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INSIDE

Science FINDINGS

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"Science affects the way we think together."
Lewis Thomas

Thermal Pollution In Rivers: Will Adding Gravel Help To Cool Them Down?

Researchers found that water emerging from gravel bars on the Clackamas River in Oregon was cooler than water in the main channel during the hottest part of the day, but that adding gravel bars was unlikely to cool the whole river.

IN SUMMARY

Thermal pollution in rivers can be caused by dams, logging, municipal wastewater treatment, and other human activities. High water temperatures stress ecosystems, kill fish, and promote disease and parasites, and so dam operators, timber companies, and municipalities are held responsible for thermal loading caused by their operations. These entities are looking for ways to mitigate environmental damage. When Portland General Electric (PGE) was applying for relicensing of its extensive hydroelectric project on the Clackamas River in Oregon, questions were raised about whether the company's existing plans to improve fish habitat on the lower river by adding gravel to the channel to replace lost sediment would also help to bring maximum summer water temperatures within regulatory limits.

A study co-led by a Pacific Northwest Research Station scientist provided critical information to PGE—and the 33 interested parties that signed off on its relicensing agreement—about how river overall temperatures are affected as water flows through naturally occurring gravel bars. The research showed that although water emerging from gravel bars tends to be cooler than the main channel, gravel augmentation alone is unlikely to cool the whole river. It could still provide positive benefits, however, by increasing the number of cool spots for fish to hide during the hottest part of the day.

"When you're conserving a river, you are conserving a life."
—Kevin Coyle

Cool, fresh water: it's what makes so many Pacific Northwest rivers prime habitat for chinook and coho salmon, steelhead, and cutthroat trout. But numerous human activities, such as operating dams, logging, and discharging industrial and municipal wastewater into rivers, adversely affect aquatic ecosystems by raising water temperatures to unhealthy levels—a condition known as thermal pollution. The federal Clean Water Act requires dam operators, timber companies, and municipalities to mitigate the effects of thermal pollution caused by their activities.

Twenty years ago, Portland General Electric (PGE) began the long and complicated process of preparing an application to the Federal Energy Regulatory Commission to relicense its hydroelectric system on the Clackamas River in Oregon. By 2005, PGE was still wondering what to do to reduce the effects of thermal pollution caused by its extensive network of dams, reservoirs, and powerhouses.

“The thermal issue was the one major sticking point preventing the negotiation from moving towards closure,” says Gordon Grant, a research hydrologist with the Pacific Northwest (PNW) Research Station. Maximum water temperatures during some times of the year along some reaches of the lowermost part of the Clackamas were estimated to be 1 to 2 degrees Celsius warmer than regulations allow for ecosystem health.

Water held behind dams has time to absorb heat from solar radiation, and once it is released back into the flow, it may not cool down enough to provide good fish habitat. “There’s a lot of thermal inertia” says Grant. “Water gives up its heat reluctantly.”

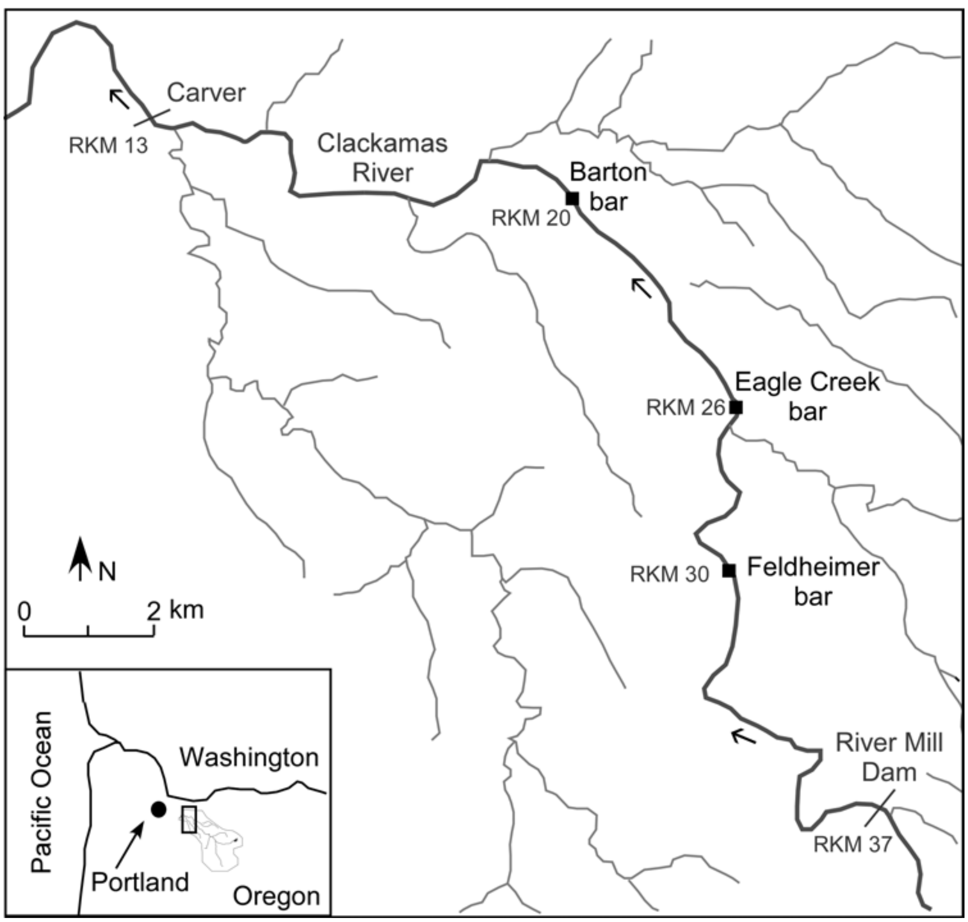
As part of its river restoration strategy, PGE had already committed to replacing sediments that have been trapped behind the dams for almost 100 years. The company is poised to annually add thousands of cubic feet of gravel into the river below the River Mill Dam—the lowermost dam in a chain of eight on the 83-mile river, located about 20 miles upstream from where the Clackamas flows into the Willamette River.

KEY FINDINGS

- Increasing flow through the hyporheic zone (i.e., the shallow layer of permeable gravels that underlies a river’s channel, bars, and flood plains) does not change the mean temperature of a river, but instead reduces maximum temperatures and increases minimum temperatures.
- Measurements of subsurface water elevations in the Clackamas River in Oregon provided data for a computer model that enabled scientists to calculate hyporheic discharge and correlate it with temperature fluctuations.
- Hyporheic flow through individual gravel bars is much less than 1 percent of the flow in the main channel. Temperature reduction was minute—approximately 0.01 degree Celsius per gravel bar.
- Although adding gravel to a river is not likely to result in major temperature reductions, it may improve habitat locally by creating cool patches that could provide refuge for fish in the heat of the day.

During the company’s relicensing process, questions were raised about whether adding gravel to the river would serve a dual purpose by cooling the water enough to bring expected temperature trends into compliance with federal regulations. The theory was supported by simple modeling and field studies, which suggested that hyporheic flow affects stream temperatures in smaller rivers. Hyporheic flow occurs through the hyporheic zone—the relatively shallow area (with an average depth of 5 to 10 feet) under a river’s channel, bars, and flood plains, where surface water and ground water mix before reentering the main channel.

At the time, no studies had looked at the potential for reducing peak temperatures in larger rivers, nor had they examined how water discharged from the hyporheic zone affects river temperatures. Beginning in 2006, Grant, Oregon State University master’s candidate Barbara Burkholder, and Roy Haggerty, geology professor at Oregon State University, collaborated on a Clackamas River study to investigate whether hyporheic flow through gravel bars could significantly cool the river. Their study was one of the first to correlate river temperature and hyporheic flow in a large river, and it contributed directly to the settlement agreement that allowed PGE to relicense its Clackamas Hydroelectric project.



The study site below the River Mill Dam is about 20 miles upstream from where the Clackamas River enters the Willamette River.

Purpose of PNW Science Findings

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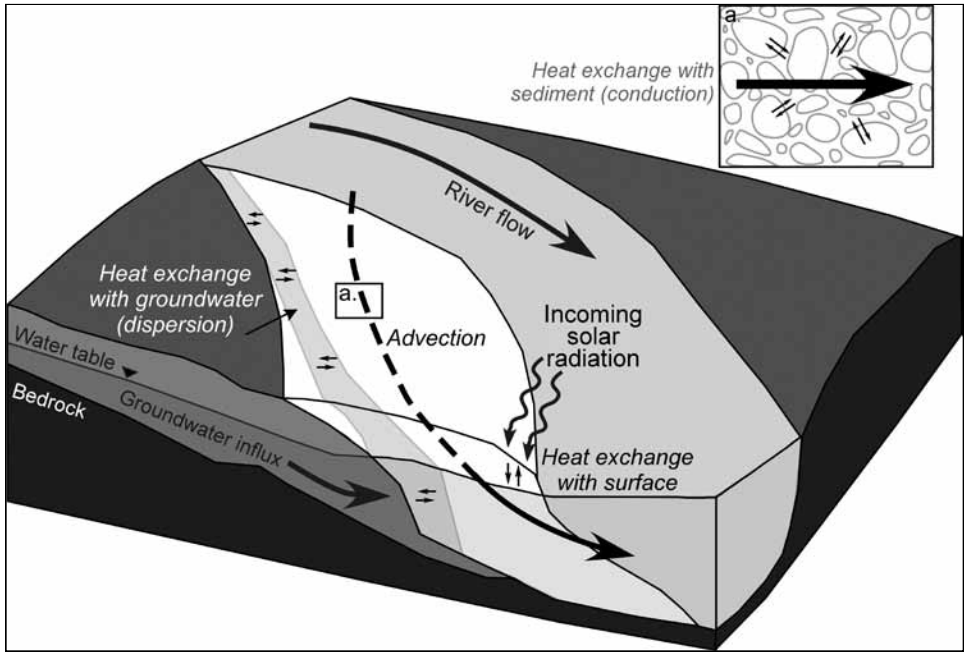
SEEKING SOLUTIONS TO HIGH WATER TEMPERATURES

Air temperature and the play of sun and shade change continually throughout a river's 24-hour cycle, influencing the amount of solar radiation the water absorbs. Human activities and structures also affect water temperatures in unpredictable ways.

As a river meanders along its channel, a certain amount of water infiltrates the riverbed and stays there for varying amounts of time, working its way through whatever sediment it encounters—sand, pebbles, silt, clay, and gravel—before reemerging into the main flow of the river downstream. The Clackamas River study addressed the question of how this process, called hyporheic exchange, affects the minimum and maximum temperatures during a river's daily cycle. "Previous work suggested that water emerging from gravel bars might actually be cooler than the surrounding water," says Grant.

The scientists did not expect that gravel augmentation would change the overall mean temperature of the river, but had hopes that it would bring the maximum temperatures down. Minimum temperatures would also change, becoming warmer. Grant and Burkholder call this a "buffering" effect.

Previous studies on hyporheic exchange and river temperature were conducted on smaller water bodies, says Burkholder, so results were not necessarily translatable to the Clackamas. "In smaller streams or rivers, you have a greater volume of discharge going through the hyporheic zone because the majority of the streamflow interacts with the streambed. A greater proportion of your water is able to enter the hyporheic zone," she says. "The Clackamas is a very large, active river."



A conceptual diagram showing the different processes that influence hyporheic (subsurface) water temperature in a gravel bar (white). Advection transports heat via fluid flow (all large arrows) while conduction transfers heat between sediment and hyporheic water (small arrows). Note: a. = heat exchange with sediment (conduction) see box in upper right corner.

EXPLORING WATERFLOW THROUGH GRAVEL BARS

Burkholder spent the summer of 2006 mapping existing gravel bars on a 15-mile stretch of the Clackamas, below the River Mill Dam. She manually measured temperatures at the upstream and downstream ends of each gravel bar and compared her findings to aerial thermographs of the area, looking for differences in temperature. "The thought behind it was that you have water entering the hyporheic zone in the morning and it takes time to travel through, emerging in the mid-afternoon," she says. "Meanwhile, it has been able to exchange heat with the sediment and has not been exposed to solar radiation, so it should be cooler."

Within the study area she found 52 temperature differences, which she calls anomalies, that confirmed a cooling effect. "All but one of the anomalies were cooler than the main stem in the afternoon," says Burkholder. "They generally ranged from 1 to 4 degrees cooler." The location and timing of temperature fluctuations confirmed that they were caused by heat exchange within the hyporheic zone and were predictable based on specific features of the gravel bars. "They tended to be located in places where previous high-flow channels were located, but the river had moved," says Grant.

After mapping the anomalies, Burkholder narrowed the scope of her research by placing instrumentation on three carefully chosen gravel bars with different histories: one older bar (estimated at 10 to 20 years of age), one new bar that had been deposited in the prior high-flow season, and one well-established bar that had been significantly altered during the prior season.

The research team was encouraged when the data showed recurrent daily fluctuations in the newest gravel bar. "You could see temperature changes from the upstream end, to the middle, to the downstream end of the bar, and daily fluctuations were out of phase with the main stem temperature," says Burkholder. "It was exactly what we had hoped to see—pretty much a 12-hour difference from when the water had infiltrated the gravel bar to when it came out."

However, on the oldest bar, no temperature fluctuation occurred at all. "It was essentially flat-lined," says Burkholder. "The water had been in the ground so long, it had lost its diurnal signal."

Next, the team built computer models that would help them understand waterflow patterns, including how ground water was affecting the hyporheic process. Their models mapped the water's path and estimated the amount of water that was flowing through each bar. "We were really interested to see how much water was coming out of these gravel bars—how much was going through the hyporheic zone and influencing the overall main stem temperature," says Burkholder.

The results were a bit disappointing. The discharge from the gravel bars was less than one percent of the overall flow of the river, and the net temperature effect from cooler water emerging from them was nominal. "Results showed a hundredth of a degree of temperature change through a single bar," says Grant. "Not much."

Sediment permeability determines the ease with which water moves through the hyporheic zone. Newly deposited gravel, which tends to be loosely packed, allows the water to move through relatively quickly, giving it less time to cool. Older bars with fine particles and compacted sediments slow the water down. The water still cools, but less is discharged within a 12-hour cycle.

"It was really interesting to see how bar history influences how the temperature of the water is buffered through the gravel bar," says Burkholder. "It's the combination of permeability, the length of the flow path, and gradient that determine whether the emerging hyporheic flow is out of phase with the main channel."

The scientists concluded that PGE would need to create 100 new gravel bars on the 15-mile stretch of river—a highly unlikely scenario—to cool the maximum temperature by approximately 1 degree Celsius.

Barbara Burkholder

Researchers found that a gravel bar's age and sediment size influenced the temperature of the water moving through it. Water moves quickly through coarse, less permeable sediment and has less time to cool.

BENEFITS FOR FISH

Although the study showed that adding gravel to the river would probably only minimally affect overall maximum river temperatures, pairing it with a concurrent study by fish biologists, enabled the researchers to conclude that adding additional gravel bars to the Clackamas would be worthwhile because they tend to create cool pockets of water that can provide refuge for fish on hot days.

"The fish study found that fish tend to use the cooler temperature anomalies to hang out in the middle of the afternoon," says Burkholder. "It wasn't the strongest correlation, but overall, when they found cool pockets of water, they would find fish there. It's still ecologically and biologically important."

Because PGE was already planning to replace sediment trapped in reservoirs by adding gravel obtained from its onsite quarry, the study provided enough positive evidence that the process would support river health to give the company the support it needed to renew the operating license. It was enough to convince the 33 parties who signed off on the agreement, including federal and state agencies, environmental organizations, Native American tribes, local governments, water districts, and recreational businesses.

Barbara Burkholder

Water moves more slowly through finer sediment and has more time to cool, but less is discharged in a 12-hour cycle.

WHAT'S NEXT?

The Clackamas River study was completed in 2008, but PGE is only now beginning to roll out its gravel augmentation plan, says Burkholder. "It's not something they're doing lightly," she says, pointing out that other environmental impact studies contributed to the decision to move forward. "I have no doubt that adding gravel to the river will have positive benefits, especially since we know that the most recent deposits of gravel set themselves up fabulously for creating these preferential flow pathways that really move water through the subsurface."

Burkholder says she would much rather see rivers "run free" than be constrained by dam operations, "but hydroelectric power is a clean source of energy and I don't really see us removing our dam infrastructure. Dams are a part of our reality, so for those that are not likely going to be removed, like the ones on the Columbia or the Clackamas, I think it is in our best interest to try and support the ecology of those systems as much as we can and mitigate the negative effects they have."

Grant said that the Clackamas River Hydroelectric Project relicensing reflected a leap of faith. "PGE got its permit because they put together a package of mitigation measures that addressed a broad range of issues—the net effect to the river will be demonstrably positive, even if it doesn't perfectly meet the standard," he says. "My own feeling is that you can't affect the main stem of the river much through gravel augmentation. But what you can do is affect the river locally."

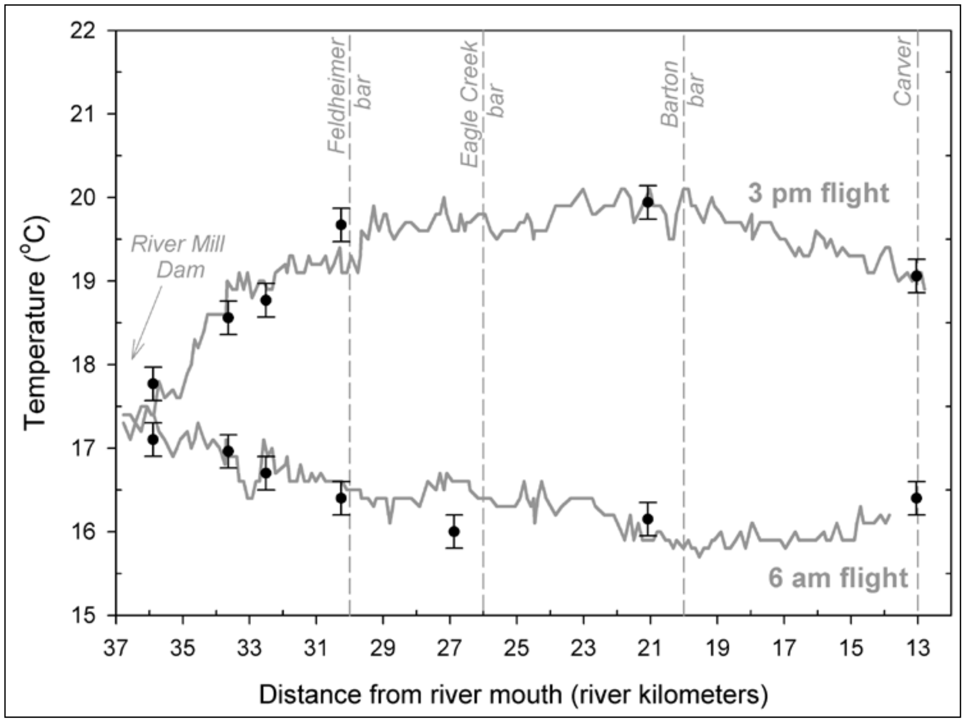
Although the gravel bar study significantly adds to the body of knowledge about how rivers self-regulate their temperature, only putting the gravel in place and observing the effects will prove or disprove the findings and justify the leap of faith. So far, says Grant, everything is based on computer models.

"How these things play off in the field in reality is a tricky business," he says. "It's very hard, for example, to predict in any kind of semi-definitive way what happens if you dump "x" amount of gravel in the river. Where will it go? What will it do when it gets there? These are computational models, and they have evolved dramatically in the last 20 years, but it's a very complicated bit of business. You can come up with a reasonable picture—what you can't do is definitely say 'I'm going to grow this bar here and put a new one over here.' So it becomes a real-time, real-life experiment."

Grant said the gravel bar study also has direct implications for current efforts to cool large rivers by removing erosion control structures, thereby allowing channels to widen and wander in the hope of increasing the amount of hyporheic exchange. "Even if the hyporheic exchange is increased, it is unlikely that this strategy will produce major cooling," says Grant. He points out that it will take a range of strategies to improve conditions on the Clackamas—adding gravel is just one of many steps that can be taken to improve habitat for the fish and other aquatic organisms that have historically populated the Clackamas River.

"Come forth into the light of things; let nature be your teacher."

—William Wordsworth



Water emerges from River Mill Dam on the Clackamas River at a fairly constant temperature. Aerial thermographs and instream data recorders revealed that at 6 am, water cools as it moves downstream, whereas by mid afternoon it gets warmer as it moves downstream. Cooler water that enters a gravel bar and is discharged later in the day can provide cool refuges for fish on hot days.

LAND MANAGEMENT IMPLICATIONS

- Water moves through the hyporheic zone much more slowly than it moves in the main river channel, so water temperatures can be thermally out of phase; however, substantial cooling of the main channel occurs only when large volumes of water move through the hyporheic zone.
- Large volumes of water can move through the hyporheic zone only if gravel bars are highly permeable, but this condition results in rapid water movement, so water reemerging into the main channel is less likely to be thermally out of phase (cooler).
- It is difficult to engineer conditions under which a sufficiently large volume of water flowing through the hyporheic zone can bring temperatures down enough to make a significant difference in a large river.
- Removing erosion control structures to enable channels to widen and wander in hopes of increasing hyporheic exchange through increased bar development is unlikely to produce major cooling.

FOR FURTHER READING

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