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Science

F I N D I N G S

issue forty-nine / december 2002

“Science affects the way we think together.”

Lewis Thomas

GEOLOGY AS DESTINY: COLD WATERS RUN DEEP IN WESTERN OREGON

“Geology plays an extremely important and previously unappreciated role in determining flow regimes.”

Gordon Grant

For most of the year, it just doesn't seem like water is a problem in western Oregon. It's a fixture, for better or for worse. Few people, including residents, fully appreciate that the warm, dry sunny weather of each summer actually constitutes a pretty reliable drought, with serious implications for water management.

A rapid scan of any regional newspaper will uncover the critical and growing importance of water availability and allocation in the Pacific Northwest. The state of the year-round supply of water relates not just to the allocation question of who gets what when, but to climate change, dam relicensing, and whole watershed management.

In western Oregon, the Forest Service sits squarely in the midst of water management issues, simply because of the extent and location of federal lands: much of the late summer flow of the region's largest river, the Willamette, originates in the federal-dominated McKenzie drainage. With steady immigration into the region likely to continue, allocation and supply of water are potentially long term and growing problems facing the agency.

But a closer look reveals that the state has been blessed with a huge geological backup plan for water supply.

“Contrary to popular belief, most summer flow out of the high Cascades is not due to snowmelt. Instead, the high Cascades form a vast hydrologic sponge that stores many decades worth of water as deep groundwater,” says Gordon Grant. “Recent analysis of streamflow patterns, ranging in scale from individual mountain streams to larger rivers such as the McKenzie, has revealed that geology plays an extremely important and previously unappreciated role in determining flow regimes.”

By relating patterns of streamflow to underlying geology, particularly rock age and drainage density, the extent of geologic control can be assessed. Knowing the geology provides a framework that can be used to predict streamflow behavior under current and future climate and land use change scenarios. In fact, not taking geology into account in managing regional water resources has been a long-standing mistake, according to Grant, research hydrologist with the PNW Research Station in Corvallis, Oregon.

In a region dominated by high winter and low summer rainfall, it would seem peak flows and low flows of rivers would simply and reliably reflect this seasonal pattern. Grant's first clue to Oregon's grand geological water plan was that a number of rivers originating in the high Cascades barely even register the dry season in their hydrographs, or flow charts.

I N S U M M A R Y

The summer of 2001 brought the second-worst drought on record in Oregon, resulting in historically low streamflows and reservoir levels, stressed aquatic ecosystems, and even dramatic confrontations between irrigators and federal resource agencies in the Klamath basin. These events underscore the critical and growing importance of water availability and allocation in the Pacific Northwest.

Yet at the scale of large river basins, such as the Willamette River in western Oregon, we have an imperfect picture of how much water of what quality is available where and when. Having accurate information on the sources of water within a watershed, and how those sources vary through time in response to both climatic fluctuations and human activities, is vital to evaluating effects of forest land use, dams, diversions, agricultural and municipal uses, and restoring instream flows.

Credit: USGS



BELKNAP CRATER LITTLE BELKNAP SHIELD MT. WASHINGTON MT. JEFFERSON BALD PETER DUGOUT BUTTE GREEN RIDGE BLACK BUTTE BLACK CRATER

A Panorama of the high Cascade region from McKenzie Pass, showing a young (1500 year old) blocky lava flow in the foreground, with older vents and dissected volcanoes in the background. Note the absence of streams or evidence of stream erosion, indicating that virtually all precipitation becomes deep groundwater, emerging as springs lower in the watershed.

THE GEOLOGIC DIVIDE

Two distinct geologic provinces—the western and the high Cascades—form the contributing slopes of the Willamette River Basin, the primary drainage system of the western slopes of Oregon’s Cascade Mountains. The western Cascades are dominated by older, deeply weathered, roughly layered volcanic rocks, with steep, highly dissected landscapes reflecting significant erosion. The region is typically well drained by a dense network of streams fed from surface and shallow subsurface runoff.

The high Cascades are much younger geologically, higher in elevation but lower in relief, and are constructed of voluminous lava flows on top of which are perched large active or quiescent volcanoes. Not enough time has elapsed since the eruptive episodes for this landscape to be significantly altered by erosion. In areas of the most recent volcanic activity, such as the McKenzie Pass area, blocky basalt flows dominate the view. Soil development is poor. The surface of these flows is highly permeable to water—there are not a lot of lakes or streams in these areas, for example—and permeability remains high throughout the deeper volcanic layers, until impermeable layers are reached at depth, where the water collects and flows as groundwater under the influence of

gravity. The two separate flow regimes organize the geomorphology of streams.

The drainage system under each of these provinces also differs, despite the fact that they both receive comparably high precipitation during the winter. In the western Cascades the drainage delivers water into larger streams quite rapidly. In the winter, the large rivers of the Willamette basin receive most of their runoff from the western Cascades, owing to both rain and rain on top of melting snow. A lot of rain routinely indicates high rivers or flooding to come, particularly when it falls on top of an extensive snowpack.

In the high Cascades, the drainage system is less organized. This water emerges from springs along both the east and west slopes of the Cascade crest, fed by very large regional aquifers flowing through the volcanic rock. Even after winter storms, the flow in these rivers does not rise appreciably, in part because much of the precipitation falls as snow, but also because most of it is stored as groundwater. In the summer, when flows are lowest in most rivers, these large groundwater reserves mean that the high Cascade rivers flow in much the same way that they do in winter.

“In fact, it is starting to appear that high Cascades water may flow from what amounts to a huge reservoir, although not

in the sense of one giant underground lake,” Grant explains. “There’s a key time element in there too: the water in these rivers today fell as precipitation as long as several decades ago. The result is that even during drought years, creeks and rivers fed by groundwater will flow at virtually constant discharges.”

If he were a planner, Grant says, he’d be thinking a lot about this.

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208
(503) 808-2137

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Science Findings is online at:

<http://www.fs.fed.us/pnw>

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United States
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THE ALLOCATION CHALLENGE

The recent findings about the two different geologic regimes will allow planners to understand the dominant controls and streamflow, in both small and larger streams. Grant and his colleague, Dr. Christina Tague of the Department of Geography at San Diego State University, have developed simple streamflow models that can be used to gain a reasonable prediction of future summer streamflow from early summer/spring streamflow measurements. Using their methods allows a view of future flow even for streams without the pre-existing long-term gauge records upon which these findings are based.

“In Oregon, competition for water in drought years between agricultural, urban, and habitat conservation has become a controversial issue and understanding both the pattern of flow regime and sources of water in larger streams is becoming increasingly important,” Grant says.

The research clearly suggests that drought effects in western Oregon can be quite variable depending on which rivers are affected. Particularly in drought years, such as 2001, managing water resources through the late summer is a daunting challenge. Knowing that a significant proportion of the flow comes from high Cascades groundwater opens up a number of management options.

“For example, the impact of drought on a particular aquatic species may depend on the flow regime of a range of different streams—streams fed by both systems—that compose the potential habitat of that species,” he explains. “Analysis and extrapolation of low flow behavior can provide insight into the degree of water limitation and where impacts will be most severe relative to the distribution of fish habitat.”

Aquatic habitat as an allocation priority has another critical variable affected by these findings: water temperature. It has been established that temperature of water is much lower for deep groundwater versus surface water sources. For example, the McKenzie River, dominated as it is by high Cascade sources of late summer stream flow, exhibits lower water tempera-

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KEY FINDINGS

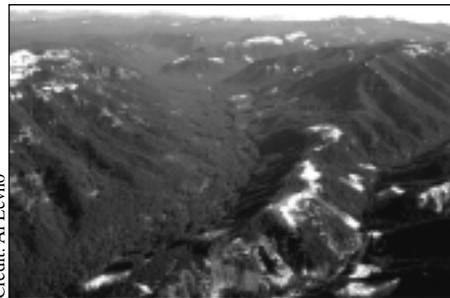
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- Strong seasonal variations in the amount and quality of water delivered by tributaries to the Willamette River occur along an east-west gradient defined by the underlying geology and topography. In the winter, most water comes from the western Cascades, while during the summer’s low flows, most water comes from the high Cascades.

- The deep groundwater stored in the high Cascades emerges as springs fed by very large regional aquifers flowing through the young volcanic rock. This water keeps flows steady even during drought years, and may have fallen as precipitation several decades ago.

- The correspondence between geologic controls and land ownership patterns in the Cascades results in a very high proportion of streamflow in the Willamette originating on national forest lands.

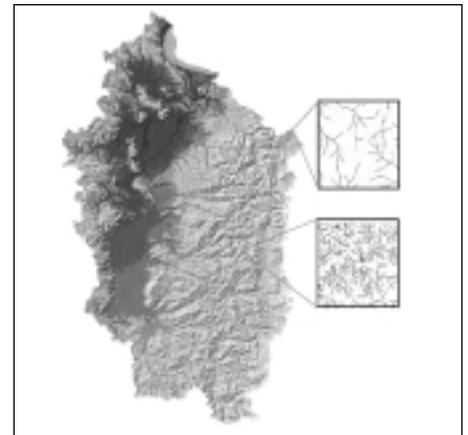
- The hydrologic and geologic context is crucial for planning water budgets, establishing stream temperature standards, and interpreting effects of land use and climate change on water resources of western Oregon.



Credit: Al Levino

▲ *Aerial photo of the older, western Cascades, which are characterized by deep, stream-cut valleys and ridges composed of older volcanic rocks millions to tens of millions of years old. Here most precipitation travels only a short distance through shallow subsurface paths before emerging as streamflow.*

tures than some neighboring basins, whose water derives from the western Cascades system. Water temperature is of course critical for some species such as anadromous salmon, which spend part of their rearing years in summer streams. This results in some counterintuitive behavior—the temperature of the McKenzie is actually colder during droughts, as proportionately more of the water is coming from cold high Cascade springs (as opposed to warmer western Cascade tributaries) than when the flows are higher.



▲ *Shaded relief map of the high and western Cascade region of Oregon, showing the contrast in drainage density (number of streams per unit area), with very low densities in the high Cascade and much greater densities in the western Cascades.*

The groundwater out of the high Cascades system is also distinguished by its high quality, with low levels of dissolved solids, Grant says. The dozen or so places in the Cascades where “gushers”—strong springs—emerge are known for the clarity and sapphire blue or emerald green of their waters.

WRITERS' PROFILE

Sally Duncan is a science communications consultant and writer specializing in forest resource issues. She lives in Corvallis, Oregon, and is a doctoral candidate in environmental sciences at Oregon State University.

DAM THE CONSEQUENCES

It has long been believed that the numerous dams on river systems in western Oregon are largely responsible for keeping late summer flows steady. Major flood-control reservoirs were constructed on many of the tributaries of the Willamette River system from 1940 to 1970, many specifically for flood control. Most reservoirs are located in the western Cascades, but several are in the high Cascades province or at the boundary between the two provinces.

“The common regulating schedule for the flood-control reservoirs is to begin draw-down—the release of additional water from reservoirs—during the summer and early fall and continue until November when lowest pool volume is reached,” Grant explains. “The reservoirs then store flood flows during the winter months and are refilled during the spring to reach full pool volume by early summer, and start the whole process again.”

Although it is true that operation of federal flood-control reservoirs has “the single greatest anthropogenic effect on flow regimes in the Willamette,” nonetheless in the later summer water of any significant volume comes from the deep groundwater systems of the high Cascades.

A comparison of flow curves, for a point on the McKenzie River below three dams, shows that low flows increased by 47 percent after construction of the dams, and high flows also increased slightly, by 8 percent. Major effect on peak flows in general, however, was to reduce the size of flood peaks.

LAND USE, WATER, AND TIME

Recognizing the importance of geomorphic controls on streamflow, Grant says, is the first step toward placing human alterations to hydrology in their proper context. Human activities such as reservoir management, irrigation, shifting land use, and urbanization have modified flow regimes of rivers and landscapes at unprecedented rates. At the same time, almost no research has tracked the impacts and their consequences at scales of large watersheds and regions over decades to centuries.

 **LAND MANAGEMENT IMPLICATIONS** 

- Stream temperature during late summer, a key stressor of aquatic ecosystems, is strongly controlled by the source of water. Groundwater out of the high Cascades keeps stream waters cold, with effects on fish biology.

- Although most of the national forest lands producing late summer water from the high Cascades are in federal wilderness status, others are not, and receive no special management protection.

- Effects of national forest lands on water production must be viewed in context of other land use and water management activities taking place within the Willamette basin. Operation of federal flood-control reservoirs has the single greatest anthropogenic effect on flow regimes in the Willamette, dwarfing any effects of forest management.

“From a regional perspective, the effect of dam regulation is to impose a more high Cascade type of flow regime on regulated western Cascade streams. This is true both in terms of the hydrology and temperature regimes,” Grant says. “Release of cold water from thermally stratified reservoirs during the summer mimics the contribution of cold water from groundwater sources in the high Cascades.”

This addresses the question of the effects of propagating a colder and more uniform flow regime further downstream “The consequences of this are not well understood. Likely ‘winners’ in an ecological sense would be those organisms adapted to cold water, such as bull trout, while warmer water species, such as some types of salmon, might be negatively affected. In fact, to restore a more “natural” temperature regime, the Army Corps of Engineers is beginning to retrofit its dams with

temperature control structures that allow for water of different temperatures to be released (from different depths) thereby mimicking natural flows.

Grant’s findings are figuring prominently in management decisions affecting relicensing of hydroelectric dams on national forest lands. “On the Clackamas River, for example, national forest land managers are using these results to distinguish the effects of dams located in the upper river, where the high Cascades flow regime dominates, from those of the lower river, where the western Cascades regime dominates.” Similar findings are informing management and policy decisions affecting relicensing of dams on the Deschutes and North Umpqua Rivers.

What other man-made disturbances to natural flow regimes might be illuminated by this research?

“The result has been that our ability to transform river systems has far outdistanced our ability to understand the implications of those transformations,” he notes.

The effects of forestry activities on streamflow have been hotly debated in the region owing in part, Grant believes, to the equivocal results of more than 30 years of research into this question. “I believe that one reason for the sometimes contradictory results of research into effects of forest management on streamflow is the difference in the larger geomorphic context in which these studies occur,”

Grant says. The response to forest cutting and road construction is likely to be different in watersheds whose hydrologic regimes are dominated by rain events versus rain-on-snow events, for example, or by differences in permeability of underlying rocks and the system’s general drainage efficiency.

The implications for water supplies under climate change are considerable. Most climate change scenarios suggest that the Pacific Northwest will become both warmer and wetter in the coming century.

“These findings concerning different winter and summer water sources suggest that western Oregon is likely to be

substantially buffered from the effects of climate change on water availability,” Grant points out. “Even if warmer winters

reduce seasonal snowpacks, deep groundwater systems will be largely unaffected as long as precipitation is unchanged.”

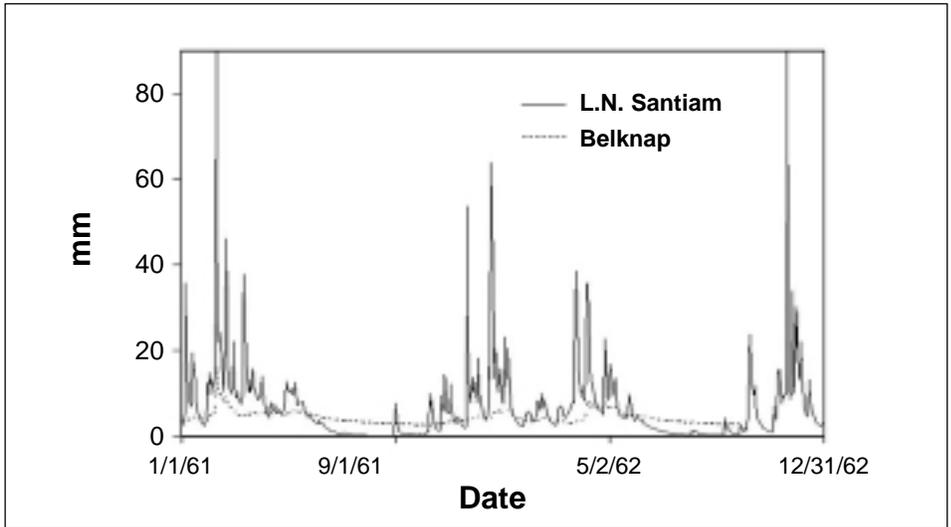
MUNICIPAL WATERS AND NATIONAL FORESTS

Meanwhile, closer to the moment, precipitation and water supplies are matters of immediate import, and the flow regimes of western Oregon rivers are key to their continuation. Under current trends, municipal demand for water in Oregon’s Willamette River basin will double by 2050. To meet this demand, many municipalities will have to develop new sources of water, placing them in direct competition with agriculture and other established uses, and also with increased demand for water to support ecological values such as fish habitat.

Grant points out that the correspondence between geologic controls and land ownership patterns in the Cascades results in a very high proportion of streamflow in the Willamette basin originating on national forest lands.

“In fact, prior to construction of dams and reservoirs on the Willamette tributaries, 60 percent of the late summer streamflow of the Willamette in Portland came from the McKenzie drainage, most of which is in Forest Service lands,” he says. “The current streamflow is modified during both winter and summer by large flood-control reservoirs, but forest lands remain the source of the water.”

This places the Forest Service in the position of playing a key role in numerous municipal water supplies in the west of the



▲ Comparison of 2 years (1961-1962) of U.S. Geological Survey streamflow data for two similarly-sized streams draining different geological provinces. The McKenzie River at Belknap is a high Cascade-dominated stream with extremely constant flow both summer and winter and only minor rises during winter storms. In contrast, the Little North Santiam is a western Cascade stream, with much more variable discharge, showing sharp fall and winter peak flows and extremely low flows during late summer.

state. National forest lands contribute most of the water in municipal water supplies in the Willamette basin. For the basin’s three largest municipal utilities—Eugene, Salem, and Portland—national forests are the largest single sources of surface water, providing 50 to 100 percent of the natural streamflow year round. For some of the basin’s other large communities, such as Corvallis, Albany, and Wilsonville,

national forests supply between 30 and 50 percent of the natural streamflow.

“This critical role of forest lands as sources of cold, clean water is underappreciated with many feeder spring systems unrecognized and unmeasured,” Grant says. “Those deep groundwater springs not in wilderness areas receive no special attention in terms of management for their protection.”

According to a 2000 analysis conducted by the Environmental Protection Agency and ECONorthwest on the Willamette River basin, there is sufficient surface water to meet the demand for the next 50 years, but many municipalities will have to develop additional points of water diversion from their rivers in order to meet future demand. Surface water supplies, the analysis concludes, may not be able to provide for all of the increased demand.

The deep groundwaters, feeding those summer low flows through the high Cascades drainage system, may just be lifesavers.

FOR FURTHER READING

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Note: The Oregon Headwaters Research Consortium partially funded the research discussed in this issue of *PNW Science Findings*.