Lakes and Rivers Are Getting Saltier

Deirdre Lockwood

Road salts, fertilizer, and other pollutants are turning fresh water salty, endangering ecosystems and water supplies.

According to an old superstition, it’s bad luck to spill salt, and if you do, you should throw a pinch over your left shoulder to reverse the curse. These days, humans are spilling so much salt into the environment, it’s hard to imagine being able to ward off the bad luck looming on the horizon. We are unwittingly adding chlorides, bicarbonates, and more into groundwater, rivers, and lakes at a pace that scientists worry is threatening wildlife as well as drinking water.

Fresh water of the type that fills streams and lakes typically has about 1% of the salt content of ocean water. In 2005, Sujay Kaushal, a biogeochemist at the University of Maryland, College Park, and his colleagues found that the chloride content of streams in the northeastern US had been rapidly increasing since the 1970s. Some streams had become so salty that their chloride levels reached about 25% of the level in seawater. In some streams supplying drinking water to Baltimore, near Kaushal’s university, levels of chloride had at least doubled over 25 years, according to long-term municipal data.

Since that early study, Kaushal’s team has discovered similar salinization trends in hundreds of streams and rivers across broad regions of North America and Europe, as well as in Russia, China, and Iran. And Hilary Dugan, an aquatic scientist at the University of Wisconsin−Madison, and her colleagues have shown that this is also a widespread phenomenon among North American lakes.

What is behind this surge in salinity? One of the biggest culprits is road salt, especially in regions that get big snowfalls in winter, like the northeastern and midwestern US. Municipalities in the US have been using road salt as a deicer since the 1940s. But over the years, as more roads have been added and people have become more reliant on clear roadways in winter so that they can travel safely and unencumbered, road salt use has mushroomed. The US now applies 22 million metric tons of it per year, compared with about 4,500 t in the early 1940s, according to reports by the Cary Institute of Ecosystem Studies.

But road salt—usually sodium chloride—isn’t the only contributor to the increase in our waterways’ salinity. As Kaushal began to look into the issue further, he found that humans are helping deliver a whole suite of salts to fresh water in various ways. For decades, acid rain has been dissolving concrete and limestone structures, releasing calcium and bicarbonate ions into the environment. Sewage disperses salts from our bodies into waterways. In agricultural regions, fertilizer application delivers potassium salts that reach waterways through runoff. And mining unleashes many different salt ions, including sulfate and bicarbonate, during the process of cracking open minerals within the earth. Kaushal calls this salting of our waterways “the freshwater salinization syndrome.”

Both he and Dugan have demonstrated that the level of salts in a body of fresh water is directly related, sometimes exponentially so, to the amount of paved area nearby. The more people and the more development, the more salt being spilled. Salts, Kaushal says, are “a universal indicator of human activity on the landscape.”

Like the old practice of salting the earth of a conquered city to curse it, increasing the salinity of today’s freshwater resources does lasting damage. High levels of chloride and other salt ions can kill freshwater animals, from zooplankton...
at the base of the food web to insects and fish, because they make it hard for the creatures to osmotically regulate their cells’ ion concentrations.

And increased salinity harms ecosystems in other ways: for example, as algae-eating zooplankton die, harmful algal blooms can rise unchecked, releasing toxins and depleting oxygen in waterways. Increased salt can also favor invasive species that better survive in brackish water. At nonlethal levels, salt can stunt the reproduction and growth of freshwater organisms, lowering biodiversity and shifting the structure of food webs. If the trends found in Kaushal’s and Dugan’s studies persist, many US streams and lakes would, in the next 50–80 years, surpass the chloride limit the US Environmental Protection Agency recommends to protect aquatic life from long-term exposure—230 mg/L.

Salting fresh water endangers people too. At chloride concentrations over 250 mg/L, the EPA’s recommended drinking-water standard, water tastes salty and can cause complications for people with kidney disease, high blood pressure, and some other health conditions. Elevated chloride levels can also corrode plumbing, releasing toxic metals into drinking water. For instance, after Flint, Michigan, switched its water supply to a river with, among other problems, higher chloride levels, lead leached from the city’s pipes into its drinking water. Elevated chloride in Kaushal’s own tap water in Washington, DC, has similarly caused leaching of manganese into drinking water. “My neighbor asked, ‘Why is our water turning black?’” Kaushal recalls. Unless you study water, he adds, you wouldn’t know it’s because of the corrosion.

David Buchwalter, an ecotoxicologist at North Carolina State University, encountered freshwater salinization syndrome firsthand while investigating how mountaintop-removal coal mining was affecting the ecology of streams in Kentucky. “People who like to fly-fish understand that mayflies are really important,” Buchwalter says. “Fish really like to eat them.” And birds do too. The insects are a crucial part of the ecosystem around these waterways. So it was troubling when Buchwalter observed that in streams near mining operations, mayflies were much less abundant than in streams unaffected by mining.

At first, he thought the scarcity of mayflies in the streams near mines might be explained by the presence of trace elements released by mining, such as selenium and manganese. The toxic elements could have been killing the insects off. But then he did an experiment to expose mayflies to salt ions, including sulfate and bicarbonate, whose levels were elevated in the streams because of mining. “That was the smoking gun right there,” he recalls.

“We were basically killing mayflies in the laboratory at salinities that are commonly observed in the field.”

Many questions remain, however, about how salts affect individual organisms and ecosystems as a whole. Buchwalter is trying to figure out why different insect species are more susceptible to salinity, or to particular salts, than others. “Plenty of insects do fine,” he says, but plenty don’t.

Rick Relyea, an environmental scientist at Rensselaer Polytechnic Institute, is tackling similarly thorny questions in upstate New York’s Lake George, which has been called the Queen of American Lakes. Relyea leads the Jefferson Project, a collaboration among RPI, IBM, and the FUND for Lake George, a nonprofit focused on conserving the lake. The project has outfitted the lake with more than 500 “smart” environmental sensors during the past four years to monitor human influence on it. Over the past four decades, according to data from the Lake George Offshore Chemical Monitoring Program, chloride levels have tripled in Lake George, adding to other environmental effects on the lake. These effects include the rise of invasive species and the delivery, through stormwater runoff, of pollutants and nutrients that can stimulate algal blooms. Because it’s hard to tease apart the impacts of these various stressors on the lake’s water quality and wildlife, Relyea’s team has done a bevy of experiments in the lab and in large outdoor tanks to isolate and examine the consequences of increasing salt.

The “most bizarre effect” Relyea has seen yet is a sex change in tadpoles. Frogs breed in the wetlands around Lake George, so Relyea wanted to study how salt affects their reproduction. By exposing tadpoles in the lab to levels
of salt typically found in wetlands next to salt-treated roadways, his research team and collaborators at Yale University found that 10% more male frogs developed in these conditions than at the lower salinity of more pristine wetlands. Yet they don’t know why. “The population depends on how many females you have,” he says. “Having more males is not necessarily a good thing to keep the population going.”

Given enough exposure time, say, 40 years of it, Relyea wonders whether animals can adapt to higher salt loads in the same way that they become resistant to pesticides. In exploring this question, he and his team found a surprising result. *Daphnia pulex*, a common freshwater zooplankton, is one of the best algae eaters in lakes, so if it is killed off by high levels of chloride, algal blooms can result. When Relyea’s team exposed *D. pulex* in the lab to levels of sodium chloride known to kill zooplankton, however, about 10% survived. Over a few months, these hardier *Daphnia* became just as abundant as those grown under low-salt conditions. “We effectively caused artificial selection for high salt tolerance,” he says. “A really rapid evolution.”

To investigate what made these individuals so resilient, Relyea’s lab members teamed up with another RPI scientist, Jennifer Hurley, who studies animals’ circadian rhythms. They found that the so-called molecular clock of the surviving *Daphnia*—the proteins that control the organisms’ awareness of day and night—was disrupted. In the animals that evolved higher tolerance to salt, the concentrations of the clock proteins didn’t go up and down throughout the day, following the daily cycle. Instead, they flatline, Relyea says. “These animals don’t know what time it is.”

This could be especially harmful for zooplankton because each day they perform a vertical migration, going to deep water to hide during the sunniest hours and coming to the surface at night to chow down on algae. “Now that they don’t know what time it is, we don’t know how that will impact the daily cycle,” he says.

A few months ago, Kaushal’s team published a study highlighting the fact that freshwater salinization syndrome has yet another worrisome dimension. When salts are spilled into the environment, they can set off a cascade that releases other contaminants from soils, including heavy metals, nutrients, and organic compounds. These contaminants are usually bound to soil, but salts’ stronger affinity for soil replaces and releases them through ion exchange. This can flush harmful metals, including manganese, copper, and zinc, into freshwater ecosystems. Salts not only mobilize these metals but can also form complexes with them that make them more soluble in water and hence more available to wildlife.

On Lake George, the Jefferson Project has deployed hundreds of environmental sensors around the lake, including on this floating laboratory, to monitor salinity and other indicators of water quality. Credit: Rensselaer Polytechnic Institute

In a series of experiments on streams in the Washington, DC, and Baltimore areas, Kaushal and colleagues found that copper concentrations spiked in the waterways after snowstorms, corresponding with the salting of roads. When the researchers added road salt to the streams themselves, they saw a similar effect. And when they repeated this experiment in the lab by adding road salt to water and sediment collected from the streams, the spikes in copper were beyond levels toxic to several species of *Daphnia*.

In the US, “we don’t regulate salts at all, and contaminants are regulated one by one” in soils and water, Kaushal says. “This work shows that we may need to think about these contaminants as cocktails, regulating and managing them holistically.”

In the town of Orleans in upstate New York, residents with private wells living near roads treated with salt in winter have found elevated levels of lead and other metals in their drinking water. A recent study showed that 21% of 90 wells surveyed there exceeded the EPA’s recommended chloride limit, and in 20% of the wells, lead or copper surpassed the EPA’s action levels for the metals. Chloride from road salt is seeping into the wells and corroding the plumbing.

According to the University of Wisconsin’s Dugan, saltier water is also becoming a concern in her home of Madison, whose water supply relies on wells. Madison’s water contains high concentrations of calcium and magnesium, which can protect pipes from corrosion, so the city’s plumbing isn’t as affected by road salt. But, Dugan says, some wells could be decades away from hitting a concentration that would make the water undrinkable because of the salty taste.
So what can be done to keep salts from damaging ecosystems and drinking water? Ultimately, Kaushal says, the EPA should regulate salts as contaminants. Dugan says she tries to bring people’s attention to the problem: “Road salt is not this environmentally safe chemical.”

In the meantime, the researchers advise using less road salt in winter. One of the easiest ways to do this is to treat roads with brine—about a 20% solution of salt water—before a snowstorm. This treatment coats the roads more evenly than road salt, and it makes the snow start melting as soon as flakes hit the road. Road salt can still be sprinkled onto highways and byways after snow starts, but the precoating of brine means that less salt is needed.

In Madison, this approach has allowed road managers to use about 70% less road salt, Dugan says. In upstate New York, thanks to the efforts of the Jefferson Project, the village of Lake George has also introduced brine treatment and has bought new plows that have five 2 ft (0.6 m) sections of plow blades on springs to better fit the curvature of the road (Relyea compares the effect to that of a multiblade razor). By implementing these tools, the village has reduced road salt application by 30% in the past two years, Relyea says, and it plans to take it down another 20% in the next two years, in part by monitoring the salt distribution of individual plows.

Though these changes cost money, Lake George residents have supported them, Relyea says. This isn’t just about saving the environment for the environment’s sake, he says. “If the lake degrades in water quality, it’s a real financial hardship, especially for a place that survives on tourism.”

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