Proper design of saturated riparian buffers critical to nitrate removal effectiveness

By Megan Sever

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Prior to installation of a saturated riparian buffer. After the installation, the field on the left will include a strip of prairie plants between the field and the stream. Photo by Lynn Betts, USDA-NRCS.

- Nitrate runoff from agricultural fields leads to toxic algal blooms, fish kills, and biodiversity loss.
- "Saturated riparian buffers" are capable of removing 92% of nitrogen before it reaches a stream—with proper design.
- New *Journal of Environmental Quality* research details how to create SRBs that more effectively remove nitrate from subsurface drainage.

About half of all nitrogen in the Gulf of Mexico comes from farms hundreds of kilometers up the Mississippi. That nitrogen contributes to the largest hypoxic zone in the U.S. and algal blooms that span, on average, 5,400 mi2. Nitrogen pollution leads to toxic algal blooms, fish kills, and loss of biodiversity, among other things, and can even render drinking water toxic locally and far downstream.

So conservationists are looking for ways to reduce nitrate runoff into streams and groundwater. Conservation practices like planting cover crops or using extended rotations offer a good start, but edge-of-field practices like using bioreactors or constructed wetlands offer even better water protection. A newer method that takes advantage of in-place subsurface artificial drainage systems may provide still better protection at minimal additional cost, according to recent research in the *Journal of Environmental Quality* (**https://doi.org/10.1002/jeq2.20160**).

Using “saturated riparian buffers” (SRBs) can remove up to 92% of nitrogen before it reaches a stream. Recent research details the optimal characteristics of saturated riparian buffers for removing the most nitrate—should farmers choose to put them in.

A Relatively Recent Technology

While riparian buffers have been around virtually forever (think floodplains), SRBs have only been around since 2010. Riparian buffers are essentially vegetated banks that separate an agricultural field from a waterway. Saturated riparian buffers are more complex, though on the surface they look the same—like a vegetated buffer zone separating an agricultural field from a stream or drainage ditch, says Andrea McEachran, a graduate engineer at ISG, a design and engineering firm, and lead author of the study in JEQ on SRBs.

Saturated riparian buffers utilize existing artificial subsurface drainage (called tile) that’s draining an agricultural field. They involve installing an underground control box to intercept the flow of water from the tile, then adding a subsurface perforated distribution pipe that runs parallel to the stream through which nutrient-rich (nitrogen, phosphorus and other fertilizers) water flows and dissipates slowly into the vegetated buffer. The aboveground buffer can be planted with trees, shrubs, grasses—most any kind of natural vegetation.

According to the USDA-ARS, SRBs are “a conservation option that removes little to no land from production, requires little maintenance, and doesn’t affect crop yields when placed in ideal sites.” They also may enhance wildlife and pollinator habitats.

On average, SRBs remove about 42% of nitrates, according to the USDA-ARS. But previous studies, such as a 2019 JEQ paper by Dan Jaynes of USDA-ARS and Tom Isenhart of Iowa State, found nitrate removal of 7–92%, with most sites on the higher end of that study (https://doi.org/10.2134/jeq2018.03.0115).

The idea is that instead of nutrient-rich water draining directly from a field into a waterway, where it then makes its way downstream, the water enters the soil of the vegetated buffer where it is cleaned up. Then, the (now cleaner) water enters the waterway.

The denitrification process either occurs through microbial immobilization in the soil or plant uptake. With enough soil organic carbon content, microbes convert nitrates to free atmospheric nitrogen, thus leaving the water clean. Vegetation uptake occurs as plants suck nitrogen out of the ground, cleaning the draining water in the process.

"Without the saturated buffer, that tile drainage will just flow straight into the stream, with high nitrates polluting the water," McEachran says.

A Very Effective Process

Whether SRBs remove 7%, 92%—or anywhere in between—of nitrate depends on a lot of different factors. These factors include soil type, hydraulic properties of the soil and watershed, organic carbon content, subsurface biochemistry, topography, and buffer width. Even temperatures and weather make a difference. Research over the last decade has tried to identify the optimal characteristics for SRBs. For example, it's become pretty clear that loamy soils are best. Clayey soils don't allow enough water movement, and sandy soils allow too much. You need at least 1.2% organic carbon content in the top 2.5 ft of soil. You also want a high water table in the buffer and a low slope to the stream—too steep and water will flow too fast and not have enough time for denitrification. And you want to have no pockets or layers of soils with high hydraulic conductivity because the water will preferentially flow through those layers and not get the full denitrification process.

Dan Jaynes of USDA-ARS inserts panels into a water control structure that diverts water from field tile into tile that runs parallel to the stream, which then flows into the saturated riparian buffer. Photo by Lynn Betts, USDA-NRCS.

In terms of buffer width, the USDA-NRCS code for SRBs requires a minimum of 30 ft of vegetation between a field and a waterway. But that is a somewhat arbitrary number, based on best practices of riparian buffers used for surface runoff, says Chris Rehmann, an associate professor of civil construction and environmental engineering at Iowa State University who works on environmental fluid mechanics. After noticing that a few wells close to streams in buffers showed virtually no nitrates, McEachran and Rehmann, who is also a co-author on the JEQ paper and McEachran's graduate adviser, started to wonder if the buffers were wider than they needed to be.

Intuitively, you'd think the wider a buffer is, the more time there is for denitrification, but that's not necessarily the case, McEachran, Rehmann, and their colleagues found. There's a "Goldilocks problem," Rehmann explains. "Buffers can be "too wide, too narrow, or just right."

So the team came up with a model to optimize nitrate removal.

Obviously, if the buffer width is too narrow, enough nitrate won't be removed. If it's too wide, a few potential problems arise, McEachran says. One, you're losing potentially productive agricultural land. Two, it's possible that the water could actually flow back toward the field. Three, if the control box is back too far and the slope is too gentle down to the waterway, you get less flow through the buffer, Rehmann says. If you have the same flow coming in from the field but less flow that you can put into the buffer, that water is going to back up and overflow, he says. Then it flows into the waterway without being treated at all.

A water control structure (foreground) is placed into the field to divert water from field tile to perforated tile running parallel to the stream, saturating the buffer. Photo by Lynn Betts, USDA-NRCS.

Thus, "with saturated buffers, wider is not necessarily better," McEachran says. A wider buffer does not necessarily mean that more nitrate will be removed and in fact, it could be the opposite.

So it's really important to optimize the buffer width. McEachran and Rehmann's research on six sites shows that 30 ft is not the optimal buffer width—it exceeded the optimal in all six cases. And that is likely true elsewhere as well, they say. The optimal width maximizes flow while maintaining adequate residence time for denitrification processes.

It seems that the code recommendations need to change, Rehmann says. He says he hopes to see more research and discussion around optimizing these buffers. More research is especially needed on hydraulic conductivity of the soil, denitrification rates and the nutrient removal process especially depending on soil properties, and the question of whether multiple distribution pipes help with flow.

Challenges to Adoption

“Although SRBs are comparatively simpler, cheaper and easier to install, and may require little maintenance and no active management—all attributes that are attractive to farmers—they are not suitable on all tile outlets,” Jaynes and Isenhart wrote in 2019. “Rather, SRBs require specific soils and landscape characteristics to function properly and thus may be more limited in placement within a watershed than other field-edge practices.”

Indeed, SRBs are “not going to be a good fit everywhere,” says Charlene Simonson, executive director of the Kinnickinnic River Land Trust in Wisconsin who studied SRB challenges to adoption as part of her graduate dissertation at the University of Minnesota. The topography and the soils have to be right, among other factors. And you need places that are drained or need to be drained.

That’s pretty common in Iowa where something like nine million acres (or more) are tile drained. Most of northern and western Iowa are essentially wetlands—they’re flat and lack natural connections to river valleys, says Joe Otto, an environmental history graduate student at the University of Oklahoma. So drainage ditches have been built across the state to drain the wetlands to create viable agricultural fields and then to connect those ditches to the river valleys that eventually flow into the Mississippi and Missouri rivers. Much of southern Minnesota is also tile drained as are parts of Illinois, Indiana, and Michigan, for example.

A lot more tiling is going in every day, Simonson says, and will probably increase even more as climate change becomes more pronounced. Most places that have tile have the potential for SRBs, assuming the slopes aren’t too steep and the soils and hydraulics are amenable.

Still another challenge is understanding. A couple of years after SRBs were first introduced, Simonson interviewed 20 farmers in southern Minnesota about them. None had even heard of them, and most were skeptical and struggled to understand the concept.

“There’s an intense technical language barrier in terms of getting folks to understand what the process is and how it works,” Simonson says. “And then there is fear,” she says. “Farmers already deal with a lot of uncertainty, and many expressed an unwillingness to add more [uncertainty] without clear benefits.”

Prep begins for installation of a saturated riparian buffer in Story County, Iowa. Photo by Lynn Betts, USDA-NRCS.

Probably the largest single barrier to adoption, though, is cost. Although several studies have suggested that the cost of installing one of these systems is similar to other edge-of-field conservation practices—on the order of US$2.94 kg-1 nitrogen removed—it’s still something that brings little to no return on investment for farmers. So to be economically viable, farmers usually have to seek out alternative funding—which is out there, Simonson says. She notes that SRBs and other edge-of-field conservation practices are basically altruistic practices. Being willing to undertake the effort to seek out funding partners, find and hire a design and engineering firm, and rip up their fields to install these belowground structures all for little tangible return on investment is “truly an extension of a producer’s ethos, available resources, and knowledge—it’s a combo platter,” Simonson says. And many farmers have already taken actions to address the nitrate issue, so they don't feel like they need to do more, she adds.

Perhaps this is why we haven't seen a huge growth in SRBs, says Dean Current, an economist at the Center for Integrated Natural Resources & Agricultural Management at the University of Minnesota, Simonson's former adviser. There was a lot of interest when the conservation method was first introduced, he says, but it really hasn't caught on. Other conservation practices are better known and more standard, like using cover crops, which take care of the nitrogen problem in the field rather than trying to clean it up later, he says. And cover crops, under the right conditions, actually do offer farmers a return on investment (over time) while cleaning up the environment as well: a win-win. For an even higher level of nitrogen removal, cover crops can be combined with SRBs in a "treatment train."

SRBs can be a great conservation practice if designed and installed properly. It will just take some effort to get there.

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- Read the associated article in the *Journal of Environmental Quality*, "Improving the Effectiveness of Saturated Riparian Buffers for Removing Nitrate from Subsurface Drainage," here: **https://doi.org/10.1002/jeq2.20160**.
- Read Jaynes and Isenhart's 2019 *Journal of Environmental Quality* research, "Performance of Saturated Riparian Buffers in Iowa, USA," here: **https://doi.org/10.2134/jeq2018.03.0115**.