

Science

FINDINGS

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“Science affects the way we think together.”

Lewis Thomas

Flows of the Future—How Will Climate Change Affect Streamflows in the Pacific Northwest?



Chris Carlson

Groundwater gushes from a spring in the Deschutes National Forest, feeding into the Metolius River. Almost half the water in the Pacific Northwest originates on national forests.

“When you put your hand in a flowing stream, you touch the last that has gone before and the first of what is still to come.”

—Leonardo da Vinci

West of the Cascade Range, winters are characterized by overcast, rainy days. In most years, ample rainfall in the valleys and snow at higher elevations are sufficient to quench the region's thirst during the dry summer months. In the rain shadow to the east of the Cascades, lower annual precipitation results in scarcer summer

water supplies, making it more challenging to meet the needs of fish, wildlife, farmers and ranchers, recreationists, municipalities, and other users.

Climate change is projected to alter the winter precipitation patterns in the Pacific Northwest and increase summer evaporation rates. This will affect the availability of water throughout the region. “You can make a pretty good argument that a lot of climate change is about a change in water: where it is and where it will be, and what form it will take when it falls,” says Gordon Grant, research hydrologist with the U.S. Forest Service Pacific Northwest

IN SUMMARY

Much of the water supply in the Pacific Northwest originates in national forests. It sustains the region's aquatic ecosystems, agriculture, hydroelectric power, and community water supplies.

Understanding how climate change will affect water supply is one of the most pressing issues of our time. Substantial changes are projected in the types of precipitation (rain vs. snow) that will fall in the region, as are smaller, but potentially important, changes in the total annual precipitation. Combined with earlier snowmelt, these changes could cause decreased summer streamflows, and some high-elevation streams may dry up.

These are the general projections, but each watershed has geological characteristics that will influence its response to changes in the type, timing, and amount of precipitation. Land managers want to know how specific watersheds are likely to respond, so scientists at the Pacific Northwest Research Station developed streamflow sensitivity maps for Oregon and Washington. Land managers across federal, state, and local governments; tribes; and private landowners now can see which watersheds have a higher risk of flooding in the future and which may be more sensitive to summer drought. With this information, land managers can develop tailored management plans for specific watersheds to adapt to the effects of climate change on streamflow.

(PNW) Research Station. “Water pervades much of what we think about when we worry about climate because climate change is hydrologic change.”

A change in winter precipitation patterns will have a direct impact on streamflow. “The snowpack in the Cascades is vulnerable to climate change because much of it falls in areas that are at or near the freezing point, so a couple of degrees of warming will cause more precipitation to fall as rain, and earlier melt of the snow that does fall,” explains Brian Staab, regional hydrologist for the U.S. Forest Service Pacific Northwest Region. He continues: “This change from snowfall to rain has the potential to cause increased winter flooding in high-elevation streams. And the snow that does fall won’t stick around as long.”

Earlier snowmelt means lower flows later in the summer for high-elevation streams. This may stress water supplies downstream and affect salmon and other fish, some of which are already threatened or endangered.

Since 2012, the Forest Service has required national forests to address climate change as they update their forest management plans. Forest staff often turn to a regional climate change toolbox, consisting of products developed by the Forest Service and other partners, to help them manage climate-related risk in their area and develop plans that build resiliency into the landscape and infrastructure. The toolbox includes several products that address changes in streamflow, but they have some limitations, particularly in how they

KEY FINDINGS	
• Sensitivity maps based on historical climate and streamflow and underlying geology are a new tool that can be used in Oregon and Washington to evaluate and identify changes in peak and low streamflows owing to climate warming.	
• A warmer climate won’t uniformly affect streamflows. Streamflows are strongly controlled by both the precipitation regime (the amount and timing of rain vs. snow) and underlying geology that together dictate recharge and discharge of water (deep groundwater vs. shallow runoff).	
• While the watersheds in Oregon and Washington that provide most of the summertime streamflow will continue to have water as the climate warms, some of their streams will be sensitive to reduced streamflow as a result of climate change.	

address the routing of water from the landscape to streams and rivers.

“There are strong geologic controls on streamflow regimes that aren’t captured in some of the existing hydrologic models commonly used in regional-scale climate change

research,” Staab says. “Consequently, using these models alone to characterize summer flows in groundwater-dominated streams and rivers can lead to sizable errors. This is problematic because we have a lot of those types of streams in our region.”

UNEARTHING THE RELATIONSHIP BETWEEN GEOLOGY AND STREAMFLOW

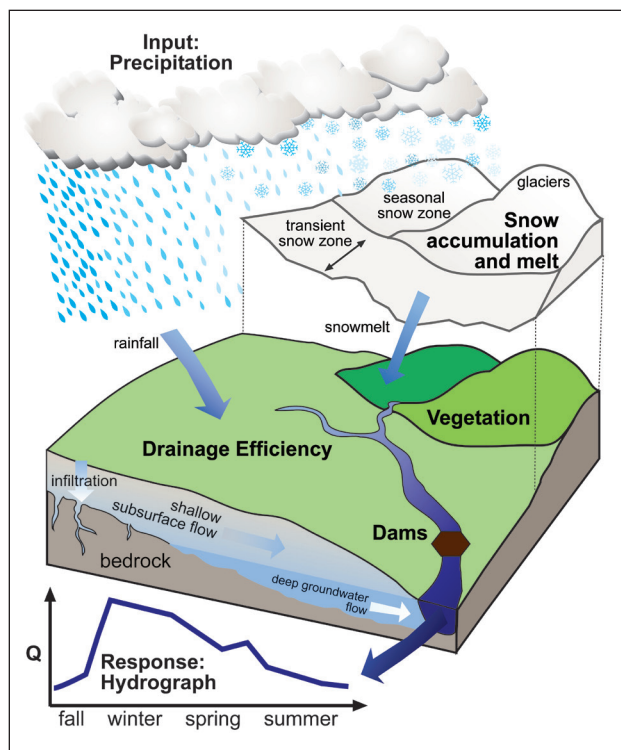
The underlying geology of the land influences how quickly water seeps into the ground and how quickly it is discharged to a stream. Volcanic eruptions

over millennia have greatly influenced the geology of the region—from vast lava flows, to columnar basalt walls, to ash and pumice deposits. Glaciers have also left their marks, as have the Missoula floods that scoured the Columbia Gorge and deposited rich silt from Montana throughout the Willamette Valley. Mix in the more mundane yet persistent forces of erosion and weathering, and it quickly becomes apparent that the geology of the region is varied.

“Along with understanding the form that precipitation will take in the future, we need to understand how water moves through the landscape, in particular, how it relates to the geology,” Grant explains.

The regionwide hydrologic models currently used to project streamflow don’t fully account for geology’s effects upon water’s movement through the landscape. When these types of models are coupled with a global climate model, which projects the temperature and amount of precipitation a region might receive in the future, the volume and timing of streamflow might be less accurate during

Tague and Grant 2009



Climate influences streamflow through the amount, type, and timing of precipitation. Streamflow also is regulated by drainage efficiency—which is strongly controlled by geology and topography. Stream volume is influenced by rate of evaporation, vegetation, and the amount of water diverted or stored for human uses.

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Rhonda Mazza, editor; rmazza@fs.fed.us
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the winter months when streams are prone to flooding or during the summer when they are prone to drying out. The models can underestimate the streamflow fed primarily by underground aquifers rather than by surface runoff or snowmelt. “The subsurface is cryptic,” says Grant. “Once the water enters the ground, it’s hard to know where it goes.”

In these top-down models, “the modelers were thinking of the landscape as a single unit and not getting into the fine details of the different types of rocks and aquifers across the region,” explains Mohammad Safeeq, now an assistant research scientist and adjunct professor at the University of California, Merced. While Safeeq was a postdoctoral research associate at Oregon State University, he worked with Grant to develop two different models that tested the effect of geology and soil type upon streamflow under drought and flood scenarios and were the basis for the stream sensitivity maps developed for Oregon and Washington.

Rather than starting with a climate model and feeding it into a hydrological model, as had been done in previous studies, Safeeq explains that Grant and he took a bottom-up approach: “We took historical streamflow and worked our way up. And the approach itself is very unique because it hasn’t been applied in many places.”

To model streamflow sensitivities during drought, they used daily average streamflow data for 227 watersheds in Oregon and Washington collected by the U.S. Geological Survey and the Oregon Department of Water Resources. Some of the data date back to 1905. Other datasets included soil permeability values from the Digital General Soil Map of the United States, which was developed by the National Cooperative Soil Survey and the National Hydrography Dataset for the drainage network of the streams and rivers within Oregon and Washington.

One of the challenges in creating this streamflow drought model, says Grant, was representing the effects of climate and geology in a mathematical relationship. “We took climate and geology, and Safeeq put them together in a way that both datasets were captured as a way of predicting where water would be if you change climate.”

The final model was validated against the recorded streamflows of 217 watersheds during July, August, and September, and through their efforts, they opened the subsurface “black box” just a bit. Not only was the model able to generate sensitivity maps of streamflows for Oregon and Washington, but it also showed which streams are fed by deep-groundwater dominated systems and which are fed by surface-flow-dominated systems.



Laura Hempel

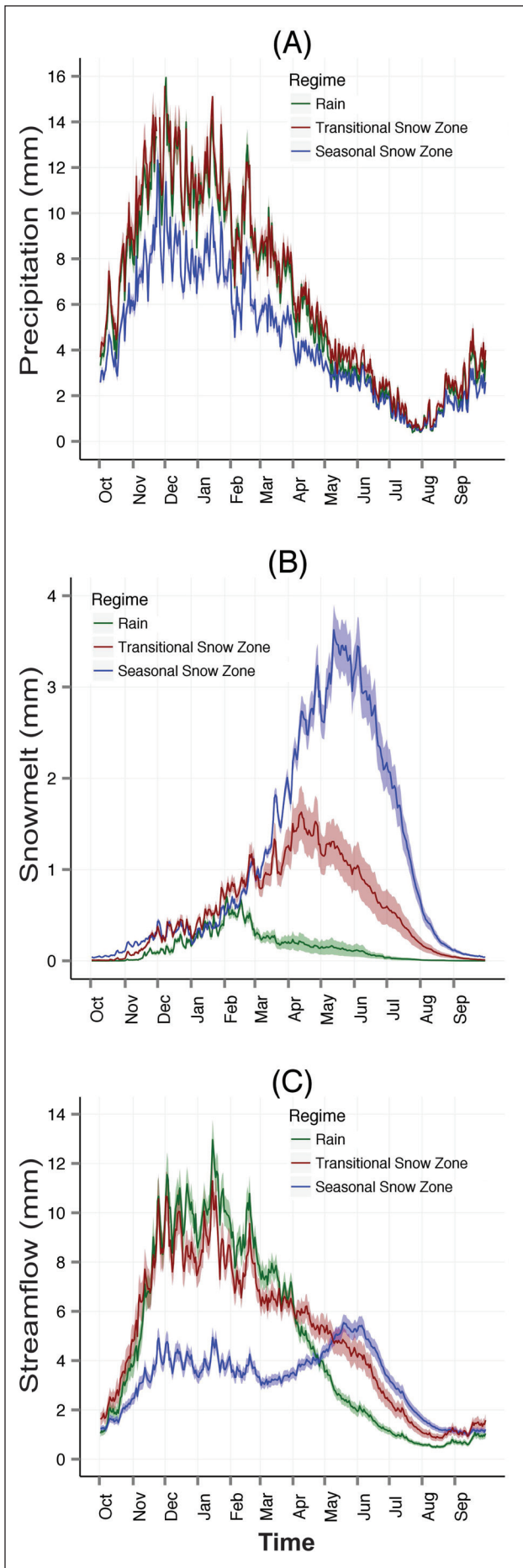
Winter flow (above) and summer flow (below) in Boulder Creek, a surface-flow-dominated tributary to the McKenzie River, Oregon.



Laura Hempel

“Creating these models illuminated things we didn’t fully know about the behavior of streamflow,” Grant says. “One thing that jumped out in the sensitivity analysis is that different places can be sensitive for different reasons, and the sensitivity is not just in response to one variable but a mix of variables.” For example, streamflows in the northern Washington Cascades had the greatest sensitivity in July, whereas streamflows in portions of the Oregon Cascades have a high sensitivity throughout the entire summer. This is because the streams in the Oregon Cascades are primarily fed by groundwater.

The scientists also developed a mathematical model that projects whether watersheds and their streams will experience flooding due to more winter precipitation and earlier snowmelt. Data included peak flow data from 1,000 gauged watersheds in Oregon and Washington, and the datasets covered 10 to 98 years. Variables for this model included the percentage of forest cover, soil conductivity (infiltration rates of water through the soil), and the amount and annual variability of snow water equivalent (the amount of water held in the snowpack). Once Safeeq identified the variables that influenced peak flows, he ran



the model to predict how streams would respond to future climate conditions in the 2020s, 2040s, and 2080s. The results revealed that large areas of the Pacific Northwest, particularly in the Cascades, Olympics, Blue Mountains, and parts of the western edge of the Rocky Mountains, may experience floods that are perhaps 30 to 40 percent larger in the future.

“Building models that are applicable at the scale of the region is something fairly new in the scheme of things, and this was something remarkable that Safaeq brought to this project,” Grant says.

PREPARING FOR THE FUTURE

With these models, resource managers can now play “what-if” games, explains Safaeq. For example, they can ask, what will happen in the future if the snow melts one week earlier? Where will water be limited during the summer? Or conversely, where will streamflows likely be higher, leading to flooding?

“When talking to stakeholders about our work, I found that people can relate to our modeling approach,” Safaeq adds. “They can look at the climate in their headwaters, look at the geology, and put these pieces together to see how their watershed will react to climate change. I think it gives them a much better understanding of how the system is functioning now, and how it might function in the future.”

The Blue Mountains Adaptation Partnership used these models as part of the climate change vulnerability assessments and adaptation strategies prepared for the Malheur, Wallowa-Whitman, and Umatilla National Forests. Similar work is underway through the South Central Oregon Adaptation Partnership, which covers the Deschutes, Ochoco, and Fremont-Winema National Forests. These adaptation partnerships, led by the Forest Service and which include other agencies and universities, develop vulnerability assessments and adaptation plans based on the conditions identified in the assessments. Resource managers have the lead on developing adaptation options, and scientists ensure that scientific documentation supports those options. In the Blue Mountains and South Central Oregon Adaptation Partnerships, the maps of streamflow sensitivity and flood potential are being integrated with other spatial analyses of key resources in national forests.

As an example, Staab explains that the hydrologic team, comprising Forest Service researchers and regional office and national forest staff, identified areas where both significant increases in flood magnitudes are likely and where roads and other infrastructure are vulnerable because they are either near streams or have undersized culverts. Other work focused on identifying areas where potentially large changes in summer streamflows intersect with important consumptive uses of water (e.g., drinking water) on and off the forest. Integrating the regional climate products with local forest datasets, enabled the team to better understand how and where these resources are most vulnerable to climate change.

A separate team, composed of researchers and forest and regional biologists, combined the sensitivity maps with local fish distribution datasets and information about the existing status of these populations and their habitats to determine if the predicted changes in streamflow and stream temperatures would negatively affect the populations. If so, the team identified strategies for helping the fish populations adapt.

“For resource managers to implement effective climate adaptation strategies, local context is needed about the specific resources that might be affected, their locations, and the characteristics that might make them more or less climate

Time series of historical daily (a) precipitation, (b) snowmelt, and (c) streamflow averaged over the length of records for low-flow watersheds analyzed in the rain, transitional snow, and seasonal snow zones. Note the difference in the precipitation and streamflow regimes due to differences in the amount and timing of snowmelt.

sensitive,” explains Staab. “This approach also helps answer the question of, ‘So what can we do about these potential impacts?’ If we’ve got a lot of roads and other infrastructure near streams in places where we expect there to be significant changes and that infrastructure is particularly important, can we move or upgrade it or take other actions to make it more resilient? On the biological side, we may not be able to do anything directly to alter the potential climate impacts, but there’s a lot we can do to reduce other stressors on those fishes, like reduce habitat fragmentation and degradation.”

Management activities, such as stream restoration for example, can sometimes increase the connectivity of streams to their historical floodplains and provide additional storage for floodwaters. Water conservation measures or development of backup water supplies can be prioritized for areas where summer water stress is likely to increase. In addition, restoration of streams and streamside forests can offset increases in water temperatures that can result from decreased summer streamflows and other effects of climate change.

LAND MANAGEMENT IMPLICATIONS

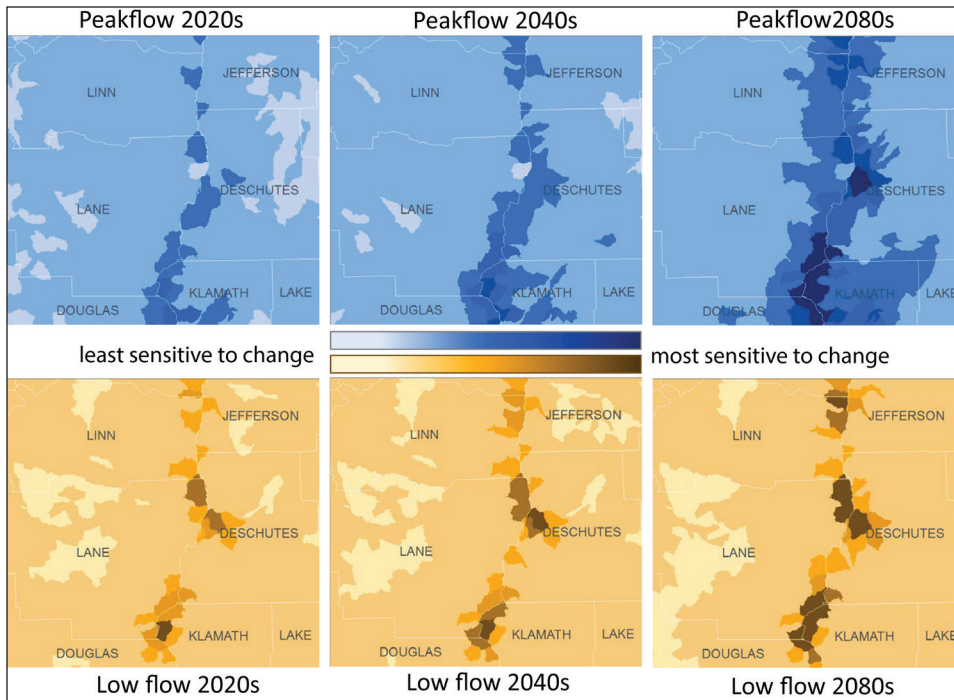
- “Wall-to-wall” sensitivity maps for Oregon and Washington provide a framework for understanding which subregions, e.g., the Cascades, Olympics, Willamette Valley, Coast Range, etc., are likely to be hardest hit by either water shortages or intensified flooding in the future.
- Planning and implementing future management activities in national forests throughout the Pacific Northwest can now be informed by more accurate predictions of future streamflows.
- Resource managers can use this information to help identify where to upgrade, relocate, or remove roads and other infrastructure, invest in watershed restoration, alter dam operations, and implement other management activities.

Even before the journal articles describing Grant and Safeeq’s research were published, land managers were asking for information that would help them better understand future streamflows. “The need for this information is what drove forward the science of understanding future streamflow,” Grant says. Though the current use of these models is on federal

land, other agencies and land managers can use these models for their respective watersheds and regions.

“For many of us, clean water is so plentiful and readily available that we rarely, if ever, pause to consider what life would be like without it.”

—Marcus Samuelsson, Chef



Sample peak and low-flow sensitivity maps demonstrating potential change from historical conditions under future climate scenarios for the 2020s, 2040s, and 2080s. The portion of Oregon counties shown above straddle the Cascade Range.

FOR FURTHER READING

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WRITER’S PROFILE

Andrea Watts is a Seattle-based freelance science writer. She can be reached at andwatts@live.com and a portfolio of her published work is available at <http://wattswritings.wordpress.com>.



U.S. Department of Agriculture
Pacific Northwest Research Station
1220 SW Third Avenue
P.O. Box 3890
Portland, OR 97208-3890

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GORDON GRANT is a research hydrologist with the Pacific Northwest Research Station. His research focuses at the intersection among geology, geomorphology, and hydrology and looks at causes and consequences of changes in flow and sediment regimes in rivers.

Grant can be reached at:

USDA Forest Service
Pacific Northwest Research Station
3200 SW Jefferson Way
Corvallis, Oregon 97331
Phone: (541) 750-7328
E-mail: ggrant@fs.fed.us



MOHAMMAD SAFEEQ is an assistant research scientist and adjunct professor with University of California, Merced. His research focuses on the complex interactions of water and climate, vegetation, soil, and geology. While at Oregon State University, he worked with Gordon Grant to develop hydrology models for the Pacific Northwest.

Safeeq can be reached at:

University of California, Merced
5200 N Lake Road
Merced, CA 95343
Phone: (209) 228-2459
E-mail: msafeeq@ucmerced.edu

COLLABORATORS

Brian Staab, USDA Forest Service Pacific Northwest Region

Sarah Lewis, Oregon State University

Marc Kramer, Washington State University Vancouver

Christina (Naomi) Tague, University of California, Santa Barbara