PNW
Pacific Northwest Research Station

INSIDE

Science FINDINGS

issue sixty seven / october 2004

"Science affects the way we think together."

Lewis Thomas

FOLLOWING A RIVER WHEREVER IT GOES: BENEATH THE SURFACE OF MOUNTAIN STREAMS

"You could not step twice into the same rivers; for other waters are ever flowing on to you."

—Heraclitus of Ephesus

There is more to a mountain stream than meets the eye. Literally. The water that we see cascading by continually flows in and out of the stream channel. Anywhere the ground is permeable, some portion of the stream is flowing beneath and adjacent to the aboveground channel. In fact, stream water can flow more than ½ mile away from the main channel before reemerging further downstream.

Credit: Steve Wondzell

Ryan Ulrich (right) and Bryan McFadin, driving a shallow well at the edge of Lookout Creek, H.J. Andrews Experimental Forest. Large rocks and lack of road access make hyporheic studies difficult.

"In the case of many rivers and streams, what you see is not what you get," explains Steve Wondzell, research ecologist at the PNW Research Station in Olympia, Washington.

When the stream water seeps out of the channel, it mixes with water in the riparian aquifer, a subsurface reservoir of freshwater. This place where ground water meets stream water is called the hyporheic zone. Wondzell defines it simply as: "…just a place in the subsurface that has stream water." And although he acknowledges that this isn't a particularly exciting definition, he is fascinated by what goes on in these "underground rivers."

Wondzell uses tracer dyes, computer models, and hundreds of streamside wells to investigate the unseen portion of mountain streams.

Over the last few decades, research into the hyporheic zone has shown that the underground portions of streams are critical to the health of watersheds. The hyporheic zone plays host to many organisms, including some highly specialized insects. It is habitat for the earliest life stages of salmon. It filters contaminants out of the water and moderates stream temperature. And perhaps most importantly, the environment within a hyporheic zone is ideal habitat for the bacteria and fungi that cycle nutrients back into the stream. These nutrients are the foundation of complex aquatic food webs.

IN SUMMARY

The flow of a mountain stream is difficult to follow, especially when it weaves in and out of the channel, flowing through streambanks and seeping through the streambed. Flowing belowground, the stream water mixes with ground water in the riparian aquifer before reemerging in the channel, sometime later and somewhere further downstream. Underground, the water undergoes filtration, nutrient cycling, and temperature moderation. In addition, the belowground environment, called the hyporheic zone, provides habitat for a diversity of aquatic organisms.

The hidden nature of the hyporheic zone has made it a difficult subject to study. Only recently have researchers begun to understand the aboveground influences on belowground flows. PNW Research Station studies in the western Cascades have shown how stream size and channel morphologic features affect the amount, distance, and duration of hyporheic flows.

As the ecological importance of the hyporheic zone becomes more widely recognized, there is increasing focus on the influence of management decisions on the hyporheic zone. Using lessons learned from the 1996 floods that impacted the H.J. Andrews Experimental Forest in western Oregon, scientists are gauging the effects of disturbance on the belowground portions of stream ecosystems. By extrapolating from flood disturbances to human influence, land managers will be better able to understand how management activities that simplify stream channels limit the exchange of stream water with the hyporheic zone and thereby alter stream nutrient cycles, temperature regimes, and the habitat available for hyporheic-dwelling organisms.

THE BEST OF BOTH WORLDS

"From the perspective of many aquatic organisms, the hyporheic zone is just a dark and well-protected extension of the stream," says Wondzell. "If you're an insect, it is a good place to keep from becoming fish food."

Aquatic insects can move through riparian aquifers while remaining bathed in oxygen-rich stream water, and depending on the size of the gravel, they can sometimes travel great distances from the stream. Wondzell shares a story of a colleague's research on the Flathead River in Montana where stonefly nymphs, the size of paperclips, were showing up in farmer's wells as much as about 2 miles from the river. "The adult stoneflies were well known, but no one had ever seen the nymphs before," he recalls. Apparently, the nymphs hang out in the hyporheic zone.

The hyporheic zone is a place of interactions, an ecotone. It is where two distinct environments—stream water and ground water—come together to form a gradient of in-betweens.

For example, within the hyporheic zone, you will find small crustaceans native to the deep aquifer. Free of eyes and pigment, this is as close to the light of day as these organisms will ever get. Distinct from these are the stream-type insects found in the hyporheic zone. They may spend much of their life cycle in the transition zone between streams and aquifers. In fact, many researchers use their presence to define the boundary between ground water and the hyporheic zone.

But it's not just bugs. Salmon also rely on this unique environment. Adults excavate the streambed with their tails to lay eggs. Buried beneath the gravel, the eggs are safe from the dangers of predators and swift currents. Moreover, the stream water flushes through the eggs, providing oxygen and controlling the incubation temperature.

"After hatching, the tiny larval salmon with their attached yolk sacs, called alevins, remain in the shallow portion of the hyporheic zone through the earliest stages of their lives. Here they can build strength and mass in relative safety while preparing for their trip to the ocean. Without the gravel for protection, they would be instant food," explains Wondzell.

KEY FINDINGS

- New methods that combined studies of visible stream features and computerized simulation models were developed that successfully quantified both the volume and residence time of hyporheic flow in stream networks.
- Within small headwater streams, pool-step sequences were the dominant morphological features driving the amount of subsurface flow. Changes in elevation across pool-step sequences created downwelling and upwelling zones where stream water entered and reemerged from the streambed.
- Within larger streams, the pool riffle sequences were the dominant features driving hyporheic exchange, but they often interacted with secondary channels and meander bends to create extensive hyporheic zones with long residence times.

SUBTERRANEAN NUTRIENT CYCLING

Just like you and me, streams have metabolisms. In mountain streams, much of the food web is fueled by leaves, twigs, and other organic matter dropping into the stream and percolating from the soil. The energy stored within the rotting debris sustains the life of the stream. Much of the most easily used nutrients rapidly leach from the leaves into the stream water. These dissolved compounds including organic carbon and nitrogen must be transformed into forms that can be used by algae and other plants.

"Biological transformations of nutrients require microbes, and in clear mountain streams they are usually attached to rock or wood surfaces as biofilms—the slippery slime on the rocks that can send you toward an unexpected swim," explains Wondzell.

As stream water rushes by, there is little opportunity for biofilms to capture and transform nutrients dissolved in the stream water. This is where the hyporheic zone becomes essential. When stream water seeps between the sand and gravel during its journey underground, it comes into intimate contact with the biofilms. And because the water is moving slowly, there are plenty of opportunities for the microbes to do their work.

"Return flows of hyporheic water can thus transport substantial amounts of nutrients back to the stream where it is available to algae and other primary producers," says Wondzell. "Because primary productivity in the western Cascade streams is typically nitrogen-limited, the cycling of nitrogen that occurs in the hyporheic zone of those cold, clear-flowing mountain streams may be crucial to supporting stream productivity."

To better understand the role of the hyporheic zone in cycling nutrients and purifying stream water, Wondzell is taking his studies

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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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USDA United States Department of Agriculture

Forest Service

out of the mountains. He and his colleagues recently began a study that spans western Oregon. The study is designed to compare hyporheic zones and their influence on the transformation and fate of nitrogen in streams from forested mountain areas to streams in agricultural and urban settings.

"The trick is to follow the nitrate being transported in the stream water, from the stream, through the hyporheic zone, and back into the stream. Nitrogen comes in two naturally occurring forms that differ only by their weight. The heavier of these is rare in nature, so it can be used to follow the movement of nitrogen through a stream ecosystem in much the same way that the tracer dyes are used to follow the flow of water through the hyporheic zone," explains Wondzell.

A DYNAMIC TEMPLATE

Back in 1989, Wondzell began studying the hyporheic zone of the Lookout Creek basin, located at the H.J. Andrews Experimental Forest, east of Eugene in the western Cascades of Oregon. "I spent so much time there that I could have jumped across the boulders with my eyes closed," recalls Wondzell. "For 6 years, everything stayed the same. There were seasonal fluctuations in the streamflow, but in general the system remained constant. And during my initial research, I viewed the valley floor and channel morphology as static."

Wondzell was working on the east coast during the winter of 1996. He didn't see the colossal flood that reshaped Lookout Creek.

"When I returned the next summer, I stuck my head through the alders to see a spectacular change. Rocks and logs I knew by name were gone and new ones were strewn throughout the creek," he recalls. Not since 1964 had there been a flood that so dramatically altered the landscape of the H.J. Andrews. "It was a tremendous disturbance to my image of the system. It showed that mountain streams are dynamic."

Major floods and related debris flows are the primary events shaping channel morphology in many steep mountain streams. Floods like those in 1996 can leave an imprint of logs and sediment that may persist for a century or longer. Questions remained, however, with regard to the influence of flooding on the belowground portion of mountain streams.

Wondzell had collected a breadth of data before the flood and now found himself in a unique position for gauging the flood-induced changes on subsurface flow.

Just as everything he was accustomed to aboveground had been shuffled, so had the hyporheic flows. "The changes we observed in the hyporheic zone are likely to have large and lasting effects on the stream ecosystem," he explains. "After the flood, the hyporheic zone had gone missing in many areas. The flood waters, carrying logs and boulders, had breached logjams, scoured and reworked the streambed, and dried up secondary channels. But the flood also formed new logjams and deposited fresh gravel, eroded new channels, and diverted flows to form new secondary channels."

"It is speculative, but it is probably a zero sum game," explains Wondzell, "just as some flow paths were destroyed by the flood, others were created." Of course, recolonization by insects and other biota, in addition to regrowth of streamside vegetation will be necessary before it is fully recovered from the flood.

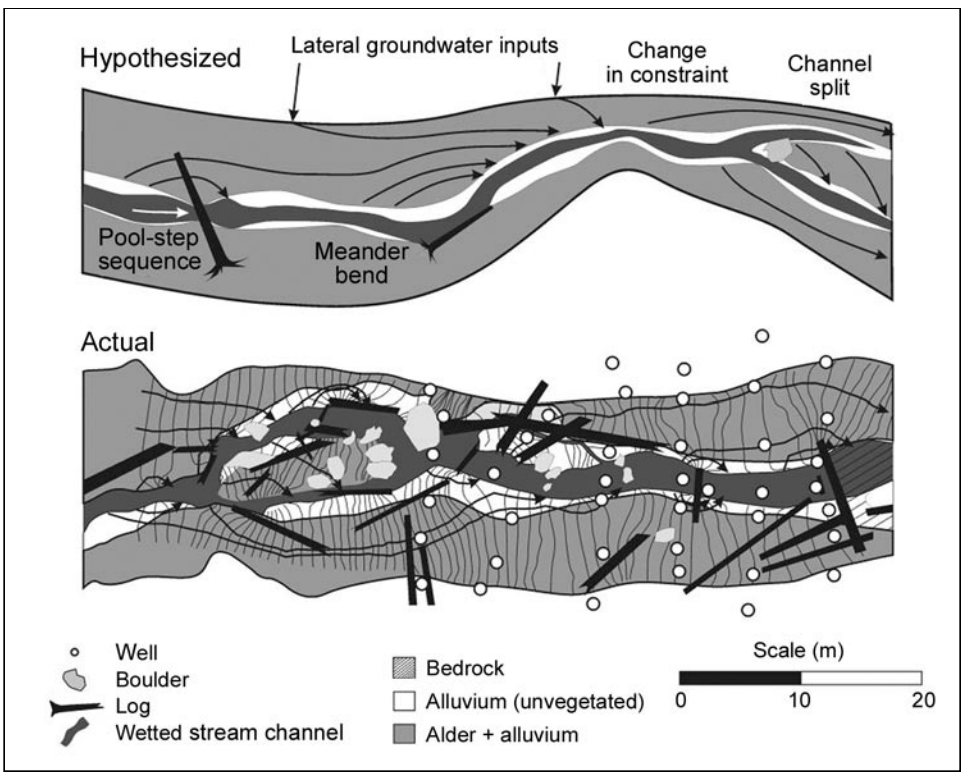
WHAT SENDS WATER UNDERGROUND?

The size of a mountain stream and the shape of its channel—whether it is straight or meandering, single-thread or braided, steep or flat, free of debris or full of logjams—greatly influences the size and function of the hyporheic zone. Such factors, in addition to the porosity of the streambed, will dictate whether the depth and width of hyporheic flows will be measured in inches, feet, or miles.

To address the relative effects of these features, Wondzell and his colleagues installed scores of wells, distributed throughout the flood plains of four unique sections of stream.

They then injected a specialized dye into the stream. The chemical composition of the dye allows it to be detected in wells at just a few parts per billion. By measuring the dye's concentration, they deduced the proportion of flow that was sent underground.

"In small streams, pool-step sequences were the dominant feature driving the exchange of stream water into and out of the hyporheic zone," says Wondzell. "Often, these



Hypothesized (top) and actual (bottom) groundwater and hyporheic flow paths in a small headwater stream. Research shows that important drivers of hyporheic exchange flows are pool-step sequences, meander bends around point bars, changes in channel constraint, and channel splits around island gravel bars.

LAND MANAGEMENT IMPLICATIONS

- The hyporheic zone is an important type of stream habitat—for the juvenile stages of many stream-dwelling insects and for eggs and the earliest life-history stages of salmon in streambed gravels.
- The hyporheic zone is sensitive to land management activities. Channel simplification through channelization and loss of large wood all lead to the loss of those morphologic features that drive hyporheic exchange flows.
- Reduction in hyporheic flows can change stream temperature regimes, reduce primary productivity through its effect on nutrient cycling, affect spawning success of salmonids, and reduce the amount of hyporheic habitat available for aquatic insects.

are the result of logs falling into the stream and trapping gravel. Water downwells into the gravel behind the log, flows under and around the log, and then upwells back into the stream on the other side." The story is more complex in larger streams where the effects of meander bends, secondary channels, and pool-riffle sequences all interact to drive flows of stream water through the hyporheic zone.

Pool-step sequences typically add water to the hyporheic zone for only brief durations. By contrast, subsurface flows created by features like meander bends can have much longer residence times.

"You can think of it as water trying to take a shortcut by flowing through the point bars created by a meandering stream," describes Wondzell. "Just like when hikers try to cut switchbacks on their way down the mountain. But shortcuts are often slower than the better traveled routes, and the same is true of water in the hyporheic zone."

Researchers are interested in the amount of time stream water remains belowground because it controls the opportunities for nutrient cycling and filtration. And so does the length of the flow path.

Flow paths around pool-step sequences are typically short, so that the stream water stays in the hyporheic zone for a few hours. By contrast, subsurface flows through point bars at meander bends, or connecting the main stem with secondary channels, are much longer so that stream water may remain in the hyporheic zone for many days.

"When streams braid into multiple channels, some of the branches are lower than others. Because water likes to flow downhill, stream water will often flow underground from higher to lower channels; in this way, lower channels act like a drain. Depending on the distance between channels, this can result in long hyporheic flow paths," Wondzell explains.

He is quick to caution against generalizations, noting that all stream systems are different, and the morphology and geology of each stream will dictate the extent and duration of hyporheic flows.

UNDERSTANDING HUMAN INFLUENCE

Flooding is not the only process that influences the structure of a stream. Management practices have long been transforming valley bottoms and stream networks. "Human-caused alterations in channel morphology most likely had major impacts on the hyporheic zone, but this has never been studied directly," Wondzell notes.

Of particular concern is the simplification of stream channels. This is often the result of road construction, which frequently uses valley bottoms as a path of least resistance. And unlike flooding, the affects of roads tend to be permanent.

"Unfortunately, the floods that drive bank erosion, cut new channels across valleys, and create large and healthy hyporheic zones are also the floods that destroy roads," says Wondzell. Stabilizing streambanks and cutting off old meander bends and secondary channels all simplify the stream channel and remove the features that drive hyporheic exchange.

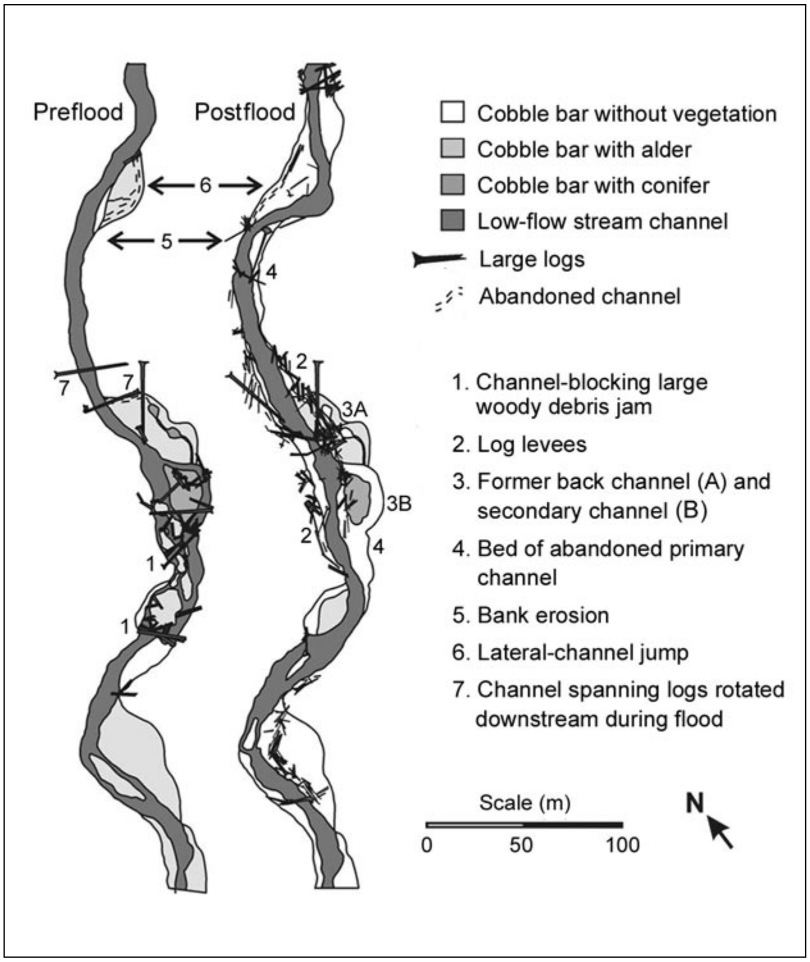
But the precise effects of management are unknown. "We have never had the opportunity to study the hyporheic zone both before and after management activities to account for the changes. But the science is advancing, and fortunately this has led to more sensitive management practices that are now considering the effects on stream networks, both above and belowground."

Credit: Steve Wondzell

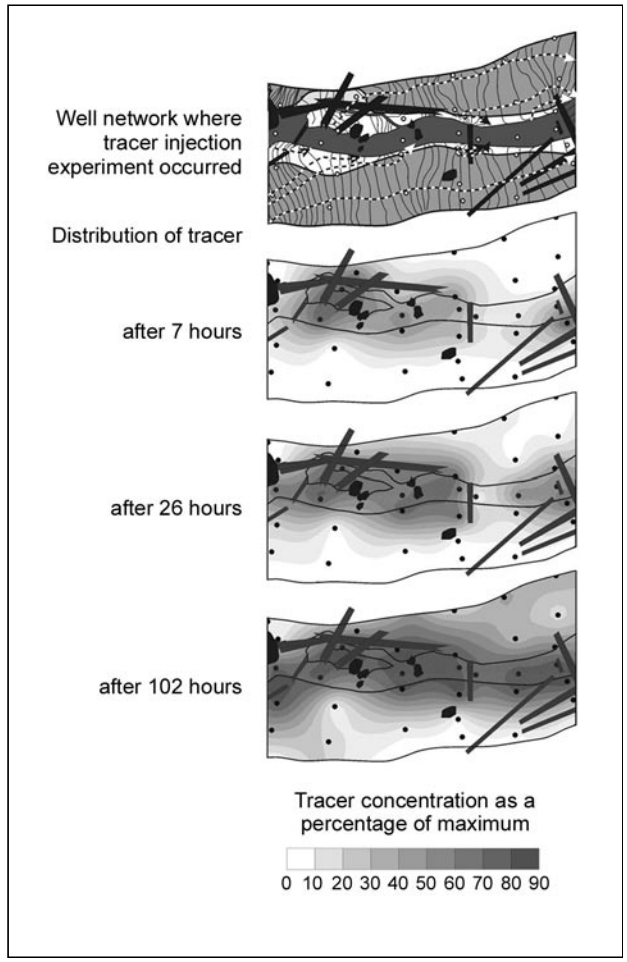
These photos of McRae Creek were taken from nearly identical locations in the summers of 1993 (top) and 1996 (bottom). During the 1996 flood, the channel shifted to the right by about 4 yards and down cut more than 1 yard. Channel spanning logs visible in the 1993 photo were swept aside, flattening groves of alders.

Credit: Steve Wondzell

These photos of McRae Creek were taken from similar locations in the summers of 1993 (top) and 1996 (bottom). The large trees on the right side of the photo provide a reference for changes. The large logjams in the main channel were breached during the flood, leading to erosion and down cutting of the main channel.



McRae Creek before and after the 1996 floods showing the active stream channel, locations of large key logs, secondary channels, and gravel bars.



Water table contours and flow paths of water through the hyporheic zone of a mountain stream predicted from a ground-water flow model (top), and distribution of tracer in the hyporheic zone 7, 26, and 102 hours after the start of a tracer injection.

Given the multiple activities and content of hidden, underground streams, their importance to healthy ecosystem function is no longer a question. What does come to mind is, what else is right in front of us, but invisible?

> *"We cannot make rivers whole unless we wholly understand them."*
>
> —Rob Brown, Wheeler School, Providence, R.I.

FOR FURTHER READING

Kasahara, T.; Wondzell, S.M. 2003. *Geomorphic controls on hyporheic exchange flow in mountain streams.* Water Resources Research. 39: 3–13.

Haggerty, R.; Wondzell, S.M.; Johnson, M.A. 2002. *Power-law residence time distribution in the hyporheic zone of a 2nd-order mountain stream.* Geophysical Research Letters. 29: 1–4.

Wondzell, S.M.; Swanson, F.J. 1999. Flood, channel change, and the hyporheic zone. Water Resources Research. 35: 555–567.

Wondzell, S.M.; Swanson, F.J. 1996. *Seasonal and storm dynamics of the hyporheic zone of a 4th-order mountain stream. I: Hydrologic processes.* Journal of the North American Benthological Society. 15: 1–19.

Wondzell, S.M.; Swanson, F.J. 1996. *Seasonal and storm dynamics of the hyporheic zone of a 4th-order mountain stream. II: Nitrogen cycling.* Journal of the North American Benthological Society. 15: 20–34.

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STEVE WONDZELL is a research ecologist in the PNW Research Station's Aquatic and Land Interactions team in Olympia, Washington. He has been studying the hyporheic zone and its influence on stream ecosystem processes in the H.J. Andrews Experimental Forest since 1988. Before that, Wondzell worked in semiarid ecosystems where he developed an interest in the ways that physical processes (runoff of rainwater, erosion, and sedimentation) influenced ecosystems—especially the pattern and location of desert-grassland plant communities. Wondzell's current research spans the wet and dry sides of the Pacific Northwest, with continuing hyporheic studies in the H.J. Andrews forest and in southeast Alaska, and projects in the Blue Mountains of eastern Oregon and Washington studying the effects of prescribed fire on erosion and stream sedimentation.

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