Nutrient Reduction and Biodiversity Impacts from Agricultural Best Management Practices in the Lower Mississippi River Basin

PREPARED FOR THE WALTON FAMILY FOUNDATION

Image credit : USDA NRCS

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Contents

Executive Summary

Nutrient runoff from agriculture and other sources in the Mississippi River Basin (MRB) impacts local water quality and contributes to the annual formation of the “dead zone” in the Gulf of Mexico (GOM). The Lower Mississippi River Basin (LMRB) is intensely cultivated and contributes a significant portion of the nutrients delivered annually to the Gulf; although the region encompasses less than 9% of the area of the MRB the LMRB delivers an estimated 11% of the nitrogen and 23% of the phosphorus to the Gulf each year. The loss and degradation of wetlands and floodplain forests has compounded this problem and reduced the capacity of the ecosystem to mitigate agricultural impacts on various ecosystem services, including water quality and biodiversity.

Agricultural best management practices (BMPs) such as cover crops, restored wetlands, reduced tillage and nutrient management can reduce the loss of nutrients and sediment, and mitigate the environmental impacts of agriculture. However, BMP effectiveness varies across the landscape, and different practices have different outcomes for water quality and habitat (Kroger et al., 2012). Additionally, the LMRB has very different climate, landscape, and management characteristics from those of the well-studied agricultural areas of the upper Midwest, requiring an examination of the potential benefits of BMPs specific to the LMRB.

This report synthesizes existing peer-reviewed literature on BMPs typically employed within the LMRB (over 85% of which is the Mississippi Alluvial Valley and the remaining is the loessal bluffs that surround the Mississippi Alluvial Valley) and their effectiveness at reducing nutrient and sediment loss. We distinguish between three categories of BMPs: 1) “in-field” practices that are implemented within fields growing commodity crops; 2) “edge-of-field” practices that generally occur on the farm but at the periphery of fields in production and not in the same area as active cultivation; 3) “downstream” practices that are off-farm and tend to be larger restoration projects. The review also addresses impacts on from both in-field management and conservation practices, like winter rice field management, cover crops, and irrigation management, as well as edge-of-field and downstream practices like wetland restoration and floodplain restoration.

Further, barriers to adoption of conservation practices are also addressed and opportunities for future work in the LMRB to reduce impacts to water quality and biodiversity identified. The primary barriers to adoption within the LMRB states include:

1. Technical difficulties in situating edge of field practices in a highly altered and channelized landscape.
2. The presence of a large percentage of non-operating landowners (>60% of all farm land is rented in the MAV) who are hesitant/ unable to adopt practices on rented land.
3. Financial barriers to adopting BMPs and limited access to federal and state cost-share dollars.

Factors like partnerships with a conservation champion farmer, dedicated local NRCS staff, grassroot organizations that can build coalitions for larger restoration projects and resource commitments such as help with administrative processes could encourage adoption of BMPs.

We identify three opportunities/needs within the LMRB for future work including:

1. Prioritization and targeting of watershed level wetland and floodplain restoration and other BMPs to cost-effectively reduce nutrient loss to the basin.
2. Development of a robust monitoring network within the basin to demonstrate the benefits from BMPs as well as leverage the use of watershed models for future assessments.
3. Establishment of partnerships across scales to support conservation practice adoption and restoration.

1. Introduction

The LMRB that includes the Mississippi Alluvial Valley covers parts of Louisiana, Mississippi, Tennessee, Missouri and Arkansas containing 68 million acres of land, a third of which is cropland. It receives nutrient-laden water from the Upper Mississippi River Basin, the Ohio-Tennessee River Basin, Arkansas-Red River and Missouri River Basins and delivers water into the Gulf of Mexico. The Conservation Effectiveness Assessment Project estimates that nutrient loss from upstream sub-basins deliver about 2.8 billion pounds of nitrogen annually to the LMRB and the basin contributes a further 400 million pounds of nitrogen to deliver a load of 3.2 billion pounds of nitrogen annually to the Gulf (USDA et al., 2013). The basin also delivers 326 million pounds of phosphorus annually to the Gulf, 75 million pounds of which originates in the basin.

This nutrient loss impacts local water quality and contributes to the annual formation of the "dead zone" in the Gulf of Mexico (GOM). The loss and degradation of wetlands and floodplain forests has compounded this problem and reduced the capacity of the ecosystems in the LMRB to mitigate agricultural impacts on various ecosystem services including water quality and biodiversity. Agricultural best management practices (BMPs) such as cover crops, restored wetlands, reduced tillage and nutrient management can reduce the loss of nutrients and sediment and mitigate the environmental impacts of agriculture. BMP effectiveness varies across the landscape, different practices have different outcomes for water quality, habitat and other benefits (Kroger et al., 2012), and there is a time lag between implementation of BMPs and achieving the desired outcomes. Information about the effectiveness of various BMPs in different locations in the LMRB can enable farmers and resource managers to target their implementation on the landscape. Further, the feasibility of implementing BMPs varies as it depends on eligibility for federal and state cost-share support and different levels of interest and acceptance by producers.

The Mississippi Alluvial Valley has fine-textured, fertile alluvial soils that make it highly suitable for agriculture. There are several features, however, that make the MAV and the larger LMRB significantly different from the upstream sub-basins in the Midwest; including geomorphology, hydrology and cropland management. The region produces 70% of all the rice grown in the US, 26% of cotton and 9% of all the soybean crop. Continuous soybean, continuous cotton and rice-soybean rotations are the most common rotations. It also has the most irrigated acres of all the basins in the Mississippi River Basin (MRB). 46% of all acres are irrigated including all the rice acres (USDA et al., 2013).

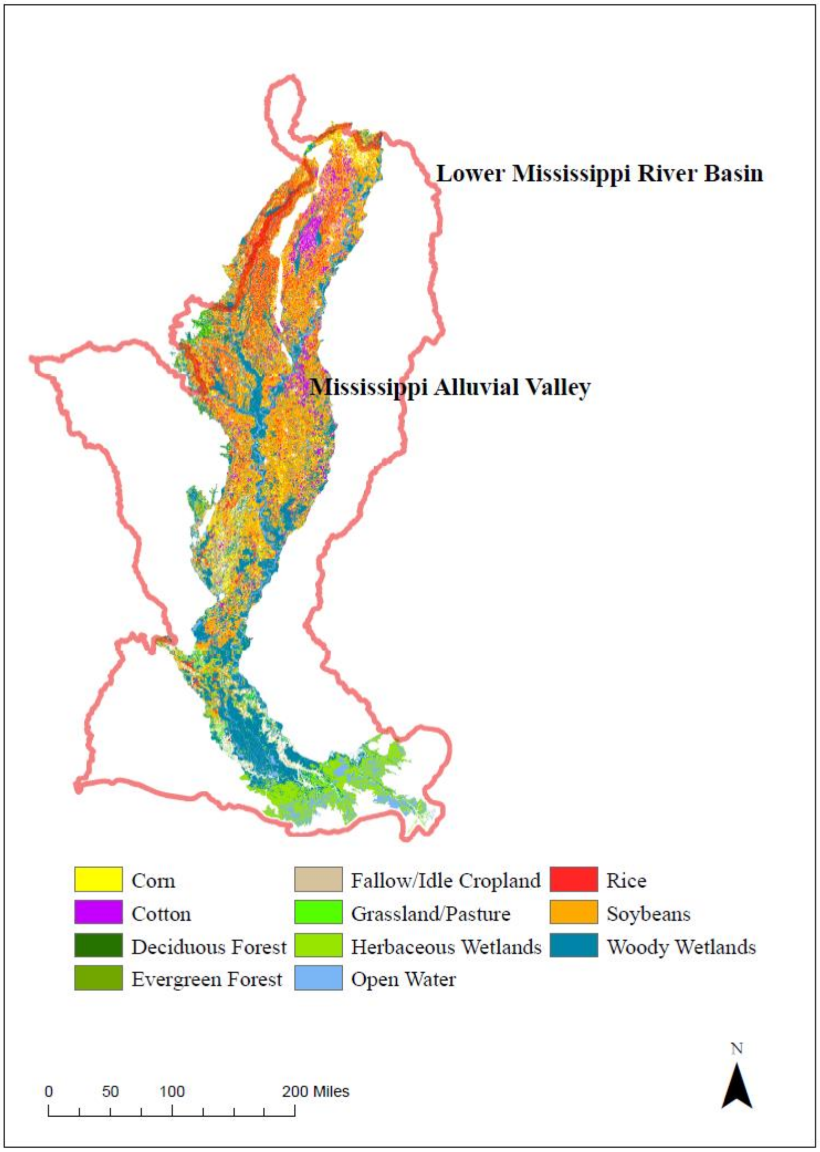


Figure 1: Extent of the Lower Mississippi River Basin (LMRB) and the Mississippi Alluvial Valley (MAV) and major Crops in the MAV. Data from 2018 Cropland Data Layer

Further, the MAV was originally covered by primarily floodplain forests, swamps and riverine wetlands, over 75% of which have been converted to cropland. This conversion also resulted in a complex system of ditches and levees that convey water away from the cropland (Locke, 2009).

The silt and clay alluvial soils have very poor soil porosity and hydraulic conductivity (Kröger et al., 2013a) meaning they don’t drain well. Ditches and other artificial surface drainage systems are used to transport water away from cropland, increasing the loss of nutrients from farms and causing significant impacts on surface and ground water. Irrigation, commonly used in cropland in the basin, increases the loss of nutrients and exacerbates impacts on local water quality and on movement of nutrients to the Gulf of Mexico (Kröger et al., 2007). Although much of the BMP literature is based on studies in the Midwest, it is important to study BMP effectiveness in the LMRB both due to difference in the physical and hydrological characteristics of the system, and because of the significant management differences, that call for a different suite of BMPs to be used in the basin. Further, Marshall et al. (2018) looked into cost-effective strategies to reduce nutrient runoff to the GOM and found that cost per unit of nutrient reduction were lowest in the LMRB because of its proximity to the Gulf and lower assimilation time through streams (Marshall et al., 2018). Therefore, practices to reduce nutrient runoff in the LMRB are crucial to achieving the nutrient reduction goals in the entire Mississippi River Basin.

This report investigates existing peer-reviewed literature on in-field, edge of field and downstream BMPs and their efficiencies within the MAV. The review will also address impacts on habitat from management and conservation practices on the field, like winter rice field management and cover crops, as well as edge of field practices like wetland restoration. From conversations with key local experts we identify barriers to the implementation of conservation practices in the basin and future opportunities and strategies to manage the landscape and reduce the impacts of agriculture on water quality and biodiversity in the LMRB.

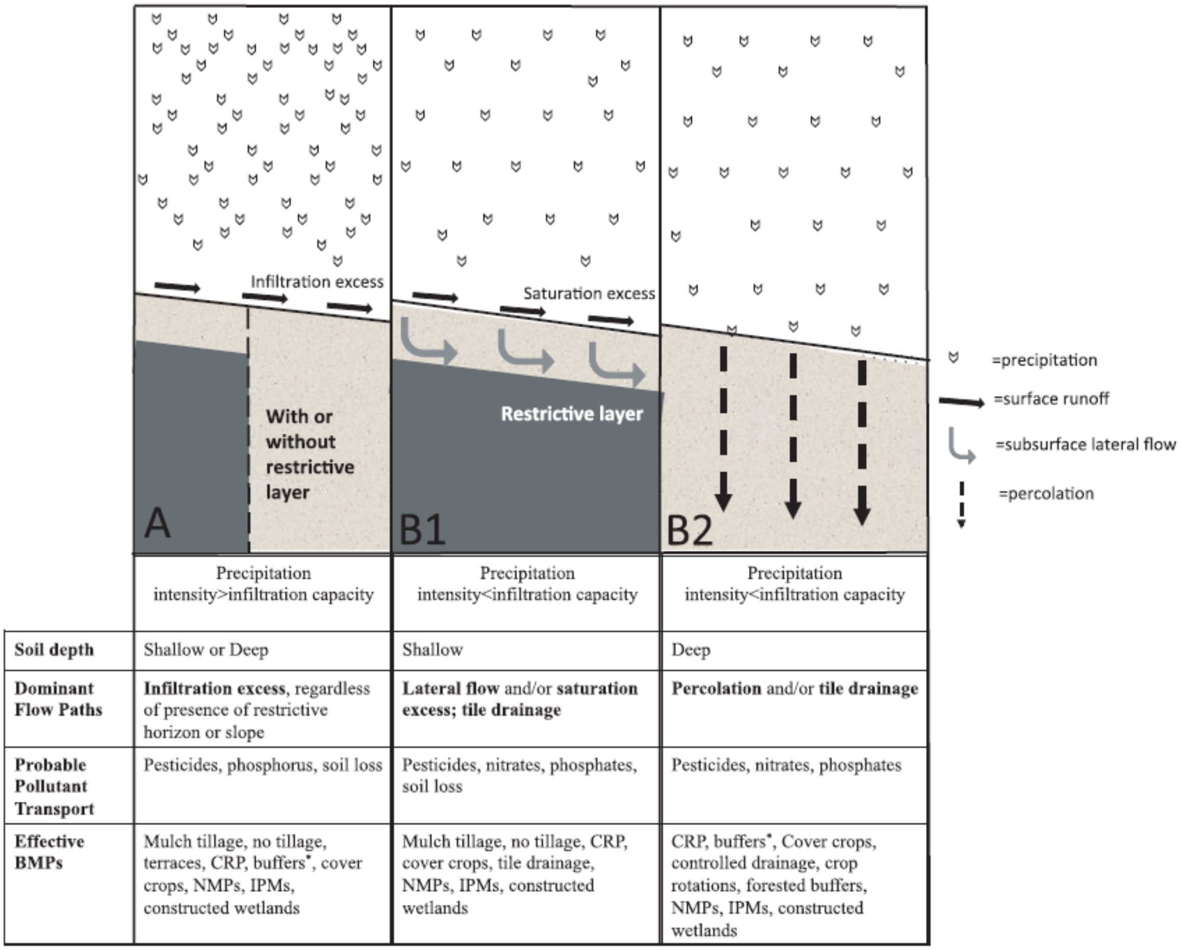
2 Effectiveness of Best Management Practices (BMPs) at reducing nitrogen, phosphorus and sediment loss the MAV

Nitrogen and phosphorus can be transported off fields through multiple pathways including overland surface runoff, subsurface flow, irrigation runoff or erosion. BMP effectiveness depends on climatological, topographical and soil properties as well as the hydrology (Rittenburg et al., 2015) and these site characteristics determine whether BMPs that avoid, control or trap nutrients and sediment could be optimally applied. While there are a number of reviews for the effectiveness of various BMPs in the Upper Mississippi River basin, there are fewer such studies in the MAV (Kroger et al., 2012; Merriman et al., 2009). The following section provides a review of existing literature on BMP effectiveness in the Lower Mississippi River Basin documenting evidence on how efficient individual BMPs are at removing nitrogen, phosphorus and sediment from the landscape.

2.1 Methodology

For this review, we follow a methodology cited in Kroger et al.'s (2012) review of best management practices and update the review with newer studies and practices between 2012-2019. We looked at studies that were field/experimental plots and paired watersheds that had quantitative data on the impacts from best management practices on Nitrogen (N) and Phosphorus (P) reduction. A previous BMP tool developed by Merriman et al. (2009) for Arkansas was also used as a database for effectiveness statistics (Merriman et al., 2009). The studies were prioritized according to their relevance with the MAV: high priority studies that were included were primarily based in the MAV or the MAV states, BMPs were implemented on row crop land that corn, soybeans, cotton or rice, which are the major crops in the LMRB. In addition, a search was run in Google Scholar to find studies in the MAV between 2012 – 2018 with the key words – 'Mississippi Alluvial Valley'/State Name + BMP Name (List as indicated in the review below) + Nutrient Reduction/Biodiversity/Water Quality. The studies in addition to Kroger et al.'s review were primarily around innovative agricultural BMPs like slotted inlet pipes and low-grade weirs for drainage ditches.

We only include practices that had at least one study in the MAV. The number of studies that came out of the review are insufficient to carry out a statistical analysis based on crop type or BMP. The reported averages are compared to Midwest BMP effectiveness numbers where available based on recommended consensus numbers for total nitrogen (TN) and total phosphorus(TP) reduction (Christianson et al., 2018) from the midwestern states of IA, IL and MN. Christianson et al. arrived at the consensus numbers after speaking to several experts who were part of the Iowa, Illinois and Minnesota Nutrient Loss Reduction Strategy (IDNR, 2013; Illinois EPA, 2015; MPCA, 2014) science assessments and does not represent a true median/average. There are significant differences between the averages in the LMAV and the Midwest consensus numbers. For example, no nitrogen benefit is attributed to conservation and reduced tillage in the Midwest. Both the Arkansas BMP tool as well as the review of BMPs by Kroger et al. (2012) assign a N benefit to tillage.



	Precipitation intensity>infiltration capacity	Precipitation intensity<infiltration capacity	Precipitation intensity<infiltration capacity
Soil depth	Shallow or Deep	Shallow	Deep
Dominant Flow Paths	**Infiltration excess**, regardless of presence of restrictive horizon or slope	**Lateral flow** and/or **saturation excess; tile drainage**	**Percolation** and/or **tile drainage**
Probable Pollutant Transport	Pesticides, phosphorus, soil loss	Pesticides, nitrates, phosphates, soil loss	Pesticides, nitrates, phosphates
Effective BMPs	Mulch tillage, no tillage, terraces, CRP, buffers*, cover crops, NMPs, IPMs, constructed wetlands	Mulch tillage, no tillage, CRP, cover crops, tile drainage, NMPs, IPMs, constructed wetlands	CRP, buffers*, Cover crops, controlled drainage, crop rotations, forested buffers, NMPs, IPMs, constructed wetlands

Figure 2: Figure from Rittenberg et al. theorizing the influence of the dominant flow paths on the effectiveness of different BMPs

Since there were only about 12 studies available that fit the criteria from Merriman et al. (Appendix A), studies from outside the MAV that had BMPs implemented on silt-loam or clay soils belonging to hydrologic groups C or D were also included. These soil groups indicate sandy clay loams or silty clay loams with a fine structure that limit infiltration of water when wet and therefore have a high runoff potential. Rittenburg et al. (2015) showed that the effect of soil type and the dominant flow path (e.g. Infiltration/Percolation versus surface runoff) have to be taken under consideration to determine BMPs that would be most effective (Rittenburg et al., 2015). Soil types effectively convey information about infiltration as well as information on the presence or absence of restrictive layers that could determine the dominant flow type, so including studies outside MAV that have C or D hydrologic groups provide additional data points from hydrologically similar regions. This is also in agreement with the methodology suggested by Kroger et al. (Kroger et al., 2012).

The review is summarized in Figures 3 and 4 below, comparing the consensus reduction numbers for total nitrogen and phosphorus from the Midwest to those suggested by the Arkansas BMP Tool and the review by Kroger et al (Kroger et al., 2012; Merriman et al., 2009).

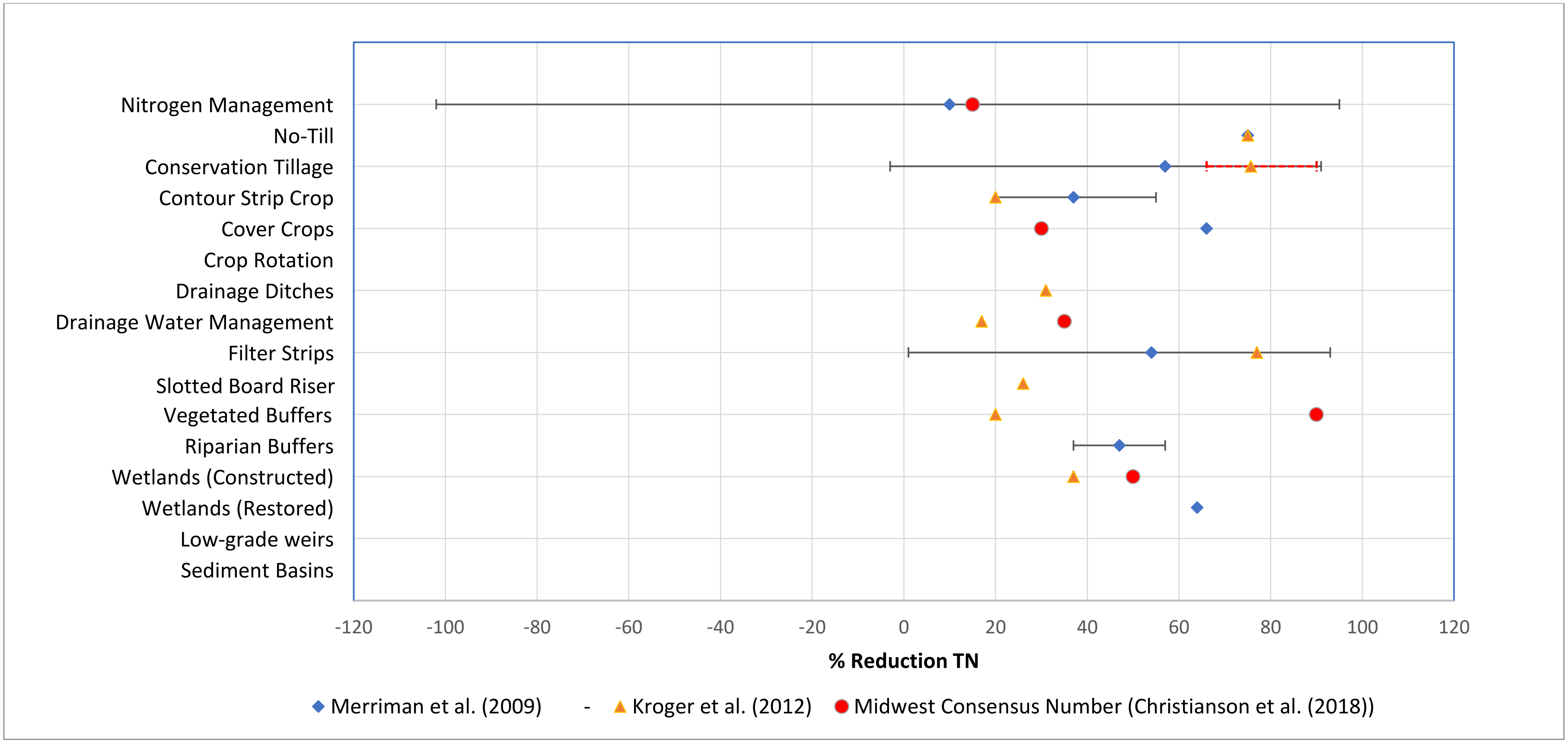


Figure 3: Reduction in Total Nitrogen provided by BMPs. Positive numbers indicate a reduction in nitrogen compared to the baseline (a system with no or before BMP treatment). The markers indicate the median/average effectiveness numbers calculated under each review. The error bars indicate the range of effectiveness indicating the maximum and minimum values of effectiveness in the studies reviewed.

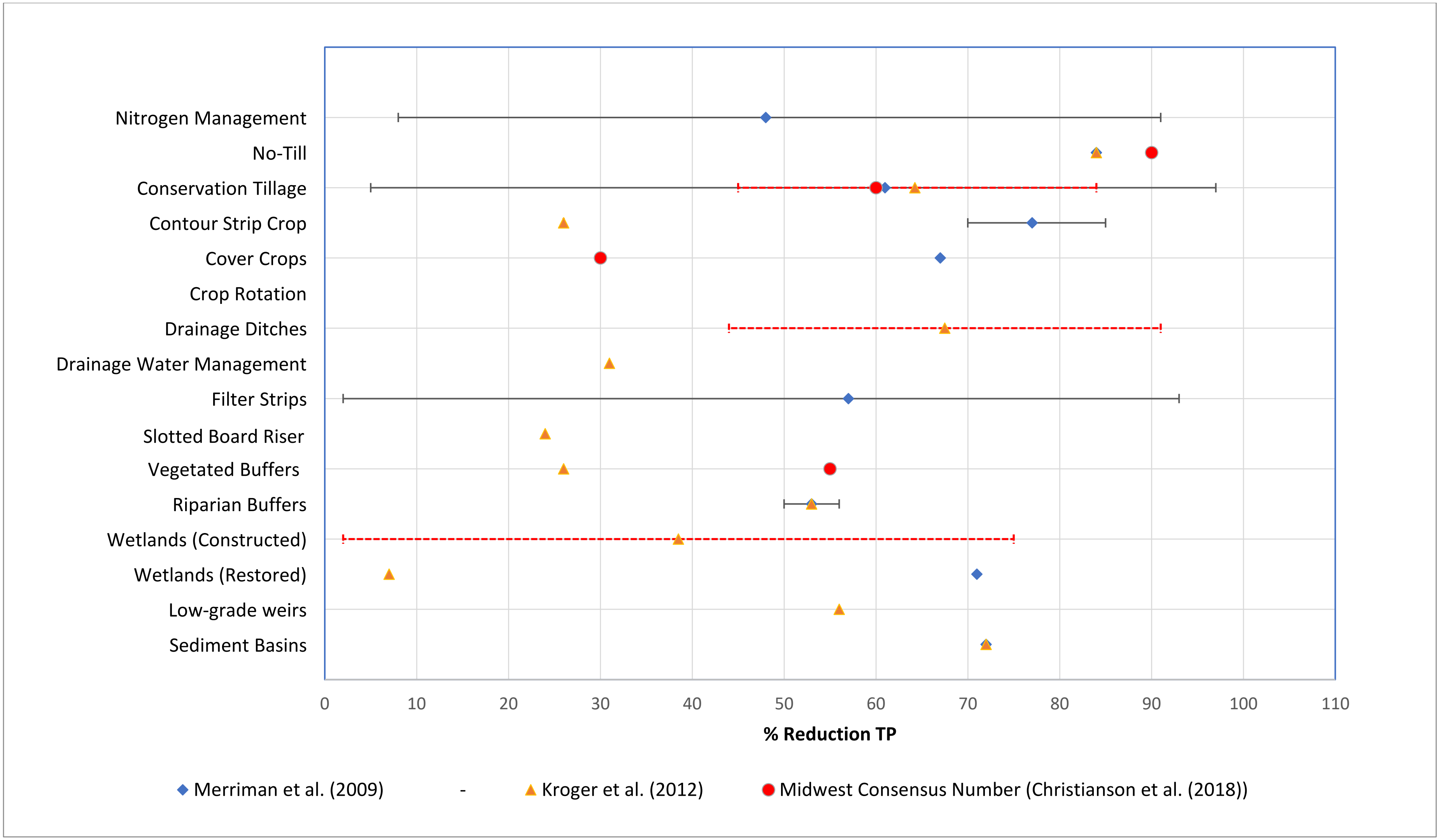


Figure 4: Reduction in Total P provided by BMPs. Positive numbers indicate a reduction in phosphorus compared to the baseline (a system with no or before BMP treatment). The markers indicate the median/average effectiveness numbers calculated under each review. The error bars indicate the range of effectiveness indicating the maximum and minimum values of effectiveness in the studies reviewed.

2.2 In-field practices

In-field practices are applied within fields in active crop production and reduce nutrients at the source or control their transport from the field. Commonly used practices include tillage and residue management, cover crops, nutrient management and irrigation management.

Tillage and Residue Management (NRCS Codes 329 and 345)

Tillage and Residue Management systems target sheet, wind and rill erosion of soils, preventing sediment loss from the fields by providing additional cover on the field. Farms with conservation tillage are managed to have at least 30% of the previous year's crop residue on the soil at planting and limit spring tillage activity (NRCS 2016). In no-till (also called zero till), strip till or row till, soil is minimally disturbed except within the row where the seeds and fertilizer are placed, and soil residue is distributed uniformly along the field. Strip tillage is conducted in a very narrow strip within the crop-row leaving more than 70% of the soil between rows undisturbed (USDA NRCS, 2017).

Practicing conservation tillage has many benefits to the soil including increasing soil organic matter, improving soil tilth and improving infiltration and soil moisture levels. Numerous studies have shown the beneficial impacts of conservation and no-till on sediment reduction (Berg et al., 1988; Merriman et al., 2009; Sharpley and Smith, 1994). Since erosion of soil and phosphorus bound to sediment is one of the primary ways P gets into surface water (Kröger et al., 2013a), conservation till is especially helpful in reducing phosphorus loss from the landscape. Kroger et al. (2012) find that the average reduction of total phosphorus is 84% from no-till and 61% from conservation tillage. No nitrogen benefit is attributed to conservation and reduced tillage in the Midwest. However, both the Arkansas BMP tool (Merriman et al., 2009) as well as the review of BMPs by Kroger et al. (2012) assign a N benefit to tillage ranging from an average of 75% reduction in total N for no-till and 57% reduction in total N for conservation till.

However, multiple studies in the reviews (J. D. Schreiber and R. F. Cullum, 1998; Sharpley and Smith, 1994) as well as a large meta-analysis of no-till literature globally (Daryanto et al., 2017) note that tillage decreases runoff volume but could increase concentration of nitrate in the leachate.

We speculate that in the Midwest, a large part of this increased leachate load finds its way back to surface water through subsurface tile drainage, short-circuiting its flow through the soil matrix and thus no surface nitrogen reduction is attributable to no-till. Because the MAV has no tile drainage, nitrate in the leachate can travel through the soil through macropores formed by increased biological activity in no-till soils. Particularly for fine-textured soils such as those in the Mississippi delta, increased infiltration can lead to preferential flow paths increasing dissolved nitrogen and particulate P losses to groundwater (Kröger et al., 2013a). For the well-drained silt-loam-clay soils of the LMAV, this may indicate a need to combine tillage with other in-field and edge of field agricultural BMPs for water quality benefits.

Figure 5: Different percentages of residue left on the ground L. No-till R. Mulch Till (conservation tillage). Image Credit: NRCS 2016

Table 1: Comparison of reviews for nitrogen and phosphorus reduction from no-till and conservation till

Study – No-Till	TN (%)	TP (%)	NO3-N (%)	NH3-N (%)	DP (%)
Merriman et al. (2009)	75	84			
Kroger et al. (2012)	75	84			
Midwest Consensus Christianson et al. (2018)	-	90			

Study – Conservation Till	TN (%)	TP (%)	NO3-N (%)	NH3-N (%)	DP (%)
Merriman et al. (2009)	57	61	37	30	-63
Kroger et al. (2012)	68.5	64.25	79`	44	
Midwest Consensus Christianson et al. (2018)	-	60			

Nutrient Management (NRCS Code 590)

Nutrient management refers to management of the rate, source, placement, timing and the addition of amendments to the soil to control nutrient loss in surface water runoff and leaching. Our methodology as well as Kroger et al. (2012) did not find any studies within the MAV on nutrient reduction efficiencies for specific nutrient management practices in the MAV. In general, these practices seek to maximize nutrient use efficiency by matching nutrient availability to crop demand for uptake through the 4Rs (Fawecett and Smith, 1999). 4Rs are one approach to nutrient stewardship recommended by the Natural Resources Conservation Service that includes using the right amount and right source, right placement, and right timing of fertilizer (United States Department of Agriculture 2012). For example, nitrification inhibitors applied with fall fertilization can make nitrogen available at the right time i.e., spring when there is demand thereby increasing nitrogen use efficiency. Making nitrogen available at the right time also increases yield and limits a nitrogen surplus leading to nitrate reductions of up to 36% (Abalos et al., 2014).

Table 2: Comparison of reviews on nitrogen and phosphorus reduction from nutrient management

Study – Nutrient Management	TN (%)	TP (%)
Merriman et al. (2009)	10	48
Kroger et al. (2012)	-	-
Midwest Consensus Christianson et al. (2018)	15	

Cover Crops (NRCS Code 340)

Cover crops consisting of various species of grasses, forbs or legumes are planted in the off-season primarily to reduce soil erosion and nutrient loss and to manage pests and weeds and build soil health. Fields can be bare for months after harvest and prior to planting the next crop and cover crops provide a critical service of holding soil on the landscape, preventing it from eroding into water bodies, and reducing nutrient pollution at the source (Strock et al., 2004). Cover crops can scavenge excess nutrients which might otherwise contribute to nutrient leaching and polluted runoff between the main-season crop.

While there are numerous studies in the Upper Mississippi River Basin documenting the nitrogen and phosphorus reduction benefits from implementation of cover crops, there are few studies in the LMRB documenting the effectiveness of both small grains and leguminous cover crops in the region. One of the few studies is a paired field study in Arkansas by Aryal et al. (2018) which analyzed the concentrations of nutrients leaving a cover crop field. The study found that cover crops reduced nitrate concentration by 86% and phosphates by 53% in the surface drainage ditch sampled. Further, they found that concentrations of nutrients were lower in the growing season than the non-growing season for cotton in Arkansas indicating the need for winter cover crops to improve water quality in the region.

Figure 6: Rye and clover crop. Image Credit: University of Georgia

However, absent any long-term studies of cover crop effectiveness in the region, the actual achievable reductions from cover crops in the delta are difficult to estimate. An older study in Missouri in a plot that had loamy-clayey soil (those similar to the MAV) by Zhu et al., studied the influence of Common chickweed, Bluegrass and Brome on a soybean field and found that cover crops reduced the nitrate in the runoff by between 74-77% and soluble P between 6-63% for (Zhu et al., 1989). The average consensus number for the UMRB for nitrate and phosphorus reduction at the field scale, from surface runoff is 31% and 29% respectively (Christianson et al., 2018). Since there is more statistical data to back these effectiveness numbers, the more conservative estimates of reduction of N and P from cover crops from the UMRB could be used in the MAV until further field data is available.

Table 3: Comparison of reviews for nitrogen and phosphorus reduction from cover crops

Study – Cover Crops	TN (%)	TP (%)
Merriman et al. (2009)	66	67
Kroger et al. (2012)	-	-
Midwest Consensus Christianson et al. (2018)	30	29

Winter Rice Field Management- Shallow water development and Management (NRCS code 646)

Rice is one of the most significant crops in the LMRB grown on 1.8 million acres. It is also unique with regard to agronomic management and conservation impact because the episodic inundation of rice fields has different implications for nutrient loss, particularly for nitrogen because aerobic (when fields are drained) and anaerobic conditions (when fields are inundated) activate different processes. Further, NRCS and conservationists recommend the development and management of shallow water through the inundation of lands to provide habitat for fish and/or wildlife. On agricultural fields (especially rice and soybeans), these environments create foraging and resting areas for migrating waterfowl (Reinecke et al. 1989).

While MAV producers are interested in management for wildlife and use winter flooding as a best management practice for rice, the impacts of flooding on soil and water conservation are not as well documented (Zekor and Kaminski 1987; Bray 1998; Manley et al. 2005). Manley et al. evaluated the potential for different winter rice field management practices to retain soil and nutrients and prevent nutrient pollution. They found that fields managed to capture winter rainfall (such as stubble flooded fields) reduced the loss of suspended solids by 64% as compared to disked-fields that were not flooded. They also note that mechanisms that control the export of total suspended soils (TSS) also limits the export of total phosphorus, which is typically bound to the mineral-rich alluvial sediment of the MAV. However, the soluble reactive phosphorus (SRP) export could be high if runoff is rapid and TSS concentrations are low, because SRP typically interacts with suspended solids to form an equilibrium between dissolved and sediment associated phosphorus (Manley et al., 2009). Overall, flooding of rice fields provides clear benefits for wildlife, but the impacts of this practice on nutrient loss and water quality are not fully understood in the MAV. Although this practice is likely to reduce the loss of soil and the nutrients bound to sediment, field flooding could potentially increase the loss of soluble nutrients. This indicates a need for edge of field or downstream practices to control SRP export. Research has also shown that draining rice fields early in the season leads to a build-up of nitrate in the soil through nitrification of the soil. When these fields are reflooded a large amount of nitrogen is lost through runoff and denitrification while also reducing uptake and yields (Linquist et al., 2011). Therefore, continuously flooded rice fields could be essential to controlling nitrogen loss.

Figure 7: Flooded winter rice field. Image Credit: John Huffman, Ducks Unlimited

Table 4: Comparison of reviews for nitrogen and phosphorus reduction from winter rice management

Study – Winter Rice Management	TN (%)	TP (%)	NO3-N (%)	NH3-N (%)	DP (%)
Kroger et al. (2012)	-	-	100	26	

Irrigation water management (NRCS Code 409)

Irrigation water management refers to the process of management and control of the volume, rate and frequency of applying irrigation water. Irrigation is used extensively in the MAV to mitigate yield impacts from droughts and counter the limited water holding capacities of the fine textured soils in the valley (Vories and Evett, 2014). Arkansas and Mississippi have the third and eighth largest irrigated cropland acreage in the US (Massey et al., 2017), including all of the rice cropland and over 70% of corn, soy and cotton acreages (USDA NASS, 2014).

The MAV is dominated by gravity irrigation systems (Stubbs, 2015) and furrow irrigated systems are also used to deliver nutrients and pesticides to rice fields in the delta (Personal Comm, Jason Milks, TNC). Irrigation management affects both water use, energy efficiency and water quality. One major concern for irrigation water management is the leaching of nutrients and pesticides to ground water and their runoff and sediment loss to surface water (US EPA Office of Water, 2003). There are several BMPs associated with the management of irrigation including Irrigation Field Ditch (Code 388) and Tail-water Recovery system (NRCS Code 447).

An Irrigation Field Ditch is a permanent ditch constructed to transport water from an irrigation source to the field and designed to prevent erosion and nutrient runoff. A Tail-water Recovery system is used to collect, store and convey irrigation tailwater so it can be re-used and improve water quality. A Tail-water Recovery ditch can be combined with an on-farm reservoir that can both reduce nutrient export from the field and provide an alternate source of irrigation on the farm (Pérez-Gutiérrez et al., 2017). Perez-Gutierrez (2017) found that a combination of an on-farm water storage system (OFWS) with a Tail-water Recovery ditch reduced nutrient loss about 50% for NO3-N, 60% for NH3-N and 10% for TP in the spring, a timing especially relevant to formation of the hypoxic zone in the Gulf of Mexico.

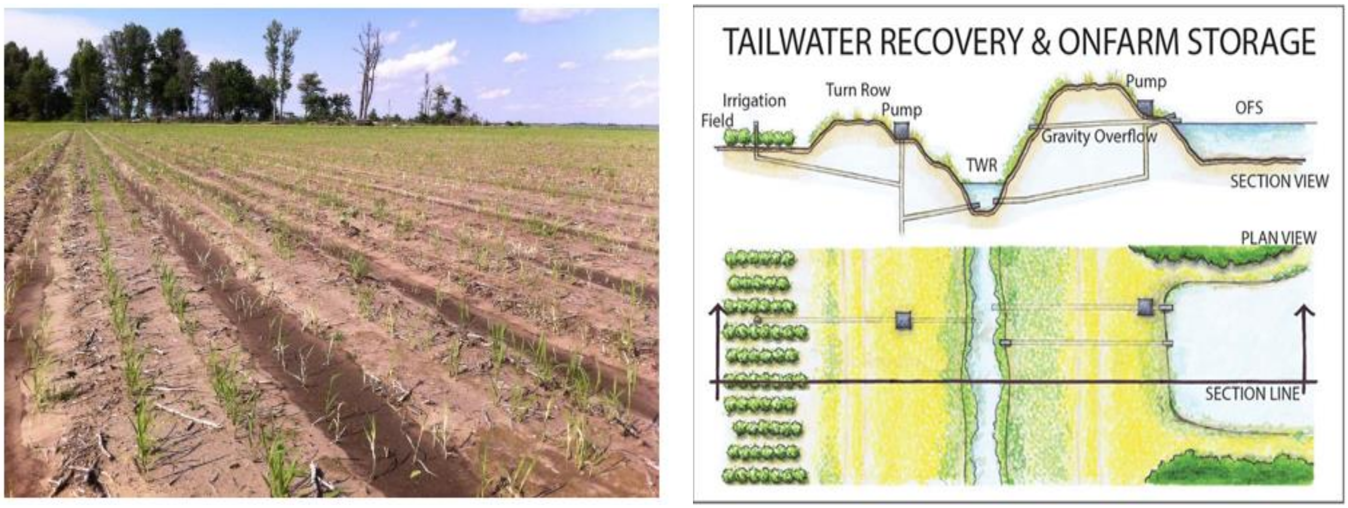


Figure 8: L - Furrow Irrigated Rice field. Image Credit: University of Arkansas Extension; Tail Recovery and On-farm Storage. Image Credit: University of Mississippi Extension

Table 5: Comparison of reviews for nitrogen and phosphorus reduction from irrigation water management

Study – Irrigation Water Management	TN (%)	TP (%)	NO3-N (%)	NH4-N (%)	DP
This review (Pérez-Gutiérrez et al., 2017)	-	10	50	60	

2.3 Edge of field practices

Drainage Practices

Surface drainage ditches *(NRCS Code 608)* are constructed to convey and collect any excess surface and subsurface water. There have been a few studies looking into the nutrient and sediment mitigation capacity of surface drainage ditches within the MAV (Kröger et al., 2008, 2007).

Kroger et al. (2008) note that since a common crop rotation is a summer row crop and winter fallow in the MAV, intense winter rainfall can lead to substantial runoff into surface ditches. Although a relatively small study of two drainage ditches over two years, they found that drainage ditches mitigated phosphorus runoff by an average 45%. However, they also note that between the years, the efficiency of mitigation of different types of phosphorus was different, and particulate phosphorus in particular is sensitive to the runoff volume delivered because it cannot quickly be adsorbed into sediment or assimilated by vegetation (Kröger et al., 2008). They find similar results for nitrogen species: drainage ditches reduced the dissolved inorganic nitrogen by 57%, nitrate by 42% and ammonium- nitrogen by 59%.

Moore et al. (2010) also studied the difference in nutrient mitigation between vegetated and non-vegetated ditches in Mississippi. While there was no statistically significant difference in mitigation of different species of nitrogen and most types of phosphorus, vegetated ditches were only half as effective in reducing total inorganic phosphorus as compared to non-vegetated ditches (Moore et al., 2010). There is a need for further research, especially to understand the interaction of phosphorus dynamics and the influence of drainage ditch size on nutrient mitigation.

Slotted Inlet Pipe (NRCS Code 410) is an innovative BMP that can be used conjunction with surface drainage to minimize erosion in the drainage ditch by directing water through the pipe a fixed elevation (Kröger et al., 2015). This reduces runoff velocity and sediment accumulates in the pipe and remains in the field. The reduction in nutrient loads is attributed to both the physical trapping of sediment within the pipe and the conditions it creates for other microbial reactions to occur to transform the pollutants. The actual phosphorus retained in the pipe depends on the catchment upstream of the pipe, the dimensions of the pipe and soil type (Kröger et al., 2013b).

Similarly, **low-grade weirs** (NRCS practice code 410 and 587) are another novel BMP that can be used in combination with drainage ditches. They are impoundments placed strategically within the drainage ditch to retain some water. Weirs can significantly reduce drainage outflow loads of nitrogen and phosphorus. Kroger et al. found a 79% reduction in nitrate concentration between inflow and outflow in a simulated drainage ditch with weirs (Kröger et al., 2011). Littlejohn et al. (2014) found a nitrate load reduction of 25% and dissolved P reduction of 14% for a weir-ditch system (Littlejohn et al., 2014).

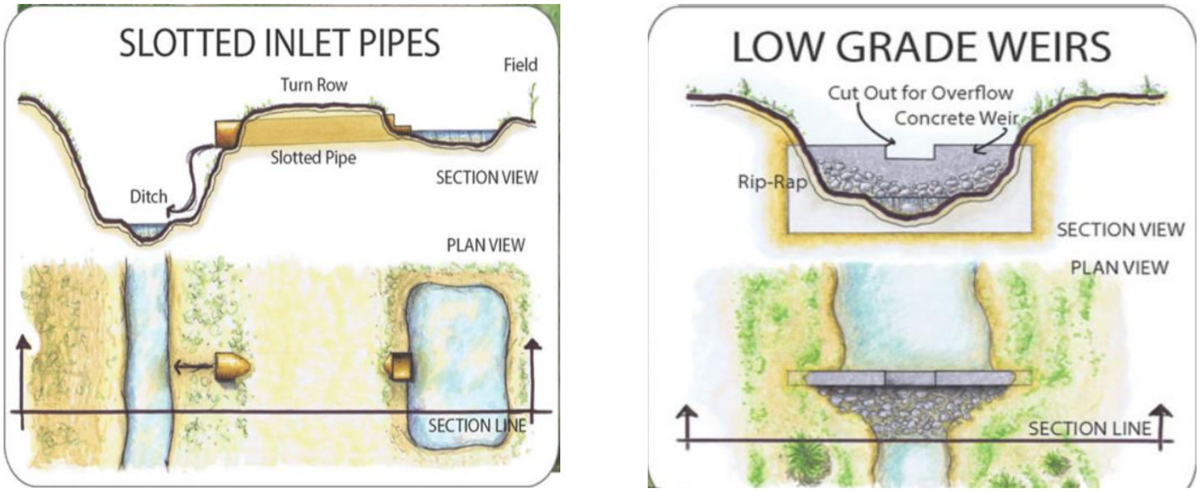


Figure 9: Slotted Pipe and Low-Grade weirs (Kroger et al. (2015))

Table 6: Comparison of reviews for nitrogen and phosphorus reduction from drainage ditches

Study – Drainage ditch and other practices	TN (%)	TP (%)	NO3-N (%)	NH4-N (%)	DP
Kroger et al. (2012)- Drainage ditch (two studies)	31	67.5	59	62.5	44

Buffers

Buffers are any permanent vegetated areas ~~or strips~~ designed to intercept nutrients before they enter streams. There are several different types of buffers that can avoid, control or trap nutrients depending on the design. Buffer width, vegetation type and water flow pathways ~~that enhance conditions for denitrification~~ are all factors that affect buffer effectiveness making it difficult to estimate an average nutrient removal effectiveness (Mayer et al., 2007). In general, buffers provide nutrient reduction benefits by increasing residence time of water flowing from the fields enhancing sediment retention, assimilation into vegetation and providing an ideal environment for denitrification.

Contour buffer strips are planted at regular intervals within the field perpendicular to the slope of the land to mitigate runoff and erosion close to the source. In addition to retaining soil, contour buffer strips effectively limit nutrient and pesticide pollution, promoting water quality largely through infiltration of runoff water and increasing the residence time of pollutants on the field

(Arora et al., 2003). **Riparian Forest Buffers** are areas of vegetation like trees and shrubs adjacent to streams. They remove or reduce nutrients and sediments before their entry into surface water or groundwater recharge. **Filter Strips** (NRCS Code 393) are composed of grass or vegetation along streams, drainage and other bodies of water. Like other buffers, they are designed to reduce sediment and nutrients in runoff as well as to provide habitat (Lenhart et al., 2017).

Udawatta et al. (2002) studied the erosion and nutrient loss reductions from contour strip treatment in a corn-soy watershed in Missouri and found that they reduced significantly reduced erosion (19%), total nitrogen (20%), nitrate (24%) and total phosphorus (8%) (Udawatta et al., 2002). Blanco-Canqui et al. (2004) evaluated a 8m wide filter strip on plots managed as continuous cultivated fallow (baseline) and found that fescue filter strips reduced sediment loss by 62%, organic N by 55%, particulate P by 36%, nitrate-N by 27%, ammonium-N by 19% and phosphate by 37% (Blanco-Canqui et al., 2004).

Table 7: Comparison of reviews for nitrogen and phosphorus reduction from riparian buffers

Study –Riparian Buffers	TN (%)	TP (%)	NO3-N (%)	NH4-N (%)	DP
Merriman et al. (2009)	47	53	59	48	
Kroger et al. (2012)		53			

Figure 10: Contour buffers. Image Credit: NRCS Iowa

Wetlands

Wetlands are places on the landscape where water covers the soil for some or all of the year. They can be strategically placed within or beyond a field to remove nutrients and sediments through assimilation into vegetation, settling or microbial processes.

Constructed wetlands simulate natural wetlands, but they are manmade and can be strategically placed to intercept and store runoff. **Restored wetlands** are similar, but they are designed to recreate the hydrological and vegetative conditions of natural wetlands that have been drained or disturbed. DeLaune et al. (2005) studied nitrate removal rates in a Louisiana coastal wetland and found that while at lower discharge rates the wetland was able to remove most of the nitrate in diverted river water, it was not as efficient during times of high discharge. Mitsch et al. (2005) compared the nitrogen retention rates between wetland basins in Ohio and Louisiana and found that the wetlands in Louisiana had a higher retention rate, resulting in an average 66% reduction in nitrate-N through retention, compared to the Ohio wetland's 34.5% reduction (Mitsch et al., 2005).

Table 8: Comparison of reviews for nitrogen and phosphorus reduction from wetlands

Study –Wetlands	TN (%)	TP (%)	NO3-N (%)	NH4-N (%)	DP
Merriman et al. (2009) - Restored	64	71	83	63	
Kroger et al. (2012) - Restored			42		
Kroger et al. (2012) - Restored	37		28		
Midwestern Consensus (Christianson et al. (2018) - Constructed	50				

2.4 Floodplain Restoration

The MAV used to support a large swathe of floodplain forests and riverine habitat, 75% of which have been converted to cropland resulting in isolated tracts of habitat of limited conservation value (US FWS, 2019). Further, a system of levees, dikes and canals implemented for flood control as well as to drain the land for agriculture have significantly altered the landscape. The floodplains of the MAV are therefore largely hydrologically disconnected from the Mississippi River reducing the potential for these areas to intercept sediment, cycle nutrients, store carbon and provide habitat (Johnson et al., 2018; Locke, 2009).

An extensive literature review conducted by TNC (Motew, 2018) found that floodplains could remove nitrogen through denitrification between 10 – 440 kg N/ha with a median of 69.5 kg N/ha. Hurst et al. (2016) studied the restoration of a bottomland hardwood forest in Louisiana and found that six years after hydrologic restoration, the floodplain was removing 12.39 kg N/ha annually, only 28% lower than a comparable undisturbed forest, demonstrating the immense potential of floodplain restoration to mitigate nitrogen runoff in the MAV (Hurst et al., 2016),

3. Habitat benefits of BMPs in the MAV

According to the US Fish and Wildlife Service, the MAV is an important migration corridor for many bird species and the Lower Mississippi River supports more than 100 species of fish, many of them threatened or endangered (US FWS, 2019). Agricultural activities such as fertilizer application, tillage, drainage and grazing are known to have significant impacts on the regional flora and fauna (McLaughlin and Mineau, 1995).

However, there are numerous benefits for habitat and biodiversity from the application of best management practices for nutrient reduction in the MAV. The observed synergistic benefits of the different nutrient reduction BMPs on biodiversity primarily impact:

1) Provision of terrestrial habitat for wintering and nesting, or a migratory corridor or creating new habitats and sources of food
2) Provision of an aquatic habitat by improving streamflow and water quality and moderating temperature of streams
3) Provision of other services including biological control

3.1 Provision of Terrestrial Habitat

Wetlands were a more prominent feature of the landscape in the MAV prior to conversion of these areas for agriculture and development. Installation of levees, dams and ditches further altered the landscape and disrupted wetland ecosystems and reduced their ability to provide habitat (King et al., 2006). . The restoration of wetlands and floodplains, especially bottomland hardwoods, are particularly important for the provision of wintering and breeding habitat for several species of birds (US FWS, 2019).

King et al. (2006) studied the conservation impact of the Wetland Reserve Program which seeks to provide migratory birds and other wildlife. While they provide no quantitative data due to a lack of monitoring, they note that there is some anecdotal evidence that waterfowl heavily utilize WRP tracts and some telemetry data that Louisiana black bears use WRP land.

Lichtenberg et al. (2006) studied the relationship between amphibians and habitat characteristics of wetlands in the MAV and found that species richness was much greater at lake sites than at riverine or impoundment sites. Based on their results, they conclude that the conservation and enhancement of amphibian communities requires diverse wetland habitats (Lichtenberg et al., 2006).

The role of managed wetlands, particularly rice/soy fields with shallow flooding in attracting shore birds and mallards is particularly well studied and rice fields are often managed to promote wildlife (Heitmeyer, 2006; Houston Havens et al., 2009). Houston Havens et al. (2009) studied the abundance of waterfowl in rice fields managed over winter. They found that when rice-fields were managed to have open water interspersed with cover with patchily burned paddies, they attracted the greatest densities of mallards and other duck species (Houston Havens et al., 2009). The MAV supports large waterfowl populations because rice and other grains in harvest fields are an important source of food for migrating and wintering birds (Greer et al., 2009). Flooding harvested rice fields during winter is essential to provide foraging and other habitat for waterfowl and other species because rice resists decomposition when flooded (Houston Havens et al., 2009; Twedt, 1996).

Field borders and other buffers also provide nesting habitat for birds. Conover (2009) notes that when row crops are farmed “ditch to ditch”, there is little successional habitat suitable for nesting by farmland birds. However, wide field borders and buffers can provide such habitat. Studies elsewhere in the Mississippi River Basin have shown that no-till fields can also provide habitat for nesting and wintering birds. One study in Iowa found 12 bird species nesting in no-till areas but only three species in the tilled fields, and nest density was nine times greater in the no-till fields (Basore et al. 1986).

3.2 Provision of Aquatic Habitat

Agricultural BMPs that reduce nutrient and sediment loss can contribute to the health and diversity of aquatic organisms by moderating streamflow, improving water quality and moderating water temperature. These improvements enhance aquatic habitat over time. Andrews et al. (2015) studied how habitat diversity provided by forested wetlands along the shore of oxbow lakes could contribute to fish diversity. Forested wetlands support plant species that provide more food and protection from predators than unvegetated open water, which tends to support mostly smaller individuals of aquatic species. Also, in typically low dissolved oxygen conditions in the summer, these connected forested wetlands allow fish to swim out to cooler, less hypoxic water, as compared to more uniform, contiguous wetlands (Andrews et al., 2015).

Riparian forest buffers also provide shade lowering the temperature of water and promoting aquatic biodiversity (Faulkner et al., 2011).

3.3 Provision of food and biological control

Vegetated buffers can serve as habitat for a variety of species, including beneficial insects which provide ecosystem services as natural pest control, although they have not been studied in the LMAV. For example, one analysis suggests that hedgerows comprising 9% or more of the landscape can support large enough populations of *Coccinella septempunctata L*. (commonly known as Seven Spotted Lady Beetles) to control aphid infestations (Bianchi and Van der Werf 2003). Such effective natural biocontrol limits the need for pesticides, avoiding economic costs and the impacts associated with environmental damages from the chemicals.

Cover crops can also provide biological control services. The suppression of weed growth has been documented for decades (Mohler and Teasdale 1993; Mirsky et al. 2013; Finney et al. 2016). Carmona and Landis (1999) found that cover crops on a Michigan plot harbored significantly more weed seed predators than plots without cover crops (Carmona and Landis 1999) and directly facilitate weed seed consumption (Blubaugh et al. 2016). In Minnesota, soybean aphids have been documented to be suppressed in fields with winter rye cover crops (Koch et al. 2012, Koch et al. 2015).

Adopting and investing in agricultural best management practices in the MAV can help support more biodiversity and greater populations of aquatic and terrestrial species, both through the provision of foraging habitat as well as through improvement of overall ecosystem health.

4. Barriers to adoption of various conservation practices and factors that contribute to improved water quality at the watershed level

Addressing the challenge of meeting the nutrient reduction goals necessary to limit the Gulf of Mexico Hypoxic area requires the large-scale adoption of best management practices. Despite the vast body of research that exists cataloguing the benefits of BMPs to mitigate nutrient and sediment loss from agriculture, progress towards mitigation is slow due to lack of adoption of these practices at the appropriate scale (Liu et al., 2018). The adoption of BMPs in the LMRB is particularly important because it is located just upstream of the Gulf of Mexico, delivering large loads of nitrogen and phosphorus to the GOM that results in significant economic and ecosystem losses. To understand the particular barriers of adoption in the LMRB, we spoke with Scott Edwards (Assistant State Conservationist for Programs, USDA-NRCS, Louisiana) and TNC staff, Ron Seiss (Director of Conservation Programs, Mississippi) and Jason Milks (Delta Program Director, Arkansas) on the barriers to adoption and opportunities to increase the pace and scale of adoption. Insights from those conversations, complemented with a short review of the barriers to adoption literature, are presented in this section.

The biggest barriers to adoption of conservation practices for nutrient reduction in the MAV likely arise from:

1) **Landscape characteristics:**
   - Technical difficulties in placing practices, especially edge-of-field practices on the highly altered, channelized and leveed MAV landscape.
   - The presence of a large number of irrigated acres (all rice acres and over 70% of corn, soy and cotton) means landowners invest in and prioritize irrigation practices over nutrient reduction practices to ensure productivity.

2) **Landowner characteristics:**

   Over 60% of producers in the MAV are renters and lessees (See Figure 11). Non-operating landowners are hesitant to invest in conservation practices or operator contracts do not allow operators to invest in conservation practices especially, edge of field practices. There is also a financial disincentive as operators are likely motivated to generate profit for the entire area of land that they rent, even if some places may be well-suited for conservation practices.

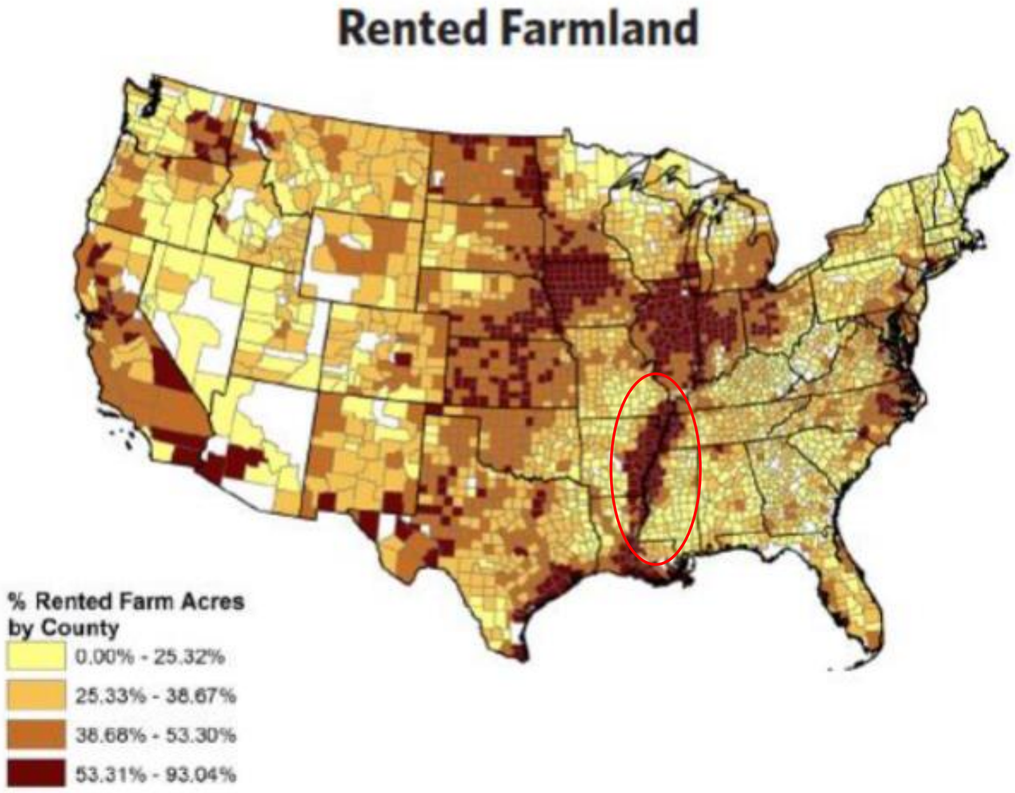


Figure 11: Map of percentage rented farmland by county (USDA NASS 2012)

3) Financial and Informational barriers

- Resistance to adoption of newer, efficient practices like drainage management and saturated buffers because their benefits have not been sufficiently demonstrated to producers.
- The cost of adoption and the opportunity cost is a barrier for some practices, especially some structural BMPs. Although cost share is available for several practices, cost-share may not completely cover the full cost of adoption. For example, in Louisiana, EQIP originally did not cover the cost of the chemical used to kill cover crops, unintentionally discouraging farmers from adopting cover crops (Personal Comm, Scott Edwards). NRCS made changes to include this cost to the funding once this was identified as a barrier.

There were other factors that were identified that could aid in the **scale-up** of practices:

1) **Dedicated Capacity to promote adoption of practices**
   It was noted that there is widespread adoption where there is more effort to put "boots on the ground" either through dedicated NRCS staff promoting practices or through partnerships with grassroot organizations that could be more effective than a top-down approach.
2) **Influencer farmer/ Conservation Champion**
   Conservation champions in a watershed can help with outreach and engagement by being trusted advisors to other farmers in a watershed.
3) **Resources Commitment**
   Longer cost-share contracts could encourage adoption but given federal funding limits, fewer contracts would be funded. NRCS also does not have funding for monitoring that could demonstrate the benefits of large-scale adoption in a watershed. Also, technical assistance and assistance with administrative processes could also encourage adoption.

Identifying barriers to adoption is essential to develop strategies and messaging to encourage producers to adopt appropriate practices. The barriers identified are similar to those identified by an extensive meta-analysis of adoption literature in the US by Baumgert-Getz et al. (2012). The study suggested that the biggest enablers of adoption of agricultural BMPs in the US include: access to information, sufficient financial capacity, a strong network including connection to agencies and local farmers and watershed groups (Baumgart-Getz et al., 2012). The factors for scaling-up adoption track closely to addressing these barriers. Further, there is a growing body of literature around barriers and opportunities for conservation on rented lands (Carolan, M.S., Meyerfeld, D., Bell, M.M., Exner, 2004; Ranjan et al., 2019)(Ulrich-Schad et al., 2016). Ranjan et al. (2019) suggest that one of the biggest barriers to adoption among renters are annual cash rent lease terms that inhibit renter's willingness to adopt conservation practices. They suggest that to overcome barriers to conservation, improved communication between non-operating landowners (NOLs) and operators and modified cash rent lease terms are necessary to encourage adoption on rented lands (Ranjan et al., 2019).

5. Future opportunities to improve water quality in the MAV

5.1 Identify and target priority areas for conservation

The Conservation Effectiveness Assessment Project estimated the LMRB contributes 400 million pounds of nitrogen and 75 million pounds of phosphorus in addition to the load upstream to the GOM (USDA et al., 2013). To meet the GOM hypoxia goals of 45% N reduction by 2035, it is necessary to focus on watersheds with the highest loading and target adoption of BMPs to the places where implementation will generate the greatest return on investment. Data from the SPAtially Referenced Regressions On Watershed attributes (SPARROW) model (Preston et al., 2011) were used to develop prioritization maps of accumulated yields of nitrogen and phosphorus (Figures 12 and 13). Accumulated yields refer to the amount of nutrients exported per unit area at the mouth of a catchment into the local waterway, accounting for everything coming in from upstream.

In addition to increasing adoption of in-field and edge-of field practices, there is a need to restore, reconnect and protect existing floodplains in the MAV. As discussed in section 2.4, floodplains have a large potential to assimilate excess nutrients and sediment. Further, floodplains enhance landscape-scale hydrologic connectivity and provide habitat for numerous species. Reconnected floodplains provide essential flood mitigation services by storing and conveying flood water. TNC has developed a "Floodplain Explorer" tool (Johnson et al., 2018) (maps.freshwaternetwork.org/missriverbasin), a web-based, data-driven decision support tool designed to prioritize where floodplain conservation and restoration is likely to be most effective. Figures 14 and 15 represent the priority areas in the MAV for floodplain protection and restoration and reconnection extents for a 5-year flood event (20% chance).

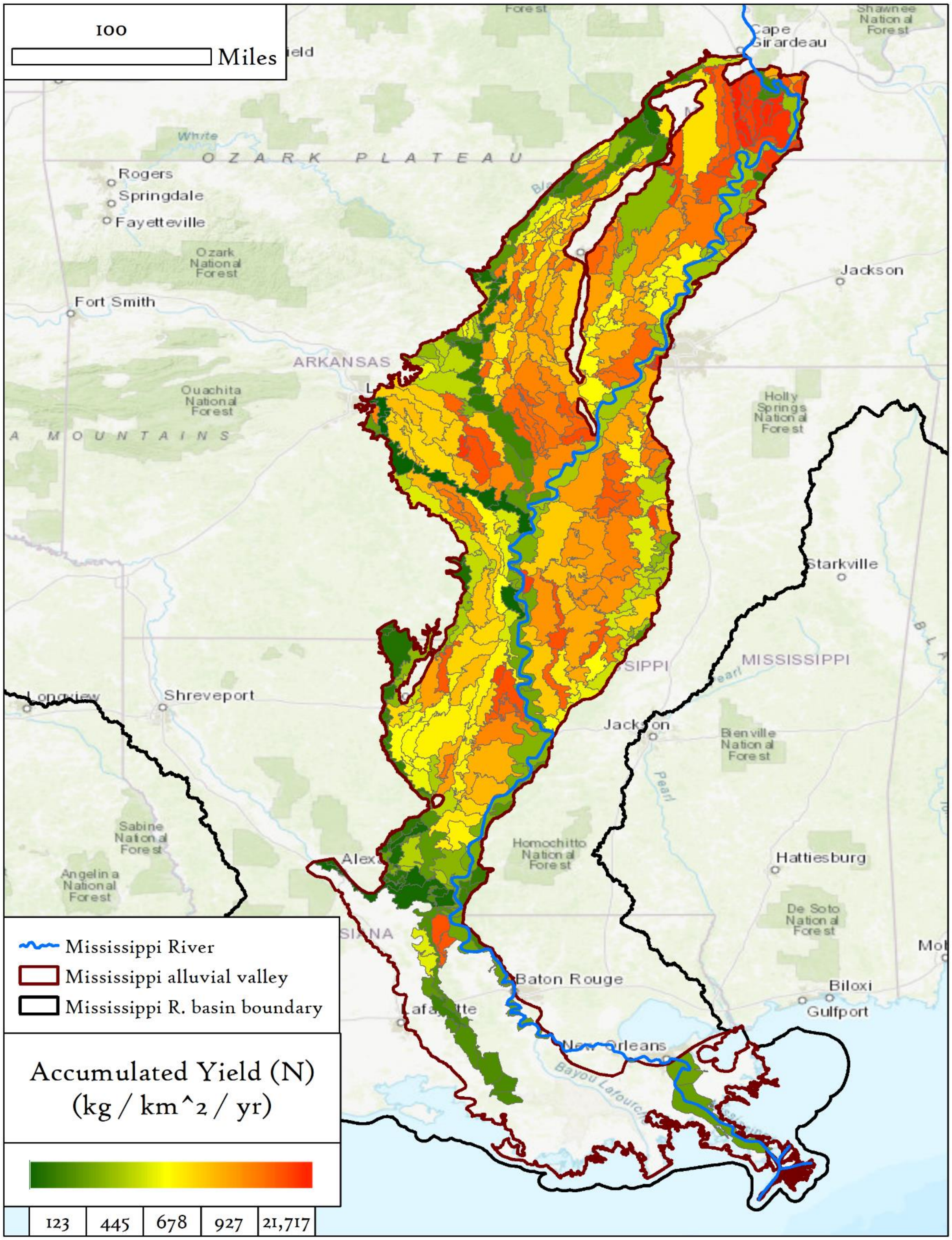


Figure 12: Accumulated yields of nitrogen in the MAV. Map: Eugene Yacobson, Conservation Information Manager, TNC

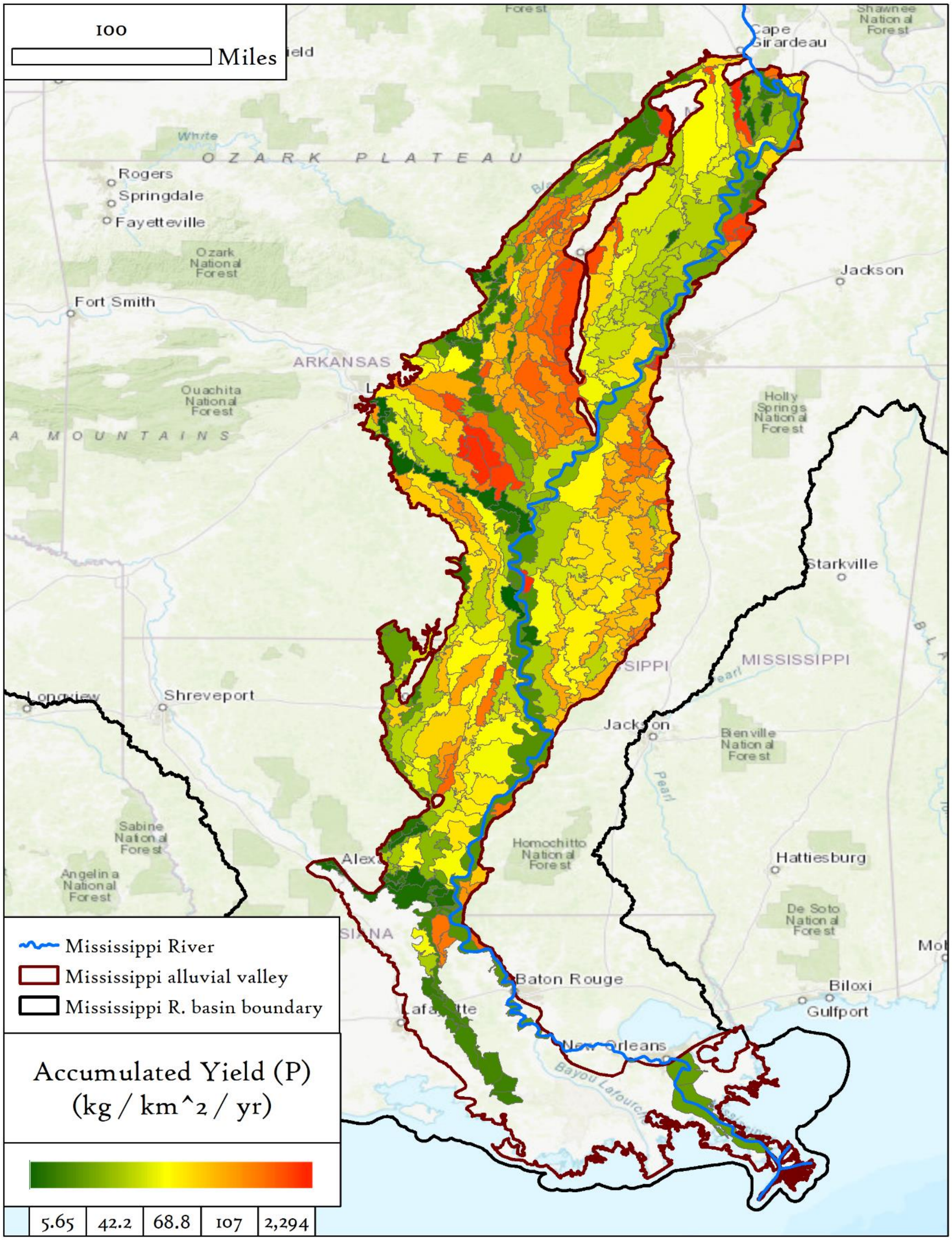


Figure 13: Accumulated yields of phosphorus in the MAV. Map: Eugene Yacobson, Conservation Information Manager, TNC

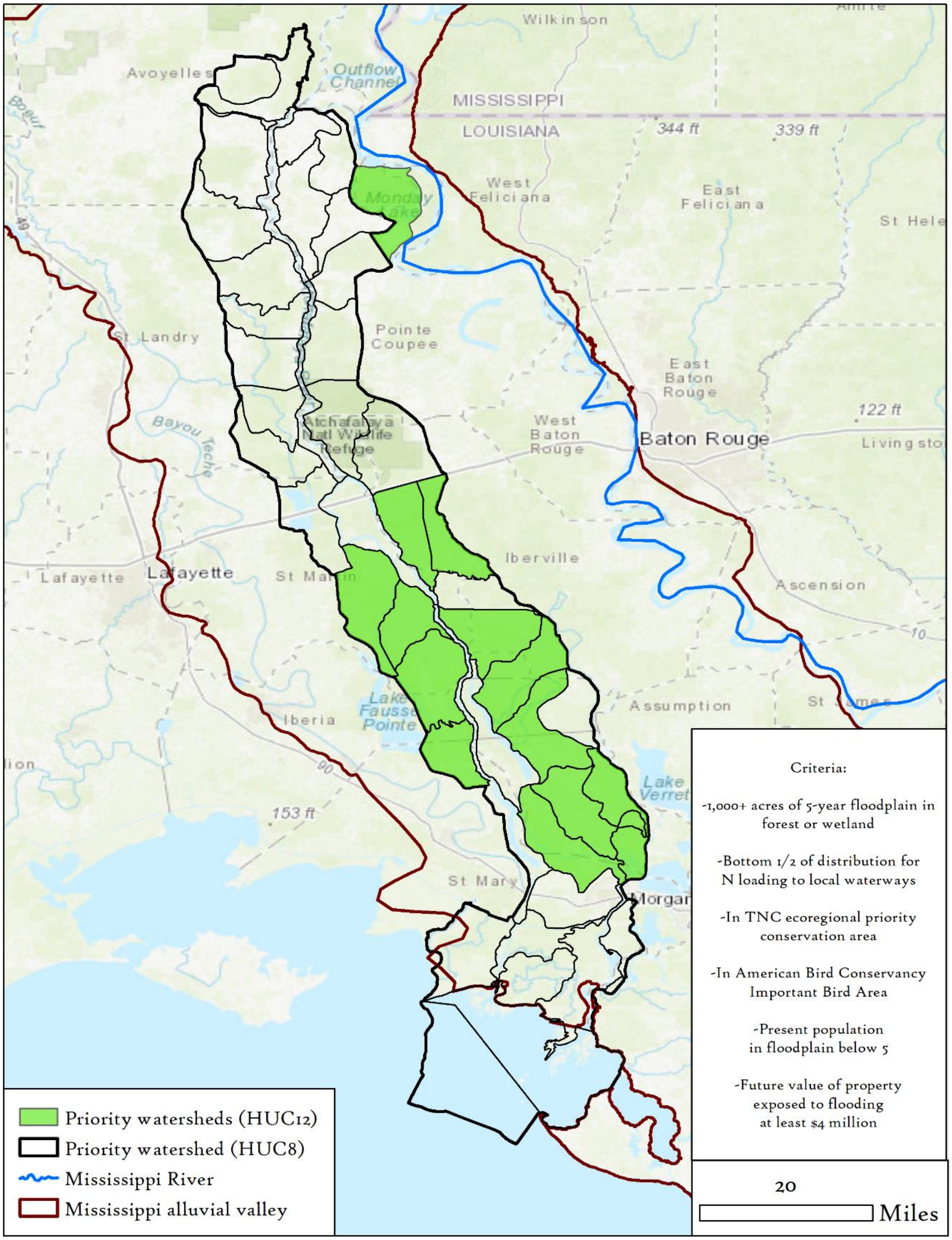


Figure 14: Priority HUC12 watersheds for floodplain protection (5-year flood): Map: Eugene Yacobson, Conservation Information Manager, TNC

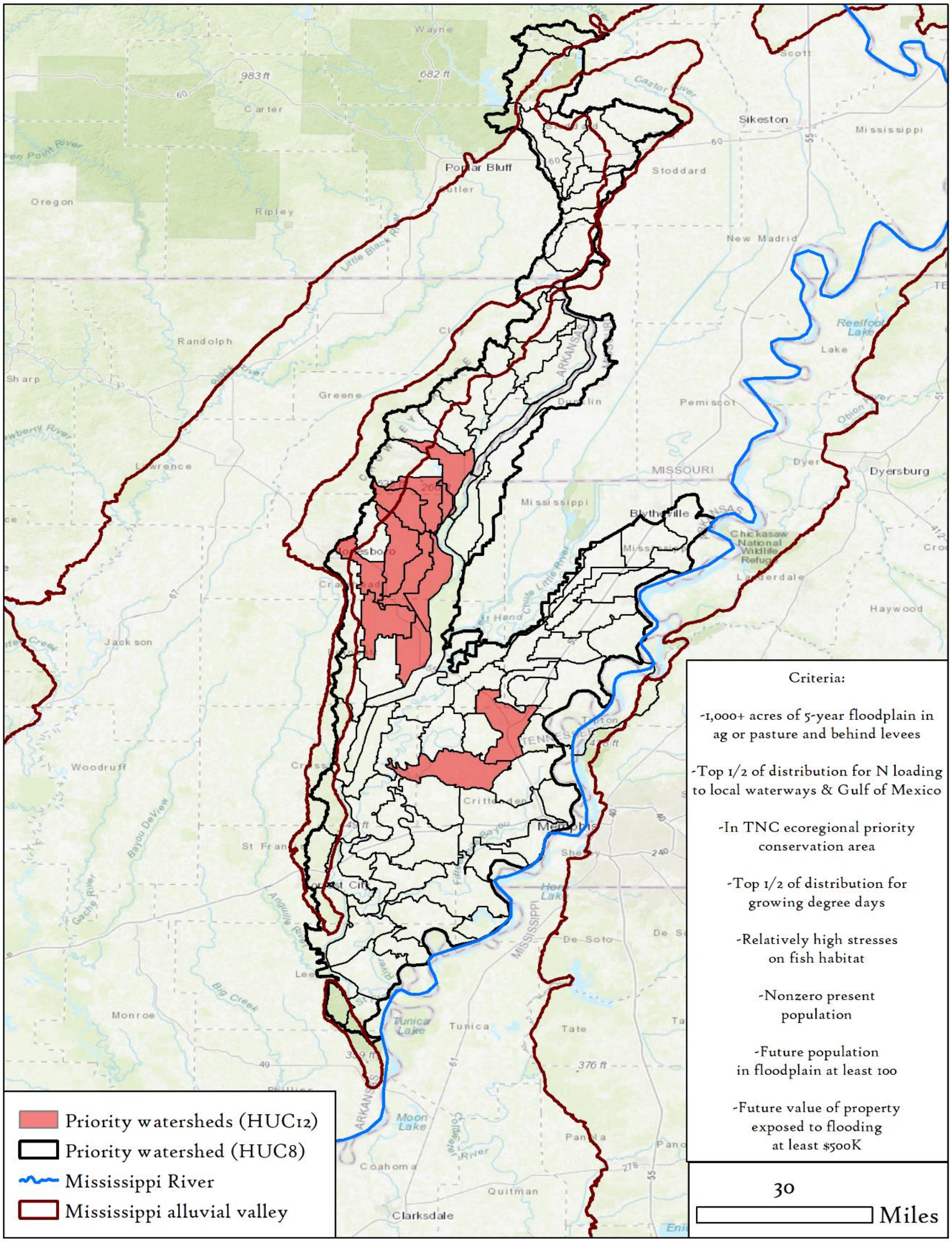


Figure 15: Priority HUC12 watersheds for floodplain restoration and reconnection in ag/pasture currently behind a levee (5-year flood): Map: Eugene Yacobson, Conservation Information Manager, TNC

5.2 Support increased water quality monitoring at the watershed level

One of the findings from the literature review was that there were an insufficient number of studies for relatively common conservation practices including cover crops to arrive at a statistically significant estimate for nutrient reduction effectiveness. Although models like the Soil and Water Assessment Tool (SWAT) can be used to simulate the watershed scale impacts of BMP practices, they still require flow and water quality data that are not readily available.

One of the barriers to the adoption of conservation practices, especially for novel BMPs, is that their benefits are not yet fully demonstrated. A robust monitoring network that can show the benefits of BMP implementation could be necessary to motivate large-scale adoption of practices. In the LMRB only Arkansas, funded through the MRBI (Mississippi River Basin Initiative) and the WREP (Wetland Reserve Enhancement Program) programs, has a good network of 30 monitoring stations (Reba et al., 2013). NRCS, at the federal or state level, currently doesn’t have the allocation to pay for the monitoring assessment of watersheds, especially for edge of field practices (Personal Comm, Scott Edwards, USDA NRCS, LA). The development of such a monitoring network will require robust partnerships and external investments.

5.3 Develop and expand partnerships across scales to support BMP adoption and restoration

Another critical need in the MAV is the development of local, bottom-up partnerships to support top-down efforts such as the EPA Section 319 program and the NRCS MRBI program and complement federal and state agency efforts to promote conservation practices (Personal Comm, Scott Edwards, USDA NRCS LA). For example, in the case of establishing the MRBI-funded monitoring network in Arkansas, there were a number of partners including universities, state and federal agencies, conservation districts and agricultural producers, who worked closely to ensure that monitoring proceeded as planned (Reba et al., 2013).

6. Conclusion

The LMRB is significantly different from the upstream basins in the Mississippi River Basin in terms of geomorphology, hydrology and management. This review synthesizes and compares nutrient reduction efficiencies of various BMPs in the LMRB to those in the Midwest. The review found that:

(a) **BMPs provide significant nutrient benefits in the basin**. For some commonly adopted BMPs like cover crops and nutrient management, there is insufficient field data available to derive defensible average nutrient reduction estimates, although studies from the Midwest indicate that these practices may indeed provide significant benefits. Other practices like irrigation management and surface drainage management are more commonly found in the LMRB than the upper basins, so while the estimates cannot be compared with numbers from the Midwest, they are crucial to nutrient reduction in basin.

(b) There is a **lack of scientific information available to conclusively understand the comparative effectiveness of various practices in this region**. Therefore, there is a strong need for much more scientific analysis, robust monitoring and measurement of benefits through field and watershed scale studies. Further, existing research highlights the importance of combining various in-field and edge-of-field practices to effectively capture or reduce nutrient loss through various transport pathways. For example, while no-till practices effectively reduce particulate phosphorus loss and nitrogen loading in surface runoff, it increases loss of nitrogen through leaching (Daryanto et al., 2017). Therefore, an impact on groundwater quality can be avoided by combining no-till residue management with nutrient management to increase plant uptake and prevent excessive loss. Such tradeoffs between practices need to be studied more extensively.

(c) The BMPs reviewed here also provide significant co-benefits for biodiversity both by direct means through provision of habitat and indirectly by improving ecosystem health (for e.g. water quality of streams) that can support healthy populations of terrestrial and aquatic species. Further, floodplain restoration and reconnection provides landscape-level hydrologic connectivity that can effectively store and convey water and provide flood mitigation. It can also improve terrestrial and aquatic habitat connectivity by providing unfragmented habitats and migratory corridors (Sparks, 2006; Twedt and Loesch, 1999).

This review also found several barriers to adoption of conservation practices through conversations with NRCS and TNC staff on the ground. The primary barriers to adoption within the LMRB states arise from (a) Landscape characteristics including the difficulty of situating practices (especially edge-of-field) in the highly channelized basin; (b) The presence of a large percentage of non-operating landowners who are hesitant/ unable to adopt practices on rented land and (c) Financial barriers to adopting BMPs and limited access to federal and state cost-share dollars.

Partnerships with conservation champion farmers, dedicated NRCS officials on the ground, grassroot organizations that can build ground-up coalitions for larger restoration projects, and resource commitments such as help with administrative processes could encourage participation in federal conservation cost-share programs and scale up adoption in the basin.

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