

Nitrogen and Phosphorus in Large Rivers

Nitrogen is a critical nutrient for plants and animals, and terrestrial ecosystems and headwater streams have a considerable ability to capture nitrogen or to reduce it to N₂ gas through the process of denitrification. Nitrogen cycling and retention is thus one of the most important functions of ecosystems (Vitousek et al., 2002). When loads of nitrogen from fertilizer, septic tanks, and atmospheric deposition exceed the capacity of terrestrial systems (including croplands), the excess may enter surface waters, where it may have “cascading” harmful effects as it moves downstream to coastal ecosystems (Galloway and Cowling, 2002). Other sources of excess nitrogen include direct discharges from storm water or treated wastewater. This indicator specifically focuses on nitrate, which is one of the most bioavailable forms of nitrogen in bodies of water.

Phosphorus is a critical nutrient for all forms of life, but like nitrogen, phosphorus that enters the environment from anthropogenic sources may exceed the needs and capacity of the terrestrial ecosystem. As a result, excess phosphorus may enter lakes and streams. Because phosphorus is often the limiting nutrient in these bodies of water, an excess may contribute to unsightly algal blooms, which cause taste and odor problems and deplete oxygen needed by fish and other aquatic species. In some cases, excess phosphorus can combine with excess nitrogen to exacerbate algal blooms (i.e., in situations where algal growth is co-limited by both nutrients), although excess nitrogen usually has a larger effect downstream in coastal waters. The most common sources of phosphorus in rivers are fertilizer and wastewater, including storm water and treated wastewater discharged directly into the river. In most watersheds, the atmosphere is not an important source or sink for phosphorus.

This indicator tracks trends in nitrate and phosphorus loads carried by four of the largest rivers in the United States: the Mississippi, Columbia, St. Lawrence, and Susquehanna. While not inclusive of the entire nation, these four rivers account for approximately 55 percent of all freshwater flow entering the ocean from the contiguous 48 states, and have a broad geographical distribution. This indicator relies on stream flow and water-quality data collected by the U.S. Geological Survey (USGS), which has monitored nutrient export from the Mississippi River since the mid-1950s and from the Susquehanna, St. Lawrence, and Columbia Rivers since the 1970s. Data were collected near the mouth of each river except the St. Lawrence, which was sampled near the point where it leaves the United States.

At the sites for which data are included in this indicator, USGS recorded daily water levels and volumetric discharge using permanent stream gauges. Water quality samples were collected at least quarterly over the period of interest, in some cases up to 15 times per year. USGS calculated annual nitrogen load from these data using regression models relating nitrogen concentration to discharge, day-of-year (to capture seasonal effects), and time (to capture any trend over the period). These models were used to make daily estimates of concentrations, which were multiplied by the daily flow to calculate the daily nutrient load (Aulenbach, 2006; Heinz Center, 2005; Runkel et al., 2004). Because data on forms of nitrogen other than nitrate and nitrite are not as prevalent in the historical record, this indicator only uses measurements of nitrate plus nitrite. As nitrite concentrations are typically very small relative to nitrate, this mixture is simply referred to as nitrate.

What the Data Show

The Mississippi River, which drains more than 40 percent of the area of the contiguous 48 states,

carries more than 10 times as much nitrate to the ocean as any other U.S. river. Nitrate load in the Mississippi increased noticeably over much of the last half-century, rising from 200,000-500,000 tons per year in the 1950s and 1960s to an average of about 1,000,000 tons per year during the 1980s and 1990s (Exhibit 1). This average decreased slightly to about 900,000 tons per year in the 2000s. Large year-to-year fluctuations are also evident. The Mississippi drains the agricultural center of the nation and contains a large percentage of the growing population, so it may not be surprising that the watershed has not been able to assimilate all the nitrogen from sources such as crop and lawn applications, animal manure and human wastes, and atmospheric deposition (e.g., Rabalais and Turner, 2001).

The Columbia River's nitrate load increased to almost twice its historical loads during the latter half of the 1990s, but by the last year of record (2014), the nitrate load had returned to levels slightly greater than those seen in the late 1970s (Exhibit 1). The St. Lawrence River showed an overall upward trend in nitrate load over the period of record from 1974 to 1996, and then a downward trend from 2008 to 2013 before increasing again in 2014. The Susquehanna does not appear to have shown an appreciable trend in either direction. Over the period of record, the Columbia and St. Lawrence carried an average of 66,000 and 67,000 tons of nitrate per year, respectively, while the Susquehanna averaged 49,000 tons. By comparison, the Mississippi carried an average of 792,000 tons per year over its period of record.

The total phosphorus load decreased in the St. Lawrence over the period of record (Exhibit 2). There is no obvious trend in the Mississippi, Columbia, and Susquehanna Rivers, and the year-to-year variability is quite large. Nitrogen and phosphorus loads tend to be substantially higher during years of high precipitation, because of increased erosion and transport of the nutrients to stream channels (Smith et al., 2003). Over the full period of record, average annual phosphorus loads for the Mississippi, Columbia, St. Lawrence, and Susquehanna were 150,000; 11,000; 5,000; and 3,000 tons, respectively.

Limitations

- The indicator does not include data from numerous coastal watersheds whose human populations are rapidly increasing (e.g., Valigura et al., 2000).
- It does not include smaller watersheds in geologically sensitive areas, whose ability to retain nitrogen might be affected by acid deposition (e.g., Evans et al., 2000).
- It does not include forms of nitrogen other than nitrate. Although nitrate is one of the most bioavailable forms of nitrogen, other forms may constitute a substantial portion of the nitrogen load. Historically, nitrate data are more extensive than data on other forms of nitrogen.
- Not all forms of phosphorus included in the total phosphorus loads are equally capable of causing algal blooms.
- The St. Lawrence has no data from 1997 to 2007 due to insufficient sampling.

Data Sources

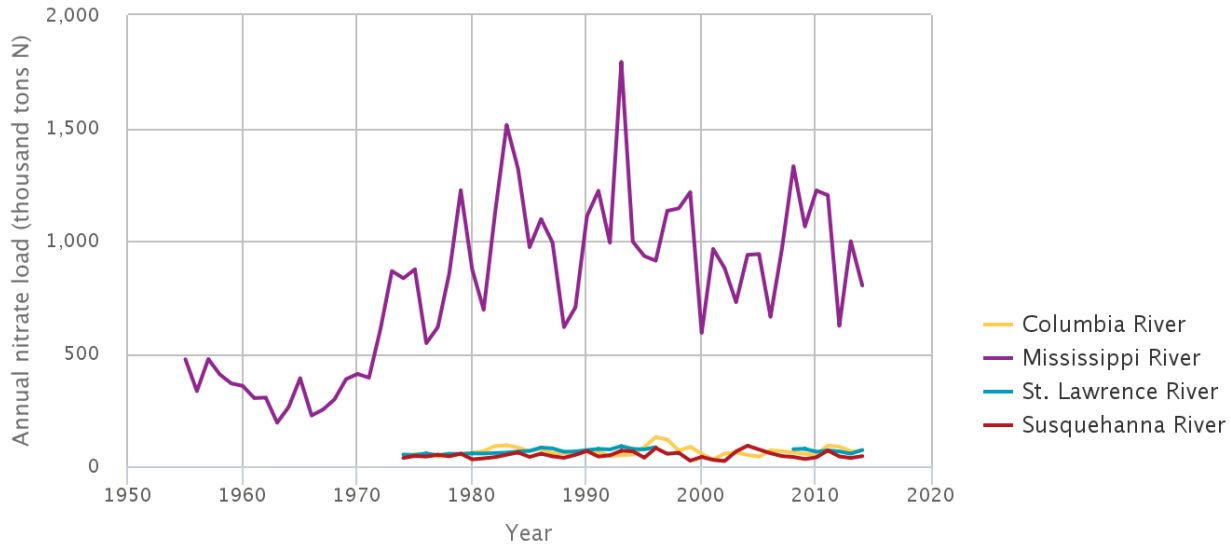
Data were collected and compiled by USGS. Historical nutrient loads for the Columbia, St. Lawrence, and Susquehanna were originally reported in Aulenbach (2006); portions of the Mississippi analysis were previously published in Goolsby et al. (1999) and a supplement to

Aulenbach (2006). Recent data were downloaded from a public USGS website at <http://cida.usgs.gov/quality/rivers>. This website provides nutrient sampling, daily stream flow, and nutrient load data as part of the USGS National Fixed Site Network (USGS, 2015).

References

- Aulenbach, B.T. 2006. Annual dissolved nitrite plus nitrate and total phosphorus loads for Susquehanna, St. Lawrence, Mississippi-Atchafalaya, and Columbia River Basins, 1968-2004. USGS Open File Report 06-1087. <http://pubs.usgs.gov/of/2006/1087/>.
- Evans, C.D., A. Jenkins, and R.F. Wright. 2000. Surface water acidification in the South Pennines I. Current status and spatial variability. *Environ. Pollut.* 109(1):11-20.
- Galloway, J., and E. Cowling. 2002. Reactive nitrogen and the world: 200 years of change. *Ambio* 31:64-71.
- Goolsby, D.A., W.A. Battaglin, G.B. Lawrence, R.S. Artz, B.T. Aulenbach, R.P. Hooper, D.R. Keeney, and G.J. Stensland. 1999. Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin—topic 3 report for the integrated assessment on hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series No. 17.
- Heinz Center (The H. John Heinz III Center for Science, Economics, and the Environment). 2005. The state of the nation's ecosystems: Measuring the lands, waters, and living resources of the United States. New York, NY: Cambridge University Press.
- Rabalais, N.N., and R.E. Turner, eds. 2001. Coastal hypoxia: Consequences for living resources and ecosystems. *Coastal and estuarine studies* 58. Washington, DC: American Geophysical Union.
- Runkel, R.L., C.G. Crawford, and T.A. Cohn. 2004. Load estimator (LOADEST): A FORTRAN program for estimating constituent loads in streams and rivers. U.S. Geological Survey Techniques and Methods Book 4, Chapter A5.
- Smith, S.V., D.P. Swaney, L. Talaue-McManus, J.D. Bartley, P.T. Sandhei, C.J. McLaughlin, V.C. Dupra, C.J. Crossland, R.W. Buddemeier, B.A. Maxwell, and F. Wulff. 2003. Humans, hydrology, and the distribution of inorganic nutrient loading to the ocean. *BioScience* 53:235-245.
- USGS (United States Geological Survey). 2015. Tracking water quality of the nation's rivers and streams. Accessed November 30, 2015. <http://cida.usgs.gov/quality/rivers>.
- Valigura, R., R. Alexander, M. Castro, T. Meyers, H. Paerl, P. Stacey, and R. Turner, eds. 2000. Nitrogen loading in coastal water bodies—an atmospheric perspective. Washington, DC: American Geophysical Union.
- Vitousek, P., H. Mooney, L. Olander, and S. Allison. 2002. Nitrogen and nature. *Ambio* 31:97-101.

Exhibit 1. Nitrate loads in four major U.S. rivers, 1955–2014

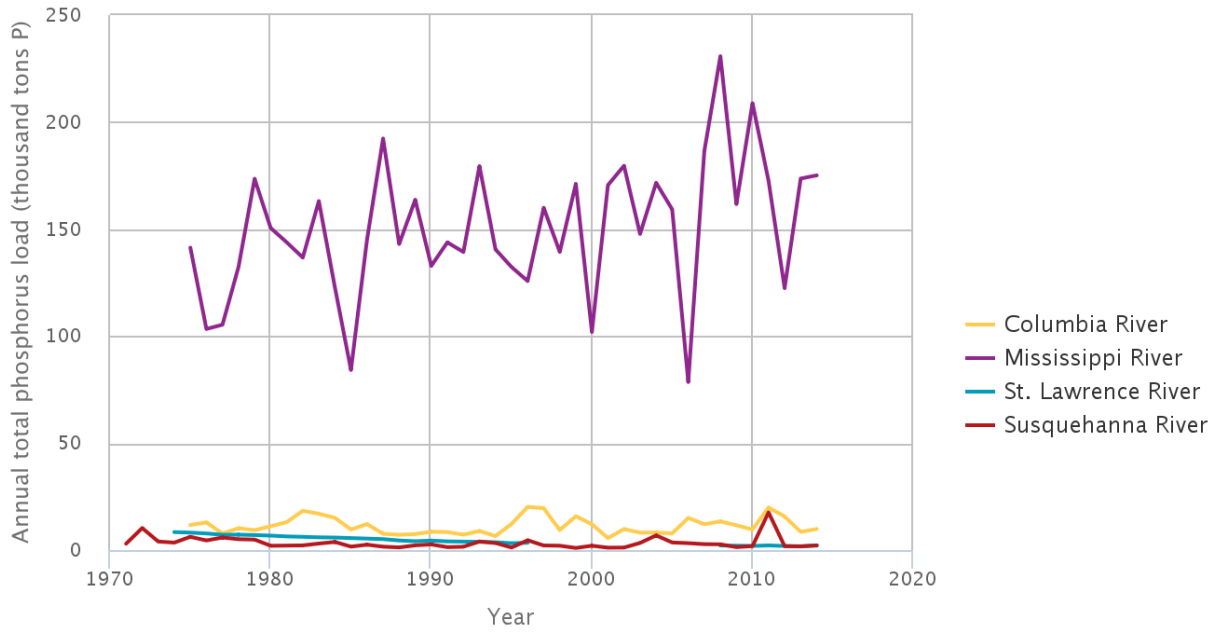


Most measurements include nitrate plus nitrite, but because concentrations of nitrite are typically insignificant relative to nitrate, this mixture is simply called "nitrate."

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: USGS, 2015

Exhibit 2. Total phosphorus loads in four major U.S. rivers, 1971–2014



Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: USGS, 2015