Science Societies

Environmental outcomes from on-farm agricultural production in the United States

Part 4: Water quality

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Farming activities have a significant impact on water quality across the United States as soil and water are inextricably linked. Nutrients and other substances applied by the farmer or deposited on the land in other ways, like dry deposition or dissolved in rainwater or irrigation water, contribute to the total loading of the nutrient or substance on a field. Most crop inputs, including organic and inorganic fertilizers and soil-applied crop chemicals, must be activated by water to be taken up by plant roots. In a perfect system, any soil-applied agricultural inputs would only be taken up by the root systems of target plants, which could be the crop absorbing nutrients or weeds imbibing herbicides. Unfortunately, crop inputs and soil particles (sediment) are often lost from farm fields during periods of high rainfall or irrigation. Eroded soil and lost inputs leaving the farm make their way into shared water resources through surface runoff, tile drainage, and infiltration through the soil profile to groundwater with numerous negative consequences for the downstream individuals and wildlife that rely on that water.

A primary barrier to understanding the impacts of conservation measures intended to improve the quality of water leaving farm fields through surface runoff, tile drainage, and infiltration through the soil profile is the confounding effect of variable rainfall. Intense rainfall and flooding accelerate soil erosion and the movement of sediment, crop nutrients, and protectants into surface waters and increase the volume of water (and the crop inputs dissolved within) moving through, and discharged from, tile drainage. In coarse, sandy soils, high precipitation may dissolve soil-bound inputs, causing them to be leached and lost to groundwater. Despite concerted efforts to optimize input applications and protect soil from erosion, extreme precipitation events can overwhelm those efforts, leading to downstream water quality impairment.

Conversely, during relatively dry years, precipitation may not exceed the water-holding capacity of the soil. In this case, very little water will leave the farm, thereby naturally reducing the amount of sediment and crop inputs entering surface and groundwater. For this reason, it is important to consider water quality outcomes in terms of long-term trends and indicators rather than measuring the success of any interventions with single-year measurements.

Although there is no shortage of examples of crop protectant chemicals such as herbicides being found in municipal drinking water supplies, excess nutrients in the water, principally nitrogen (N) and phosphorus (P), have led to decades-long efforts to reduce losses from farm fields. Nitrogen and P stimulate the growth of photosynthetic organisms, which is why they are so valuable to crop production and yields. But, when lost to aquatic systems such as rivers, lakes, bays, and gulfs, N and P stimulate the growth of photosynthetic algae, which leads to a cascade of negative impacts, including hypoxia (severely depleted oxygen levels). Hypoxic waters cannot support diverse aquatic populations. Fish and other mobile, aquatic animals can flee hypoxic areas, but stationary wildlife such as mussels, clams, and oysters have no such escape and die, creating dead zones.

Assessing Water Quality

Water quality is a complex environmental metric to measure and model, as it is affected by many site-specific factors, such as soil properties and topography. Further, it is influenced by both short- and long-term management decisions such as the timing of fertilizer application and type of tile drainage system installed. Field to Market's **Fieldprint Platform** uses the USDA-NRCS Stewardship Tool for Environmental Performance (STEP) to calculate each field's specific risk of nutrient loss. The estimate is based on soil and field physical properties, such as field slope and soil texture, and assesses the effectiveness of conservation practices at mitigating loss for four specific pathways: surface nitrogen loss, surface phosphorus loss, subsurface nitrogen loss, and subsurface phosphorus loss.

A Word About Phosphorus

Phosphorus is generally considered "immobile" in the soil, meaning it does not readily move from where it was applied. Over many years of farming and applying P to fields, the nutrient can accumulate in the soil and may be flushed out during significant precipitation events. Most P in the soil is in the particulate form or occluded within soil granules. This has led to the misconception that controlling soil erosion will effectively control P export from agricultural land (Baker et al., 2014), but recent developments have shown that a significant portion of P losses can be in the dissolved form (Baker et al., 2007; Joosse & Baker, 2011).

Water Quality Indicators

Here we will further examine the water quality trends of three large water bodies in the United States that have been profoundly affected by agriculture: the Chesapeake Bay, the Gulf of Mexico, and the Gulf's primary tributary, the Mississippi River. Trend analyses were drawn from meta-analyses of scientific research papers published by Chesapeake Progress, America's Watershed Initiative, and Virginia Marine Research Institute as well as government reports from the USEPA and NOAA.

Water Quality in the Chesapeake Bay

At 200 mi long, the Chesapeake Bay is the largest estuary in the United States. Connected to the Atlantic Ocean at its mouth in Norfolk, VA, the Bay is fed by 50 rivers originating in New York, Pennsylvania, West Virginia, Maryland, Delaware, Virginia, and the District of Columbia. The Chesapeake Bay Program, in partnership with the USEPA and other agencies and organizations, monitor the water quality of the Chesapeake Bay, which has been on the USEPA's Impaired Waters List for decades. Agricultural runoff is a primary non-point source of nutrients affecting water quality in the Bay. Since the Clean Water Act was implemented in 1972, efforts have been underway to clean up the Chesapeake Bay. Progress toward clean water goals is determined by measuring dissolved oxygen, nutrients, and chlorophyll (an indicator of algal abundance) in water at different depths along the Bay. Other variables are also measured, such as oyster and aquatic grass abundance. Results indicated slower-than-desired progress in reducing nutrient pollution from agriculture and urban areas in the early 2000s (Chesapeake Bay Program, 2019). In response, in 2010, the USEPA embarked on its largest cleanup effort to date: it established the Chesapeake Bay Total Maximum Daily Load (TMDL), a comprehensive and explicit limit on the amount of N (185.9 million lb), P (12.5 million lb), and sediment (6.45 billion lb) permitted to reach the waters of the Bay each year by 2025. To achieve these TMDL reductions, each of the six states on the Chesapeake Bay and the District of Columbia have implemented their own Watershed Implementation Plans (WIP). Figures 1–3 illustrate modeled nitrogen, phosphorus, and sediment loads to the Chesapeake Bay by source (Chesapeake Progress, 2019). Although agriculture is the primary source of nitrogen loading in the Chesapeake Bay, runoff from forests is the primary source of sediment.

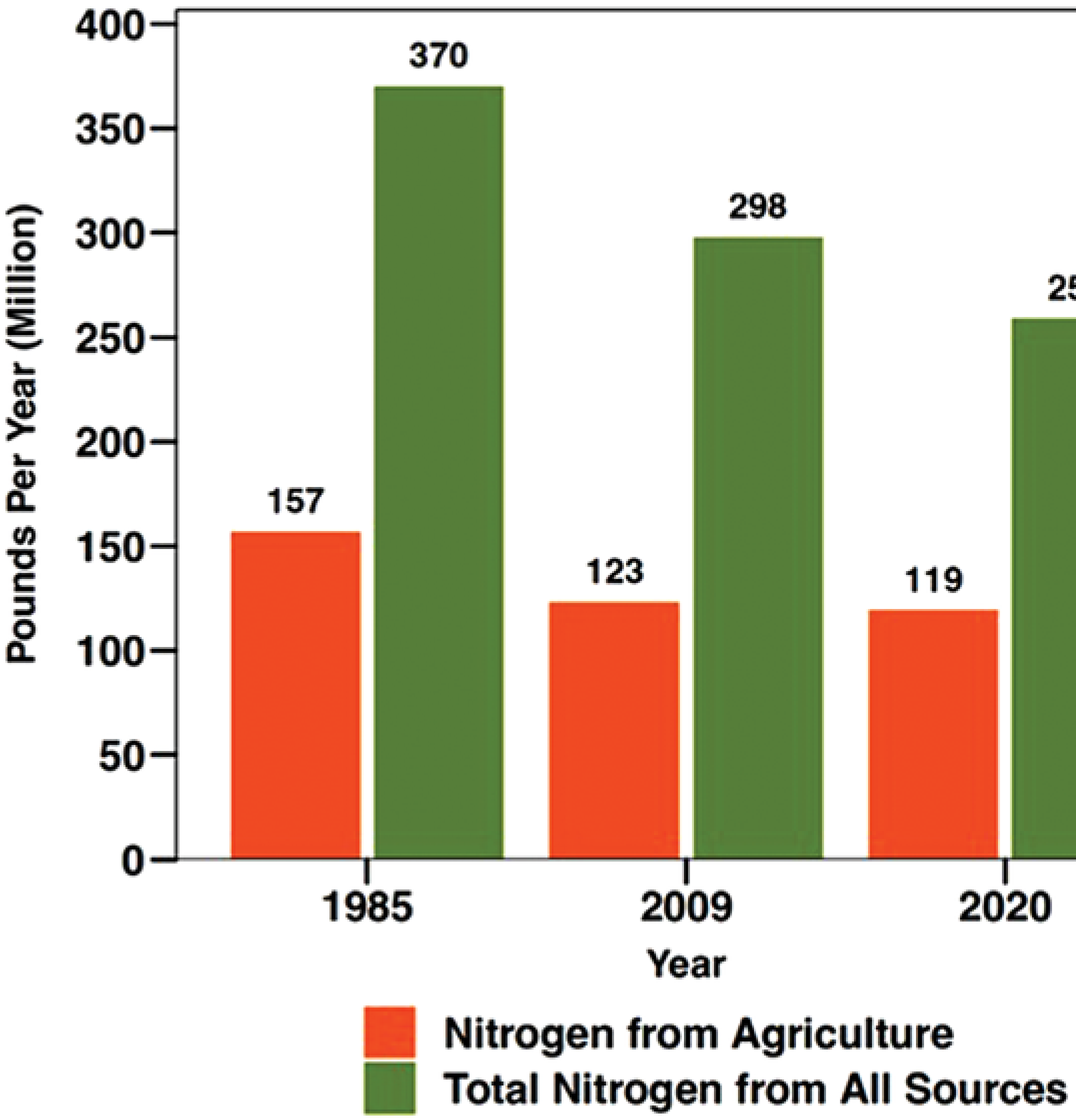


Figure 1, *Annual nitrogen loads in the Chesapeake Bay.*

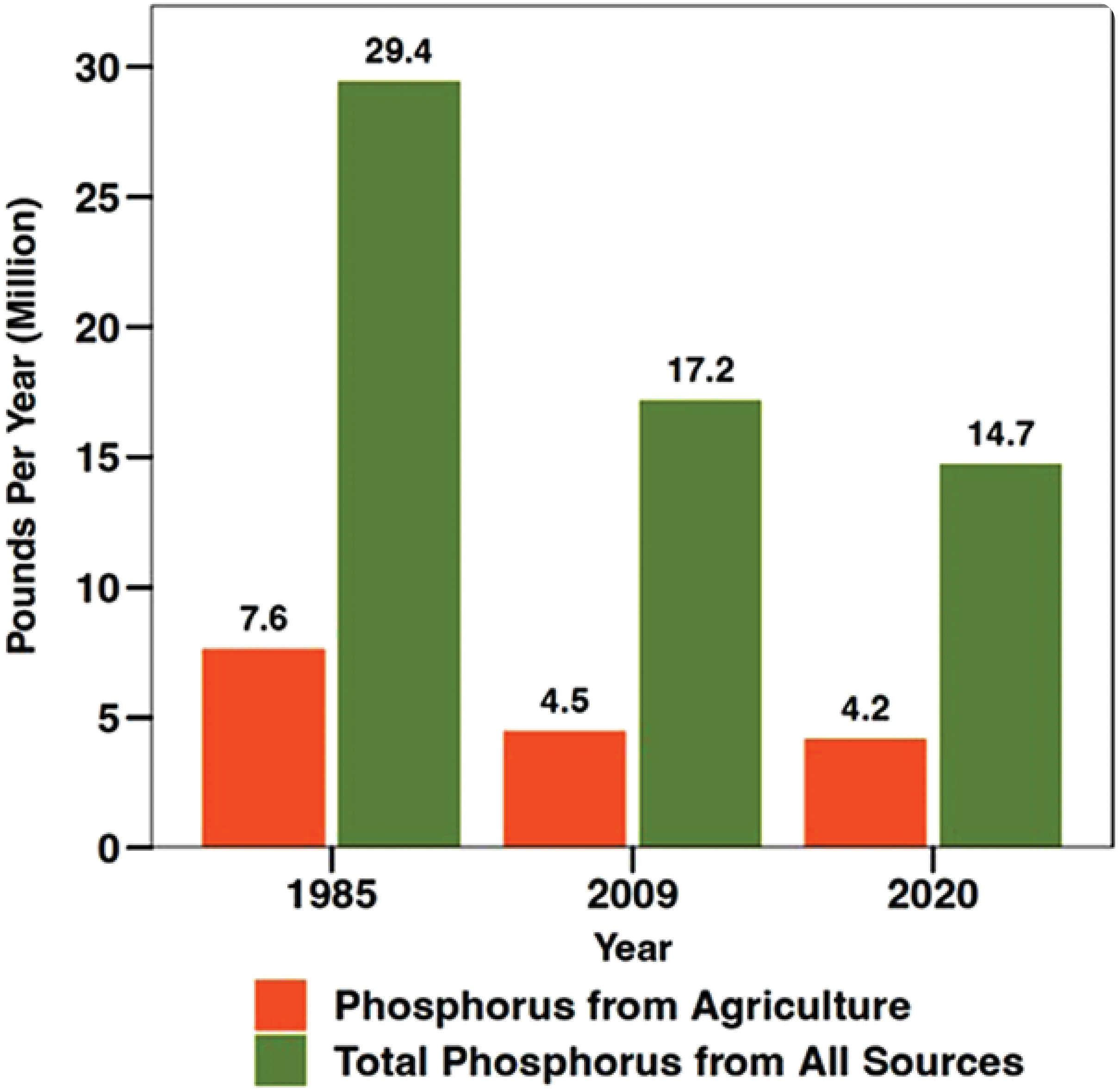


Figure 2, *Annual phosphorus loads in the Chesapeake Bay.*

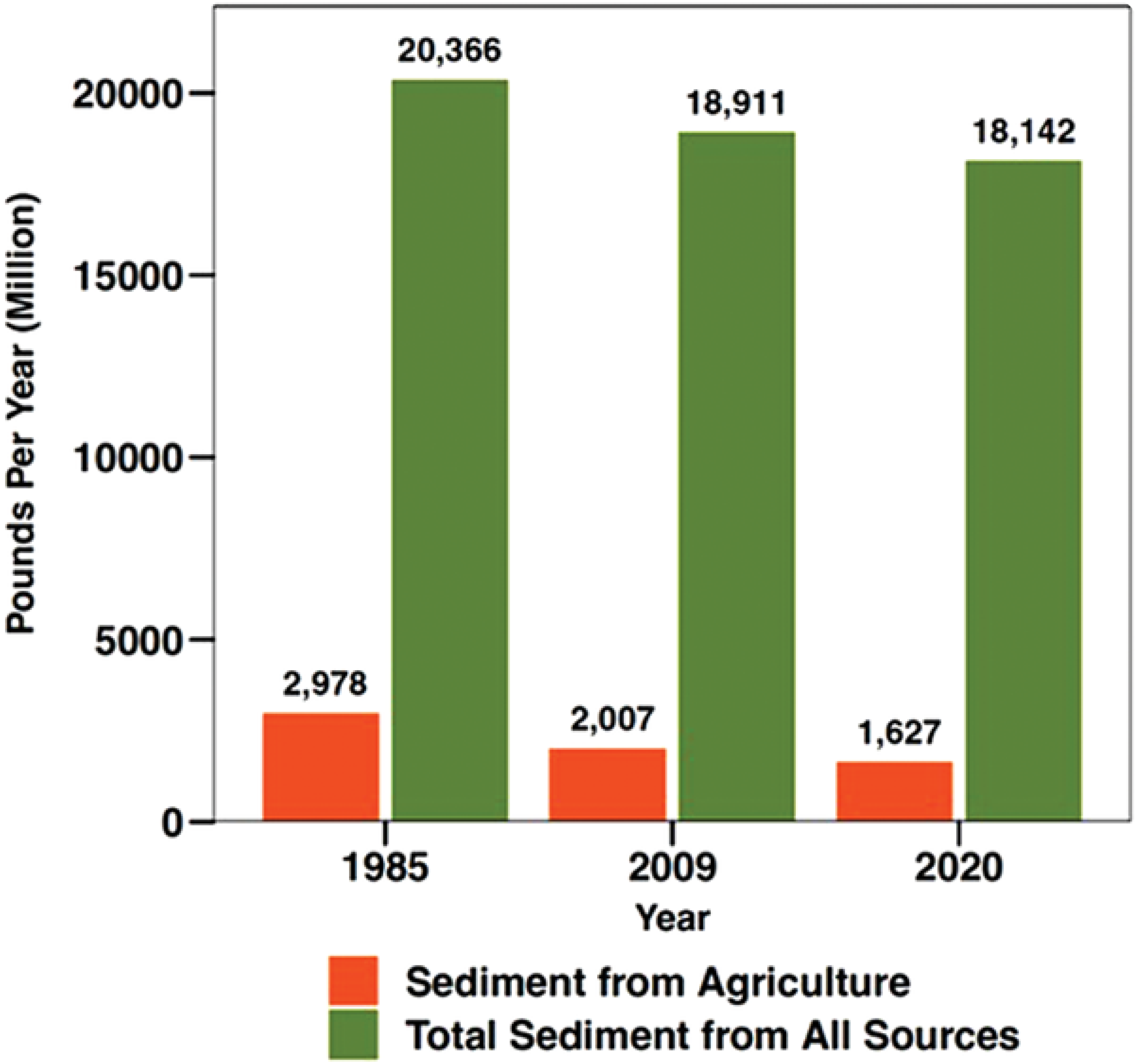


Figure 3, *Annual sediment loads entering the Chesapeake Bay from agriculture.*

Using regulatory frameworks for nutrient management and voluntary incentive programs, such as Maryland's Cover Crop Program, these states are expanding agricultural best management practices (BMPs) to reduce the loading of sediment, nitrogen, and phosphorus into the many rivers and streams that empty into the Chesapeake Bay. Among these BMPs are cover crops, eliminating or reducing tillage, nutrient management plans, and edge-of-field practices like grassed waterways and bioreactors, which are proven to reduce soil and input losses. Between 2012 and 2017, cover crop adoption in

Maryland grew 6% with about 33% of farmland planted in cover crops (Wallander et al., 2021). As a result of implementing these BMPs across the Chesapeake Bay watershed, nitrogen loads from agriculture were reduced by 3% between 2009 and 2020, phosphorus was reduced by 7%, and sediment by 19% (Chesapeake Progress, 2021).

In 2020, the volume of the hypoxic zone in the Chesapeake Bay was the seventh smallest ever recorded and lasted for a fairly short duration (Figures 4, 5 and 6).

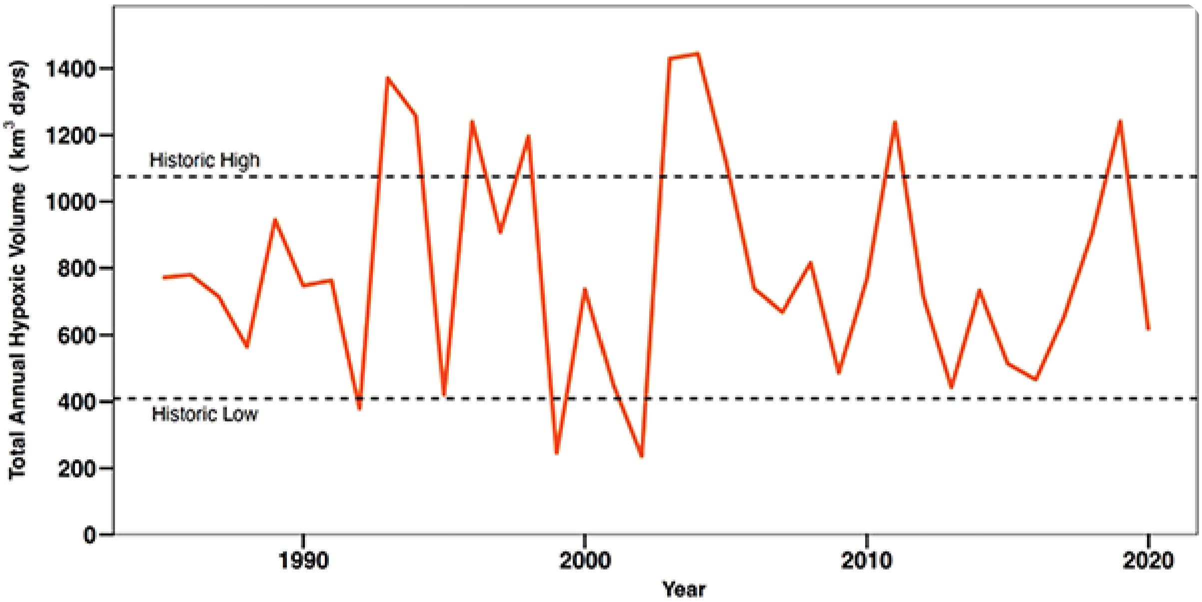


Figure 4, *Historic volume of the Chesapeake Bay Hypoxic Zone (Virginia Institute of Marine Science, 2021). Historical values represent the normal based on a 35-year simulation.*

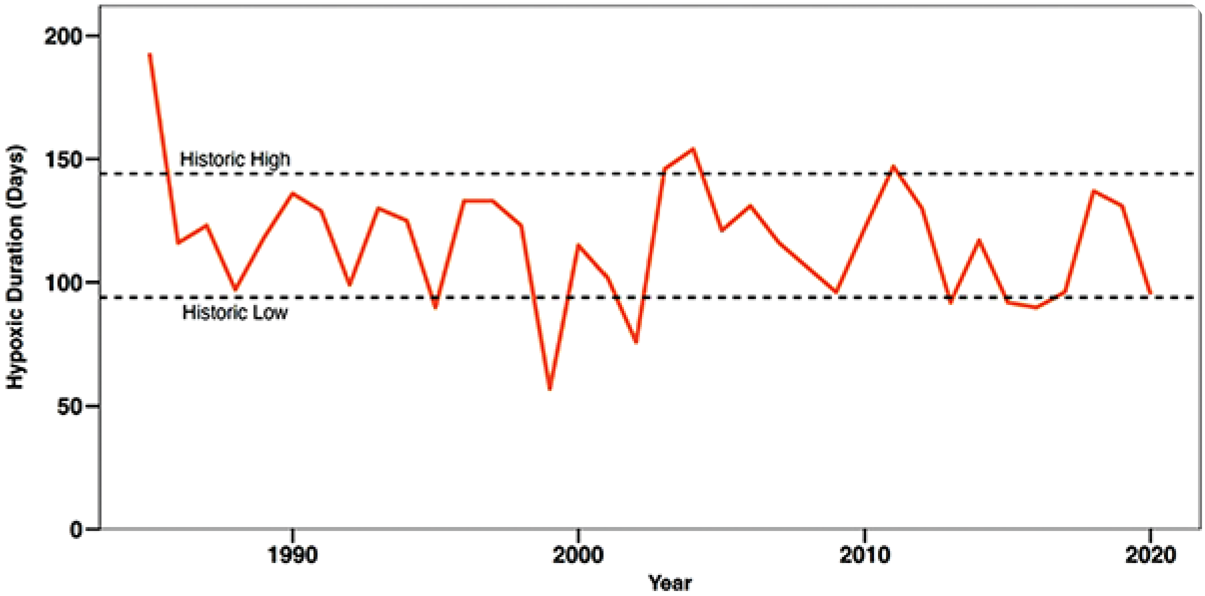


Figure 5, *Historic duration of the Chesapeake Bay Hypoxic Zone (Virginia Institute of Marine Science, 2021). Historical values represent the normal based on a 35-year simulation.*

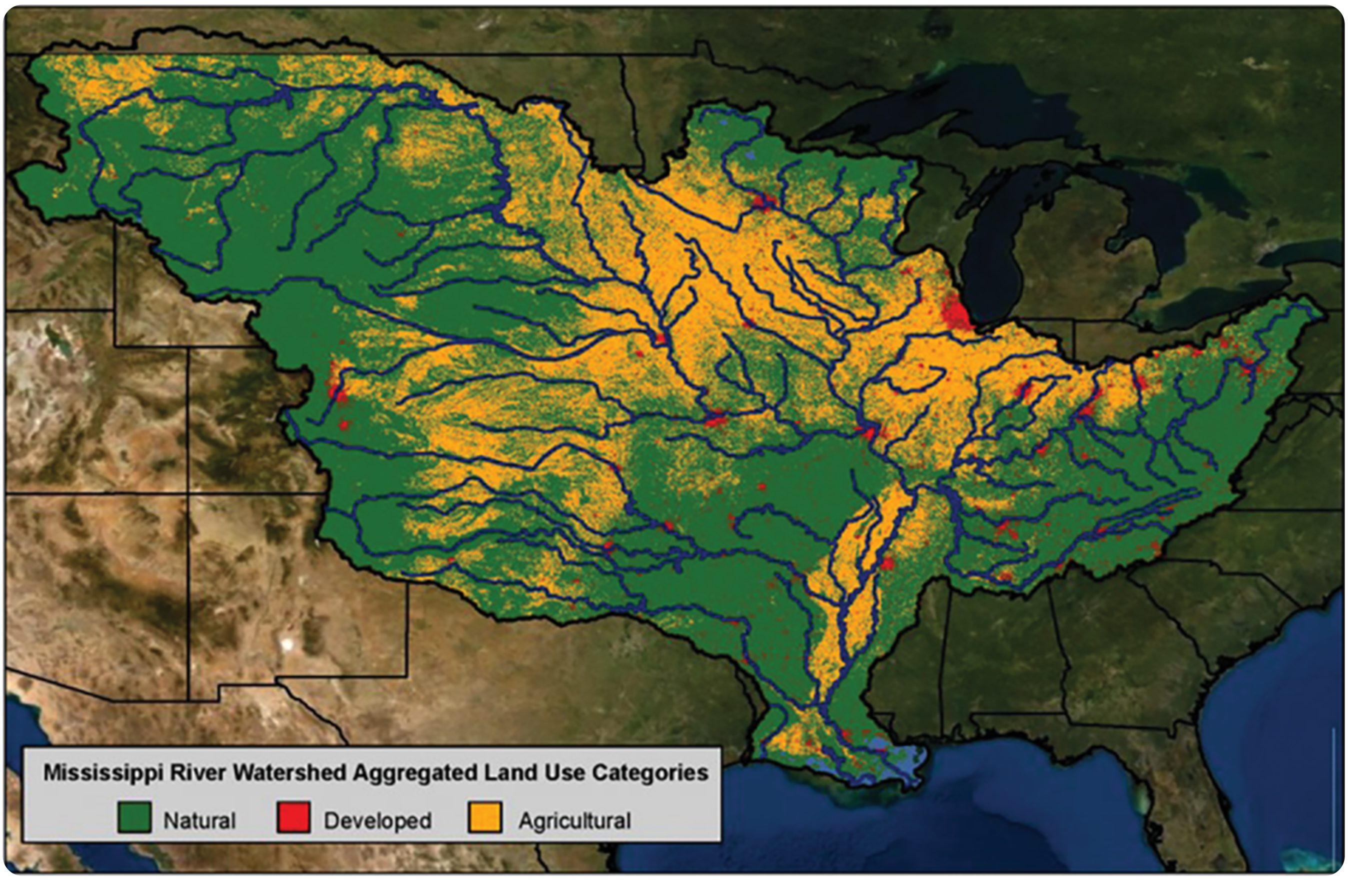


Figure 6, *Mississippi River Watershed land use categories.*

Water Quality in the Mississippi River, Gulf of Mexico

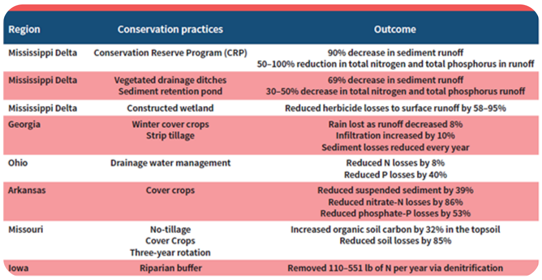
The Mississippi River watershed is the largest drainage area in North America, originating in Canada and emptying into the Northern Gulf of Mexico, 2,350 mi south. The watershed covers 1,245,000 s mi^2, which is 41% of the contiguous U.S., spanning 31 states. Fed by the Ohio and Missouri Rivers, plus hundreds of smaller tributaries that cut across agricultural lands, the Mississippi River has been significantly impacted by sediment and agricultural runoff containing fertilizer and chemicals. NOAA monitors the hypoxic zone in the Gulf of Mexico and publishes annual reports on the zone's anticipated size and duration (NOAA, 2020).

In 2020, the non-profit America's Watershed Initiative scored the Mississippi River watershed a "D," a downgrade from their 2015 assessment that earned a "C" (America's Watershed Initiative, **2020**). Nutrient concentrations, primarily N and P, increased over that time period, and it is estimated that more than 1.5 million tons of N enter the Gulf of Mexico via the Mississippi River every year with the majority of the excess nutrients coming from agricultural fields. Irregular weather patterns in the watershed, particularly flooding and drought, have a strong influence on the volume of water in the river, which also impacts the amount of sediment, nutrients, and other agricultural inputs carried within that water. Because of this relationship between weather and river water volume, it can be difficult to definitively tie water quality outcomes to upstream agricultural practices except over the long term.

Water quality in the Gulf of Mexico is impacted by the quality of water flowing down the Mississippi River. Nutrients entering the Gulf feed large algal blooms, which ultimately result in hypoxic zones, just as in the Chesapeake Bay. In 2017, the hypoxic zone reached a record 8,776 mi^2, the largest ever recorded. It should be noted that the hypoxic zone in the Gulf of Mexico is still largely measured and reported in units of area, rather than volume although volume offers insight into the depth of the zone, which has impacts on aquatic wildlife (Scavia et al., 2019). This is likely due to the large volume of water traveling down the Mississippi River. Mixing of surface and bottom waters as a result of tropical storms distributes oxygen throughout the water column and decreases hypoxia. Thus, a direct annual relationship between agricultural nutrient management and hypoxic zones is not expected. Instead, it’s important to consider the trends over long-time intervals and include consideration of other nutrient sources and hydrologic and weather conditions for the rivers as well as the coastal waters.

The outcome of reductions in nutrient and sediment loading on the size and duration of the hypoxic zone has not shown a clear trend. The area of the Gulf hypoxic zone was 2,116 mi^2 in 2020 (USEPA, 2021), the third smallest size recorded in the 34 years it has been tracked but was still larger than the 1,950 mi^2 goal set by the Hypoxia Task Force. This smaller size has been attributed, in part, to water mixing caused by the strong winds from Hurricane Hanna. Given the impact of weather variability from rainfall patterns across the Mississippi watershed on sediment and nutrient loads to the Gulf, and intensity and timing of tropical storms on the hypoxic zone extent, it is important to look at the long-term trend when determining whether progress is being made.

Gauging the Efficacy of Conservation Practices on Water Quality



Region	Conservation practices	Outcome
Mississippi Delta	Conservation Reserve Program (CRP)	90% decrease in sediment runoff 50–100% reduction in total nitrogen and total phosphorus in runoff
Mississippi Delta	Vegetated drainage ditches Sediment retention pond	69% decrease in sediment runoff 30–50% decrease in total nitrogen and total phosphorus runoff
Mississippi Delta	Constructed wetland	Reduced herbicide losses to surface runoff by 58–95%
Georgia	Winter cover crops Strip tillage	Rain lost as runoff decreased 8% Infiltration increased by 10% Sediment losses reduced every year
Ohio	Drainage water management	Reduced N losses by 8% Reduced P losses by 40%
Arkansas	Cover crops	Reduced suspended sediment by 39% Reduced nitrate-N losses by 86% Reduced phosphate-P losses by 53%
Missouri	No-tillage Cover Crops Three-year rotation	Increased organic soil carbon by 32% in the topsoil Reduced soil losses by 85%
Iowa	Riparian buffer	Removed 110–551 lb of N per year via denitrification

Table 1. *Efficacy of successful implementation of various best management practices to improve water quality outcomes from agriculture (Moriasi et al., 2020)*

The Conservation Effects Assessment Project (CEAP) was created in 2003 as a partnership between USDA-NRCS, the National Institute of Food and Agriculture (NIFA), other federal offices, and private entities to quantify the water quality impacts of government conservation practices and programs on a watershed at the regional and national scale

(Moriasi et al., 2020).

Conservation efforts to improve water quality focus on reducing sediment, nutrient, and crop protectants lost from agricultural fields, and therefore reduce these components entering surface and groundwater through runoff, infiltration, and tile drainage. In-field practices, including cover cropping and reducing or eliminating tillage, were evaluated as well as edge-of-field practices like drainage management and grassed waterways, singly or in combination. Table 1 summarizes a synthesis by Moriasi et al. (2020) focusing on CEAP assessments at the plot, field, and edge-of-field scales during the program's first 15 years.

Summary

Agricultural lands play a critical role in ensuring clean water for society and ecosystems throughout the country. Complex weather factors, and the complexity of the biogeochemical cycling of nutrients and the fate and transport of chemicals in the soil, make it particularly challenging to quantify water quality and to attribute changes to any specific cause. Therefore, tracking water quality change is a long-term endeavor. Fortunately, there is ample evidence from research at field and watershed scales that certain agricultural practices retain nutrients and soil in the field and thereby reduce the risk of losing nutrients and chemicals to waterways.

Research at the plot, field, and landscape scales looking at the effects on water quality of in-field practices like cover crops, reduced tillage, and edge-of-field practices, including riparian buffers and constructed wetlands, demonstrates measurable improvements in nitrogen, phosphorus, and sediment losses from farms. Although there has been a steady increase in the number of acres receiving NRCS Conservation Stewardship Program support for these practices between 2017 (728,607 acres) and 2020 (1,701,880 acres), this still only represents 1% of the total U.S. cropland (897,400,400 acres) (NRCS, 2021).

For these practices to reduce the negative impacts from agriculture on a watershed scale, they need to be implemented ubiquitously, according to local physical conditions and cropping systems.

Overall, the trends in water quality for economically important watersheds like the Chesapeake Bay and Gulf of Mexico over the past five years do not suggest improvement. Hypoxia in both areas remains problematic and is closely linked to precipitation patterns that either increase or decrease flow in the tributaries and the amount of nutrients, crop protectants, and sediment dissolved within.

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