Natural Resources Conservation Service
U.S. DEPARTMENT OF AGRICULTURE

Maximizing the Water Quality Benefits of Wetlands in Croplands

Conservation Effects Assessment Project (CEAP)
Conservation Insight

Key Takeaways

- Nutrient loads from croplands continue to negatively affect surface water quality, despite considerable investments in and adoption of agricultural conservation practices aimed at reducing nutrient losses.
- Numerous studies indicate that effective restoration and management of wetlands in and adjacent to cultivated croplands could reduce surface and subsurface nutrient loads to downstream waters.
- Current drainage basin-scale models do not effectively account for the local-scale processes that are important in understanding the functional variability of wetlands and their potential as conservation practices across different spatial and temporal scales.
- Findings presented here from a literature review and simulation modeling study help inform bottom-up field-scale modeling of nitrogen and phosphorus dynamics and improve our understanding of the capacity for wetlands to provide nutrient retention services in agricultural drainage basins to inform strategic agricultural wetland restoration.

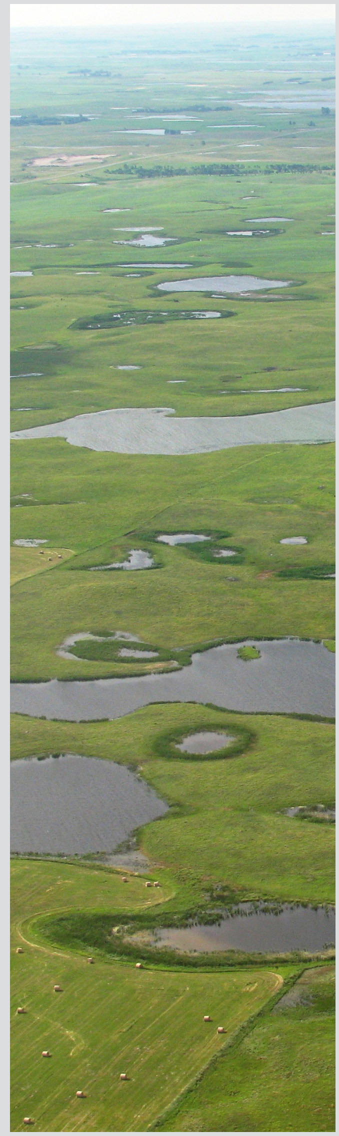
Conservation Investments to Reduce Agricultural Impacts on Water Quality

Nutrient inputs to agricultural land support high crop yields and food production. However, excess nutrients from croplands may move into downstream waters and negatively impact water quality. Excess nutrients in waterways may result in harmful algal blooms, low oxygen or hypoxic zones, and compromised water quality for human uses.

One region of high concern is the expansive Mississippi River Basin that drains into the Gulf of Mexico. This region contains the highly productive croplands of the Northern Plains, North Central, and Midwest Regions of the United States (Figure 1). In total, these three regions contain 175 million acres, or 55% of the United States' cultivated cropland, and have experienced the greatest expansion of cultivated acres from 2003–2016. (USDA-NRCS 2022).

In order to improve our understanding of the efficacy of conservation practices, the multiagency Conservation Effects Assessment Project (CEAP) uses natural resource and farmer survey data, along with modeling of physical processes, to quantify trends in cropland conservation practices, and associated outcomes, over time. The U.S. Department of Agriculture's (USDA's) National Agricultural Statistics Service (NASS) conducted the first set of farmer surveys in 2003–2006, known as CEAP I, with reports released from 2010 through 2014. These reports are available by region under the Croplands section on the CEAP Publications webpage.

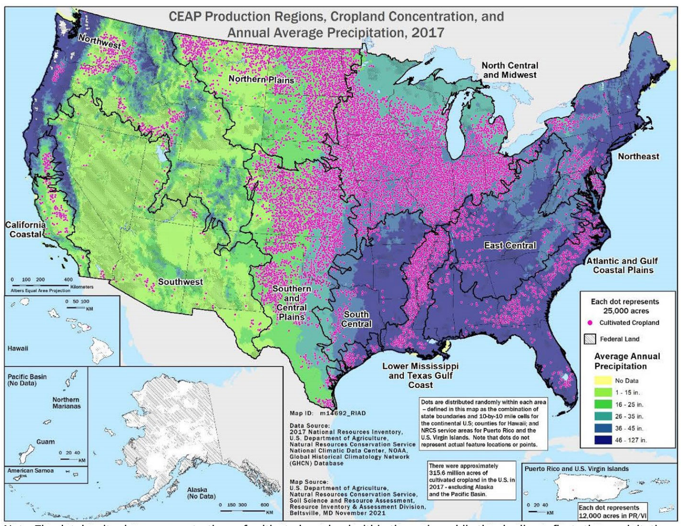
More recently, comparison data from farmer surveys conducted for 2013–2016, known as CEAP II, make it possible to estimate shifts in the adoption of conservation practices and their effects between the two CEAP survey periods (USDA-NRCS 2022). The national CEAP II report shows that investments in soil, water, and nutrient conservation practices continue to expand, and producer adoption of structural practices and conservation tillage, alone or in combination, increased by nearly 42 million acres nationwide between the two CEAP surveys. Despite the widespread expansion of conservation practices, nutrient inputs from croplands to streams, rivers, lakes, and the Gulf of Mexico continue to exceed reduction targets (Basu et al. 2022).



Prairie-pothole wetlands, and others across the United States, have capacity to capture cropland nutrients like nitrogen and phosphorus. By preventing these nutrients from leaving the local landscape and negatively impacting downstream water quality, wetlands play an important role in agricultural nutrient management.

Photo by USFWS.

Although progress has been made in reducing surface nutrient losses from cultivated croplands, soil incorporation of nutrient applications has declined. Consequently, the shifts in rate, timing, and method of nutrient application resulted in overall increases in subsurface nitrogen and soluble phosphorus losses from croplands to downstream waterways over the decade between the CEAP I and CEAP II surveys (USDA-NRCS 2022). This indicates that additional conservation practices are needed to alleviate nutrient inputs to downstream waters in order to achieve water quality goals. To that end, understanding the potential of wetlands as mitigation for both surface and subsurface nutrients is essential for guiding effective wetland restoration and management in cultivated croplands (Mitchell et al. 2022).



Note: The dot density shows concentrations of cultivated cropland within the region while the shading reflects the precipitation.

Figure 1. Conservation Effects Assessment Project (CEAP) Production Regions, Cropland Concentration, and Annual Precipitation.

The Potential of Wetlands to Benefit Downstream Water Quality

Wetlands have been shown to reduce nutrient concentrations in rivers located in intensively managed agricultural drainage basins (Golden et al. 2019). This has led to various field studies and modeling approaches to guide effective wetland restoration and management aimed at maximizing wetland ecosystem services such as nutrient retention (Cheng et al. 2020, Evenson et al. 2021, Hansen et al. 2021, Lane et al. 2022). Many of these approaches are top-down tools that can estimate the potential for wetland nutrient retention and transformation across large drainage areas, but may not accurately capture important local-scale variability. This local and field scale information is fundamental to understanding the capacity of individual wetlands to reduce downstream nutrient loads from cultivated croplands (McKenna et al. 2020).

To improve our understanding of local scale processes, this report summarizes results from the Ross and McKenna (2022) literature review of studies reporting field measurements of nitrogen and phosphorus storage, and processing rates, for depressional prairie-pothole wetlands. These wetlands provide important wildlife habitat and other ecosystem services and are found throughout parts of Montana, North Dakota, South Dakota, Minnesota, and Iowa. Empirical measurements of wetland nutrient processing efficiencies can be incorporated into field-scale modeling of these wetlands (McKenna et al. 2020) that can then be scaled up to improve estimates of wetland nutrient storage potential at basin-scale, for example in the Upper Mississippi River Basin (Evenson et al. 2021). Combining field data with local and landscape-scale modeling approaches can improve our understanding of these complex processes across drainage basins and lead to more effective investment of conservation dollars in cultivated croplands and adjacent wetlands.

Improving Models to Better Inform Conservation Strategies

The number of field studies in agricultural wetlands is limited, but this review highlights the variability of nutrient dynamics and their response to different hydroclimatic conditions. Overall, nitrogen retention by wetlands ranged from 15% to 100%, while phosphorus retention ranged from 0% to 100% (Figure 2). The published data also indicate that overall, prairie-pothole wetlands retain and process nitrate much more efficiently than phosphate (Figure 3). This is consistent with the variability of phosphorus retention observed in other wetland systems. As additional field data become available, there will be more opportunities to validate process models from the field scale to the catchment scale.

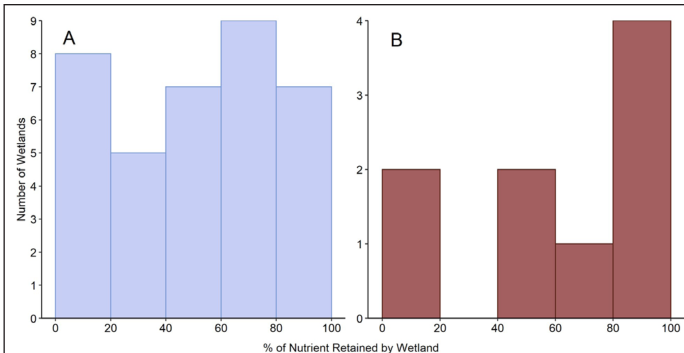


Figure 2. Distribution of percent nutrient retention in study wetlands. Panel A blue bars represent the number of wetlands within each range of percent nitrate retained. Panel B red bars represent the number of wetlands within each range of percent phosphate retained. Each bar represents 20 percent increments.

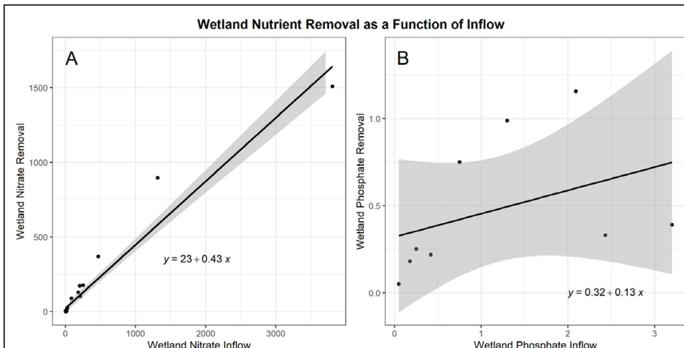


Figure 3. Linear regression models showing the relationships between nutrient inflows into wetlands and the amount of that nutrient removed by wetland. Panel A is the best-fit model for nitrate (R^2=0.94); (p=<0.001) and Panel B is best-fit the model for phosphate (R^2=0.03); (p=0.30). Gray shaded area represents 95% confidence interval.

The Agricultural Policy Environmental eXtender (APEX) is the physical process model used to assess field-level effects of conservation practices. APEX simulates day-to-day farming activities, wind and water erosion, loss or gain of soil organic carbon, and edge-of-field losses of soil, nutrients, and pesticides (Williams et al. 2006). McKenna et al. (2020) modified APEX to simulate wetland nutrient storage capacity, with results indicating that restoration of just 6% of a cultivated crop field to a wetland can reduce annual surface runoff by 8% and mean annual dissolved nitrogen (DN) and phosphorus (DP) losses by 29% and 28%, respectively (Figure 4). McKenna et al. (2020) also found the presence of the depressional wetland could lead to an average reduction of edge-of-field losses of sediments by 20% and of sediment-bound nitrogen (N) and phosphorus (P) by 23% and 19%, respectively.

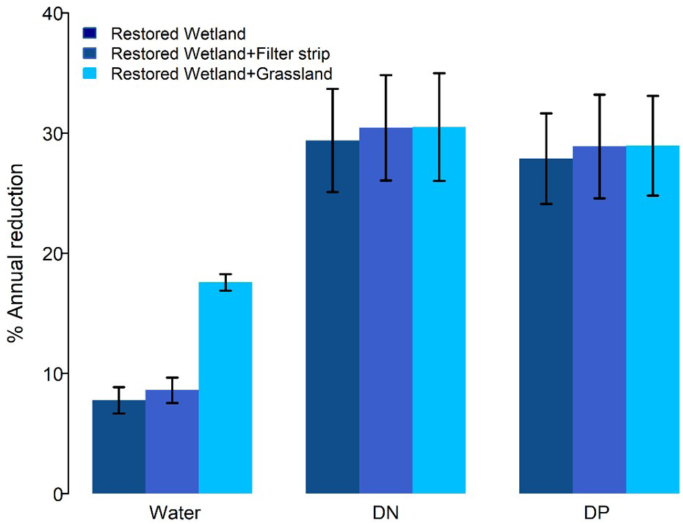


Figure 4. Percent annual reductions in runoff loss relative to a no-wetland scenario for surface water, dissolved nitrogen (DN), and dissolved phosphorus (DP) from a 16 ha field in corn-soybean rotation under three restored wetland scenarios. The dark blue bars represent mean percent annual reductions when a 0.92 ha drained wetland receiving runoff from 2.19 ha (of the 16 ha total) cultivated cropland was restored as a functioning wetland. The medium blue bars represent mean percent annual reductions when the 0.92 ha was restored as a functioning wetland along with 0.15 ha of the field surrounding the wetland converted to a grass filter strip. The light blue bars represent mean percent annual reductions when the cultivated cropland in the entire 2.19 ha wetland catchment is replaced by grassland. All scenarios were for a 30-yr simulation and include runoff from the remaining 12.88 ha outside the wetland catchment. Black error bars represent yearly variance as standard error.

A wetland's overall effectiveness and sustainability as a conservation practice to remove excess nutrients and sediment will be dependent upon upland management practices within its catchment. When considering wetland construction, restoration, or preservation as an agricultural conservation practice, it is important to note vulnerability to physical processes such as sedimentation, particularly when adjacent to cultivated lands. While wetlands can help reduce erosion and nutrient levels in downstream waterbodies, accumulation of sediments from agricultural runoff eventually leads to infilling of the wetland and reduced water storage capacity. Even a small buffer between cultivated cropland and the receiving wetland can reduce sedimentation and provide large conservation benefits, as evidenced by the model results when a 0.15 hectare (ha) grass strip or conversion of the catchment to grassland is included (Figure 5).

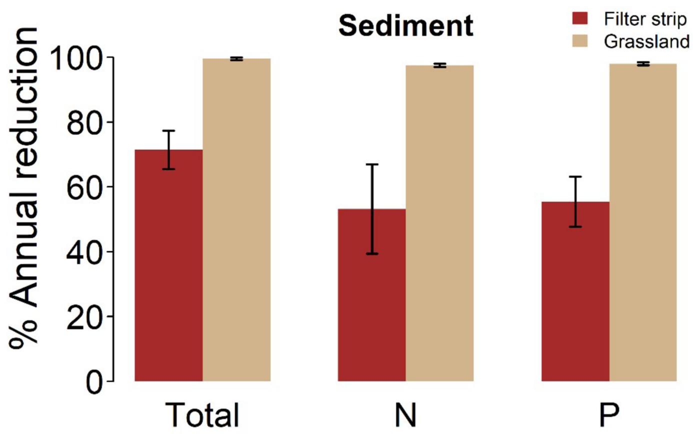


Figure 5. Percentage annual reductions of field-to-wetland sediment total, nitrogen (N), and phosphorus (P) inputs from a 2.19 ha catchment to the restored wetland during a 30-year simulation. Dark red bars represent mean percentage annual reduction in sediment-derived field-to-wetland inputs when a 0.15 ha grass filter strip surrounds the simulated depressional wetland. The tan bars represent mean percentage annual field-to-wetland reductions when the whole 2.19 ha catchment is converted from a cultivated crop field to a grassland. Black error bars represent yearly variance as standard error.

Implications for Conservation

Field-scale measurements and models allow for the incorporation of spatial and temporal variability into basin-scale models, thereby providing more accurate estimates of wetland nutrient storage potential across large river basins. One study concluded that targeted restoration of 22% of wetlands in the entire Mississippi River Basin could lead to as much as a 54% reduction in nitrate loading to the Gulf of Mexico (Cheng et al. 2020). Another study estimated restoration of 2% of wetlands in the Upper Mississippi River Basin would reduce mean annual nitrate loads by 12% (Evenson et al. 2021).

Continued interagency cooperation and coordination at the drainage basin scale is required to achieve substantial, economically viable improvements in water quality under intensive row crop agricultural production (Hansen et al. 2021). Wetlands are an important component of drainage basin management, but their functions are sensitive to landscape context, emphasizing the importance of integrating local variability into drainage basin-scale planning to realize potential benefits of wetland restorations. USDA's Agricultural Research Service and university partners, with support from CEAP, developed a GIS toolbox called the Agricultural Conservation Planning Framework (ACPF) to improve landscape planning and increase the efficacy of conservation planning at drainage basin scales.

ACPF can be used to identify areas within a watershed most vulnerable to runoff and leaching losses using elevation, soils, land use, and hydrology data, and then identify effective conservation practice options. These practices can include construction of nutrient removal wetlands and wetland restoration designed to intercept overland or tile-drained flows, decrease erosion potential, and/or increase retention time allowing denitrification and phosphorus removal. The data summarized here will help improve these modeling efforts and inform more effective conservation planning and increased accuracy of outcome assessments.

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Conservation Effects Assessment Project: Translating Science into Practice

The Conservation Effects Assessment Project (CEAP) is a multiagency effort to build the science base for conservation across the nation's working lands. Project findings are used to guide conservation program development for the U.S. Department of Agriculture (USDA) and support conservationists, agricultural producers, and partners in making informed management decisions backed by data and science.

One of CEAP's objectives is to quantify the environmental benefits of conservation practices for reporting at the national and regional levels. CEAP Wetlands assessments complement national assessments for cropland, wildlife, and grazing lands to support conservation actions on a variety of landscapes. The CEAP Wetlands team works with numerous partners to support relevant assessments.

This project was conducted through collaboration among USDA's Natural Resources Conservation Service (NRCS) and researchers from the U.S. Geological Survey (USGS), Northern Prairie Wildlife Research Center. Primary investigators on this project were Owen McKenna and Caryn Ross of USGS. This Conservation Insight was written by Owen McKenna, Caryn Ross, and Joseph Prenger, CEAP Wetlands Lead.

Visit the CEAP Wetlands webpage at nrcs.usda.gov/ceap/wetlands for more information, or contact Joseph Prenger at joseph.prenger@usda.gov.

Wetland in the Kulm Wetland Management District, located in North Dakota.

Photo by USFWS.