Phosphorus in the Minnesota River Basin

The debate over its source and ways to mitigate impacts

by Erik Ness

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The Minnesota River has long been a significant conservation challenge for Minnesota. Recognition that land use was causing water quality problems began during the Depression. Drought in the region was so severe that in some places, even the river bottom was tilled. Challenges from flooding and excess nutrients accelerated through the last century, and in 1995, the advocacy group American Rivers named the Minnesota River among the most endangered in the United States. But to understand the complicated problems in the Minnesota River, you have to go all the way back to last ice age. Because there is no Minnesota River without Glacial Lake Agassiz.

A massive lake formed from the meltwater of retreating glaciers, Agassiz at its peak spanned central Canada 3,000 km east to west and contained nearly twice the freshwater now in Lake Superior. About 13,000 years ago, it unleashed a torrent in what is now thought to be a series of floods over several thousand years. Much of that water rushed down what is now the Minnesota River, carving a channel as much as 5 miles wide and 230 ft deep through an otherwise flat landscape. The flow was sometimes so great that when it joined the Mississippi, it forced the mighty river to flow backwards.

Fast forward to today’s Minnesota River Basin. The soils formed from the glacial sediment throughout southern Minnesota don’t drain particularly well, explains Laura Triplett, a geologist at Gustavus Adolphus College not far from the river’s banks. “That’s been one of the big controlling factors on agriculture in southern Minnesota,” she says. “Lake Agassiz also controls what’s happening in our rivers and streams today.”

When the meltwater floods gouged the Minnesota River valley, it stranded many tributaries high above the floodplain. Waterfalls at first, these streams...
have been grinding deep ravines through the glacial till on their way to join the river. They have been some of the fastest downcutting rivers in the world over the last 13,000 years.

Long before European settlers broke sod, the river ran cloudy. “The river at its stages of flood becomes whitishly turbid,” reads an old history. Dakota women would explain the name by dropping a little milk into water and calling the clouded water “Minne sota” (“minne” meaning water and “sota” meaning somewhat clouded).

Today large stretches of the Minnesota River and its tributaries are listed as impaired. The cloudy water is at the heart of vigorously debated research over how to best farm the basin’s fertile fields while still cleaning up the river.

**The Sediment Tells a Story**

About 60 miles downstream of where the Minnesota joins the Upper Mississippi, the river pools behind another glacial remnant, the outwash of the Chippewa River. Lake Pepin, 21 miles long and averaging nearly 2 miles wide, is an unusual in-channel lake for such a substantial river. When the water slows, sediment drops out. Lake Pepin’s sediments contain a rare history of upstream land use.

The lake also focuses upstream pollution problems. At the height of the historic drought of 1988, low water and high nutrient levels led to severe algal blooms and fish kills in Lake Pepin. It catalyzed a growing concern for the health of the Minnesota River, widely believed to be the most polluted of the three major Mississippi tributaries that join around the Twin Cities. In 1992, then Governor Arne Carlson launched a cleanup program.

In 1995, soil scientist David Mulla was hired by the University of Minnesota specifically to work on some of the controversial issues surrounding restoration plans. It was assumed that the major pollutants were nitrogen, phosphorus, and sediment. At the time, state agencies were of the opinion that 80% of the sediment in the Minnesota River was from farm fields.
These seemed like fair assumptions: rivers and lakes all over the world suffered from a similar array of problems. Many freshwater ecosystems are phosphorus limited, and agricultural phosphorus from manure and fertilizer combined with urban sources were seen as a primary culprit. Yet something about the local history of the Minnesota River demanded further inquiry. Not only had it always run cloudier than the Mississippi and the Saint Croix, a few tributaries in particular seemed like outsized contributors to the problems.

In 2000, a chemical analysis of Lake Pepin sediments confirmed that between 80 and 90% of its sediment comes from glacial deposits predominantly in the Minnesota River Basin. That made sense: next to the Upper Mississippi and the St. Croix, it was the predominant agricultural watershed.

Mulla, an SSSA and ASA Fellow and current director of the university’s Precision Agriculture Center, began surveying stream banks on a tributary of the Minnesota River. It didn’t take long before he realized that a small number of stream bluffs were generating significant amounts of sediment. When flooding undercut an 80-ft bank, huge volumes of glacial till can be released in seconds. “They were just dropping directly into the tributaries,” he says. They initially estimated that perhaps 40 to 45% of the Minnesota River sediment was due to this streambank erosion.

Mulla and hydrogeologist Adam Sekely went on to look at how much phosphorus these banks were releasing into the Blue Earth River, a major tributary of the Minnesota. They estimated that maybe 7 to 10% of the phosphorus in the river was coming from the streambanks. Eventually, Mulla identified about 600 sites in the watershed that contribute roughly two-thirds of the sediment.

In 2009, Daniel Engstrom, director of the St. Croix Watershed Research Station of the Science Museum of Minnesota, published an analysis of sediments in Lake Pepin, showing that probably 70% of the sediment is coming from bluffs and ravines. Subsequent work solidified the finding. “Scientists have all come to agreement that the majority of the sediment in the Minnesota River is coming from bluffs and ravines and that field sources of sediment are relatively small—30%,” Mulla says.

Engstrom’s core samples told a distinctly human story. When European settlers introduced the plow, there was “a dramatic increase in sediment.” Since 1830, sediment loading has increased by an order of magnitude while phosphorus loading has increased sevenfold. Yet “the most dramatic changes in nutrient and sediment inputs to Lake Pepin have occurred since 1940,” he reports. Sediment accumulation rose sharply between 1940 and 1970 and then leveled.
off. The highest levels of phosphorus are recorded after 1970. Mulla and Sekely simultaneously reported that the Lake Pepin sediment phosphorus was significantly correlated with increases in row crop acreage, river flow, and discharges from metropolitan area wastewater treatment plants.

During the last 20 years, monitoring shows that urban sources of phosphorus have been in decline, primarily due to its removal from detergents and upgrades in wastewater treatment systems. It’s also presumed that agricultural sources have been declining; rising prices for phosphorus inputs have led to tighter management regimes, and modern cropping systems extract more from the soil. Has there been meaningful change? Monitoring of state river systems between 1976 and 2005 showed phosphorus levels remaining more or less constant. On a grander scale, phosphorus loading of the Mississippi River to the Gulf of Mexico shows virtually no decline in total phosphorus since 1980.

Where is the Phosphorus Coming from?

SSSA and ASA Fellow Satish Gupta looked at the relatively flat Minnesota landscape and tightening nutrient management practices and decided to look elsewhere for phosphorus. After working on a LIDAR evaluation of Blue Earth and the Le Sueur rivers that helped confirm that eroding banks were a major source of sediment, he pursued a novel legacy phosphorus concept: That the historical phosphorus found in Lake Pepin sediment cores did not come from farms, but from sewage and industrial waste phosphorus. Wastewater treatment plants were already known sources of phosphorus pollution. Gupta compiled other historical sources, including a massive slaughterhouse and a leaking fertilizer plant.

Gupta argues that sediments from bank collapse bound to this phosphorus and carried it to Lake Pepin. His conclusion: to “achieve a substantial reduction in total P loads to Lake Pepin, the major pathway is to eliminate bank sloughing.” But because, he argues, bank sloughing is mainly caused by natural forces, “elimination ... will be expensive, difficult, and likely unattainable.”

“The farmers, they are being blamed for something that they didn’t do,” Gupta says. “We’re not saying agriculture is not contributing anything,” he clarifies. “We do not believe that a lot of phosphorus is moving from the agricultural landscape.”

Phosphorus is tricky to study. It’s ubiquitous in natural systems, occurring in both dissolved and particulate form. Both dissolved and particulate phosphorus can come from streambank and bluff materials and from agricultural sources. Tracing the precise source, and the flux between particulate and dissolved form, has not yet been accomplished in the Minnesota River Basin.

Engstrom disagrees with Gupta’s interpretation of the Lake Pepin sediment record. While the narrative is plausible, it neglects the fact that the lake is still a river. Particulate phosphorus may settle out, but much of the dissolved phosphorus remains in the water or has been incorporated in algae, and most of this continues downstream. “There’s a whole lot of phosphorus that doesn’t go to the bottom,” Engstrom says. “He is only accounting for at most 20% of the phosphorus.”

Jacques Finlay, also at the University of Minnesota, adds that within the Minnesota River Basin, there is a lot of dissolved phosphorus that’s unaccounted for. “It’s just not on the radar screen,” he says. “The sources aren’t well defined, and they are elusive.” Research by his graduate student, Evelyn Boardman, suggests that the strongest correlation to phosphorus levels in the water is agricultural land.

How much of this dissolved phosphorus is simply from current agricultural practices or the result of legacy phosphorus is very difficult to say. Either way, some watersheds “are losing large amounts of phosphorus through dissolved pathways,” Finlay says.

Wherever the phosphorus is coming from, there is one thing we do know, Finlay says: “We haven’t improved water quality in proportion to the effort and dollars that we’ve put into the problem.”

That’s the crux of the challenge identified in “Sustainable Phosphorus Management and the Need for a Long-Term Perspective: The Legacy Hypothesis,” an opinion published in 2014 in Environmental Science and Technology and co-authored by SSSA President-Elect Andrew Sharpley, an SSSA and ASA Fellow. Another co-author, ASA member Heidi Peterson, is now a research scientist with the Minnesota Department of Agriculture and has spent time studying legacy phosphorus in the Albert Lea watershed, just to the south of the Minnesota River. “If you start with a simple balance, then you’re able to see if more is going into the system than is coming out,” she says.

Though the Albert Lea doesn’t have the same stream dynamics as the Minnesota River, the landscape
and cultivation history are otherwise similar. She found that farmers there have been very efficient with their inputs and outputs. “If we’re operating very efficiently and still seeing high phosphorus levels in our rivers and streams, then that means there is likely a legacy issue,” she explains. “It may be a long time before we see changes in water quality because of the legacy effect.”

**What’s Driving Increased Streamflows: Land Use or Climatic Changes?**

Phosphorus accounting cannot be divorced from sediment, and sediment issues are becoming phosphorus issues because of steadily increasing flows in the Minnesota River Basin. Debate about the causes turns on the question of agricultural drainage. Drain tile installation in the basin has increased steadily over the last few decades as corn and soy production has supplanted small grains. But precipitation levels have also steadily increased over that time.

“Uncertainty in separating these drivers of streamflow fuels debate between agricultural and environmental interests on responsibility and solutions,” says Shawn Schottler of the St. Croix Watershed Research Station in a study published in *Hydrological Processes* in 2014. He examined 21 Minnesota watersheds from 1940 and found that those with large changes in land use showed increases in seasonal and annual water yields of more than 50% since 1940. Changes in precipitation and evapotranspiration explained less than half of the increase. The bulk of the flow came from artificial drainage and the loss of natural water storage on the landscape.

Tom Kalahar spent more than 30 years as a conservation technician in the Renville Soil and Water Conservation District, and his experience confirms Schottler’s analysis. “We haven’t had a natural rain event for about 50 years,” he argues. “We store no water on the landscape anymore. We have directed every drop of water to get to the Minnesota River as rapidly as possible.”

David Mulla disagrees. “Yes, the flows in the Minnesota River have gone up a lot since the early 1900s, but what we’ve found is that a lot of that increase was due to changes in our climate,” he says, flipping the equation. “That’s responsible for at least 60% of the increase in the river flows. The other 40% is due to non-climatic effects: drainage, cropping system changes, development.” Satish Gupta makes a similar case, and in a 2015 Water Resources Research article argues that Schottler’s analysis “fails to fully account for similarity in the streamflow versus precipitation relationships … and in turn fails to tease out the true anthropogenic impacts.” Gupta’s methods and conclusions have drawn fire from several quarters, and rebuttals are working their way toward publication.

In 2012, the University of Minnesota–Twin Cities received a $4.3 million grant from the National Science Foundation to study interactions between water and land-use systems. The proj-
ect explores human-amplified natural change and benefits from the large body of research being generated by efforts to untangle the complexity of the Minnesota River Basin. Among the investigators is Patrick Belmont, now associate professor of watershed sciences at Utah State University. A hydrologist and geomorphologist, he first came to the National Center for Earth-Surface Dynamics at the University of Minnesota in 2007.

Belmont set out to build a sediment budget, finding all sources and sinks of sediments in the Le Sueur River, one of the most turbid tributaries of the Minnesota. Using geochemical fingerprinting, terrestrial LIDAR, field surveys, air photos going back eight decades, and an extraordinary amount of water and sediment gaging data from Minnesota state agencies, his team built all of this information into a single balance sheet.

“Between the bluffs and the streambanks and the channel just downcutting, those three sources were about 70% of the sediment,” he says. “That was the first time we could really say that on the landscape scale.” Agricultural fields contributed about a quarter of the sediment.

Comparing these findings with geochemical measurements in Lake Pepin sediment cores, they were also able to plot change over time. The geochemistry tells us that 500 ago, the sediment was all derived from channel sources: banks and bluffs. In the mid-20th century, there is an increase in sediments from field erosion, rich in agricultural chemicals. But over the last three decades, Lake Pepin sediment origins have switched back toward bluffs and banks. The amount of sediments hasn’t changed much, “but geochemically, we can see that the source has actually shifted,” Belmont says.

The good news is that agricultural sediment is down. The bad news is that it has been offset by increasing channel erosion. Drainage can increase water infiltration and thus decrease surface runoff. But the drain tiles are also increasing high flows, which are nearly doubled at high water.

“That makes the channel more dynamic. It’s moving around laterally more, so it’s eroding the banks and the bluffs more aggressively,” he says. And while increasing precipitation plays a role, he asserts there is no question drainage is the real driver.

The best proof of this, he says, comes from Efi Foufoula-Georgiou, a civil engineering professor in the University of Minnesota College of Science and Engineering and lead investigator on the NSF grant. She examined the conversion of cropland around the Minnesota River from hay and small grains to corn and soybeans, which has gradually swept across the basin. In the Le Sueur area for example, this happened in the 1950s and 1960s. The transition didn’t occur in the furthest reaches of the basin until 1991. This change in cropping systems is a proxy for drainage.

“If you track how the hydrology has changed according to when those land use conversions occurred, you can see very clearly that the hydrologic changes match land use conversion,” Belmont says. “Climate change has played some role. It is raining a bit more. But all the drainage has exacerbated those increased flows.”

The Debate Continues

Debate will certainly continue. The NSF team has a number of papers slated for release in the next few years while other researchers continue their work. Some of the state’s new water quality standards are also facing legal challenge.

David Mulla is encouraged by the development of aggressive new nutri-

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the reductions in residual agricultural nitrogen or nitrate discharge from Chicago caused changes in nitrate concentrations or loads in the river. The results are, however, strongly suggestive of the connections.”

Precipitation, River Flow Are Important Factors

Nitrate loads are strongly influenced by precipitation and river flow, which can be highly erratic. It is promising that nitrate loads have declined in recent years despite higher-than-average river flows. The five-year average river flow from 2007 to 2011 was the highest recorded since the start of measurement in 1939.

Nitrate concentrations, on the other hand, have declined more consistently since about 1990, which was a period of high concentrations. The reason for the divergence between nitrate concentration and load, explains McIsaac, is that the load is the product of both concentration and river flow and the flow is strongly influenced by precipitation while concentrations are not. Higher flows allow the river to carry more pounds of nitrate, but it doesn’t necessarily change the concentrations.

Whether nitrate concentrations and loads continue to decline in the future depends on several factors, according to the researchers. “If the annual river flows return to their 1976–2005 average values, and if nitrogen fertilizer efficiency remains high or continues to improve, there likely will be a decline in nitrate loads in the Illinois River,” David explains. “On the other hand, if river flows remain high, which may be a consequence of climate change, meeting the nitrate reduction goals will likely require more conservation effort than originally proposed.”

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ent reduction strategies, which have an interim goal of a 12% reduction by 2025. The toolkit is wide open, including cover crops, buffers, reduced tillage, optimization of fertilizer, and converting row crops to perennials. New in-ditch bioreactor technology is being developed to remove nutrients in place (learn more about the latest in bioreactor technology here: http://bit.ly/1TLFykv). And he remains hopeful that we’ll find a way to help stabilize collapsing river banks. “If we can find a solution, it would not need to cover a very large area,” he says.

Patrick Belmont is more interested in controlling flow. The good news for farmers is that he doesn’t think removing tile is the right solution. It’s not economically feasible and will ultimately just shift the sediment source back to agricultural lands.

“But we do need to slow the flow,” he cautions. That means installing wetlands and detention basins to temporarily store water locally. Slowing the rush to the river won’t be cheap but can be done in ways that not only reduce sediment, but also provide other benefits like nitrogen reduction. Another option would be to increase soil organic matter, which would also provide resilience to drought.

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