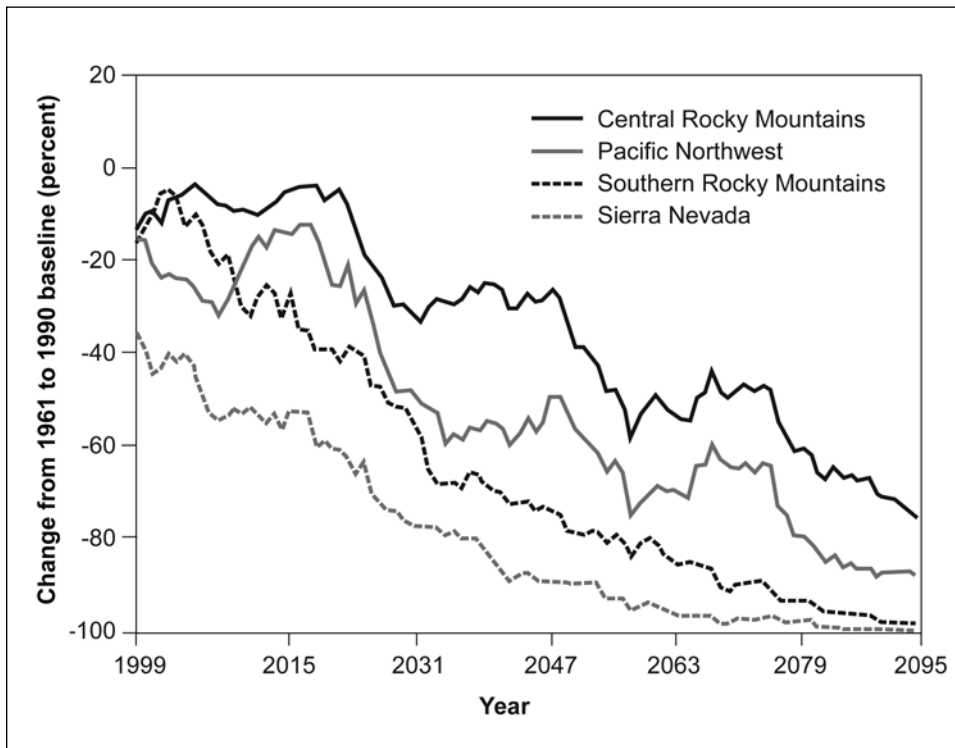
Jefferson, A.; Grant, G.F.; Rose, T. 2006. *Influence of volcanic history on groundwater patterns on the west slope of the Oregon High Cascades*. Water Resources Research. 42: W12411, doi:10.1029/2005WR004812.

Tague, C.; Farrell, M.; Grant, G.; Lewis, S.; Rey, S. [In press]. *Hydrogeologic controls on summer stream temperatures in the McKenzie River basin, Oregon*. Hydrologic Processes.

Tague, C.; Grant, G.E.; 2004. *A geological framework for interpreting the low flow regimes of Cascade streams, Willamette River Basin, Oregon*. Water Resources Research. 40: W04303, doi:10.1029/2003WR002629.

Tague, C.; Grant, G.E. [In review]. *Groundwater dynamics mediate low flow response to global warming*. Proceedings of the National Academy of Sciences.

Tague, C.; Grant, G.; Farrell, M.; Choate, J.; Jefferson, A. [In press]. *Deep groundwater mediates streamflow response to climate warming in the Oregon Cascades*. Climatic Change.



Climate change is expected to sharply curtail the volume of water available for ecosystems, agriculture, drinking water, and recreation.



Clean cold groundwater will be an increasingly valuable resource under a warmer climate.

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GORDON GRANT is a research hydrologist with the U.S. Forest Service, Pacific Northwest Research Station. Grant is based in Corvallis, Oregon, and also is a Professor (courtesy) in the Departments of Geosciences and Forest Science at Oregon State University. He earned a Ph.D. from Johns Hopkins University in 1986, following a 10-year career as a whitewater river guide. His research focuses on the geomorphic response of rivers to changes in streamflow and sediment

transport owing to land use, dams and dam removal, and climatic variation. This work includes extended collaborations with research groups in Japan, China, and Italy. Grant is a former deputy editor and current associate editor for the journal *Water Resources Research*.

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