How does a river breathe? The answer could lead to a better understanding of the global carbon cycle

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Scientists at Pacific Northwest National Laboratory have been studying processes that affect how rivers and streams breathe, particularly in the Columbia River Basin, to help prepare for future changes related to water quality and climate change. Credit:Andrea Starr | Pacific Northwest National Laboratory

Take a deep breath. Pay attention to how air moves from your nose to your throat before filling your lungs with oxygen. As you exhale your breath, a mix of oxygen and carbon dioxide leaves your nose and mouth.

Did you know that streams and rivers "breathe" in a similar way?

The United States is home to more than 250,000 of these flowing bodies of water that connect to coastal zones and oceans. They vary in size, from small streams to large rivers, but all take in oxygen and give off carbon dioxide and other greenhouse gases like methane.

Over recent years, a team of scientists led by Pacific Northwest National Laboratory (PNNL) has been immersed in crucial research around the processes and interactions that contribute to greenhouse gas dynamics. Their work focuses on whole networks of streams and rivers, as well as the land surrounding these systems.

Their work also includes factors that can disturb how streams and rivers breathe. Some of these disturbances happen beyond streams, like wildfires, but still impact how streams breathe by changing how material enters streams. Understanding these impacts is key to addressing challenges related to water quality, global carbon cycling, and climate change.

PNNL scientists have been conducting modeling, field, and laboratory studies across the United States, with some studies being particularly intensive within the Columbia River Basin. This area covers 258,000 square miles, and the Colombia River flows over 1,270 miles from the Canadian Rockies to the Pacific Ocean. This basin includes lush forests, dry deserts, and vast agricultural lands. PNNL's main campus is housed within the basin in Eastern Washington.

Research led by PNNL has produced models and data that can help predict how to protect the nation's streams and rivers and the communities that depend on them. The work is published in the journal *Frontiers in Water*.

"Our team uses models and data to gain new insights and develop predictions that will inform decisions made by regulators and natural resource managers," said Timothy Scheibe, a PNNL Lab Fellow and Earth scientist who is one of the leaders of this research.

Models and data can help inform water and land use management practices, including how to respond to natural disasters such as wildfire and drought. They can also help inform how future changes in the environment might affect natural and human systems that are important to the health of our planet.

What is respiration?

One of the drivers behind understanding how streams and rivers breathe is a set of processes known as respiration—a collection of chemical reactions that together determine how much carbon stays put and how much enters the atmosphere as carbon dioxide.

Respiration combines carbon and oxygen to generate energy for living organisms. This process also creates some "exhaust" in the form of carbon dioxide that is "exhaled" by organisms such as algae and bacteria within stream and river ecosystems. By studying respiration across many kinds streams and rivers, researchers can learn why some systems respire more than others.

Understanding the "why" is key. That's what allows researchers to predict the future of streams and rivers.

It's also important to understand whether water or sediment in rivers and streams has more respiration. To answer this, PNNL partnered with researchers at Washington State University and the University of Montana. The team found that in the Columbia River, most respiration is done by organisms in the water. This is likely because the Columbia River contains a lot of water in which respiration can happen.

But in other stream systems, microbes in sediments are doing most of the breathing. Some sediments "breathe" a lot faster than others, and as a result, make more carbon dioxide.

The PNNL team has shown that the amount of carbon dioxide produced by sediments is linked to the size of rocks that make up riverbeds. Bigger rocks often lead to more breathing. That's important because the faster sediments breathe, the more they can clean out pollutants from streams and rivers.

What is organic matter?

In addition to gases like oxygen and carbon dioxide, streams and rivers contain particles of dead organisms like plants and algae. This is known as organic matter, and it's the "fuel" or "food" that powers respiration and plays a role in water quality and the health of aquatic species. The makeup of organic matter is controlled in part by land use, pollutants, forest management, and natural and human disturbances, so understanding its relationship to respiration may motivate different land and water management practices.

The PNNL team led research looking at how changes in the kinds of organic matter cause changes in respiration. In a series of studies, the team showed that respiration in sediments is linked to the chemistry of organic matter. The *Frontiers in Water* study, conducted in partnership with University of Nebraska researchers, revealed general rules across diverse streams that define how organic matter chemistry links to sediment respiration.

PNNL scientists also revealed how wildfire can change organic matter in streams following a wildfire. The team found that there was a linkage between organic matter composition and how fires impacted the landscape during the first storm after a major wildfire event in 2020. This makes it difficult to figure out how microbes use different kinds of organic matter to fuel respiration in streams and rivers.

There are tens of thousands of different compounds that make up organic matter. There's also a variety of organisms that use organic matter as fuel. This makes it difficult to figure out how much respiration takes place across different kinds of organic matter and organisms in streams and rivers.

Despite the challenges, PNNL and partnering researchers have revealed general rules for how these complex systems work. These rules allow scientists to solve other important challenges like how to improve water quality and predict how much carbon dioxide will leave streams and rivers following big events like wildfires.

"Understanding what principles regulate processes and how they work across systems is a key goal of our work," explained PNNL Earth scientist Allison Myers-Pigg. "This knowledge provides a foundation for building models that can predict the future health of streams and rivers, including how they might be impacted by big disturbances. Without this knowledge, we cannot make accurate predictions."

More information: Firnaaz Ahamed et al, Exploring the determinants of organic matter bioavailability through substrate-explicit thermodynamic modeling, *Frontiers in Water* (2023). DOI: 10.3389/frwa.2023.1169701

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