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AGRICULTURAL PRACTICE EFFECTIVENESS FOR REDUCING NUTRIENTS IN THE RED RIVER BASIN OF THE NORTH

A WORKSHOP SUMMARY REPORT



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EXECUTIVE SUMMARY

Adopting agricultural beneficial management practices (BMPs) is critical to reducing nutrient runoff into and improving water quality of the Red River and, ultimately, Lake Winnipeg. At the same time, the impacts of these BMPs on other resource concerns, such as flooding, habitat, and soil health, must be considered. Recent research, however, suggests that the effectiveness of many BMPs in cold climates such as the Red River Basin (RRB) differs from warmer regions where much of the body of knowledge has been developed. It is critical to summarize scientific research on BMP effectiveness in cold regions prior to approaching the agricultural community about implementing BMPs that reduce nutrient loading into the Red River.

The Red River Basin/Cold Climate Agricultural Nutrients BMP Workshop (the Workshop) was held April 16–17, 2019 at the University of Minnesota Crookston in Crookston, Minnesota and focused on summarizing scientific findings for BMP effectiveness and suitability in cold regions such as the Red River Basin. The Workshop was attended by a broad cross section of university researchers, state/provincial and federal government researchers and extension staff, and industry professionals involved in studying BMPs in agricultural landscapes. The purpose of the workshop was to review and explore the available research on the effectiveness of BMPs in cold climates and develop consensus recommendations. Workshop attendees were asked to lend their expertise to the following tasks:

1. Describe the current factors and mechanisms affecting nutrient fate and transport on cold region agricultural lands and their delivery to surface waters.
2. Discuss pertinent research regarding the effectiveness of BMPs designed to reduce nutrient loss from cold region agricultural lands.
3. Identify gaps in our understanding of BMPs designed to reduce nutrient loss in cold regions and determine the potential for collaborative research efforts to address those gaps.

The structure of the workshop consisted of presentations by experts in various BMP topic areas followed by breakout discussion groups. Breakout discussions focused on what practices work and do not work well, factors affecting BMP effectiveness, how practices can be integrated/stacked, characteristics of vulnerable systems and areas, and research gaps. BMP effectiveness was discussed in the context of both cropping systems and integrated cropping and livestock systems. The workshop presentations and breakout discussion groups were organized under the following BMP categories:

1. Nutrient management BMPs for nitrogen (N) and phosphorus (P) load reduction
2. Erosion and runoff control BMPs for N and P load reduction
3. Vegetative practice BMPs for N and P load reduction
4. Structural management BMPs for N and P load reduction

The purpose of this report is to summarize the information presented at the workshop by (a) describing the geographic, climatic, and hydrologic context for the Red River Basin, and (b) documenting Workshop discussions and potential areas of consensus regarding the effectiveness of BMPs in reducing N and P losses to surface waters in cold agricultural production regions of the Red River Basin. Therefore, the report does not necessarily present a full-scale discussion on

agricultural practice effectiveness for reducing nutrients in the Red River Basin. While comprehensive, the report is not exhaustive as it is limited to topics discussed at the Workshop.

There are numerous and considerable challenges in determining the effectiveness and suitability of BMPs for nutrient load reduction in the RRB. Some of the key challenges include the following:

- Limited research, knowledge, and understanding of processes resulting in nutrient loading in the cold climate environment of the RRB
- Numerous sources of variability operating over different scales, including existing soil and landscape factors, changing temperature, precipitation and frequency and intensity of storm events, agricultural management systems, jurisdictional regulation, policy and market conditions, economics, and access to equipment and technology
- Scale applicability of BMPs—some BMPs are generally applicable at the regional scale while some are more suitable and effective for specific soil, landscape, and climatic combinations
- Trade-offs—many BMPs are effective at reducing either N loading or P loading but not necessarily both. In some cases, BMPs that effectively reduce N loading may increase P loading. The impact BMPs have on other aspects of the environment also need consideration, including soil health, natural habitat, flood reduction, and greenhouse gas emissions.

These challenges demonstrate that there are no simple solutions to improving water quality in the Red River Basin. Solutions necessitate numerous, stacked measures targeted to the most vulnerable soils and landscapes throughout the RRB, as determined to be appropriate, to achieve the objective of nutrient load reductions for the Red River.

Cropping systems in the RRB are diverse. Nitrogen and phosphorus fertilizer, as well as manure containing these nutrients, are primarily applied to wheat (and other small grains), corn, canola, and sugar beet crops grown in a variety of crop rotations throughout the RRB. In addition, legumes such as soybean and alfalfa can fix nitrogen. BMPs in these crops and related cropping systems are particularly important to reduce N and P losses in the RRB and should be targeted at the most vulnerable and hydrologically active landscapes in the RRB where losses from fertilizer and manure are greatest.

In addition to its cropping and nutrient management systems, the RRB has diverse climatic factors, soil characteristics, and landscape features that affect water quality and quantity, as well as the effectiveness of BMPs. Mean annual precipitation varies from less than 20 inches (494 mm) in the northwestern part of the RRB to 30 inches (757 mm) in the southeastern part of the RRB. Average annual temperature varies from 35 °F (1.5 °C) in the northern part of the RRB to 44 °F (6.5 °C) in the southern part.

Landscapes in the RRB range from flat to steep (10°) in slope and from nearly impermeable, poorly drained soils to permeable, well-drained soils with infiltration rates of up to 16 inches/hr (40.6 cm/hr). The slope of the landscape and infiltration rate of the soil can be combined with climatic factor combinations (e.g., colder/drier) to develop a framework for discussing how the effectiveness of nutrient management, erosion control, vegetative, or structural BMPs varies across the RRB.

Generally, nutrient management BMPs are broadly applicable across all areas of the RRB. However, flatter, poorly drained areas with higher applications of N and P from fertilizer or manure should be especially targeted for nutrient management BMPs. Specific portions of these areas have large acreages of corn, and BMPs such as soil profile nitrate testing, grid soil sampling for soil test phosphorus, variable rate applications of N or P, and incorporation or banding of N or P should be promoted there. In areas with high applications of N and P from animal manure, BMPs such as manure testing, incorporation or injection of manure, manure hauling, conservation crop rotations, pasture and hayland plantings, siting feedlots or bale feeding operations in areas not hydrologically connected with nearby surface waters, or livestock exclusion from streams should be promoted.

Areas with significant soil loss by tillage, water, or wind erosion can be a significant source of P to surface waterways. Tillage and water erosion tend to occur in steeper landscapes, such as those that occur in the western RRB (e.g., Pembina Hills Upland region). BMPs to control tillage and water erosion in these areas could include contour farming (throwing the furrow slice uphill or away from surface ditches) or conservation tillage. Sediment losses in flatter, poorly drained areas tend to be dominated by streambank and channel erosion, or wind erosion from agricultural fields. Wind erosion BMPs such as planting windbreaks and orienting crop rows perpendicular to the prevailing wind direction are recommended in these areas. The soils most vulnerable to wind erosion tend to be flat, poorly drained, fine-tilled soils, especially those with higher calcium carbonate content.

The effectiveness of vegetative practices at reducing P and, to some extent, N losses from agricultural fields is poor in areas where a significant proportion of annual runoff occurs during spring snowmelt events. Spring snowmelt is a significant contributor to annual runoff throughout the RRB, particularly in the colder and dryer northern portions of the Basin and to a lesser extent in the warmer and wetter southern and eastern portions of the Basin. The limited effectiveness of filter strips or cover crops is caused by dead, flat vegetation in winter and spring accompanied by freeze-thaw cycles (FTCs) that rupture plant cells, leading to loss of P and, to a lesser extent, N during snowmelt runoff events. Cover crop effectiveness is also limited by soil moisture and the short period available for establishment after crop harvest in the fall. With these caveats in mind, the effectiveness of vegetative practices such as filter strips and cover crops is greatest in the warmer and steeper landscapes of the RRB, which occur in the southeast and southern portions of the RRB. In other regions and along stream channels, reductions in P losses to surface waters could be enhanced by removing vegetation before the onset of freeze-thaw cycles.

Structural practices can be effective at reducing N and P losses as well as mitigating flood damages. Drainage-related structural practices are generally limited to flatter, poorly drained landscapes along the mainstem of the Red River. Controlled drainage practices are restricted to the flattest of these landscapes with subsurface tile drainage. Bioreactors are even more restricted than controlled drainage to flatter, warmer landscapes with subsurface tile drainage. Structural practices to store and/or treat water include wetlands, water and sediment control basins, and small dams, ponds and reservoirs. Wetlands are most effective at removing N in areas of the southern RRB that are warmer, wetter, flatter, and poorly drained. Their effectiveness decreases as the climate becomes colder and dryer or steeper and well drained. The effectiveness of water and sediment control basins is similar to wetlands, and these structures are not well

suited to steeper, well-drained landscapes. In steeper landscapes (e.g., northwestern RRB), water retention is often achieved using small dams, ponds, and reservoirs.

The “stackability” of BMPs refers to their ability to be combined in the same field. The most cost-effective practices (such as in field nutrient management practices) are generally stackable with a wide range of erosion control or structural practices. Nutrient management practices are not as compatible with certain vegetative practices, including perennial crops or animal grazing systems, but could be combined with other vegetative practices, such as cover crops or filter strips. In-field BMPs that are effective during the growing season can often be combined with in-field BMPs that are effective during the non-growing season. An example of this is combining contour farming with cover crops. Another option for stacking BMPs is to combine in-field BMPs with edge-of-field BMPs. An example of this is stacking conservation tillage with bioreactors in fields that are tile drained. Many vegetative BMPs can be stacked with other vegetative BMPs, and similarly, many structural practices can be stacked with other structural BMPs. For example, cover crops can be stacked with filter strips, and controlled drainage can be stacked with bioreactors. A final consideration is stacking BMPs to provide both N and P reduction, or at least to reduce either N or P without increasing the other.

Given the magnitude of reductions in N and P loadings needed for the Red River and Lake Winnipeg, research is vital to improve our understanding of N and P loading sources and pathways, identify critical source areas and priority watersheds, improve the effectiveness of existing BMPs, and develop innovative BMPs that have greater effectiveness at reducing N and P losses, particularly during snowmelt runoff events. Some of the most pressing research needs related to an improved understanding of N and P loading sources and pathways include study on the magnitude of N and P transport to surface waters by wind erosion, documenting the role that legacy P from historical buildup of P in soils and total P transport to Lake Winnipeg play in eutrophication, and identifying the impact on N loadings to the Red River from expanded adoption of subsurface tile drainage coupled with climate change. Establishment of research/demonstration farms is needed in the most vulnerable areas (e.g., those areas with highest N and P loadings to major watersheds) where suites of BMPs can be evaluated for their effectiveness at reducing N and P losses. Research is needed to improve the effectiveness of existing BMPs through development of stacked synergistic practices that combine protection during the growing and non-growing season by integrating in-field and edge-of-field practices. Finally, research is needed to develop innovative new BMPs that have greater effectiveness. Examples of this include more effective bioreactors and tillage practices that enhance random roughness to reduce erosion and runoff while reducing crop residue cover to minimize the risk of P leaching and loss from crop residues during winter and snowmelt runoff events.

The Workshop resulted in useful summaries of BMP effectiveness at reducing N and P loss from cold agricultural regions in the RRB. To build on this progress, the following are recommended next steps to be taken by the Red River Basin/Cold Climate Agricultural Nutrients BMP Committee (the Committee) and the Workshop participants:

1. Confirm BMP effectiveness rankings summarized in this report and prioritize through broad consensus BMPs for implementation planning discussions.
2. Establish research priorities to address key knowledge gaps.

3. Discuss policy and regulation for jurisdictions across the RRB, and identify policy and regulatory priorities for governing agencies to consider to aid in achieving objectives.
4. Evaluate preliminary cost of implementation.
5. Develop strategies to move toward implementation in the context of a BMP suitability framework outlined in Appendix C.

To implement selected BMPs, it is recommended that the Committee organize and coordinate another workshop. This should involve the research and extension community, as well as representation from the agricultural community across the RRB. The workshop should focus on those BMPs for which there is broad consensus amongst the research and extension community and those that will be most effective at reducing N and P loading into the Red River.

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Cooperating agencies and organizations: North Dakota State University; NDSU Extension; University of Minnesota Extension; University of Manitoba; South Dakota State University Extension; International Plant Nutrition Institute; Manitoba Agriculture; Manitoba Sustainable Development; Minnesota Board of Soil and Water Resources; Minnesota Department of Agriculture; North Central Region Water Network; North Dakota Association of Soil Conservation Districts; North Dakota Department of Agriculture; Barr Engineering; Pembina Valley Conservation District; Red River Basin Commission

All of the workshop presenters.

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ABBREVIATIONS

AA – Anhydrous Ammonia

BMP – beneficial management practices

the Committee – the Red River Basin/Cold Climate Agricultural Nutrients BMP Committee

CRP – Conservation Reserve Program

DP – dissolved phosphorus

DRP – dissolved, reactive phosphorus

ESN – Environmentally Smart Nitrogen

FDR – Flood Damage Reduction

FTCs – freeze-thaw cycles

N – nitrogen

NBMP Tool – Nitrogen BMP Tool

P – phosphorus

PDSI – Palmer Drought Severity Index

PP – particulate phosphorus

RIM – Reinvest in Minnesota

RRB – Red River Basin

SRP – soluble, reactive phosphorus

STP – soil test phosphorus

TDN – Total Dissolved Nitrogen

TDP – Total Dissolved Phosphorus

TP – Total Phosphorus

UAN – Urea Ammonium Nitrogen

WEP – water extractable phosphorus

The Workshop – the Red River Basin/Cold Climate Agricultural Nutrients BMP Workshop, held April 16–17, 2019 at University of Minnesota Crookston

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1 INTRODUCTION AND OBJECTIVES

Adopting agricultural beneficial management practices (BMPs) is critical to reducing nutrient runoff into and improving water quality of the Red River and, ultimately, Lake Winnipeg. Recent research, however, suggests that the effectiveness of many BMPs in cold climates such as the Red River Basin (RRB) differs from warmer areas where much of the body of knowledge has been developed. It is critical to get the science right prior to approaching the agricultural community about making changes in agricultural production management systems through implementation of BMPs for reducing nutrient loading into the Red River.

The Red River Basin/Cold Climate Agricultural Nutrients BMP Workshop (the Workshop) was held at the University of Minnesota Crookston in Crookston, Minnesota on April 16–17, 2019¹ as a first step in this process, with a focus on ensuring the science of BMP effectiveness and suitability are right. The agenda for the Workshop is presented in Appendix A. It was attended by a broad cross section of university researchers, state/provincial and federal government researchers and extension staff, and industry professionals involved in BMPs in agricultural landscapes (see Appendix B for a list of Workshop attendees). The purpose of the workshop was to review and explore the available research on the effectiveness of BMPs in cold climates and develop consensus recommendations on BMP effectiveness. Workshop attendees were asked to lend their expertise to the following tasks:

1. Describe the current factors and mechanisms affecting nutrient fate and transport on agricultural lands and their delivery to surface waters.
2. Discuss pertinent research regarding the effectiveness of BMPs designed to reduce nutrient loss from agricultural lands.
3. Identify gaps in our understanding of BMPs designed to reduce nutrient loss, and determine the potential for collaborative research efforts to address those gaps.

The structure of the workshop consisted of presentations by topic experts in various BMP topic areas followed by breakout discussion groups. Breakout discussions focused on what practices work and do not work well, factors affecting BMP effectiveness, how practices can be integrated/stacked, vulnerable systems and areas, and research gaps. This included discussion of BMPs for cropping systems and integrated cropping and livestock systems. The workshop presentations and breakout discussion groups were organized under the following BMP categories:

1. Nutrient management BMPs for N and P load reduction
2. Vegetative practices BMPs for N and P load reduction
3. Erosion and runoff control BMPs for N and P load reduction
4. Structural management BMPs for N and P load reduction

¹ A pre-workshop webinar series on April 3 and 12, 2019 presented background information on the environmental conditions of the RRB environmental conditions (geology, soils, soil nutrient characteristics, hydrology, and nutrient trends and loads) and set the stage for the workshop.

Copies of Workshop presentations are available at a website established to disseminate Workshop information².

The purpose of this report is to summarize the information presented at the workshop, with the primary objective of documenting discussions and potential areas of consensus regarding BMP recommendations to the agricultural community. Therefore, the report does not necessarily present a full-scale discussion on agricultural practice effectiveness for reducing nutrients in the Red River Basin. While comprehensive, the report is not exhaustive as it is limited to topics discussed at the Workshop. The report does not include additional research or references and was coordinated and reviewed by the workshop organizing committee (the Committee).

² The presentations provided at the Workshop, as well as the pre-Workshop webinars, are available via the following link: <https://sites.google.com/view/nutrientreductionworkshop/workshop-presentations>

2 THE RED RIVER BASIN – CHARACTERISTICS AND ISSUES

2.1 THE RED RIVER

The Red River of the North (RR) flows north from primarily Minnesota and North Dakota into Manitoba, where it discharges into Lake Winnipeg. The Red River Basin (RRB) covers an area of approximately 14.8 million ha (36.6 million ac; 45,000 mi²), of which 73.2% is agricultural land, 10% is wetlands, 7.2% is prairie grassland, 5.5% is forest, 3.5% is open water, and 0.6% is developed. The Red River Basin includes 46% of its area in North Dakota, 40% in Minnesota, 13% in Manitoba, and 1% in South Dakota. The Red River mainstem flows 885 km (550 mi) through flat lacustrine sediment deposited by glacial Lake Agassiz 10,000 years ago. The Red River Basin encompasses 34 separate major watersheds (Fig. 2.1), each having an individual area greater than 1,000 km² (386 mi²).

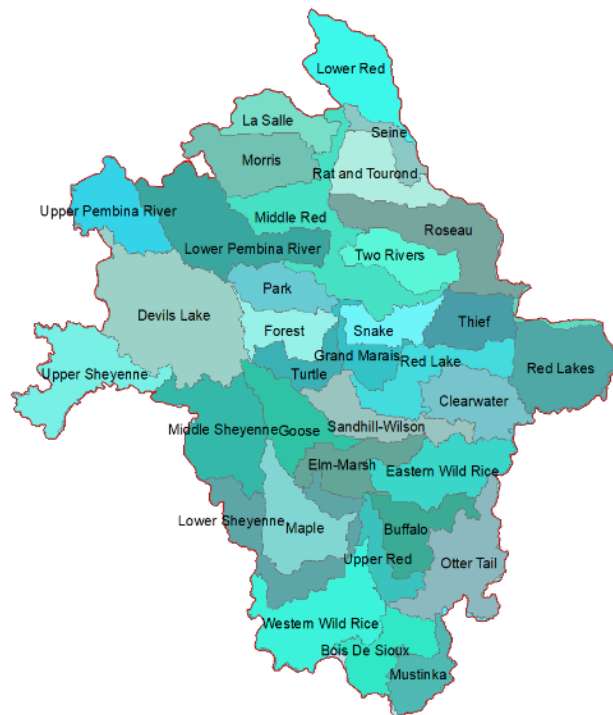


Figure 2.1: Major Watersheds in the Red River of the North Basin (Data from USGS 2011a; WSC 2010)

Lake Winnipeg is a shallow eutrophic water body that receives 16% of its inflow from the Red River. While the Red River contributes a small fraction of the flow entering Lake Winnipeg, this flow carries 64% of the annual phosphorus loading and 34% of the annual nitrogen loading. Lake Winnipeg has a vibrant commercial fishing industry; the annual value is CAD \$17.8 million per year. In addition, the recreational fishery contributes \$221 million each year to Manitoba. Seventeen communities in Manitoba get all or part of their drinking water from surface waters in the RRB, particularly west of the Red River.

2.1.1 Monitoring for Water Quality and Discharge

Monitoring for discharge and water quality occurs at many locations within the Red River Basin. Seven long-term monitoring sites have data from 1970 to present, while most of the other sites have data from 1995 to present. Ten monitoring stations are located along the Red River mainstem (7 in the United States and 3 in Canada). Major tributaries to the mainstem are also monitored at 12 sites in Minnesota, 6 sites in North Dakota, and 8 sites in Manitoba.

2.1.2 Water Quality

Water quality trends in the Red River and its tributaries were evaluated by Rochelle Nustad, Hydrologist with the U.S. Geological Survey Dakota Water Science Center. Nustad conducted trend analysis using QWTREND for three periods from 1970 to 2017 using data from seven long-term monitoring sites, and for 2000 to 2015 using data from the remaining monitoring sites.

Based on Nustad's analysis, concentrations of Total P (TP) have increased from 2000 to 2015 in the northern portion of the RRB while a decreasing trend was observed in the southern part of the RRB. Increases are dramatic downstream of Fargo–Moorhead. In addition, TP loads at Emerson (Manitoba) increased from 2.8 tons/day in 1970 to 6.7 tons/day in 2015. Loads at Selkirk (Manitoba) increased from 8.1 tons/day to 11.1 tons/day over the same period. Together, these trends show that daily TP loads have increased significantly in both the U.S. and Manitoba portions of the Red River Basin. TP load targets set by policy in Canada are 3.84 and 7.67 tons/day at Emerson and Selkirk, respectively. Both of these load targets are exceeded by a large margin. In high flow years (1997, 2006, 2009, and 2011), 70% or more of TP load was transported during March through May. In low flow years (2003, 2008, and 2012), 30% to 50% of the load was transported during spring to summer.

At Fargo and Grand Forks, dissolved reactive P (DRP) represents from 40% to 90% of TP. Largest proportions of DRP occur in winter while the lowest occur in spring. Because TP loads vary spatially from one watershed to another, strategies for reducing TP loads should place a higher emphasis on controlling P losses in watersheds with the highest TP loads.

Nitrogen trends differ from TP trends. Trends from 2000 to 2015 show that nitrate+nitrite-N (referred to later as nitrate-N) concentrations have increased. Increasing trends in the Bois de Sioux watershed, located in the southern portion of the Red River Basin, could be due to an increasing area of farmland with tile drains. Trends also increase northwards but not as quickly. Nitrate-N concentrations increase abruptly downstream of Fargo–Moorhead. In high flow years, more than 80% of the nitrate-N load was transported from March–May. In low flow years, 30% to 60% of nitrate-N load was transported during spring and summer.

Trends in nitrate-N concentration from 1970 to 1985, 1985 to 2000, and 2000 to 2015 show that at Emerson, concentrations from 1970 to 1985 averaged 1.58 mg/L, but in 2015 averaged 1.64 mg/L, a slight increase. At Emerson, N loads increased from 36 to 37 tons/day from 1978 to 2015. At Selkirk, N loads increased from 53 to 73 tons/day from 1978 to 2015, a large increase. This indicates a large increasing N contribution from the Manitoba portion of the Red River. The draft loading target for Lake Winnipeg set by the Canadian government for N loading is 26 tons/day. This target is exceeded by a large margin in both the U.S. and Manitoba portions of the Red River Basin.

2.1.3 Discharges

Kelly et al. (2017) showed that trends in annual discharge, represented as water yield for the Red River Basin, have increased dramatically since 1990 (from <1 inch to over 4 inches), with lower values to the west (North Dakota) and higher values to the east (Minnesota). The largest increases in water yield have occurred over the months of November–February. Drivers of hydrology include climate and human activities, and altered hydrology involves changes in pathways, storage, and hydrologic response. Precipitation has not increased as rapidly as stream discharge since the 1980s. Water storage has increased in fall and decreased in spring. On an annual basis, storage has decreased and evapotranspiration has increased. This indicates a cropping system change, resulting from increasing acreage of corn and soybeans.

In Minnesota, precipitation in the Red River Basin has increased by 1 to 3 inches annually. Winter precipitation has increased by up to 15%. Storm intensities of 2 to 3 inches rainfall events have also increased, leading to increased runoff. Seasonal runoff shows peak discharge in April or May, and there are higher flows in fall compared with historic conditions. Runoff as a percentage of precipitation currently ranges from 10% to 20% in Minnesota, which is double the range in this percentage from 1971 to 2000.

Flooding is a serious concern in the Red River Basin, particularly during spring snowmelt, which begins in southern tributaries and proceeds northward. Catastrophic flooding occurred in the following years, from the most severe to least: 1826, 1852, 1997, 2009, 1861, 1950, 1979, 1996, 2006, 1974, and 2011. According to the Palmer Drought Severity Index (PDSI), the current climate is wetter than normal. Hydrologic management for flood damage reduction (FDR) has focused on strategies such as altering the timing of tributary flows to stage runoff from early, middle, and late contributing areas (Anderson and Kean, 2004). For a spring hydrograph, areas surrounding the Red River mainstem contribute most to the early portion of the hydrograph, while areas to the west and east of the mainstem contribute to the middle portion of the hydrograph, and areas farthest west and east of the mainstem contribute to the late portion of the hydrograph. Management activities that prevent these three areas from contributing runoff to the mainstem at the same time are useful for reducing peak flows during flooding.

Strategies for achieving FDR include reducing flood volume, increasing conveyance capacity, increasing temporary flood storage, and building levees. As an example, in Minnesota, strategies for reducing flood volume can be achieved through wetland restoration, cropland BMPs that increase ET and infiltration, conversion of cropland to prairie, perennial grassland or forests, and implementing land retirement through programs such as the Conservation Reserve Program (CRP) or Reinvest in Minnesota (RIM). Reducing flood volume can be achieved through structural practices such as building levees or increasing flood storage capacity by moving levees. Increasing temporary flood storage can be achieved through measures that include building water impoundment structures, impounding water in wetlands, increased drainage to lower shallow water tables, and resizing culverts to hold back water temporarily. The costliest flood reduction strategies involve building urban, farmstead, or agricultural levees.

A wide range of agricultural BMPs are available to reduce flood volume and decrease peak flows (Table 2.1). These include better crop and soil management practices to increase infiltration and ET such as conservation tillage, conservation cover, cover crops, manure application, and

conversion of cropland to perennial vegetation. Installing grass waterways and filter strips can also enhance ET. Improved drainage can increase temporary water retention through practices such as controlled drainage, replacing open tile inlets with surface risers or blind inlets, or installing subsurface tile drainage with shallow depths and narrow spacings. Short term water retention can also be increased through practices such as two-stage ditches, restricted culvert sizing, and water and sediment control basins. Long-term water retention can be promoted through practices such as construction of water impoundments, ponds, and wetlands. Details regarding the performance of these BMPs for nutrient reduction are discussed later in this report.

Table 2.1: Examples of Agricultural BMPs that Reduce Flood Volume and Peak Flow

Strategy Type with Specific Practice	Increase ET	Increase soil water holding capacity	Increased short-term surface storage (detention)	Increased long-term surface storage (retention)
Crop and Soil Management				
Cover Crops (340)	x	x		
Conservation Cover (327)	x	x		
Conservation Crop Rotation (328)	x	x		
Conservation Tillage (329, 345 and 346)	x	x		
Contour Farming (330)	x	x	x	
Field Borders (386)	x	x		
Forage and Biomass Plantings (512)	x	x		
Manure Application	x	x		
Land use change to perennial cover	x	x	x	
In-field Drainage Water Management				
Controlled drainage (DWM 554)			x	
Alternative Tile Inlets			x	
Alternative drainage design			x	
Surface Flow Management				
Grassed Waterway (412)	x			
Filter Strips (393)	x			
Contour Buffer Strips (332)	x			
Water Storage & Infiltration				
Saturated buffers ()	x	x		
Small Impoundments (356-dike)			x	x
Large Impoundments (356-dike)			x	x
Constructed Wetland (656)			x	x
Wetland Restoration (657)			x	x
Ponds (378)			x	x
Water and Sediment Control Basins (638)			x	
Terrace (600)			x	
In-Channel Water Retention				
Two-staged ditch with restricted size culverts			x	
Protection/management of existing ditches with two-stage channel			x	
Design standards for surface drainage			x	
Restricted culvert sizing			x	
Ditch Plugging and/or abandonment			x	
Grade stabilization				
Setting back existing levees			x	

It should be noted that at times BMPs for flood volume reduction are inconsistent with goals for nutrient reduction. For example, installing filter strips may reduce flood volume but also may increase losses of soluble phosphorus from the edge of field.

2.2 RED RIVER BASIN CHARACTERISTICS

Characteristics of the physical environment are highly variable across the RRB. From the foundational elements of geology and hydrogeology and soils and landscapes to the agro-climatic conditions and weather patterns, this variability poses a substantive challenge to the agricultural community in understanding the effectiveness of various BMPs at reducing nutrient loading to surface waters within the RRB. It also poses challenges concerning selection of the optimum locations for BMP implementation within and across the RRB.

A summary of the Red River Basin's physical environment characteristics is presented in the following sections.

2.2.1 Climate and Weather

The climate and weather patterns are highly variable within the RRB, including a couple of key patterns or regional gradients. Mean temperatures follow a gradient of relatively warm to relatively cold from the southern portion of the RRB to the northern portion (Fig. 2.2). This is not only an important agronomic factor (e.g., heat units and crop type selection) but an environmental one, as it helps determine how long soils are frozen and the frequency and intensity of FTCs. Mean annual temperatures range in variability by approximately 5 °C, with a high of 6.5 °C in the southern extent of the RRB and a low of 1.5 °C at the northern extent.

Another important climatic and weather pattern is precipitation, which decreases in a southeastern to northwestern gradient (Fig. 2.2). The range of variability in annual precipitation is over 250 mm, with the northwestern extent of the RRB receiving approximately 500 mm and the southeastern portion over 750 mm. The amount of precipitation is an important factor in hydrology, including the amount of snow accumulation and potential for surface runoff during the snowmelt period and throughout the remainder of the unfrozen period within the year.

The temperature and precipitation gradients have been used to develop temperature and precipitation classes (Fig. 2.3; developed by D. Mulla and J. Galzki using data from Jenkinson and Benoy 2015). These can be useful in determining the effectiveness of BMPs for nutrient load reduction across the RRB and for identifying which regions are suitable to BMPs that are affected by these climatic factors.

The selection of BMPs for nutrient load reduction must consider not only the current climate patterns and weather conditions, but the likely changes in these patterns and conditions into the foreseeable future. This should include factors such as temperature, total rainfall, timing of rainfall, and storm intensity. Current predictions suggest a lot of variability in precipitation amounts but generally an increasing trend in precipitation including the potential for substantially more winter precipitation. These factors will impact the suitability and effectiveness of BMPs within the RRB.

Adaptation needs to be woven into the planning and implementation framework in order to respond to changing climate patterns and weather conditions and build a resilient system that effectively manages nutrient load reduction into the future.

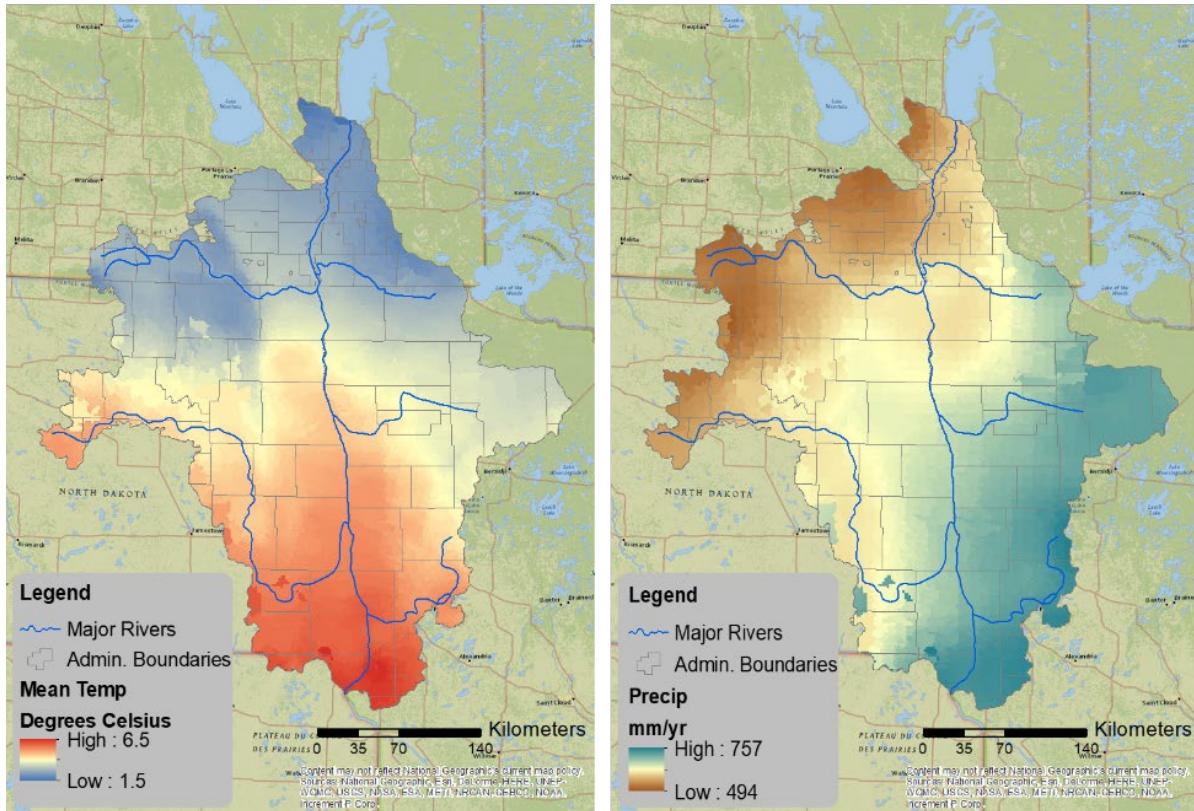


Figure 2.2: Average Annual Air Temperature (left) and Precipitation (right) in the Red River Basin (adapted from Jenkinson and Benoy 2015)



Figure 2.3: Temperature and Precipitation Classes in the Red River Basin (developed using data from Jenkinson and Benoy 2015)

2.2.2 Geology and Hydrogeology

Geology has played an important role in the physical and chemical properties of the surficial materials in the RRB. Glacial processes resulted in the formation of areas of lower-permeability sediments, such as tills and lake-bed soils, as well as areas of coarser-grained soils associated with deltaic fans, sand plains, and beach ridges. The chemical properties of soil parent materials were affected by the underlying geology on which glaciers advanced and retreated during the last glaciation in the region, which last occurred 12,000 to 13,000 years ago.

The low slopes areas in the RRB correlate with the extent of Glacial Lake Agassiz (the highest extent or the Lockhart Phase), a pro-glacial lake that formed at the toe of the glacier as the ice retreated. As the ice melted, sediment that was bound in the ice was mobilized. Surficial materials consist of till drift, or unsorted materials, and stratified drift, or well-sorted sediment, laid down by glacial meltwater.

There are numerous deltaic aquifers that were formed along the shoreline of Lake Agassiz:

- Sandilands region located in the northwest portion of the RRB was formed by sub-aqueous glacial fluvial deposits.
- Sheyenne delta aquifer is the largest aquifer in the RRB in North Dakota.
- Several other deltaic or underflow fans, consisting of coarser textured materials, are found along the western extent of former Lake Agassiz.

Other aquifers include lake deposit aquifers along the eastern extent of the RRB in Minnesota, sand plain aquifers, such as the Otter Tail Plain region in the southeastern extent of the RRB, and numerous buried valley aquifers, formed when coarser textured materials filled valleys as the glacier retreated. Examples of buried valley aquifers include a small buried valley aquifer found in the northwestern extent of the U.S. portion of the RRB just south of the Manitoba border and the Buffalo aquifer, which parallels the Buffalo River in Minnesota.

There are some beach ridges comprised of coarser materials, for example below and to the east of the escarpment. In some cases, thin coarse-textured and permeable surface soils are found overlying till within the soil zone, such as the highly permeable soils in the central portion of the RRB.

An evaluation of water quality was completed on the Sheyenne Delta aquifer in North Dakota and the Otter Tail aquifer in Minnesota. These aquifers are similar in nature but have different water quality with the Otter Tail aquifer showing a higher degree of impact from agricultural activities. For example, there appears to be a correlation between fertilizer applications and groundwater nitrate concentrations in the Otter Tail aquifer but not in the Sheyenne area. Similar patterns have been found in other counties in North Dakota and Minnesota, with groundwater quality generally being better in North Dakota. So, why this difference? The Red River is a good boundary between sedimentary rocks (e.g., shales) west of the Red River and igneous and metamorphic rocks (i.e., pre-Cambrian shield) east of Red River, with the majority of Minnesota underlain by these types of rocks. The water quality differences are, therefore, largely attributable to different chemical characteristics between the underlying geology and associated groundwater characteristics.

Shales of the Jurassic and Cretaceous periods were formed by buried organic materials in an offshore, marine environment. Shales are typically rich in organic C, organic S, pyrite and Fe(II) minerals, which are considered electron donors and can be very reactive with nitrate. Aquifers within materials derived from high concentrations of shale (i.e., drift aquifers) can be effective at reducing nitrate concentrations through autotrophic denitrification. For example, researchers have concluded that, while being highly vulnerable to nitrate contamination, the unconfined Elk Valley Aquifer in eastern North Dakota has sufficient pyrite-S to support denitrification at current nitrate loading levels for 11,000 to 175,000 years depending on location. Therefore, the focus of BMPs for keeping nitrogen from leaching below the rooting zone and potentially impacting groundwater should focus on aquifers vulnerable to water quality degradation from nitrogen loading, including those with low denitrification potential located in areas of materials derived from crystalline bedrock units.

In North Dakota, there are high enough groundwater concentrations of calcium (>10 mg/L) and enough fluoride (>0.2 to <0.5 mg/L) that a mineral called fluorapatite is found in a super-saturation state which results in P precipitating out of the solution and water column. However, in areas of low concentrations of calcium, such as the Precambrian Shield, which is comprised of igneous bedrock, phosphate can be soluble. This can be an issue on the east side of the Red River Valley.

2.2.3 Soils and Landscapes

The Red River Plain, which formed under Glacial Lake Agassiz, is characterized as having flat or level topography with low slope gradient classes (Fig. 2.4). Flat and level topography extends through most of the northeastern portion of the RRB. The RRB is dissected by an escarpment, known as the Pembina escarpment on the U.S. side of the border and the Manitoba escarpment on the Canadian side. This feature is distinguishable in Fig. 2.4 by the break in slopes running in a general south to north orientation parallel with the Red River at the western extent of the low slopes associated with the Red River Plain. The escarpment is an area of predominantly medium to high slopes with a topographic rise of approximately 90 to 120 m from the Red River Plain. Above the escarpment to the west is the undulating or rolling topography of medium slope classes associated with the glacial till plain. Other notable areas of high slope gradient classes include a region in the southeast portion of the RRB in Minnesota known as the Alexandria Moraine (this represents a large area in the RRB with some of the steepest slopes) and steep slopes along the western extent of the RRB.

The undulating topography of the glacial till plain in the western portion of the RRB has poorly developed regional surface drainage. Locally, water moves effectively from higher elevation areas into closed depressions where water can collect (Fig. 2.5). Soils are predominantly Chernozemic/Mollisols, are medium (loamy) to moderately fine (fine loamy) to fine (clayey) textured, and have well to poor internal drainage. Severe loss of topsoil is common in upper to crest landscape positions and is attributable to tillage erosion. Low-lying and depressional areas typically have thicker topsoils, which are due to natural soil-forming processes as well as receiving eroded topsoil from up-slope areas. Preferential flow paths can be important in these soils, particularly under low disturbance tillage systems experiencing rainfall runoff.

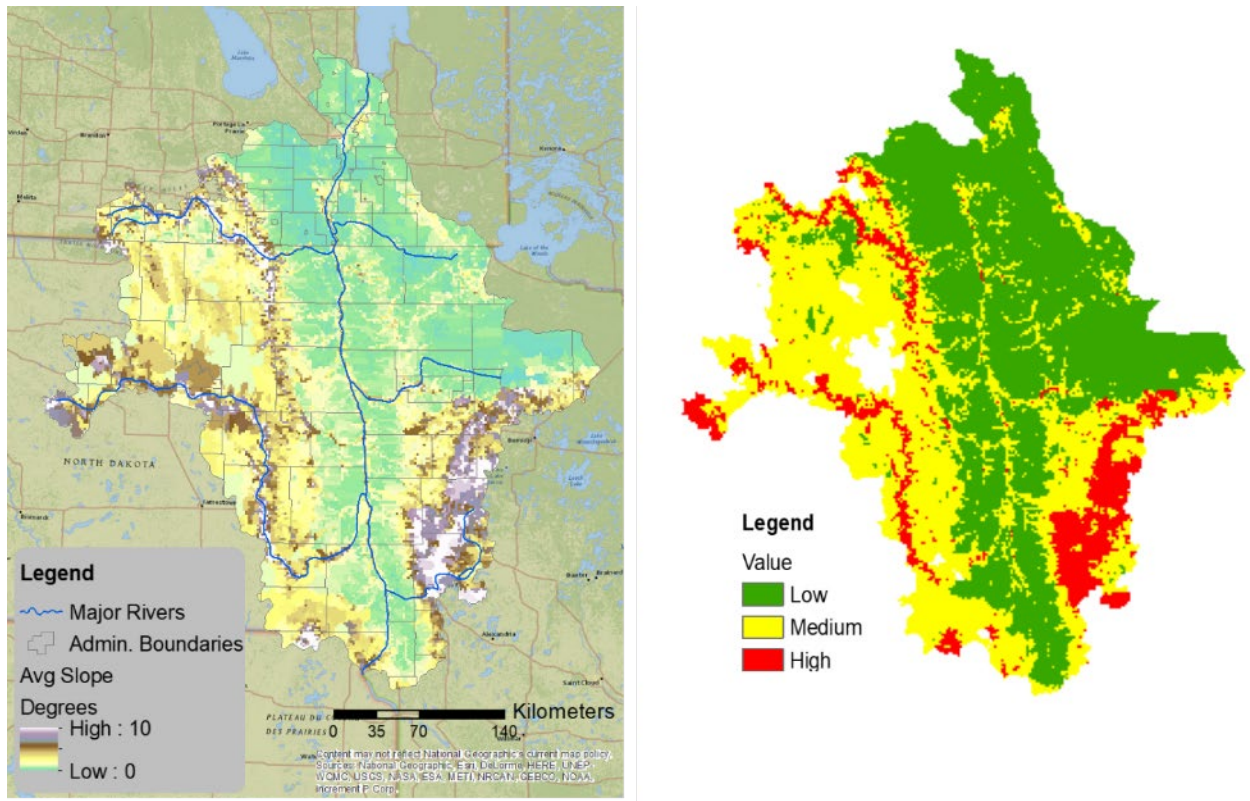


Figure 2.4: Slope Gradient (left) and Slope Classes (right) in the Red River Basin (adapted from Jenkinson and Benoy 2015)

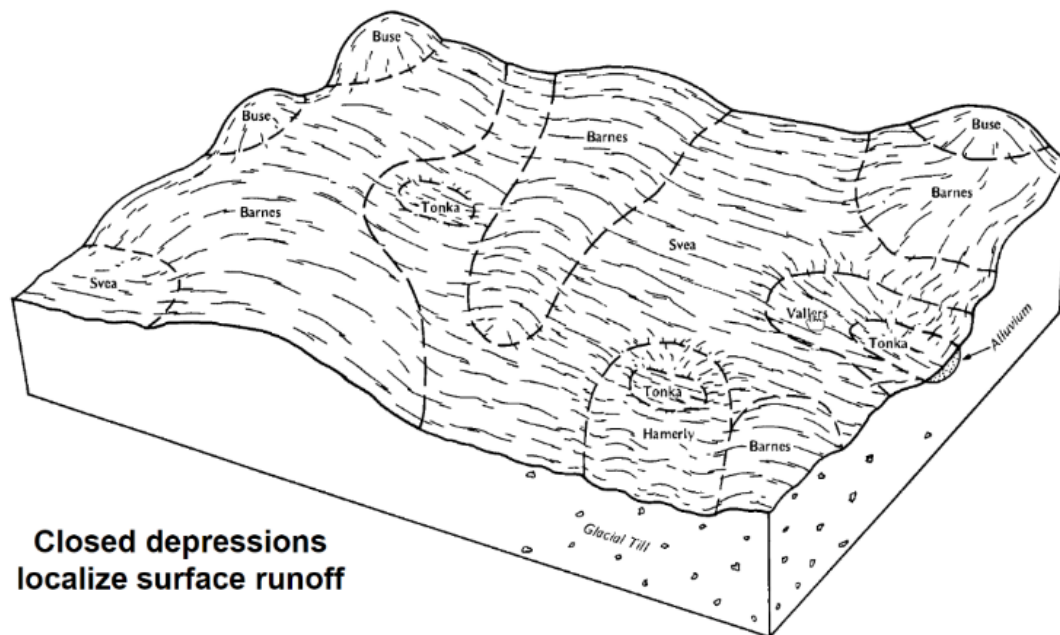


Figure 2.5: Undulating Topography in the Glacial Till Plain (USDA-SCS 1985)

The low relief glacial lake plain is characterized as flat with micro-relief in the form of ridges, swales, and some small, closed depressions (Fig. 2.6). Due to this micro-relief and the low permeability of the soils, this region is prone to flooding that can affect large areas. Soils are predominantly Vertisolic and are characterized as predominantly very fine textured (heavy clay) sediments with shrink-swell properties; however, inclusions of medium (silty) and fine (clayey) sediments are also found throughout this area. Infiltration is very slow and internal drainage is predominantly imperfect to poor. Owing to the proneness to inundation and flooding, this area of the RRB has undergone significant artificial surface drainage development in order for the land to be used for intensive cropping. Preferential flow paths can be important in these soils due to the cracking associated with these clays.

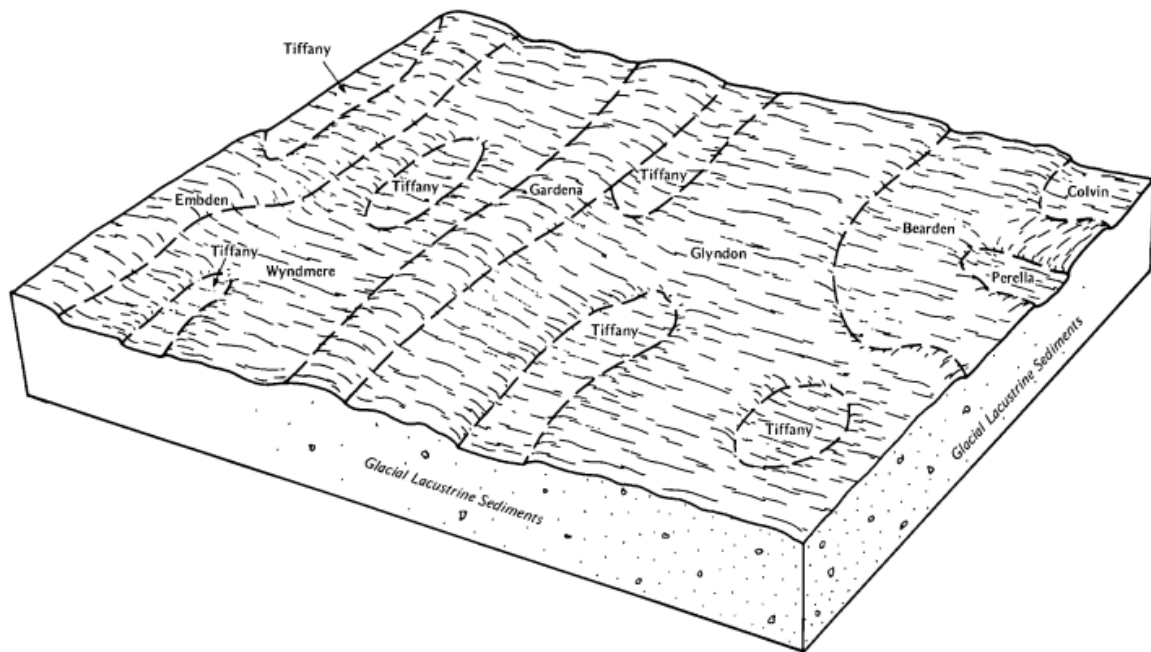


Figure 2.6: Flat Topography with Micro-Relief in the Glacial Lake Plain (USDA-SCS 1985)

Areas of sandy sediments or deposits are associated with outwash and lake plains scattered throughout the RRB.

The predominant soil management concerns include the following:

- Salinity in soils developed on marine shales to the west of the Red River
- Erosion throughout the RRB, with erosion risk due to wind, water, and tillage
- Flooding, primarily throughout the Red River Plain

Soil texture (% sand and % clay groupings) and permeability classes are shown in Fig. 2.7 (developed by D. Mulla and J. Galzki using data from USDA-NRCS 2019 and AAFC 2016). Combining soil datasets from different sources leads to unavoidable but questionable changes in soil texture across national, state, and county boundaries permit only general interpretations. In general, low permeabilities are associated with the finer textured surficial materials within the Red River Plain. Medium permeability is found in the western portion of the RRB in association

with the till plain and throughout much of the eastern portion of the RRB. High permeability soils are primarily associated with the coarse-textured, deltaic, and fluvial deposits and beach ridges throughout the RRB.

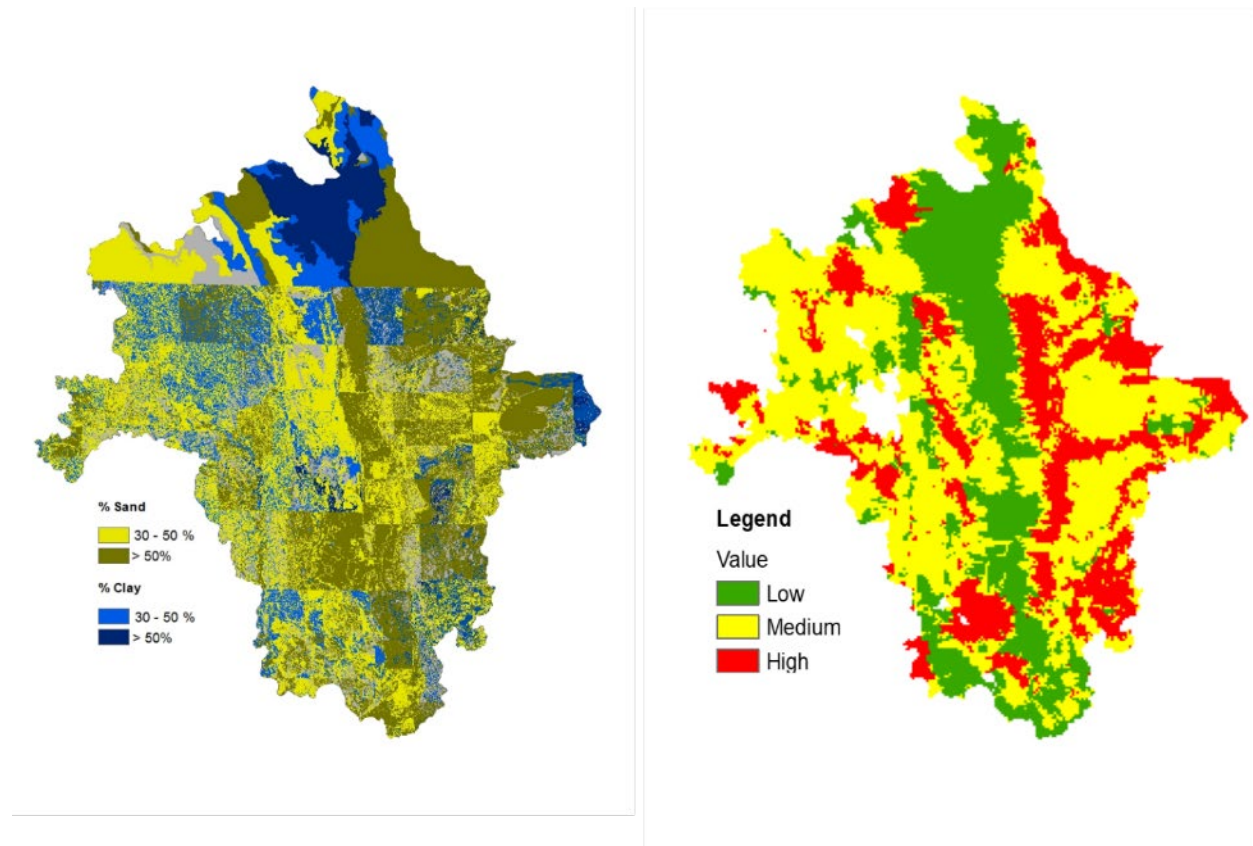


Figure 2.7: Soil Texture (left) and Permeability Classes (right) in the Red River Basin (USDA-NRCS 2019; AAFC 2016)

2.2.4 Surface Water

The Red River is the predominant surface drainage course in the RRB and collects water from all the sub-basins and drains into Lake Winnipeg, north of Winnipeg, MB (Section 2.1). Including the Red River, there are six major rivers and three major sub-basins in the RRB (Fig. 2.8). From south to north, these rivers and sub-basins include the following:

- The Bois De Sioux River originates at the northeastern corner of South Dakota and collects drainage from the southern portion of the Upper Red sub-basin.
- The Red River, the predominant river in the RRB, originates at Breckenridge, Minnesota / Wahpeton, North Dakota at the confluence of the Bois De Sioux River and the Otter Tail River and carries water through the central portion of the RRB and spills into Lake Winnipeg, north of Winnipeg, Manitoba.
- The Sheyenne River originates in central North Dakota and collects surface water from the southwestern portion of the RRB. It flows past the Devils Lake Sub-Basin, a closed basin with no significant discharge.

- The Red Lake River drains the southern portion of the Lower Red sub-basin, which comprises a good portion of the RRB in the northern half of Minnesota.
- The Pembina River originates in Manitoba and crosses into North Dakota prior to entering the Red River near Pembina, North Dakota and Emerson, Manitoba. It drains the northwestern portion of the Lower Red sub-basin.
- The Roseau River originates in northern Minnesota, just south of the Canadian border and crosses into Manitoba prior to entering the Red River north of Emerson, Manitoba. It drains the northeastern portion of the Lower Red sub-basin.



In addition to reductions in water storage on the landscape, there have been major changes to cropping practices in the RRB (i.e., shift from hay and small grains to soybeans), which have amplified streamflow (Kelly et al. 2017). This change in vegetation and cropping practices has had a major impact on runoff and flow in the RRB since the mid-1990s following a relatively stable period since the 1940s. This has increased the runoff per unit precipitation. In addition, precipitation has been higher in the spring (March) and fall (October) in the last approximately 40 years (1975 to 2013) compared to the previous 40 years (1935 to 1974). There have been increases in streamflow in every month except for April.

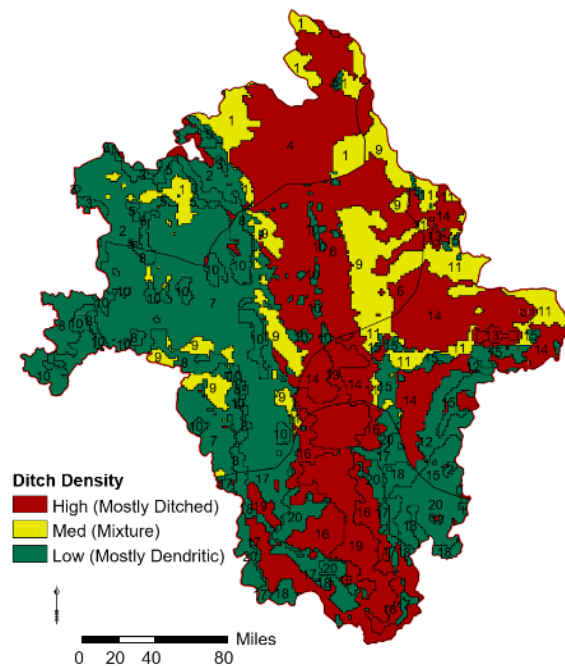


Figure 2.9: Prevalence of Artificial Drainage in the Red River Basin (numbers and solid boundary lines represent BMP suitability zones; USDA-NRCS 2019 and AAFC 2016)

Surface water runoff is an extremely important hydrologic mechanism in the RRB when considering BMPs for agricultural nutrient load reduction. At a broad level within the RRB, runoff from agricultural fields occurs predominantly as snowmelt runoff in the spring. Runoff events during the summer and fall are generally of smaller magnitude than snowmelt runoff events; however, these events can occur following heavy rainfall events on finer textured soils and sloping lands where infiltration is limited.

In addition to local soil texture and topography variability, the regional climatic gradient within the RRB (Section 2.2.1) is an important determinant in field-scale surface runoff. Snowmelt contribution is greatest in the northeastern portion of the RRB and least in the southeastern portion. In other words, rainfall runoff events are increasingly important as the climate warms and becomes wetter in the southern portion of the RRB (Rahman et al. 2014).

Surface runoff ranges in variability by over 140 mm/yr, with the highest runoff in the eastern extent of the RRB with values up to 160 mm/yr. Most of the RRB is characterized by much lower runoff values to below 20 mm/yr (Fig. 2.10).

Non-contributing areas should be considered in the discussion of suitability of BMPs across the RRB.

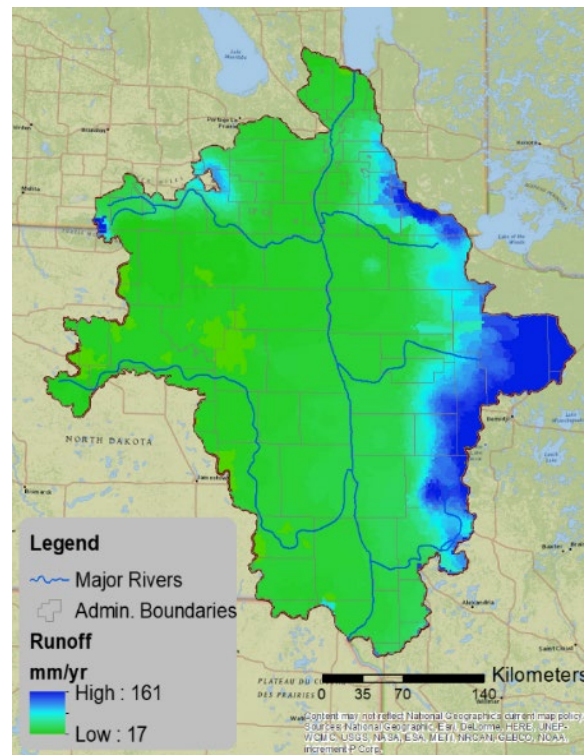


Figure 2.10: Surface Runoff in the Red River Basin from 1971–2000 (adapted from Jenkinson and Benoy 2015)

2.3 LAND USE AND AGRICULTURAL MANAGEMENT

2.3.1 Existing Land Use

Land use in the Red River Basin is diverse (Fig. 2.11) and includes agricultural crops, wetlands, prairie grassland, forest, open water, and urban development. Land use has a significant impact on runoff, erosion, and export of N and P to ditches and rivers (Fasching et al. 2019). In watersheds having >30% to 40% non-cropland cover, concentrations of N and P decrease as flow increases. In watersheds with >60% of land in agriculture, concentrations of N and P increase as flow increases. The authors indicate this may be partially due to decreased hydrological connectivity in more natural catchments owing to more heterogeneity relative to their anthropogenic counterparts.

Acreages of major agricultural crops grown in the United States and Manitoba are summarized for 2018 in the Red River Basin (Fig. 2.12). The U.S. portion is based on the 2018 Cropland Data Layer (USDA-NASS 2018), while the Canadian portion is the equivalent 2018 Annual Crop Index (AAFC 2018). Production of major agricultural crops covers over 17 million acres in the U.S. portion of

the Red River Basin as compared with over 4.4 million acres in the Canadian portion. Crop acreages on the U.S. side in decreasing order include soybeans (6.1 million acres), small grains (4.1 million acres), corn (2.6 million acres), grass/pasture (1.9 million acres), alfalfa/other hay (0.93 million acres), canola (0.62 million acres), sugar beets (0.47 million acres), dry beans/peas (0.47 million acres), and sod/grass seed (0.06 million acres). On the Canadian side, crop acreages include small grains (1.3 million acres), soybeans (0.97 million acres), canola (0.96 million acres), grass/pasture (0.75 million acres), corn (0.35 million acres), and dry beans/peas (0.1 million acres). Differences in reporting methodology exist in the United States and Canada, particularly with regards to underreporting of alfalfa/other hay in Manitoba. Crops that require N and P applications from fertilizer include primarily corn, small grains, canola, and sugar beets. Larger acreages of these crops exist on the U.S. side (7.32 million acres) relative to the Canadian side (2.61 million acres).

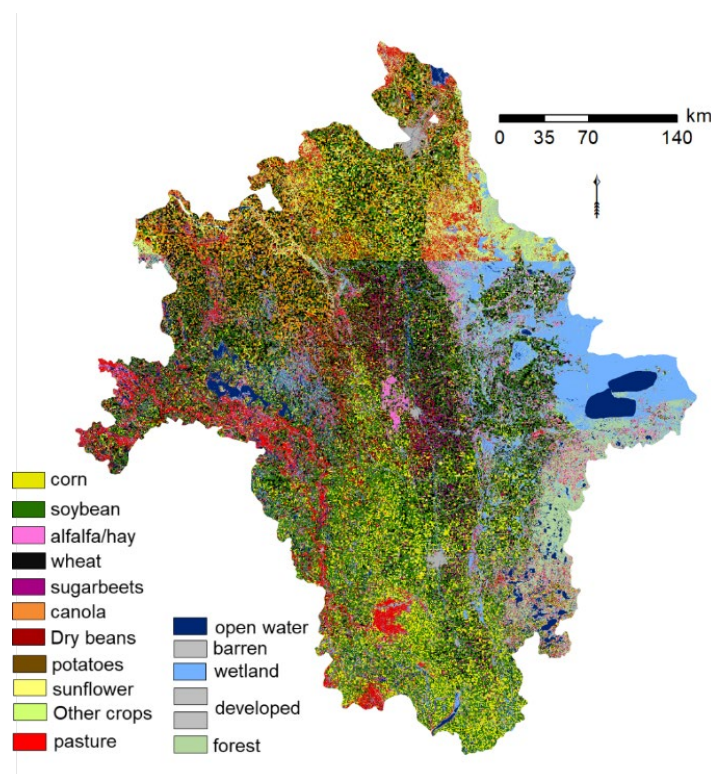


Figure 2.11: Land use in the Red River Basin 2018 (developed by D. Mulla and J. Galzki using data from USDA-NASS 2018 and AAFC 2018)

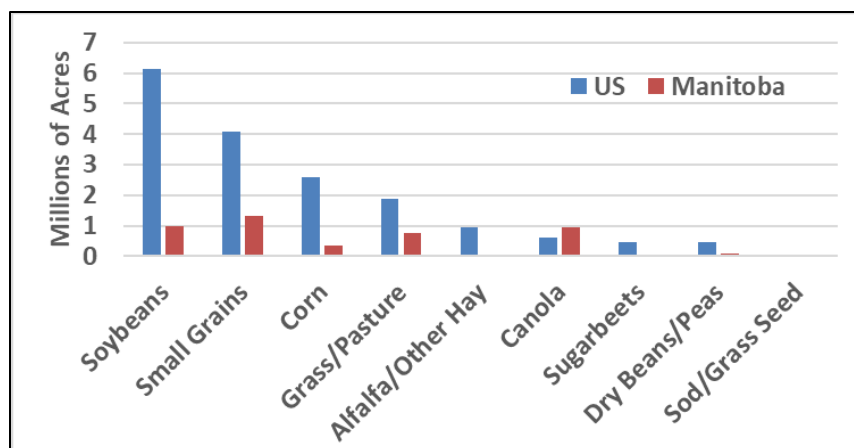


Figure 2.12: Comparison of 2018 Acreage for Agricultural Crops in the U.S. and Manitoba Portions of the Red River Basin (USDA-NASS 2018; AAFC 2018)

2.3.2 Agricultural Management Systems and Practices

Agricultural management systems across the RRB are highly variable. This variability is driven by multiple factors and affects management systems at various scales. The RRB comprises two federal jurisdictions and four state/provincial jurisdictions. These geo-political boundaries superimposed on the RRB affect agricultural management through policy and regulation as well as the market environment, including the following examples:

- Environmental regulations preclude winter manure application in Manitoba while this practice is still conducted in the United States, including North Dakota, Minnesota, and South Dakota.
- The Conservation Reserve Program in the United States resulted in large acreages of sensitive lands being converted to permanent cover for a contracted period. Now some of these lands are being converted back to annual crop production.
- Sugar beets are no longer grown in Manitoba but are popular in North Dakota and Minnesota due to active processing plants in those states.

Other sources of variability at the regional scale include suitability of practices relative to climate and weather (Section 2.2.1) and soil-landscape conditions (Section 2.2.3), and access to knowledge and advice (e.g., extension support). Local variability can be due to economics of operations and access to equipment and technology and legacy (traditional practices) issues.

Production Systems

In the Manitoba portion of the RRB, crop rotations are relatively diverse. Canola, wheat, and soybean are the primary annual crops grown in rotation. Corn and soybean acreage have increased dramatically in recent years, with soybean acreage increasing 168% between 2011 and 2018 from 705,000 to 1,890,000 acres and corn acreage increasing 81% between 2011 and 2018 from 211,000 to 382,000 acres. Forage is also present in areas of integrated livestock and cropping systems for feeding cattle and is common in southeastern portion of the RRB in Manitoba and in the western portion of the RRB in the till plain. Cover crops are not commonly grown in MB as a result of short post-harvest growing season and cold temperatures. However,

there is increasing interest in sowing cover crops like hairy vetch before harvest to build soil health.

Common crop rotations throughout much of the RRB in North Dakota and Minnesota are corn-soybean and continuous corn systems. Wheat is also an important rotational crop. Sugar beets are common in the crop rotation in the Red River Plain and typically include corn, soybean, and wheat in rotation. Forage crops and pasture are grown in conjunction with integrated livestock and cropping systems throughout the western portion of the RRB in North Dakota.

Livestock operations are spread throughout the RRB but are more common outside of the Red River Plain. Livestock types include beef cattle, pigs, poultry, and dairy cows. Generally, the intensity of livestock production is relatively stable in the region and areas of livestock production are not changing. The areas of N and P loading from manure sources provides an indication of where within the RRB livestock intensity is most important from a BMP focus perspective (Fig. 2.13).

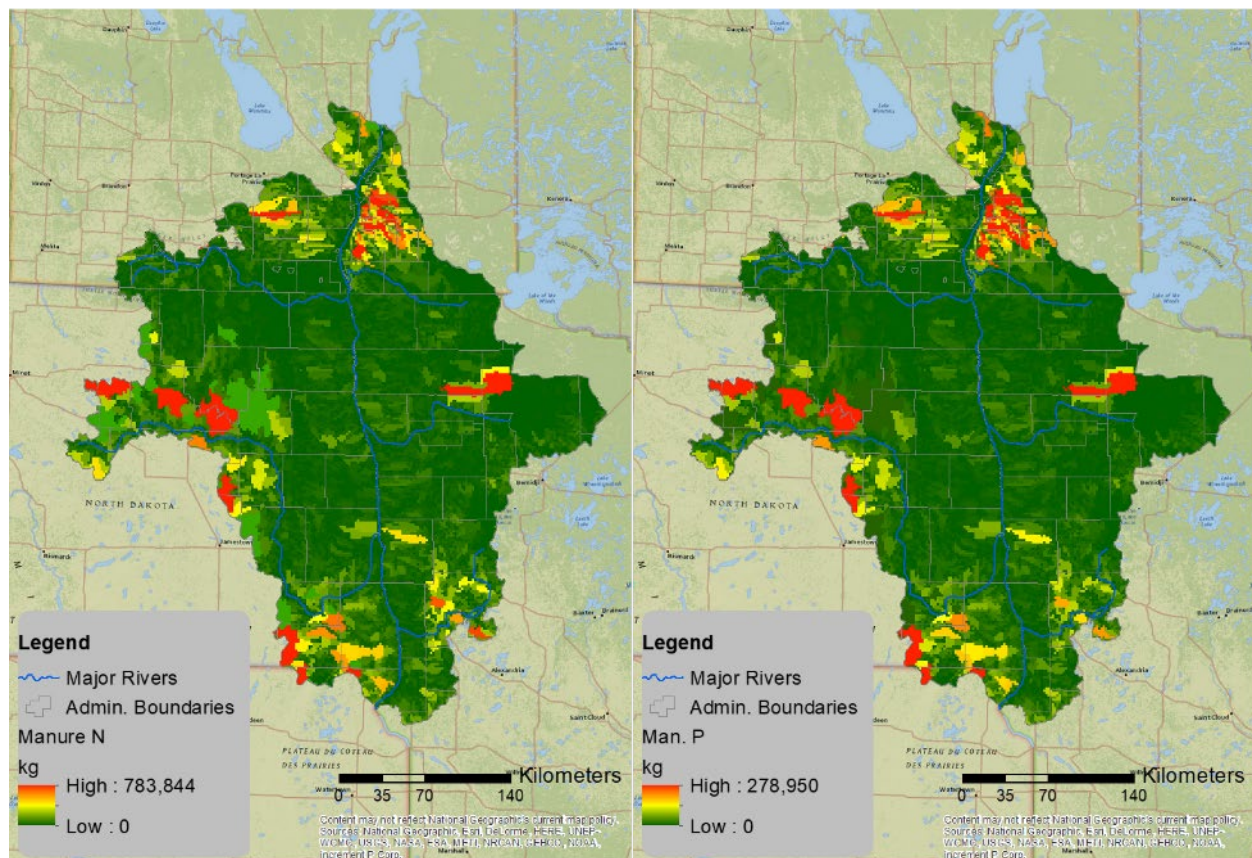


Figure 2.13: Kilograms of manure N (left) and P (right) applied within each minor watershed for the year 2002 in the Red River Basin (adapted from Jenkinson and Benoy 2015)

Nutrient Management

In consideration of nutrient management, it is important to again mention the complexity in the soil-landscape and agricultural management systems across the RRB. In addition to the need to consider BMP suitability relative to regional and local soil-landscape characteristics and variability (e.g., slope and permeability), current and future management practices (e.g., crop rotations, drainage management) have an impact on the feasibility and suitability of individual BMPs, or specifics of implementation of those BMPs that are suitable in a broad sense.

In Manitoba (between 2015 and 2018), the vast majority of nitrogen for wheat and canola was spring banded before or at seeding or seed-placed (wheat – 94%; canola – 83%), with only 4% and 13% broadcast and incorporated, respectively. Only 2% of nitrogen for canola was broadcast and not incorporated. For grain corn, banding and in-crop (in-season) application represents the majority of application; however, broadcast and incorporation is an application method reported on approximately 35% of acres, and broadcast without incorporation was reported on 11% of acres. In corn, supplemental nitrogen application in-crop is common (22% of acres). Timing of application of N in Manitoba during this period was 32% in fall, 48% in spring (preplant), 23% at seeding, and 22% at post-seeding (in-crop).

For phosphorus in Manitoba, most applications to wheat and canola were conducted as seed-placed (wheat – 54%; canola – 62%) and only a small proportion was broadcast and incorporated (wheat – 3%; canola – 9%). For grain corn, while most crop needs were satisfied using banding at or prior to seeding, 35% was broadcast and incorporated and 5% was broadcast without incorporation. Timing of application of P in Manitoba during this period was 23% in fall, 34% in spring (preplant), and 55% at seeding.

In northwestern Minnesota, many producers apply nitrogen in the spring, with only 25% practicing fall application, most of which was incorporated. Urea is the popular choice for fall application. One third of producers applying fall urea practiced variable rate N applications. A deep soil nitrate test was conducted by 29% of farmers planting corn.

Areas of N and P loading (kg applied within each minor watershed) from fertilizer sources in 2001 to 2002 are presented in Fig. 2.14.

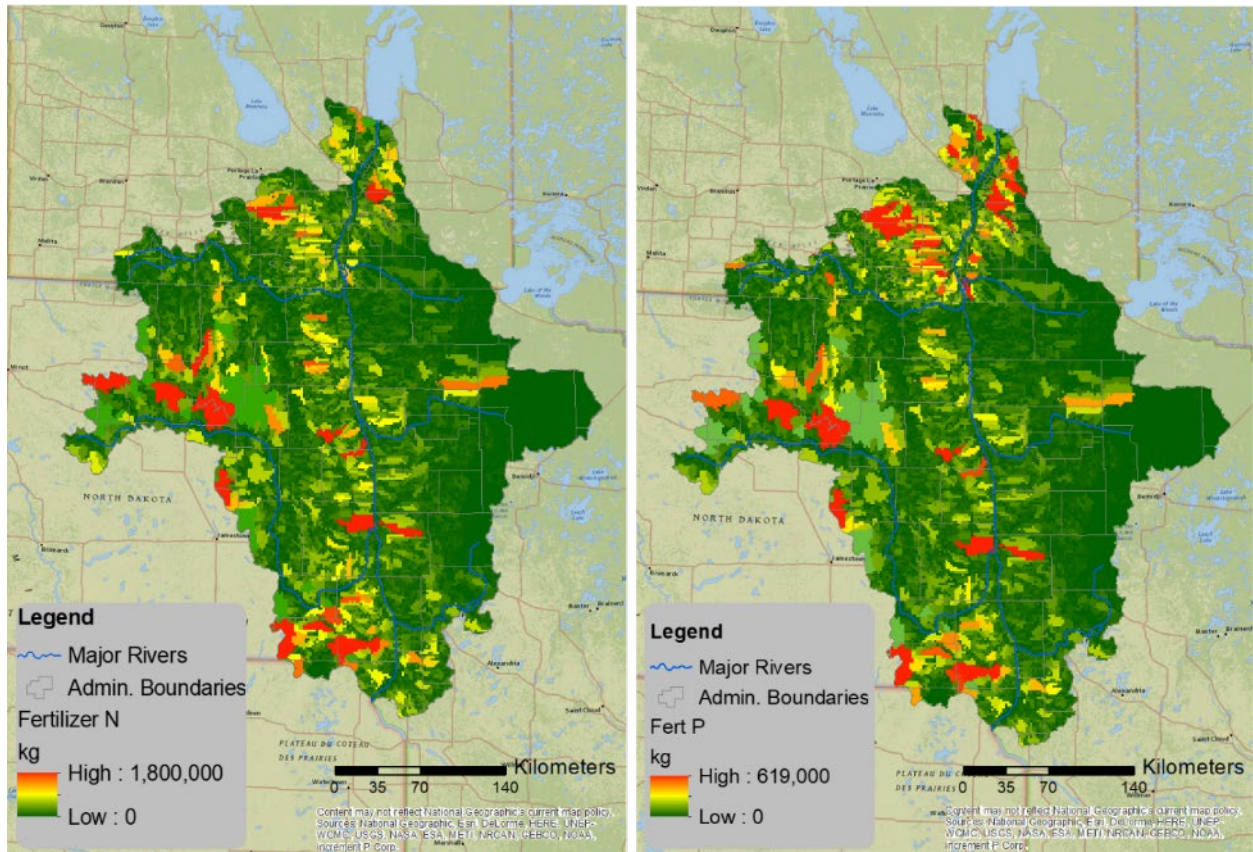


Figure 2.14: Fertilizer loading of N (left) and P (right) from 2001 to 2002 in the Red River Basin (adapted from Jenkinson and Benoy 2015)

Hotspots, or areas of high nutrient loadings, for fertilizer and manure sources of N and P loading across the RRB derived from Figs. 2.13 and 2.14 are shown in Fig. 2.15. These hotspots can be used to direct BMP decision making, as appropriate. For example, some areas are both N and P application hotspots, and some areas have loading issues from both fertilizer and manure. The Seine, Morris, La Salle, Upper Sheyenne, and Western Wild Rice watersheds are examples of watersheds within which there are both N and P application hotspots from fertilizer and manure sources.

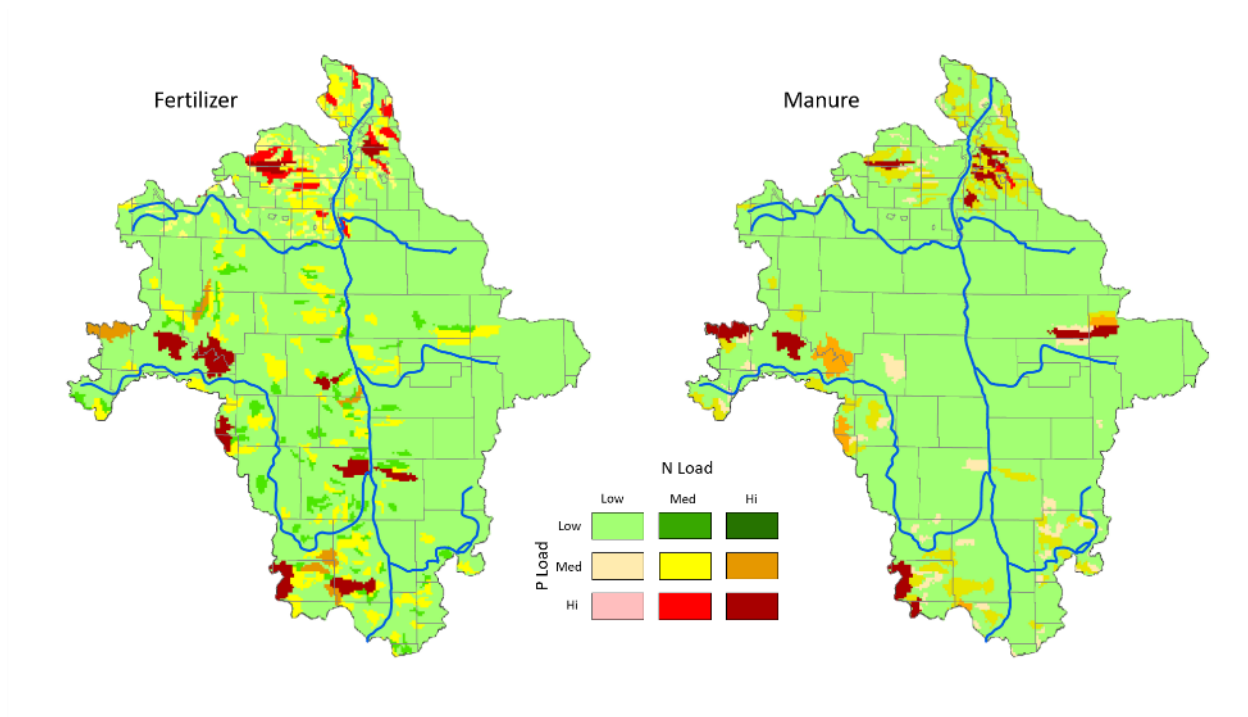


Figure 2.15: Fertilizer (left) and manure (right) hotspots for N and P loading from 2001 to 2002 in the Red River Basin (adapted from Jenkinson and Benoy 2015)

Tillage

In Manitoba, soil management on hilly lands in the western RRB is important to reduce erosion rates by water. Manure applications can be used to help improve soil health. Conventional tillage (i.e., tillage practices that leave <30% of the surface covered with residue at planting) is predominant in the central portion of the RRB where heavy clay soils predominate, and producers use tillage to manage residue levels and associated soil wetness challenges. Conservation tillage (i.e., tillage practices that leave >30% of the surface covered with residue at planting) is largely practiced in the western portion of RRB in areas where undulating topography and steeper slopes are common.

Like Manitoba, conventional tillage is the prominent tillage system in the Red River Plain and other flat regions of the RRB in Minnesota and North Dakota. Conservation tillage represents the majority of tillage management in the till plains region in the western portion of the RRB as well as in the steeper slope areas in Minnesota.

Tile Drainage

Subsurface or tile drainage is a land improvement practice that alters the pedo-hydrology within fields. At the scale of the entire RRB, tile drainage affects only a small proportion of land; however, it is a practice that is growing in importance as a means for producers to manage excess water. A brief summary by jurisdiction is as follows:

- Minnesota – considering the Minnesota portion of the RRB, in 1992, the percent of harvested acres with tile drainage were limited. In 2012, the number of drained acres had

greatly expanded in the RRB (up to 5%). Between 2012 and 2017, the number of drained acres doubled, especially within the southern RRB in MN (up to 20% of area).

- North Dakota – tile drain systems have increased dramatically since 2001, with the majority of tile drainage occurring in the Red River Plain within counties adjacent or in close proximity to the Red River.
- Manitoba – while the acres tile drained in Manitoba are much lower than in Minnesota (in area and percentage of land base), the trend is similar with a rapid expansion of tile drainage as a practice. In 2015, an estimated total of 25,000 ac of cropland were tile drained in Manitoba (~0.3% of cultivated acres) but 82% of these drains were installed in a five-year period between 2010 and 2015. The majority of these drained acres are within the RRB, with a high concentration in the northwestern portion of the RRB. Only a handful of fields are drained east of the Red River.

2.3.3 Other Considerations

Other issues of importance to agricultural producers and society in general must be considered in the evaluation of suitability of BMPs for implementation in the RRB. With many BMPs there are trade-offs in that some practices may be beneficial with respect to some issues while adverse to others.

Flood damage reduction is a major resource concern across the RRB, particularly in the flat landscapes and finer textured soils of the Red River Plain. Flooding can occur either during snowmelt or summer rainstorm events. Floods can have huge economic and financial consequences including damage to infrastructure. Flood protection consumes major economic resources. For example, there are 18 watershed projects that are in the planning stages to reduce flooding, improve water quality, and address other concerns on the U.S. side of the RRB. Consideration of streamflows should be included in BMP decision-making. For example, cleaning out drainage ditches can increase flooding downstream.

Soil health is critical to the sustainability of agricultural production in the RRB. Loss of soil health is detrimental. Negative effects to soil health result from loss of soil organic matter, loss of soil biodiversity, and compaction. These effects can lead to reduced infiltration, reduced water holding capacity, increased runoff and salinity. Management practices such as crop rotations, crop selection, and tillage practices are key to maintaining and promoting healthy soils. Generally, more diverse crop rotations, incorporation of cover crops, perennial crops and/or permanent cover, and conservation tillage are beneficial to soil health.

Soil salinity and sodicity are serious management concerns across the RRB. For example, soils in the Manitoba portion of the RRB are predominantly at moderate risk for salinization, a risk level that hasn't improved between 1981 and 2011 (AAFC 2020). It is estimated in North Dakota that 90% of producers are experiencing some sort of reduced productivity as a result of soil salinity (NDSU 2014). Salinity can develop because of natural processes acting on soil parent materials containing soluble salts; however agricultural management has altered the soil-water balance and has driven salinity development in many cases. Sodicity occurs when there is a high percentage of sodium in the soil. Salinity and sodicity issues can be detrimental to productivity. Decisions for BMP adoption for nutrient reduction should consider impacts to soil salinity and sodicity conditions and management. BMPs for management of salinity and sodicity include permanent

cover using salt-tolerant forages, tile drainage improvements, and soil amendments (e.g., gypsum for sodic soils). These practices can help maintain and improve productivity in areas of these problem soils, in turn, improving nutrient use. In addition, these BMPs can be beneficial to other aspects of soil health, including improved soil structure, increased infiltration, and water holding capacity, all of which can also improve nutrient management and reduce nutrient losses.

Riparian function and health are important for water resource protection. Farming to water's edge leads to degradation of riparian function and health, including bank destabilization and increases in sediment and nutrient loading of waterways.

A reliable and good quality water supply is required in the Red River Basin, and demand is increasing for human consumption, agricultural product processing, and livestock production. Water for crop irrigation is also important, particularly in the northwestern portion of the RRB where the need for reliable and good quality sources of water for irrigation is increasing. At the same time, water supplies are becoming a challenge in some areas. For example, groundwater supplies in glacial drift aquifers in eastern North Dakota are reaching maximum allocation.

Lake Winnipeg has a vibrant commercial fishing industry. The annual value is C\$17.8 million per year. The recreational fishery contributes C\$221 million each year to Manitoba. Seventeen communities in Manitoba get all or part of their drinking water from surface waters in the RRB, particularly west of the Red River. BMPs for nutrient management can affect water quantity and quality that can in turn affect other water resource users. For example, BMPs that reduce sediment entry into surface waters can result in reduced sedimentation of reservoirs.

BMPs for nutrient reduction can also impact greenhouse gas emissions, insect and disease management, fish and fish habitat, and wildlife and wildlife habitat (e.g., waterfowl, pollinators). For example, fish can be affected by quantity and timing of discharge, ammonia nitrogen, temperature, total suspended sediment and total dissolved solids, and emerging contaminants of concern such as neonicotinoids and pharmaceuticals.

3 CHALLENGES TO IDENTIFICATION OF BMPs

There are numerous and considerable challenges in determining the effectiveness and suitability of BMPs for nutrient load reduction in the RRB. Some of the key challenges are as follows:

- Lack of knowledge – in many cases the science supporting suitability and effectiveness of BMPs in cold climate regions like the RRB are lacking. After all, this lack of complete and consolidated information was a key driver to undertake the workshop and this report.
- Variability – there are multiple sources of variability operating over different scales (most of which have been introduced in the preceding chapters):
 - Environmental factors – climate and weather, geology and hydrogeology, and soil and landscape conditions are variable from regional to local scales. Temporal variability in climate and weather is also important to consider, namely climate change predictions in temperature, precipitation, and extreme weather events;
 - Geo-political/jurisdictional – the federal and state/provincial jurisdictions superimposed on the RRB affect management and production systems through policy, regulation, and policy influences on the market environment;
 - Agricultural management systems – aspects of cropping and livestock systems vary across the region and to the scale of individual operations and farmer preferences, including practices such as crop selection, crop rotations, nutrient and manure management practices, and tillage systems; and
 - Economics and access – economics and access to markets, equipment, and technology vary throughout the RRB. This is primarily an implementation issue with respect to BMPs but these factors influence the current management systems and practices across the region.
- Scale applicability of BMPs – some BMPs are generally applicable at the regional scale (e.g., principles of 4R nutrient stewardship) while some are suitable and effective at the local scale or field level (e.g., controlled tile drainage) or even specific areas within a field (e.g., feedlot siting).
- Trade-offs – many BMPs are beneficial for reducing N loading or P loading but not necessarily both. In some cases, BMPs that effectively reduce loading of one constituent may increase the loading of another (e.g., cover crops can effectively reduce N losses but senesced vegetation can become a source of P following freeze-thaw cycles). The impact BMPs have on other aspects of the environment also need consideration, including soil health, natural habitat, flood reduction, greenhouse gas emissions, and natural resource availability such as energy involved in the production of inorganic fertilizer. For example, bioreactors can effectively reduce N in tile drainage discharge but may result in small losses of nitrous oxide (a greenhouse gas) to the atmosphere through incomplete denitrification.

These challenges do not include consideration of factors important for implementation, such as economics and practical challenges associated with landowners and farmers adopting BMPs that are the most effective. While agronomic production is inherently woven into the consideration of BMP suitability, the objective of this Workshop summary is determining BMP effectiveness and suitability across the RRB.

4 EFFECTIVENESS OF BMPs FOR NITROGEN LOAD REDUCTIONS

4.1 OVERVIEW

This section summarizes the effectiveness of various BMPs in reducing nitrogen losses from agricultural fields in the Red River Basin. The summary is from information presented and discussed at the Workshop and does not include additional research or references. Therefore, this section does not necessarily present a comprehensive or exhaustive discussion on BMPs for nitrogen load reduction in the Red River; rather, it is limited to topics discussed at the Workshop.

Nitrogen occurs in two primary forms in soils, as nitrate-N ($\text{NO}_3\text{-N}$) and as ammonium-N ($\text{NH}_4\text{-N}$). Both forms can be taken up by crops. Fertilizer and manure N applied to soil are most effective when converted to ammonium-N. Ammonium-N is a cation and is sorbed to soil particles or incorporated into organic matter. Ammonium-N can be lost to surface waters during erosion of soil and loss of soil organic matter, and it is less likely to leach through soils unless there are preferential pathways. Application of anhydrous ammonia (AA) or urea to soils could lead to volatilization losses if not properly injected or incorporated in a way that the ammonia has a chance to be converted to ammonium-N. Nitrification converts ammonium-N to nitrate-N. Nitrate-N is an anion and is more susceptible to leaching or drainage losses than losses in runoff. Nitrate-N can be converted into nitrogen gas through denitrification, which generally occurs in wet or saturated soils.

The discussion is organized according to themes for presentations and breakout discussion groups at the workshop:

- BMPs for Nutrient Management
- BMPs for Erosion Control
- BMPs for Vegetative Management
- BMPS for Structural Management

4.2 BMPs FOR NUTRIENT MANAGEMENT

Nitrogen fertilizer and manure are commonly applied to agricultural land in the Red River Basin. In addition, nitrogen is released by soils through mineralization of soil organic matter. The major challenges in managing nitrogen inputs to crops include the following:

- Yield and quality of crops such as corn, wheat, canola, and sugar beet are strongly dependent on having sufficient N from fertilizer, manure, and organic matter
- Estimating the variable supply of N to crops as affected by mineralization of soil organic matter
- Reducing variable and potentially large losses of N by leaching, drainage, denitrification, runoff, and temporary immobilization by crop residue
- Adapting management practices based on the variable and potentially large impact of precipitation and temperature on the fate and transport of nitrogen

Management of nitrogen applied to agricultural land is constrained by precipitation and temperature. Soils are generally more trafficable during fall after harvest than in spring before

planting. Application of N fertilizer in the fall is risky from the perspective of N losses by volatilization, denitrification, leaching, runoff, and immobilization before the N becomes available to crops planted in the following spring. Applying N fertilizer in the spring before planting is risky from the perspective of crop production because wet soils may not be trafficable long enough to complete seedbed tillage, fertilizer application, and planting operations. Balancing the trade-offs between nitrogen applied for crop production and the need to minimize environmental losses of N is a difficult challenge.

There is broad consensus that 4R nutrient stewardship is beneficial to reducing nitrogen loading to surface waters. The 4Rs describe Right Rate, Right Source, Right Time, and Right Placement for agronomic and environmental management of soil fertility for crop nutrition and apply to both fertilizer and manure management. The specific discussions and recommendations under the 4R umbrella are described below for cropping systems and integrated cropping and livestock systems.

4.2.1 Cropping Systems

Right Rate

The right rate of nitrogen application from fertilizer depends on a variety of factors, such as potential crop yield and residual N in the soil profile. Residual N in the soil profile reflects mineralization of N from soil organic matter or animal manure and N fixed by legume crops like soybean and alfalfa. The right rate also depends on the magnitude of N losses through volatilization, leaching, drainage, or denitrification. All of these are complicated by variability from year to year and from location to location within a field.

Potential crop yield often depends on soil moisture status. Potential yield for spring wheat and barley is typically greatest for crops grown on fine-textured soil due to high availability of soil moisture. Yield potentials are moderate for light-textured soils on moderately well-drained sites. Smallest yield potentials are associated with light-textured soils at well-drained sites. Yield potentials for spring wheat can vary from 65 to 48 to 34 bu/ac on moist, dry, or arid soils, respectively, associated with these three soil moisture availability classes. Wheat or barley grown on moist soils require more N fertilizer than crops grown on dry or arid soils.

It is important to sample residual soil N in the fall at the 0 to 6 inch and 6 to 24 inch depths to estimate the rate of N fertilizer needed in the subsequent crop of spring wheat, corn, or sugar beets. Residual soil nitrate in fall may indicate if too much N was applied during the previous growing season. Residual soil N levels consistently under 30 lb/ac for spring wheat indicate under fertilization. Levels consistently greater than 50 lb/ac indicate over fertilization. AGVISE laboratory data from 2014 to 2018 showed an average of 32 to 39 lb/ac of residual soil N following spring wheat (AGVISE 2020). Over the last 10 years, AGVISE showed that residual N following corn ranged from 30 to 54 lb/ac, indicating that N fertilizer is over applied to many corn fields. According to a survey of Minnesota corn farmers in the Red River Basin (MDA 2015), the average rate of N fertilizer applied to non-manured fields was 149 lb/ac in corn following soybeans. Over the last 10 years, residual nitrate following sugar beets averaged 10 to 15 lb/ac. Based on these data, over fertilization with N is a widespread issue in corn, while N fertilization in

wheat is marginally on the high side, and N fertilization in sugar beets is generally not a significant risk for environmental losses.

Avoiding overapplication of N fertilizer can help improve crop quality and prevent lodging. In spring wheat, protein contents less than 13.5% or kernels with more than 20% starch indicate N deficiency. In sugar beets, N deficiencies in July are undesirable, but sugar beets with a yellow color at the end of the season will have increased sugar content. Oil content can be diminished when high rates of N are applied to canola, especially in dry soils.

The reductions in losses of nitrogen to surface waters associated with the management of the rate of application depend primarily on the rate of N applied relative to fertilizer guides. On average, reducing N rates to extension-based guidelines in the Upper Midwest for any field applying more than recommended would result in an estimated 16% reduction in N loss to surface waters (Christianson et al. 2018). N reduction also depends on climate (dry, average, or wet years). Potential reductions in N loss in the Minnesota portion of the Red River Basin can be explored using the Nitrogen BMP tool (NMBP Tool) (Lazarus and Mulla 2013). For example, in the Wild Rice watershed of Minnesota for an average climatic year, an estimated 16% of the area applies N fertilizer at rates higher than extension recommendations (with no N inhibitors). If 80% of these farms reduced their N fertilizer rate to extension recommendations, estimated N loss from edge of field would be reduced by 6% relative to baseline losses in the watershed. In the Bois de Sioux watershed, estimated N applications are higher than recommended on 25% of the area. Reducing N fertilizer applications to the recommended rate would generate an estimated 10% reduction in edge-of-field losses of N relative to baseline N losses in this watershed.

Right Time

Nitrogen use efficiency is maximized and environmental losses are minimized when application of N fertilizer and the availability of N from this fertilizer are synchronized to the timing of crop N uptake requirements. Survey data (MDA 2015) show that 30% of N is applied in fall, and 40% to 50% is applied preplant in spring for wheat and canola. Typically, the greatest uptake efficiencies are achieved when N fertilizer is applied in spring at the time of seeding or after planting with sidedress applications. Fall application of N fertilizer typically results in larger losses of N through volatilization, leaching, denitrification, and immobilization than applications at or near planting in spring. Fertilizer application on snow with frozen ground is not desirable and can lead to large yield reductions for the subsequent crop. Fall application should be avoided on sandy soils and soils prone to waterlogging in the spring to reduce leaching and denitrification losses.

To reduce environmental risks of over applying N fertilizer in corn, split application or variable rate application are good options. In sandy and poorly drained soils, split application is a BMP for corn. One-third of the N fertilizer is applied preplant, and the rest is applied in-season. In-season management can be based on pre-sidedress nitrate test (PSNT) for 0 to 1 ft nitrate when corn is 1 ft tall. The critical soil level is 20 to 25 ppm, above which N fertilizer is recommended. Sidedress N applications can also be based on optical sensing with satellite, airplane or drone mounted cameras, and farm tractors and fertilizer applicators equipped with active-optical sensors sensitive to crop biomass and leaf chlorophyll content.

The NBMP Tool (Lazarus and Mulla 2013) can be used to illustrate the impact of N fertilizer application timing on N losses to surface waters. On average, switching N application from fall to spring in Minnesota for any single field would result in up to a 10% reduction in N losses.

Right Source and Right Placement

The primary sources of N fertilizer include urea, urea ammonium nitrate (UAN) and AA. In the Minnesota portion of the Red River Basin, most producers apply nitrogen for the corn crop as urea (MDA 2015). Typically, the vast majority of Minnesota producers who broadcast urea across the soil surface follow up with a subsequent tillage operation to incorporate urea in the soil. Incorporation of urea is important to prevent volatilization of ammonia gas. When urea is incorporated to a 2 to 4-inch depth into soil, ammonia released from urease activity is converted to ammonium-N, and volatilization risk is reduced considerably. Because most urea is incorporated using tillage, very few of the Minnesota producers who reported using urea also applied Environmentally Smart Nitrogen (ESN), N-Serve, NBPT, Agrotain or Super U products to slow the conversion of urea to ammonia-N, to slow the conversion of ammonia-N to nitrate-N, or to slow both types of conversions. Spring broadcast N application on no-till fields should include a urease inhibitor containing NBPT (e.g., Agrotain™).

As an alternative to broadcast application of urea followed by incorporation, N fertilizer may be sub-surface banded before planting or drilled with the seed (Manitoba Soil Fertility Advisory Committee 2007). The best method for N application in hard red spring wheat is spring banding. This avoids denitrification from fall-applied N in wet soils and reduces immobilization. The Manitoba Soil Fertility Advisory Committee (2007) stated that spring banded N has a 120% efficiency for plant uptake relative to spring broadcast N. Cereal grain crops are less sensitive to N drilled with the seed than canola crops and can tolerate higher rates of N, especially in finely textured soils with sweep applicators. Subsurface placement is common for N in half of wheat acreage and 40% of canola and grain corn crops.

4.2.2 Integrated Cropping and Livestock Systems

Integrating livestock into cropping systems has many benefits. It increases diversity, creates opportunities for perennial forages and rangeland, creates food from crops that may not be suitable for human consumption, and the manure enhances the soil, adding nutrients and carbon to the system.

Manure management also has many challenges. Most livestock are confined during the winter, increasing the density of livestock. Specific regions of the Red River Basin where high amounts of manure are generated by livestock operations are illustrated in Fig. 2.13. Due to high costs of transporting manure, increased buildup of nutrients occurs near confined feeding operations. Land application losses for N are generally by denitrification/volatilization, plant uptake, runoff/erosion and leaching. BMPs to reduce manure N losses include rate, method of application and timing of application. Having and following a nutrient management or manure management plan helps reduce nutrient losses.

Rate of Application

Manure has a low N:P ratio in comparison with crop needs. Historically, manure was land-applied based on crop N requirements, leading to buildup of P in soils. Applying manure to meet crop P requirements will result in a need for supplemental N applications from fertilizer but will help reduce the risk of P loss to surface waters. Content and availability of N from manure is variable and decreases from year to year after land application. N content depends to a large degree on animal species, animal feed composition, livestock housing and bedding, and methods for collection, handling, storage, and land application. Average losses by volatilization during handling and storage are 25% to 30% in cattle operations, and 20% to 25% in hogs (MDA 2012). Composting of manure can be used to reduce the mass and volume of manure, concentrate nutrients, and destroy weed seeds and pathogens. Composted manure has a N:P ratio of 1:2, much lower than N:P ratios in most crops (Augustin and Rahman 2010). Composted manure is most often land-applied based on crop P requirements, and supplemental N fertilizer is needed. One drawback to composting manure is that large quantities of N are volatilized during the process as greenhouse gasses and ammonia.

Since manure N content is variable, book values are a poor measure of N content and a manure test is essential. Plant nutrient availability for N is difficult to estimate following land application, assuming that manure N content is known from a manure nutrient test. Organic N is released slowly. Generally, 55% of total N in land-applied dairy manure or 80% of N in swine manure is available in the first year. In the second year 25% and 15% of total N from dairy and swine manure, respectively, is available. Proper credits for manure N application should be accounted for when deciding what rate of N fertilizer to apply on top of manure N. Total application rates for N are commonly excessive when manure N is not properly credited in N fertilizer recommendations.

Method of Application

Incorporation and injection are important BMPs for land applied manure and are widely practiced in the Red River Basin. This substantially reduces total N loss. Incorporation or injection typically reduce losses of NH_4 (1% to 5%). The percent of total N available for plant uptake in year 1 or 2 increases with quick incorporation or injection after land application. Broadcast application with no incorporation is risky. There is substantial loss of ammonia by volatilization in the first day (up to 50% loss) with broadcast application. Odors can also be an issue. Manure application setbacks are important for protection of surface water from ammonium loss and ground water from nitrate loss. For example, no manure application is allowed in Minnesota within 50 ft of wells or within 25 ft of waterways and lakes (MPCA 2005).

Timing of Application

Application timing affects loss. Most manure applications occur in fall on fields that will be planted to crops that respond to N such as corn and wheat. It is not recommended to apply manure on land that will be planted to soybeans or alfalfa because these crops fix N from the atmosphere. There is more time for field operations in fall, and the soil is less susceptible to compaction. There is also more time for manure N to mineralize if there is a high C:N ratio. A drawback to fall application is more time for nutrient losses by denitrification or leaching. This is especially true on sandy soils. For other soils, manure application should be delayed until soil temperatures are less than 50 °F to minimize nitrification. Application near freeze-up in the late fall should be avoided to reduce risk of manure freezing in the furrows.

Spring applications are advantageous from the point of view of synchronizing application with plant uptake, especially on sandy soils. However, climatic conditions such as a wet spring can limit the trafficability of soil for manure application operations. Another disadvantage to spring application is less time for mineralization for manure with a high C:N ratio, leading to immobilization of N in corn. In summer, there is time for sidedress applications in a growing crop. Disadvantages include damage to growing crops. During post-harvest, it is common to apply manure in crops with relatively short growing seasons.

Nutrient application timing is not always ideal for manure. Sometimes manure needs to be land-applied based on storage cleanout. Winter applications of manure should be avoided, and are prohibited in Manitoba under most circumstances. In some years winter application is unavoidable due to lack of storage and poor fall weather. The advantage of winter application is no compaction if manure is applied on frozen soil. The disadvantage is the inability to incorporate manure. The major drawback of winter application for manure is a high nutrient loss potential in snowmelt. Discovery Farms research in Minnesota found that 40% of annual nutrient losses were in snowmelt. If winter application is necessary, apply manure far (e.g., greater than 300 ft) from waterways on flat ground.

4.3 BMPs FOR EROSION CONTROL

Erosion can occur by water, wind, or tillage that moves soil downslope or into ditches and streams at the edge of fields. When the sediment is enriched in ammonium-N or the runoff that carries sediment is enriched in nitrate-N, loss of nitrogen can occur to nearby surface waters. In the case of water and wind erosion, the main processes involved are detachment, transport, and deposition. Detachment by water occurs primarily through the action of raindrop impact; almost no detachment occurs during snowmelt runoff. Snowmelt runoff is, however, capable of transporting nitrate-N, even in the absence of sediment. Detachment by wind occurs primarily through bombardment of surface soil by saltating sediment carried by the wind. Transport of sediment by water occurs primarily through rill or sheet erosion. Deposition occurs when the energy of the water or wind that transports sediment is reduced as the water runoff or wind velocities decrease. For water erosion, this typically occurs at the footslope of a hill, whereas deposition by wind erosion can occur many miles or hundreds of miles from the location where sediment was initially detached. Sediment can also be lost by erosion in gullies or streambanks and stream channels, although the latter two are not thought to be major sources of nitrogen loading to rivers. Tillage erosion also includes the throw of soil from the field into ditches, which is a widespread form transfer of soil and nutrients from fields to ditches. This form of soil/sediment transfer to ditches almost certainly exceeds the transfers by wind erosion given the thousands of miles impacted by the former each and every year.

Controlling erosion by water or wind relies on strengthening the soil against detachment, decreasing the likelihood of transport and increasing deposition. BMPs to reduce erosion by water or wind erosion are often classified according to where the BMPs are installed on the landscape. BMPs at upper slope positions help to avoid or prevent detachment from occurring. BMPs at mid and lower slope positions are designed to control the transport processes that carry sediment. BMPs at the edge of field are intended primarily to trap sediment originating from upslope regions before it can enter ditches and streams.

In order to reduce repetitive mention of BMPs for erosion control in this section as well as in the sections dealing with vegetative and structural practices, here we focus primarily on tillage and residue management BMPs that prevent detachment and improve infiltration. In addition, we focus on practices to reduce tillage erosion and wind erosion. Vegetative and structural practices that are effective at reducing wind and water erosion are primarily discussed in sections more specific to those two classes of BMPs.

4.3.1 Cropping Systems

Research results from the headwaters region of Manitoba's Tobacco Creek (Koiter et al. 2013) showed that tillage erosion is the major cause of severe soil loss on agricultural lands. Soil losses can range up to 250 t/ha/yr from this process, but average 50 t/ha/yr on 20% to 30% of the field. The loss of nutrients from these fields is small relative to sediment loss. In the flat land of the Red River Plain (e.g., La Salle watershed Manitoba), there are dense networks of surface ditches and subsurface drainage features. Tillage at the edge of fields throws sediment into ditches.

A majority of producers in Manitoba practice conventional tillage with chisel plows and disks. Conservation tillage and no-till tend to leave the soil cool and wet in spring, delaying planting and germination. Chisel plow and tandem disks are capable of causing significant tillage erosion, especially on steep slopes. Vertical tillage may leave residue on the surface but causes high amounts of tillage erosion. To reduce tillage erosion, it is important to practice contour plowing and avoid throwing the plowed soil downslope. Uphill and downhill plowing should be avoided. Tillage practices should be avoided next to ditches and streams by leaving a vegetated buffer strip.

Wind erosion from agricultural fields is a significant problem in the Red River Basin, leading to deposition of sediment in snow-filled ditches. This sediment is enriched in N (Cihacek et al. 1993). Wind erosion can average over 10 tons/ac in western areas of the Red River Basin. In one Soil Conservation Service (SCS) study, they measured 34 inches of topsoil at a site in the 1960s. Today, as measured by NDSU scientists, there are only 14 inches at the same location, indicating a loss of 20 inches of topsoil from wind erosion. Soils high in carbonates are very susceptible to wind erosion loss. Carbonates reduce aggregate stability in clay soils. Wind erosion is a bigger problem than water erosion throughout the western portion of the Red River Basin where rainfall is sparse.

Wind erosion is often controlled by planting windbreaks perpendicular to the prevailing wind direction. Windbreaks trap saltating particles, causing deposition and breaking the cycle of bombardment that produces detachment. The effectiveness of windbreaks depends on their height and density. Typically, windbreaks produce substantial reductions in wind erosion for a distance ten times the windbreak height. Wind erosion during the growing season can also be controlled by planting crop rows perpendicular to the prevailing direction of wind. Finally, wind erosion can be controlled using tillage practices that protect the soil by leaving crop residue after harvest.

Water erosion from agricultural fields is a less significant problem than wind erosion in flat portions of the Red River Basin. On steeper landscapes, water erosion can be significant, especially during intense rainstorms when soil is bare or unprotected. Water erosion generally transports larger quantities of ammonium-N than nitrate-N. Crops with low biomass and later

planting dates, such as soybean, are more vulnerable to water erosion than crops with high biomass and earlier planting dates, such as corn.

An important beneficial management practice for controlling water erosion is conservation tillage that leaves more than 30% of the soil surface covered at planting. Conservation tillage is currently more widely practiced in the western part of the Red River Basin on steeper slopes than in the central and part on flatter slopes. Conservation tillage is effective at preventing erosion and building soil health on steep sandy soils in the western Red River Basin. Conventional tillage, which leaves less than 30% of the surface covered with residue, is more widely practiced in flatter portions of the Red River Basin, where heavy clay soils exist, and high residue levels interfere with soil drying and warming during spring. Control of water erosion in these areas is often achieved by using vegetative and structural practices described in later sections of this report.

Soil erosion by water is always accompanied by runoff, but runoff is not always accompanied by soil erosion. Most runoff losses of N in the northern part of the Red River Basin occur in snowmelt when frozen soils limit infiltration. Nitrate-N concentrations are greater in snowmelt runoff events than in summer rainfall runoff events, where nitrate-N tends to move vertically downward in soil by leaching or is lost by denitrification. More snowfall leads to more snowmelt runoff. Over 75% of N transport at the field scale in far northern parts of the RRB occurs in snowmelt runoff (Corriveau et al. 2011; Rattan et al. 2017). Most of the N in snowmelt runoff monitoring in Manitoba (2013 to 2017) is in the form of nitrate-N when soils are frozen. Ammonium-N losses are important on manured lands and in rare erosion events.

There are trade-offs for conservation tillage between reducing soil loss by wind and water erosion and reducing nutrient losses in snowmelt runoff (Tiessen et al. 2010). Conservation tillage leads to smaller N losses in snowmelt runoff than conventional tillage but higher P losses. Stubble left behind traps drifting snow, leading to more runoff with conservation tillage. Other studies show the effect of tillage on surface roughness and snowmelt runoff for a no-till field on clay soil relative to conservation tillage. Surface roughness differs with tillage (chisel 23 mm, no-till 7 mm, cultivate/harrow 15 mm, rototiller 6 mm). Volume of snowmelt runoff increases with snowfall amount, snowpack depth, tillage roughness, and fall soil moisture. Snowmelt volume decreased as random roughness increased. Increasing random roughness with conservation tillage could be more effective at reducing snowmelt runoff and associated losses of N than no-till.

4.3.2 Integrated Cropping and Livestock Systems

Grazing animals create opportunity for improved water quality if grazing is properly managed. Improved soil management on steep knolls in the western Red River Basin is important to reduce erosion rates by water. Manure applications on degraded soils coupled with other BMPs (e.g., conservation tillage, cover crops) could help reduce erosion and build soil health.

Integration of cropping systems with properly managed livestock systems allows for farming landscapes that have more wetlands, grasslands, and trees than landscapes without grazing. However, grazing animals can increase erosion of streambanks and directly pollute surface waters with their urine and feces if allowed unfettered access to streams for watering. Livestock exclusion is a proven BMP to reduce streambank erosion and improve water quality.

Careful control of stocking densities and grazing periods are needed on pasture or grassland to reduce soil compaction and avoid grazing plants down to very low heights that provide little protection against soil erosion. This is true whether continuous grazing or rotational grazing is practiced. Rotational grazing does not necessarily produce greater water quality benefits than continuous grazing at moderate stocking densities (Briske et al. 2008). Rotational community grazing is practiced at a stocking density of roughly 1 animal unit/ha on large areas of native grassland in the Gardenton-Pansy area south of Winnipeg.

Research was conducted at South Tobacco Creek to compare water quality impacts of confined winter feeding versus winter bale feeding (Chen et al. 2017). Bale feeding of animals overwintering on croplands improves soil fertility but causes elevated ammonium-N in soil. The losses of N in runoff are similar to those from confined feeding operations. Compared to confined winter-feeding sites, the volume of runoff per animal unit day is much higher from winter bale feeding sites but the concentrations of N in the runoff are lower. Management options to reduce runoff from winter bale feeding sites revolve primarily around siting bale feeding operations on landscapes that are not hydrologically connected to surface waters.

4.4 BMPs FOR VEGETATIVE MANAGEMENT

Vegetation can play an important role either as a source or sink for nitrogen. These roles vary between the growing season and the cold season after vegetation has senesced. Senescence is associated with volatilization losses of ammonia from leaves, leaving relatively low tissue N concentrations in crop residue after harvest. During the growing season, plant roots actively take up nitrogen from the soil. Plants also help stabilize soil during the growing season, reducing water and wind erosion. Rainfall runoff during the growing season, if not present as concentrated flow, is slowed when it passes through growing vegetation, thereby increasing infiltration and reducing runoff losses of nitrogen. Infiltrated water and the associated nutrients can be subsequently taken up by vegetation. When discharge of water does not pass through growing vegetation, as with subsurface tile drain discharge, nitrogen passes under the rooting zone and has no interaction with vegetation, limiting uptake, before the edge of field.

During the cold season vegetation ceases to grow and roots cease to take up water and nutrients. Freezing temperatures can rupture plant cells, releasing nutrients taken up during the growing season. However, due to senescence of leaves the previous fall, concentrations of N in crop residue is lower than concentrations of P, leading to more loss of P than N in snowmelt runoff passing through crop residue. Snowmelt runoff on frozen ground can transport these nutrients to nearby surface waters. Harvesting and removing dead vegetation and crop residue before winter sets in can help lower snowmelt runoff losses of nutrients. However, disadvantages of removing dead vegetation include increased potential for wind erosion and loss of adsorbed nutrients on windblown sediment.

4.4.1 Cropping Systems

Crop Rotations

Significant shifts have occurred in crop rotations in the Red River Basin between 2011 and 2018. Corn and soybean acreages have increased by 29% and 22%, respectively, while grassland and

pasture acreage has decreased by 25%, leading to greater runoff and erosion. Fallow or idle cropland has decreased dramatically by 95%.

As crop diversity has decreased, crop rotations have become shorter and nitrogen fertilizer applications have increased. Less acreage is devoted to longer term crop rotations in favor of shorter-term crop rotations. The wheat-canola-soybean rotation is still popular in Manitoba.

During the growing season, there are significant benefits to water quality from diverse crop rotations. Oquist et al. (2007) showed that nitrate-N losses in tile drainage at Lamberton in southwest Minnesota were reduced by about 60% for a longer-term corn-soybean-alfalfa organic rotation in comparison with a shorter-term corn-soybean conventional rotation.

Gaudin et al. (2015) showed that a rotation of corn-soybean-winter wheat in Ontario significantly improved corn and soybean yields in comparison with a corn-soybean rotation. Rates of N fertilizer could be reduced in the corn year with a corn-soybean-winter wheat rotation compared with N fertilizer rates in the corn year with a corn-soybean rotation. Mineralization of wheat stubble and root biomass was responsible for increased availability of soil N and reductions in N fertilizer rate. A more diverse crop rotation is expected to decrease losses of N by leaching and runoff.

Cover Crops

Cover crops are designed to complement annual cash crops by providing soil cover after harvest of the cash crop and before planting of the subsequent crop. Benefits of cover crops include reduced soil loss by wind and water erosion, improved soil organic matter, infiltration and soil tilth, and reduced runoff and leaching. A major drawback to incorporating cover crops in cold regions include the short growing season after harvest of the cash crop, which limits germination and establishment of a cover crop planted after harvest. Aerial seeding of cover crops during the late stages of an annual cash crop can potentially improve germination and establishment of cover crops; however, aerial seeding suffers from poor seed-to-soil contact and loss of seed by rodent activity. Cover crops perform best when seeding after harvest of shorter season crops, including small grains and crops such as peas or sweet corn. The effectiveness of cover crops at removing nitrogen increases with the amount of cover crop biomass produced at the onset of frozen soils and winter snow.

Cover crops remove nitrogen by increasing infiltration of rainfall and runoff, by plant uptake of nitrogen, and by reducing runoff and soil loss by wind and water erosion. When cover crops are successfully established into shorter season crops, they can remove as much as 50% of the nitrogen leaving the field (Christianson et al. 2018). However, when they are planted into longer season crops such as corn, their effectiveness at removing nitrogen drops to only 13% (Strock et al. 2004).

Cover crops have proven to be successful in soil conservation and water quality improvement at the Menoken Demonstration Farm in North Dakota. Winter rye cover crops are planted after wheat harvest in a practice known as planting brown (into wheat stubble). Cover crops do best in years with above average precipitation, and worst in years with below average precipitation. The following spring, soybeans or canola can be planted into the winter rye cover crop (planting

green). Planting green can address wind erosion and salinity concerns, while increasing nitrogen uptake and improving water quality.

Vegetated Buffer Strips

Vegetated buffer strips involve planting grass and forbs in a narrow band between a stream or ditch and the adjacent agricultural land. For greatest effectiveness (95% removal of nitrogen), surface runoff from the agricultural land passes through the buffer strip during the growing season as uniform sheet flow. Nitrate-N is removed from runoff by infiltration in the buffer strip followed by plant uptake and denitrification in the rooting zone. Ammonium-N is removed by settling with fine sediment as it passes through the buffer strip. Effectiveness is substantially reduced when snowmelt runoff passes through the buffer strip when soils are frozen.

Concentrated flow also reduces the effectiveness of filter strips.

Effectiveness of vegetated buffer strips can be enhanced, especially during the growing season, by increasing filter strip width on steeper soils, on slowly permeable soils (Hydrologic Class C or D), when upslope contributing areas are large or in cases where concentrated flow occurs.

Saturated Buffers

Saturated buffers are designed to remove nitrate-N transported in subsurface tile drains during the growing season from cropland upslope of the saturated buffer. Stop logs are used before the tile drain discharges into a ditch to divert subsurface drainage laterally into a second set of shallow tile drains aligned parallel to the ditch in the rooting zone of the saturated buffer. Roots in the saturated buffer take up nitrate-N while carbon associated with organic matter in the rooting zone stimulates microbially mediated denitrification. Water then moves laterally through subsoil to the ditch by seepage. Averaged over eleven Midwestern states, saturated buffers removed from 23% to 61% of nitrate-N loads entering through subsurface tile drainage (Chandrasoma et al. 2019). Saturated buffers were more efficient when vegetation was more than 3 years of age, when subsurface soil had elevated carbon contents, and when there was an impermeable layer at depth.

4.4.2 Integrated Cropping and Livestock Systems

Perennial Forage Crops

Forage crops in flat areas of the Red River Basin with a high concentration of dairy tend to involve alfalfa. In steeper topography with grazing cattle, grasslands and forage legumes are more common. Perennial forage crops are very effective at reducing soil erosion and runoff, especially when animal stocking densities are low to moderate.

Huggins et al. (2001) observed that nitrate-N losses in tile drainage at Lamberton were 4 to 5 times larger for a corn-soybean rotation than a rotation involving alfalfa-corn-corn-soybean. The same study showed that nitrate-N losses in tile drainage were about 14 times greater for the corn-soybean rotation than a grass-corn-corn-soybean rotation.

Vegetated Filter Strips

Vegetated filter strips consist of permanent warm and cold season grasses (e.g., tall fescue) or crops such as sorghum and oats planted along the contour perpendicular to runoff of livestock wastewater from feedlots or areas receiving land applications of manure. Vegetated filter strips

cause settling of sediment and solids and increase infiltration during the growing season. Removal efficiencies of vegetated filter strips during the growing season ranged from 84% for total N and 93% to 99% for nitrate-N (Young et al. 1980; Fajardo et al. 2001). Reduction efficiencies would be substantially decreased during snowmelt runoff events on frozen soils.

4.5 BMPs FOR STRUCTURAL MANAGEMENT

Flat terrain in agricultural regions of the Red River Basin with high soil clay content is nearly all artificially drained (Fig. 2.9), leading to the disappearance of many wetlands and swamps, while improving soil productivity. The primary mechanism for drainage is a combination of shallow in-field surface furrows connected with nearby road or surface ditches. This combination improves hydrologic connectivity between agricultural fields and surface waters, leading to rapid removal of surface water and lowering the water table to promote aeration of the rooting zone and better trafficability of soils. Excess water can also be removed via surface culverts that pass through small berms along the edge of fields.

In addition, subsurface tile drainage is expanding across the Red River Basin. For example, in Manitoba, subsurface tile drainage increased from less than 5,000 acres in 1996 to over 25,000 acres in 2015. On the U.S. side of the Red River Basin, the percent of harvested acres with subsurface drainage was nearly nonexistent in 1992. In 2012, tile-drained acres included up to 5% of agricultural land. Between 2012 and 2017, the number of drained acres doubled, especially in the southern Red River Basin in Minnesota, where up to 20% of agricultural land was tile drained.

The impacts of artificial drainage on stream discharge and water quality are complex. Generally, surface drainage increases both stream discharge and peak flow, whereas subsurface drainage increases stream discharge but decreases peak flow as a result of reduced surface runoff during non-frozen events (Skaggs et al. 1994). Surface drainage can lead to increased transport of ammonium-N and nitrate-N during periods of snowmelt and frozen soil, while subsurface drainage increases the transport of nitrate-N during periods of non-frozen soil.

Many structural BMPs are available to counteract the negative impacts of artificial drainage on surface discharge and water quality. These include controlled drainage, bioreactors, culvert resizing, two-stage ditches, wetland restoration, saturated buffers, and installation of small reservoirs and holding ponds.

4.5.1 Cropping Systems

Subsurface Tile Drainage

In Manitoba, Kokulan et al. (2019) studied overland flow and tile flow from two adjacent fields with shallow surface ditching; one field also had subsurface tile drainage. Discharge losses were 70% from surface runoff and 30% from tiles, while 60% of nitrate-N loss was from surface runoff and 40% from tiles. Tile drains did not flow during periods of frozen soils. Most of the overland flow occurs during snowmelt runoff when soils are frozen. Concentrations of N are elevated in tile drains compared with snowmelt runoff. In Manitoba, most runoff occurs as surface runoff during snowmelt when soils are frozen, and tiles are decoupled from surface. Tiles can produce significant flow in summer, but discharge is small compared to snowmelt runoff losses. Simultaneous

hydrologic responses from runoff and tile drainage are rare in Manitoba, indicating a lack of preferential flow to tile drains.

In Minnesota, Discovery Farms demonstration sites are led by farmers to collect water quality information under real world conditions. Discovery Farms located in the Red River Basin were studied from 2013 to present in Norman County and from 2013 to 2018 in Wilkin County. These are on sandy loam soils with traditional tillage (fall ripping, secondary tillage in spring). Annual precipitation is strongly correlated with annual tile flow discharge. Annual tile flow at Norman is generally low, while at the Wilkin site up to 5 inches of tile flow discharge occurs.

Average runoff in Norman County is 0.59 inches and 51% of this arises in June and 12% occurs in April and May. At Wilkin the average is 2.91 inches, and 40% of this arises in June and 27% occurs in April and May. The rest of the annual runoff occurs mainly in September and October. Runoff varies tremendously from one year to another according to precipitation and type of crop. Runoff as a percent of precipitation varies at Norman from 0.4% to 8%, while it ranges from 2% to 23% at Wilkin. Runoff after dry years tends to be low. Runoff during the non-frozen season dominates. Nitrate concentrations are 20 mg/L in non-frozen periods and 9.6 mg/L in frozen periods. When subsurface tile drainage is present, nitrate losses are primarily through tile drains.

A third drainage study site with tiles draining to a surface ditch is located in Clay County. Surface runoff is about 32% of total discharge, and the remaining 68% is from tile drainage (1 to 4 in/yr). Nitrate-N losses range between 2.5 to 5 lb/ac. Nitrate losses are primarily (90%) through tile drains.

BMPs for installation of subsurface tile drainage revolve around design specifications. Generally, tile drain discharge (and nitrate-N loss) increases as tile drain depth increases, as tile drain spacing decreases, and as the drainage coefficient (maximum daily discharge) increases. Drainage coefficient is affected by tile radius, density of perforations, and slope of the tile drain system. Recent research suggests that loss of nitrate-N can be decreased by installing tile drains at more shallow depths with narrower spacings. This seems to involve greater denitrification losses to some extent.

Nangia et al. (2010) modeled the impact of tile drain spacing and depth on nitrate-N losses from a cold region site on lacustrine clay soils in Nicollet County, Minnesota. As tile drain spacing decreased from 131 to 88 ft for a fixed depth of 4 ft, nitrate-N losses increased by 55%, whereas tile drain flow increased by 12%. The disproportionate increase in N loss is due to decreasing denitrification. At a tile spacing of 88 ft, as tile depth decreased from 4 ft to 3 ft, nitrate-N losses decreased by 52%, while discharge decreased by 18%. These results clearly show that shallower tile drains are more effective at reducing nitrate-N losses than deeper drains.

Controlled Subsurface Tile Drainage

Water control structures can be installed to reduce tile discharge in fields with subsurface drainage. Controlled drainage is only feasible on very flat landscapes, typically with less than 1% slope. Stop logs in the control structures are typically raised to prevent tile discharge during the summer and winter months. To improve trafficability of the soil, control structures are lowered in spring, when soils thaw before planting, and during later fall, before harvesting operations.

Controlled drainage typically reduces total discharge and nitrate-N losses through tile drains in comparison with conventional subsurface drainage.

Conventional and controlled drainage are being compared on the Red River Valley Drainage Water Management demonstration site located in Wilkin County, Minnesota. Controlled drainage had less discharge than conventional drainage. Nitrate concentrations were reduced with controlled drainage, and this, along with lower discharge, led to N load reductions of 30% in 2017 and 60% in 2018. Controlled drainage can be used to reduce salinity or sodicity problems in soil, with special modifications.

The impacts of adopting controlled drainage in tile-drained watersheds of the Red River Basin can be explored using the N BMP Tool (Lazarus and Mulla 2013). On average, this tool indicates that for any field switching from conventional to controlled drainage, reductions in N loss to surface waters would range from 33% to 44% (Christianson et al. 2018). In the Wild Rice River watershed of Minnesota, less than 7% of the area is flat enough for adoption of controlled drainage. If controlled drainage were adopted on 80% of these areas, negligible reductions in nitrate-N loss would occur relative to baseline watershed scale N losses. In the Thief River watershed, about 10% of the area is suitable for controlled drainage. With 80% adoption of controlled drainage on this area, nitrate-N losses would be reduced by about 1% relative to watershed scale baseline N losses. Thus, adoption of controlled drainage in these watersheds would have limited water quality benefits due to the lack of suitability of topography for this practice.

Bioreactors

First generation bioreactors involve a trench at the outlet of a tile drain filled with wood chips. Tile drain discharge entering the trench is treated for N removal through denitrification. Average effectiveness of first-generation bioreactors is limited by short hydraulic residence times and cold temperatures during spring tile discharge. The average effectiveness of first-generation bioreactors at removing N for any given field is 13% (Christianson et al. 2018).

Second-generation bioreactors involve tile drain discharge entering a vertical flow bioreactor installed in a ditch, with a wood chip and corn cob substrate and acetate dosing. In the lab, addition of acetate to such a bioreactor reduced N loads dramatically. Almost all of the N could be removed with wood chips plus acetate at warmer temperatures. Even at 5 °C, N removal was 80%. At Lamberton, a second-generation bioreactor was installed in a ditch at the end of a tile outlet. Hydraulic residence times were 3 to 4 hours for the vertical bioreactor. Average annual N removal rates ranged from 28% to 43%, depending on the substrate in the bioreactor.

Culvert Resizing

Many roadside and drainage ditches are bordered by soil berms. Runoff from adjacent fields is often routed through soil berms using a culvert. Culvert resizing involves replacing the culvert with another having a smaller diameter to restrict the amount of runoff. The intent of resizing is to create temporary water storage at the edge of fields for a day or two in fields farther away from the Red River mainstem (Solstad et al. 2007). This decouples runoff from fields closer to the mainstem from runoff farther from the mainstem, resulting in lower peak flows in the Red River. The primary objective for culvert resizing is to reduce flood flow volumes, but there may be additional water quality benefits from settling out of sediment that carries ammonium-N.

Two-Stage Ditches

Two-stage ditches involve reconstructing artificial V-shaped ditches so that they have a low flow channel in the middle, surrounded by a wide flat bench followed by flatter ditch side slope. During low flows, vegetation can become established along the bench. During moderate flows, this vegetation, along with the saturated soil along the bench promotes nitrate-N uptake and denitrification. A ditch study at Lamberton compared a control channel with another treated channel having a rectangular check dam weir to slow water flow. As flow was slowed, nitrate concentrations decreased in the treated channel. Cumulative drainage discharge decreased by 66% with flow restrictions, as compared with discharge in the control channel. Reductions of 76% and 64% in nitrate-N loads were observed in 2017 and 2018, respectively.

Wetland Restoration

Wetlands provide water retention on the landscape and wildlife habitat benefits. Loss of wetlands can contribute to nutrient mobilization and loss of nutrient sinks. Wetlands function similar to small reservoirs and are more biologically active in summer. Nutrient removal efficiency is variable and depends on hydraulic residence time. Wetlands can become a source of nutrients if they spill over and become hydrologically connected to other surface waters. Restored wetlands in Manitoba are typically larger and fewer in number than the original wetlands that were individually scattered throughout the field.

Removal of N in constructed wetlands was studied at Lamberton (Feyereisen/Strock) using three paired wetlands. One pair of wetlands involves surface flow, another pair involves tile drains to promote vertical flow, while a third pair of wetlands has horizontal flow through the subsurface. Water level controls at the outlet of each wetland were used to regulate discharge and hydraulic residence times. Nitrate-N losses to the outlet of each wetland were reduced when hydraulic residence time was increased. The horizontal flow wetland reduced ammonium-N concentrations more effectively than concentrations in the surface or vertical flow wetlands. Nitrate-N concentrations were about the same in each wetland.

Small Dams, Ponds and Reservoirs

Small dams were studied in the South Tobacco Creek watershed located on the Manitoba escarpment. These small dams were originally installed for downstream flood protection. Dams typically impound water in an area <5 ha. Twenty-six small dams were installed to treat 30% of the total drainage area. Flow volume reductions were 9% to 19% from snowmelt and 13% to 25% from rainfall runoff (Yarotski 1996). Volume was less affected than timing. Sediment retention was 49% to 83%, implying that these structures would lose their effectiveness due to sedimentation in 300 years, if not maintained. Tiessen et al. (2011) observed average annual N reductions of 15% to 20% behind small dams.

Nutrient removal mechanisms in water retention structures include sedimentation, and plant or algal uptake. Denitrification of N was important when dissolved oxygen was low and organic C was high. Water retention ponds could be installed on marginal croplands to treat ditch water. Research at Morden Manitoba on retention ponds was conducted in 2016 (a high summer runoff year) and 2017 (a high snowmelt runoff year). Reductions in flow volumes were about 75% on

average. Water retention structures can also decrease peak flows and flooding. Nutrient loads can be reduced due to runoff volume reduction.

4.5.2 Integrated Cropping and Livestock Systems

Holding ponds can capture runoff from wintering sites at feedlots. Feedlots have high concentrations of nutrients but low amounts of runoff. Holding ponds should be located in areas receiving concentrated flow. Diversion of clean water around the ponds is important to maintain pond capacity for treatment of polluted runoff. Ponds must be engineered to avoid failure during extreme storm events. If containment fails there is a risk for off-site contamination, therefore proper sizing is critical.

Holding ponds remove N through ammonia volatilization and denitrification. Water should be reused for irrigation in summer to remove sequestered nutrients. Water from holding ponds could be treated using bioreactors.

Catastrophic spills from large manure storage facilities can occur primarily through overflow following large storms or by intentional releases. The impacts on surface water quality and aquatic life from manure lagoon and storage basin spills can be devastating. However, the number of documented serious water quality pollution problems involving manure lagoon spills and feedlot runoff is generally small. Only a handful of events per year occur in each of the states or provinces with high concentrations of feedlots.

There are several BMPs for manure storage. Storage location is recommended to be at least 300 ft from a well or surface water and six feet above the water table in Manitoba. Storage structures should not be located within a natural conveyance system that channels runoff water toward a surface water body. Doing so increases the potential for transport to surface waters of manure spilled during emptying, pumping, or hauling.

Three primary types of structures for liquid manure storage are earthen basins, lined basins, and concrete tanks (aboveground or buried). Risks for seepage of nitrate-N are greatest in unlined earthen basins on sandy soils. Unlined earthen basins on clay soils have a moderate risk of seepage loss. Above and belowground concrete tanks have a low risk of seepage but should be covered to prevent volatilization losses. Earthen basins with a synthetic or clay liner have a low risk of seepage if installed on clay soils and a moderate risk if installed on sandy soils.

Manure storage facilities should be engineered to have storage for 6 to 9 months of manure in order to reduce cleanout emergencies and spills or releases. Rain should be kept out of the storage area. Rainwater runoff from open lots and building roofs should be diverted from any storage area. Any “clean” runoff that is not diverted adds to the risk of storage overflow and increases the volume of manure to be transported to the field.

Feedlots have high concentrations of nutrients but low amounts of runoff. If not properly collected and prevented from entering surface waters, this feedlot runoff can severely degrade surface water quality. The most significant pollutant in surface runoff from feedlots is ammonium-N because of its large and immediate toxicity to aquatic life. Nitrate-nitrogen is rarely a significant contaminant in surface runoff from feedlots.

When storage pits are absent, manure is often stockpiled on a concrete or clay pad. Runoff from stockpiled manure should be contained by low sidewalls or gutters. This runoff should be collected, stored, and land applied or treated. In some situations, collecting or treating runoff may be more difficult and expensive than covering the stockpile. Holding ponds can capture runoff from wintering sites at feedlots.

N losses by volatilization from manure can occur during storage. Storage losses for N vary from 25% with scrape and haul, to 50% with open lots, and 30% with earthen storage pits. A portion of the volatilized N from these sources can be redeposited on agricultural land and waterways in nearby areas through atmospheric deposition and rainfall.

5 EFFECTIVENESS OF BMPs FOR PHOSPHORUS LOAD REDUCTIONS

5.1 OVERVIEW

This section provides a summary of information on effectiveness of BMPs targeted to reduce P loading into surface waters, downstream into the Red River and, ultimately, Lake Winnipeg. The summary is from information presented and discussed at the Workshop and does not include additional research or references. Therefore, this section does not necessarily present a comprehensive or exhaustive discussion on BMPs for phosphorus load reduction in the Red River; rather, it is limited to topics discussed at the Workshop.

There is less crop demand for P relative to N, but naturally available, plant-available P concentrations are generally low in soils across the RRB. Therefore, P fertilization is a common practice. However, there is low efficiency in applied fertilizer P, with typically less than 25% of P being available to the crop in the year of application. When in contact with soil, P is typically strongly adsorbed to soil particles or is otherwise immobilized as various forms of precipitates and organic P. Organic P forms can comprise a large proportion of P in soil. There are generally low P concentrations in the soil solution, predominantly comprised of ortho-P forms (H_2PO_4^- or HPO_4^{2-}).

Sources of P loss and loading to surface waters across the RRB include soil, fertilizer, manure, municipal biosolids, and senesced vegetation at the soil surface. Unlike N, P is predominantly lost from agricultural fields with surface runoff. Phosphorus is prone to loss from agricultural fields as particulate P (PP), either adsorbed to the surface of soil particles or as bulk solids, when soil particles become detached from the soil surface by runoff and erosion, predominantly by water and wind. However, these events can be rare and difficult to predict. Solution P can be lost from agricultural fields with runoff, such as snowmelt. For example, Corriveau et al. (2011) found 82% to 87% of total P that was lost in snowmelt in small watersheds in Manitoba was in the dissolved form, and Hansen et al. (2000) found that 75% of total P that was lost with snowmelt in runoff plots in Minnesota was in soluble form. Solution P is measured and evaluated using different methods, including dissolved P (DP), dissolved reactive P (DRP), and soluble reactive P (SRP), each of which represents a different fraction of P in solution. The relative importance of PP and DP loss across the RRB is related to topography, runoff, and management practices. For example, PP loss is of lesser importance in areas of the RRB with low slopes, zero tillage management, and snowmelt-dominated runoff. In addition to P lost via surface runoff from agricultural fields from various sources, direct impact of surface water quality can occur from animal urine and feces when livestock are permitted direct access to surface water bodies.

The discussion is organized according to the following themes of presentations and breakout discussion groups at the workshop:

- BMPs for Nutrient Management
- BMPs for Erosion Control
- BMPs for Vegetative Management
- BMPs for Structural Management

5.2 BMPs FOR NUTRIENT MANAGEMENT

There is broad consensus that 4R nutrient stewardship is beneficial to reducing phosphorus loading to surface waters. The 4Rs describe Right Rate, Right Source, Right Time and Right Place for agronomic and environmental management of soil fertility for crop nutrition and apply to both fertilizer and manure management. The specific discussions and recommendations under the 4R umbrella are described for cropping systems and integrated cropping and livestock systems below.

In consideration of nutrient management, it is important to mention the complexity in the soil-landscape and agricultural management systems across the RRB. In addition to the need to consider BMP suitability relative to regional and local soil-landscape characteristics and variability (e.g., slope and permeability), current and future management practices (e.g., crop rotations, drainage management) have an impact on the feasibility and suitability of individual BMPs, or specifics of implementation of those BMPs that are suitable in a broad sense.

One of the most important management considerations is subsurface or tile drainage, which has emerged as an important practice across the RRB that is altering the pedo-hydrology within fields where implemented. Considering the Minnesota portion of the RRB in 1992, the percent of harvested acres with tile drainage were limited. In 2012, the percentage of tile-drained acres had greatly expanded in the RRB (up to 5%). In 2017, there was a doubling of tile drainage especially in the southern RRB in MN (up to 20% of area).

The agricultural community must consider current and future management as well as changing environmental conditions (climate change) in consideration of BMP recommendations and adoption. Adaptive management must also be considered and integrated into ongoing planning.

5.2.1 Cropping Systems

The following BMPs were recommended and discussed for nutrient management for cropping systems.

Right rate

There was consensus amongst workshop attendees that soil testing for soil test phosphorus (STP) and applying P at rates based on STP and crop needs are BMPs that are recommended for application across the entire region. Olson P should be used as the basis for STP determination in basic or calcareous soils, which are predominant across the RRB.

Results for STP from soil samples taken in 2018 across the RRB demonstrate variability across the region (Fig. 5.1). However, many regions were found to have a large proportion of samples with STP below 10 ppm (Olsen P). For example, northwestern Minnesota and much of North Dakota had over 50% of samples below 10 ppm. Areas with the lowest percent of samples below 10 ppm included much of MB, central and southern Minnesota (SW and SE corners), and much of South Dakota.

There are conflicting philosophies regarding fertilizer P application rates: build and maintain vs. sufficiency. These two philosophies are summarized as follows:

- Build and maintain – build up levels to optimum or high, then maintain STP at or above that level with periodic applications.
- Sufficiency – apply P as directed by STP; if STP is very high (i.e., well above critical value) and response to additional fertilizer P is unlikely, then no fertilizer P should be added.

Soil samples with soil test phosphorus below 10 ppm (Olsen P) in 2018

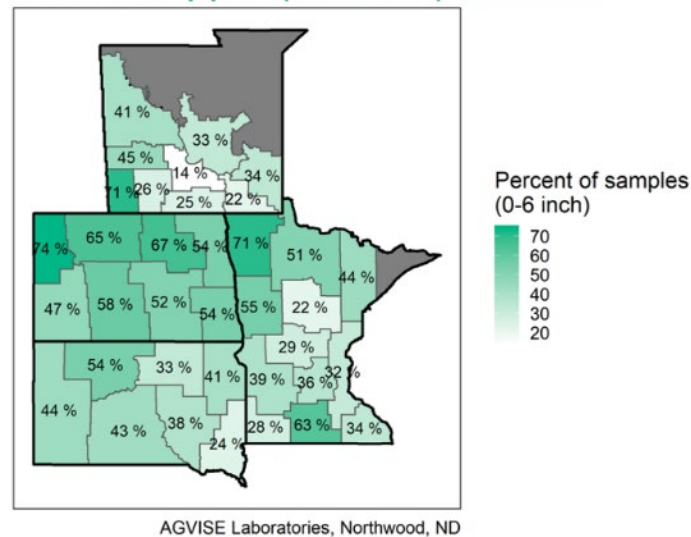


Figure 5.1: Soil test phosphorus across the Red River Basin (AGVISE Laboratories)

While build and maintain is a common approach across the RRB, are high rates of STP necessary to maintain yields? Long-term P trials were conducted at 6 locations in Minnesota, comprised of building STP to different STP levels (low, medium, high, very high) over 4 years, and comparing corn and soybean yields. While corn yields between 2015 and 2016 at Crookston responded to P application to soils in the low STP category, no statistical yield response was found for other categories (i.e., yields were not affected by the build and maintain approach). For soybeans in 2017, there was no statistical difference found between yields in response to P application at any of the STP levels. Corn and soybean yields at Crookston and Morris sites leveled off at approximately 10 ppm STP (Olsen P). Further, when P was applied at removal rates (i.e., sufficiency-based approach), STP increased slightly (1.5 ppm/year for acidic soils and 0.2 ppm/year for basic or calcareous soils). It is generally accepted now that the industry should adopt a sufficiency-based approach in order to manage STP and reduce excessive STP concentrations, as the build and maintain philosophy is associated with higher STP concentrations that elevate the risk of P losses in runoff.

Application of P to soils with STP at levels above which a crop yield response will occur (i.e., rates above which there will be an economic return) poses a P loss risk. Generally, as STP increases, the risk of P loss (and loading) increases. However, losses can be the same or greater in low STP soils when compared to high STP soils, and high STP soils can have low P losses (loads). For example, an edge-of-field evaluation conducted in Ohio within the western Lake Erie basin concluded the following:

- In some cases, soils with STP below the agronomic/economic threshold contributed to P loading above the recommended P loading goals.
- Conversely, in some cases, soils with STP well above the agronomic/economic threshold (i.e., at concentrations $> 75 \text{ mg kg}^{-1}$ to $\sim 120 \text{ mg kg}^{-1}$ Mehlich III P) sometimes did not contribute to P loading above the recommended P loading goals.

In other words, STP itself does not equal P loss risk. Therefore, there is more to consider than a simplified linear relationship between STP and P loading. The complexity in this relationship means there is not a magic number for STP that will, on its own, adequately protect watersheds from P loading. Other factors need to be considered, such as placement and timing of P application and hydrologic connectivity, such as preferential flow paths to tile drains and closed basins.

Right Source

While source is an important factor for consideration for management of P, the source is less important than other factors (rate, placement, and timing) for P loss and loading.

In cases where high STP occurs in fields, it can be important to understand the source behind the high concentrations in order to best manage and correct these situations. For example, while high STP concentrations are often assumed to be the result of applications of animal manures (see Section 5.2.2), they may be from legacy issues associated with overapplication of conventional fertilizers.

Placement and Timing

There is general consensus amongst workshop attendees that placement and timing are important or even critical to P management and that there is room for improvement in the timing of fertilizer applications and fertilizer placement practices. Generally, P loss risk decreases from broadcast and not incorporated $>$ broadcast and incorporated $>$ injected $>$ banded. With respect to timing of application, workshop participants agreed that spring application is preferred over fall application.

Across the RRB, there is a range of placement and timing practices for P fertilization, which vary across jurisdictions and by cropping system. In the Red River Basin on the U.S. side, the majority of P fertilizer is broadcast-applied. In Manitoba, P is generally applied in spring and fertilizer is generally seed-placed in wheat and canola crops (54% to 62%); however, seed placement is practiced on a smaller proportion of corn crops (32%).

P fertilizer is broadcast in the fall often because of the limited timing window in the spring. Spring application can be risky for producers due to the short window following spring thaw and in consideration of the need to seed in a timely fashion.

Additionally, the dominance of corn and soybean in the cropping system, particularly in the United States, is a driver in broadcast operations due to limitations in row seeding equipment (i.e., applying P with seed in the spring). With the increasing prevalence of corn and soybean acreages in the Manitoba portion of the RRB, this may become a more important issue in that portion of the basin as well.

Broadcast P applied in fall can result in higher losses of P, including surface and subsurface losses. In particular, if broadcast P is not incorporated well it is at higher risk of surface runoff losses that

can occur during runoff events post-application. This can occur in the fall if there are runoff-producing rainfalls; however, losses are more likely to result from snowmelt and spring runoff. Moreover, subsurface losses following broadcast P applications are of concern in shrink-swell clay soils as more RRB farmers transition to reduced tillage systems. In a post-harvest rainfall simulation experiment conducted in Ohio in October 2017 (Williams et al. 2018), broadcast P was found to have higher dissolved reactive phosphorus (DRP) concentrations in the leachate (and into tile drains) compared with injecting P or incorporating P using tillage. When P is surface broadcast and not incorporated there is a substantial opportunity for P to be either carried away with rainfall and surface runoff or leach into tile via preferential flow pathways. However, when P was incorporated with tillage or was injected directly into the soil, there was a 70% reduction in DRP concentration in leachate. Although there are fewer opportunities for this scenario to arise in the Red River Basin (e.g., fall P application on a lakebed clay soil following wheat harvest) it is crucial to consider alternate pathways of P transport beyond surface runoff. Even though preferential flow pathways are not currently believed to be a major transport mechanism in the RRB clay soils (see additional discussion in Section 5.5.1), even minor increases in P loss can contribute to downstream water quality impairment.

Conversion to reduced or zero tillage creates some challenges for P loss/load reduction, including timing of P application (e.g., conversion to no-till soybeans in Ohio resulted in more P broadcast in fall due to the slow operation of subsurface P application in this system) and lack of disturbance to (and promotion of) preferential flow paths.

There is a big opportunity across the RRB for increased adoption of P fertilizer practices that incorporate P into the subsurface or that place it there directly (injection or banding).

Site-specific P application is a practice that is generally applicable and should be used in areas of the landscape with increased vulnerability to P loss, such as low-lying areas, depressions, wetlands, and other hydrologically-connected areas.

Variable rate P application provides an additional means of managing concentrations of P in soil. This involves having surface soil samples collected across a regular grid or within defined management zones in a field analyzed for STP. Application rates are tailored to STP across the field using a sufficiency-based approach. Therefore, locations with STP levels above the critical STP threshold receive no P fertilizer and locations with STP levels below the critical STP threshold receive P fertilizer. This approach can also be used to guide manure application rates.

5.2.2 Integrated Cropping and Livestock Systems

Livestock manure as a source of P is important in limited portions of the RRB. Portions of the RRB in Manitoba have substantive livestock presence. The highest concentration of livestock is on the east side of the Red River, however other important areas of livestock include west of Portage la Prairie and north of Winnipeg. In the U.S. portion of the RRB, important areas of livestock include west of Devils Lake and southwest of Wahpeton in North Dakota, and along the eastern extent of the RRB in Minnesota.

Phosphorus loss from livestock systems is mostly derived from land application of manures and subsequent runoff, and to a lesser extent, leaching. While livestock manure can be a great source

of macronutrients (including P), nutrient management with manure is more complicated relative to conventional fertilizers for the following reasons:

- Nutrient concentrations are low, typically <10% by weight. This results in high transportation costs and greater time requirements.
- Nutrient ratios are fixed. If applying to target one nutrient, other nutrients will be over- or under-applied.
- Nutrient availability can be difficult to estimate (lesser concern for P relative to N).
- Nutrient application timing may not be ideal. Timing of application can be influenced and/or dictated by manure storage capacity (i.e., application is necessary when capacity is used up). This can result in late winter application, for example, which can in turn increase runoff losses during snowmelt.
- Nutrient content in manure is not uniform across time, space, and operations (i.e., animal species, diet, housing and bedding, dilution, manure storage, and handling systems).

As noted above, timing of manure application can be a challenge due to farm infrastructure limitations resulting in higher risk of P loss. For example, limited manure storage capacity may require producers to apply manure in the winter. In order to reduce the risk of P loss following manure application, Manitoba implemented a provincial regulation prohibiting winter application of manure. Livestock producers were able to access funding to offset additional costs associated with improving and increasing manure storage capacity in advance of the implementation of this prohibition. Manure application is currently happening on a year-round basis in the U.S. portion of the RRB.

While losses from storage and handling are smaller than from land application of manures, they are still important to consider. Storage and handling losses of P are generally small for many systems (5% to 15% loss) but higher rates of loss can occur in open, paved feedlots where runoff collection systems are not in place (20% to 40% loss).

The suite of BMPs for nutrient management to minimize manure P losses includes the following:

- Nutrient management planning (rate and source)
- Application method (placement)
- Application timing
- Storage and handling

Rate

While book values are common for nutrient concentration in manure and are often included with beneficial management recommendations, they are not accurate and should not replace sampling manure and testing for actual nutrient concentrations.

STP in the near-surface should be used to confirm soil STP concentrations prior to determining application rates. It is recommended that a shallow STP test (i.e., 0 to 5 cm) be used for sampling in soils that receive manure.

Manure management planning is an effective practice to reduce nutrient losses. This should be integrated with nutrient management planning in years when manure is not applied.

As nutrient content in manure is fixed and the limiting macronutrient factor in manure is generally P, it is recommended that manure application rate determination be P-based.

A cautionary note is that sometimes high STP are from legacy issues associated with overapplication, rather than simply as a result of application of manure. However, the intensification of livestock operations and costs and logistics associated with transporting and applying manure are practical challenges in spreading manure over a sufficient land base to manage overapplication of P.

Source

As discussed in Section 5.2.1, while source is an important factor for consideration for management of P, the source is less important than other factors (rate, placement, and timing) for P loss and loading. Rather than source, it is the amount of P being applied with manure and supplemental fertilizer that is most important.

Phytase additives in hog feed are widely used in the hog industry to reduce phosphorus concentrations in manure.

Placement

There are three main manure application methods:

1. Surface application with no incorporation – P losses can occur via surface runoff and erosion.
2. Surface application with incorporation or injection – reduces P losses from surface runoff and erosion.
3. Irrigation – limited practice in the RRB.

For surface applied manure, timing to incorporation is a critical factor to reduce N losses (Section 4.2), but it is also important for P management. The sooner manure is incorporated, the lower the risk of P losses via surface runoff and erosion or infiltration into surface cracks and entry into tile drains, where these systems are in place.

Management of manure for P in zero tillage systems is a challenge, as manure is typically surface-applied without incorporation and therefore subject to losses via surface runoff or infiltration into preferential flow pathways via surface cracks and biopores. Rotational tillage in zero tillage systems is a practice that can be used to reduce preferential movement of P and reduce stratification of P in the surface portion of the soil profile.

Injection is the preferred application approach for liquid manures.

In-crop application of manures using side-dressing is a potential BMP in crops that require additional P (e.g., corn, soybeans), but is a challenge to apply in the spring at seeding

Setback requirements and/or guidelines should be followed to avoid applying manures in proximity to lakes, wetlands, streams, wells, tile inlets, and other hydrologically-connected areas of the landscape.

Application on saturated soils and depressional areas should also be avoided. Mobile P tends to accumulate with erosion in low-lying and depressional areas and where yields (and P uptake) are often lower due to moisture stress.

In-field feeding is a practice that is beneficial due to reduced costs associated with feed preparation, transport, and manure handling when compared to confined winter feeding, and it can also result in soil fertility improvements in croplands. However, elevated concentrations of P in snowmelt runoff have been observed following bale grazing in Saskatchewan, which is likely attributable to uneaten feed, bedding, urine, and dung left on the frozen soil or snow surface. P losses have been found to be similar for bale grazing and confined feeding without capture of runoff. Findings of research conducted at South Tobacco Creek in Manitoba (Chen et al. 2017) indicate that high volumes of runoff from bale feeding overwintering animals have to be addressed. Management options to reduce runoff revolve primarily around siting bale feeding operations on landscapes that are not hydrologically connected to surface waters. Capture and treatment of runoff may also be used to reduce P loading from watersheds, and is more cost-effective for higher-density, lower-volume designs. Runoff containment and diversion of clean water is discussed in Section 5.5.

Timing

Fall application following crop harvest is favorable with respect to timing windows and logistics. Additionally, soils are generally less subject to compaction (relative to spring). However, fall application allows more time for nutrient losses prior to utilization by the crop the following spring and summer. Surface-applied manure in the fall is also subject to high snowmelt losses, particularly if manure is not incorporated.

With spring application, one of the advantages from a loss perspective is the short window between application and uptake. However, due to narrow spring timing windows for field operations, manure application time and logistics can be a challenge for annual crops. Spring application to established, perennial forage crops is a recommended practice; however, caution must be exercised to reduce potential for crop burn from N.

In summer or late summer, liquid manures can be applied in-crop using side-dressing which is easy to apply following harvest of short season crops. However, in-crop application can be a challenge due to potential damage to standing crops.

Winter application is not recommended as there are many drawbacks and few advantages. Winter-applied manures cannot be incorporated and there is high nutrient loss potential (snowmelt runoff, frozen ground), and potential to burn perennial crops from overapplication of N. If winter application is necessary, manure should be applied on level ground and in fields or areas within fields with more residue.

Storage and Handling

Liquid manure should be stored in impermeable concrete, synthetic, or clay-lined storage pits. Planning and monitoring should be practiced to prevent overflows.

Solid manure stockpiles should be stored on level ground and above seasonal high-water tables or flood/inundation prone areas. Catch basins or runoff collection systems should be used to capture

any nutrient-laden runoff from storage areas. Additionally, clean water diversion should be used to divert surface runoff around storages via gutters/ditches and berms.

5.3 BMPs FOR EROSION CONTROL

Erosion can occur by tillage, water, and wind and can result in soil export from the field. Tillage generally results in erosion that is contained within the field, but it can act as a delivery mechanism for water erosion by delivering eroded soil to convergent areas of the landscape where it is prone to losses from the field by water erosion. Water and wind erosion can result in loss of soil from the field and deposition into ditches and waterways adjacent to field. Wind erosion can deliver soil, particularly fine particles, further afield.

Wind erosion generally occurs following crop harvest and through crop establishment in the spring on soils that have reduced or little vegetative or residue cover. Water erosion occurs in conjunction with runoff events, which predominantly occur during snowmelt in the spring, but can occur through the remainder of the season following major rainfall events. However, for runoff to contain sediment, soil must become detached from the surface. Raindrop impact can detach soil particles while spring snowmelt generally does not if the ground is frozen. However, during snowmelt some surface soil can become mobile once it becomes saturated over the underlying frozen layer. Water erosion can occur in the field as rill or sheet erosion and in other landscape features such as gullies, streambanks, and along channels and streams. Tillage erosion occurs when tillage is conducted and is affected by the frequency and intensity of tillage (number of passes, type of tillage, speed of travel) and tillage path in relation to slope direction. Tillage erosion also includes the throw of soil from the field into ditches, which is a form of transfer of soil and nutrients from fields to ditches.

P loss to surface waters can occur when soil with adsorbed P is eroded. There is a strong correlation between river discharge, sediment load, and P load including both PP and DP. The relationship between sediment load and PP load would suggest that erosion must be directly involved. But the linkages between the processes causing soil loss from agricultural land, the sediments being exported from agricultural watersheds, and the sediments heading downstream in the Red River are not so clear. The linkages are complex, discontinuous, and indirect, making them difficult to manage with agricultural BMPs. For example, P dissolved in runoff leaving agricultural land will bind with sediments coming from gullies and streambanks, thus appearing as particulate P as the streamflow leaves the watershed.

The focus in this section is primarily on tillage, residue management, and livestock management BMPs that prevent soil detachment and improve infiltration, which reduce runoff and soil erodibility. Vegetative and structural practices that are effective at reducing wind and water erosion are primarily discussed in sections more specific to those two categories of BMPs (Sections 5.4 and Section 5.5, respectively).

5.3.1 Cropping Systems

Summary of the State of Practice in the RRB

According to Agriculture and Agri-Food Canada soil erosion indicator, while the risk of soil loss by erosion generally decreased across the Canadian prairies between 1981 and 2011, the risk has

remained neutral or increased in the Manitoba portion of the RRB (2020). The reduction in risk across the prairies is attributable to shifts towards no tillage or conservation tillage and a reduction of summer fallow, while in the RRB, tillage is still prevalent and crops with low residue are becoming more common. Erosion risk is still an issue within cropped lands in the RRB, and there is opportunity for improvement through tillage and management of surface residues.

A high-level summary of the current state of tillage and residue management practices across the RRB is as follows:

- Conservation tillage, including practices such as no-till, strip-till, mulch-till and ridge-till that leave more than 30% of the soil surface covered with residue after planting, is one of the most common practices for controlling erosion. Currently, this practice is essentially limited to the western part of Basin in areas of more sloping landscapes. Conservation tillage is effective at preventing erosion and maintaining soil health in these sloping landscapes in the western RRB.
- Conventional tillage, which leaves less than 30% of the surface covered with residue after planting, is practiced mainly in flatter portions of the Red River Basin. In these areas, characterized by heavy clay soils, producers use tillage to manage crop residue for improved soil drying in the spring. Erosion control in these areas is often achieved by using vegetative practices (see Section 5.4) and structural practices (see Section 5.5).

Cropping and nutrient management have important connections to the discussion of P losses by erosion. Low-yielding areas of the landscape result in the accumulation of mobile P when blanket rates of P fertilizer are applied for crop production. These often correspond to wet (e.g., depressional) or dry (e.g., knolls, upper slopes) areas within a field where productivity is limited by excessive or insufficient soil moisture. The wet locations of the landscape are typically the most problematic as they tend to be hydrologically connected. While targeted drainage can increase productivity in these areas resulting in greater crop removal of P, drainage improvements can reduce water storage on the landscape and increase the volume of water transported. Areas of the landscape that have insufficient moisture are commonly the hilltops. These areas of the landscape are prone to erosion losses of P-rich soil. Tillage erosion can deliver soil to convergent areas of the landscape where it is prone to running off the field by water erosion, while wind erosion can deliver sediment directly to surface water bodies and drainage ditches.

Artificial surface drainage is a significant surface water management practice in the RRB, and drainage intensity has increased over time. Artificial drainage influences runoff and affects P transport as follows:

- Increases snowmelt runoff by reducing storage
- Increases total P load
- Increases high P export with extreme summer rainfalls
- Results in lower N:P export ratios in summer

The artificial surface drainage density is an important factor in understanding this problem. For example, it is estimated that within the La Salle River watershed, each section of land has, on average, 20 to 25 km of in-field surface drains, and 40 to 60 surface drain outlets. It is estimated that roadside drainage ditches and in-field drains within the Tobacco Creek and La Salle River watersheds have the potential to deliver hundreds of tonnes of P per year from sediment and

vegetation (100+ tonnes of P per year) via surface runoff. As such, the practice of artificial surface drainage should be considered a significant transport system (for P in sediment and runoff from fields) and source of phosphorus (dissolved P from vegetation in drains) entering streams and lakes.

Erosion and Sediment Transfer Mechanisms in Cropping Systems

In the South Tobacco Creek watershed in Manitoba, field experiments have been conducted to measure wind, water, and tillage erosion. In these soil erosion studies, cultivated, hilly land has been the focus because these landscapes have widespread severe soil losses and crop yield losses. Soil erosion within cultivated hilly land is caused by wind, water, and tillage erosion, and is commonly seen as the culmination of all three. However, research is showing that severe soil losses are normally caused by tillage erosion, not wind or water erosion, in this hilly landscape. Therefore, the losses of sediments and associated nutrients from fields represent a relatively small amount of soil that is eroded within the field. But, as noted above, tillage represents an important delivery mechanism whereby tillage-induced soil erosion results in eroded soil being delivered to convergent areas of the landscape where overland flow concentrates and carries sediment and associated PP from the field. Therefore, tillage erosion is indirectly responsible for the sediment-bound nutrients that leave from fields via runoff.

Some tillage practices that are designed to retain crop residue on the soil surface to protect against wind and water erosion can move a lot of soil and cause high rates of tillage erosion, including the following:

- Vertical tillage promotes maintenance of crop residue on the surface to protect against wind and water erosion but is a cause of high amounts of tillage erosion.
- Chisel plow and tandem disks can cause more tillage erosion than the moldboard plow, unless moldboard plowing throws the furrow slice downhill. This is not to say that moldboard plow is a recommended practice—it is not—rather, it is intended to dispel any potential misconceptions of reduced disturbance by tillage practices currently in use.

Wind erosion is a concern following crop harvest in fall and through to crop establishment in the spring. As discussed in Section 4.3.1, wind erosion from agricultural fields is a significant problem in the Red River Basin, leading to deposition of sediment in snow-filled ditches. Nearly all ditches in the RRB alongside low residue tilled fields have significant wind-blown deposits in the snow. The wind-blown soil in the ditch has been found to have nearly two times the P as soil in the field (Cihacek et al. 1993). It is unknown how much P load occurs as a result.

Surface soils with little residue cover and high intensity of tillage increase the potential for wind erosion. Soils high in carbonates are very susceptible to wind erosion loss, as the carbonates reduce aggregate stability in clay soils. Tillage can also result in more exposed soil at the soil surface that is at higher risk for wind erosion losses. This can be particularly injurious if tillage exposes subsoils that are highly erodible to wind (and also water) erosion. As noted above, wind erosion can transport soil particles significant distances and deposit them in ditches and other areas of the landscape where they may enter surface waters. Wind erosion is a bigger problem than water erosion throughout the western portion of the Red River Basin, where rainfall is sparse.

Water erosion from cropped fields is of primary concern during the spring thaw period; however, it can also occur throughout the spring, summer, and fall seasons following heavy rainfall events. Water runoff from fields can cause erosion that can result in P export from fields through soil particulate transfer, as well as the loss of dissolved P from disrupted plant cells from surface vegetation.

Some observations on runoff in edge-of-field pathways with relevance to erosion are as follows:

- Most runoff from cropland moves through buffers in streams of concentrated flow.
- Increasing storage in the field or in the watershed will reduce water erosion, runoff volume, and nutrient loads.
- Reducing concentrations of nutrients near the soil surface in areas of flow accumulation is likely to reduce concentration in runoff and potential for P-rich soil transport with snowmelt.
- Importance of near surface processes and vegetation is high for snowmelt because frozen soils often prevent interaction or runoff with deeper soils.

Sedimentation, or the entry of soil into surface water bodies, is an important factor to consider in understanding the magnitude and sources of P entry into waterways in the RRB which can allow us to better address the cause and focus mitigation efforts. Current assessments of soil erosion and sedimentation in the Tobacco Creek and La Salle River watersheds in the Red River Plain are being undertaken to focus on the surface drainage systems of this landscape, including (1) the quantification of the amount of sediments accumulating within surface drains and (2) the quantification of nutrient content of these materials to assess the implications of their management on phosphorus loading on Lake Winnipeg. Sediment enters into surface drains by wind, water, tillage erosion, and even by the action of gophers (however, it is unknown if this is a significant contribution—the volume of soil entry may not be high, but soil is usually nutrient rich).

The vast majority of sediments in the lower reaches of the Tobacco Creek watershed are from channel bank and channel bed material, likely between 70% and 90% of total sediment load. Exposed bedrock outcrops along the channel are a major source of this material. Escarpment-like features may dominate sediment production within the region. Why is this important? The major source of this sediment is low in P, which would mean sediment must be adsorbing DP being transported to Lake Winnipeg and that P is highly reactive in waterways.

BMPs for Erosion Control

BMPs to reduce nutrient-rich sediments from leaving fields must control wind, water, and tillage erosion within fields. For effective erosion control we must minimize soil movement and maximize crop residue cover to reduce wind and water erosion.

As discussed in Section 4.3, BMPs to reduce erosion by water or wind erosion are often classified according to where the BMPs are installed on the landscape. BMPs at upper slope positions help to avoid or prevent soil detachment from occurring. BMPs at mid- and lower slope positions are designed to control the transport processes that carry sediment. BMPs at the edge of field are intended primarily to trap sediment originating from upslope portions of the landscape before it can enter ditches and streams. Reduction of tillage erosion requires management decisions to

reduce the frequency and intensity of tillage and how tillage is conducted in relation to the surface form of the landscape.

Generally, BMPs to address the issue of erosion in the RRB should include the following:

- A reduction in tillage, where feasible. For example, cropping practices that require less tillage and provide more crop residue cover and longer cover to reduce wind and water erosion and to reduce runoff.
- Tillage practices that reduce the amount of soil movement and the amount of crop residue on the soil surface that is exposed and can become a source for dissolved P through freeze-thaw cycles.

Adoption of no-till management or conservation tillage is beneficial in reducing soil erosion risk. To reduce tillage erosion where tillage is practiced, it is important to do the following:

- Practice contour plowing and avoid throwing the plowed soil downslope.
- Avoid up and down hill plowing.
- Avoid tillage practices next to ditches and streams by leaving a vegetated buffer strip.

Wind erosion is often controlled by planting windbreaks perpendicular to the prevailing direction of wind. The effectiveness of windbreaks depends on their height and density. Typically, windbreaks produce substantial reductions in wind erosion for a distance ten times the windbreak height. Wind erosion during the growing season can also be controlled by planting crop rows perpendicular to the prevailing direction of wind. Finally, wind erosion can be controlled by maintaining surface residue cover. Where tillage is part of the management system, this includes using tillage practices that protect the soil by leaving crop residue after harvest.

While maintenance of surface crop residues following crop harvest in the fall are promoted to provide soil cover, reduce soil erosion, conserve soil water, and trap snow, the issue of dissolved P loss from surface vegetative material must be considered. Removal of vegetation so that it does not become a source of P (see Section 5.4) is a means of reducing P loss from surface vegetation. If vegetation cannot be removed, runoff must be reduced to decrease nutrient delivery downstream.

Water management in field can achieve reduced runoff volumes through such things as crop interception, increased ET, and increased soil water holding capacity. An example of this would be upland crop interception. The resulting runoff can have increased P concentrations, but since there is less volume, it is easier to manage using other practices, such as capture, retention, and treatment.

A current knowledge gap is related to the trade-off between the benefit in sediment load reduction provided by vegetation and crop residues and the P source provided by the vegetation and crop residue itself. Do we have to make a choice between reducing sediment loading and increasing organic P sources with vegetation and residue on the landscape, or can we accomplish both? Additional research will aid in understanding and quantifying the costs and benefits of these management practices for more informed decision-making.

Related to artificial surface drainage, the intensity of drainage improvements within the RRB can be used as a factor to aid in spatially targeting BMPs to reduce water erosion and runoff. Targeting areas of high artificial surface drainage intensity for implementation of BMPs that reduce erosion

and runoff may provide an effective approach for P load reduction. For example, restoring surface water storage potential on the landscape is likely to reduce P export in artificially drained areas.

5.3.2 Integrated Cropping and Livestock Systems

The integration of livestock into areas of cropping allows for additional diversity in the agricultural landscape. As previously mentioned, grazing animals create opportunity for improved water quality if grazing is properly managed. However, some challenges related to erosion need to be managed.

If not properly managed, grazing animals can increase erosion risk in grazing lands including along streambanks. Livestock exclusion from streambanks is proven to reduce erosion.

Grazing management is important for maintaining soil health, including minimizing soil compaction and erosion. The key management considerations are stocking densities, grazing duration relative to vegetation health, and return periods between grazing events. Overgrazing through excessive animal density, leaving animals within a field for too long, or returning animals to a field prior to adequate vegetation recovery, will lead to vegetation damage, poor surface cover, and could result in increased erosion risk. Rotational grazing is one method of managing grazing lands, but its use still must consider the basic grazing management considerations. As mentioned in Section 4.3.2, rotational grazing does not necessarily produce greater water quality benefits than continuous grazing at moderate stocking densities, unless rotational grazing involves intervals longer than one year for recovery of vegetation (Briske et al. 2008).

Improved soil management on steep knolls in the western portion of the RRB is important to reduce erosion rates by water. Manure applications on degraded soils help reduce erosion and build soil health. However, these applications need to be balanced with productivity to ensure excess P buildup does not occur.

5.4 BMPs FOR VEGETATIVE MANAGEMENT

Vegetation management for reduced phosphorus loading is a challenge. Vegetative practices such as cover crops, vegetated ditches and vegetated buffers, including field edges and riparian zones, have been promoted in agricultural systems as beneficial practices. These practices have been promoted due to a range of benefits they provide, such as soil health benefits, soil erosion control, salinity control, water conservation, weed suppression and nutrient recovery. However, recent research is showing that these practices can contribute increased loss and loading of P.

Therefore, advances in understanding of the range of benefits and costs of vegetative practices will help inform the agricultural community in making decisions involving the trade-offs associated with these practices.

This section addresses BMPs for P loss and load reduction to the Red River, and includes a discussion of practices that reduce P source and/or reduce P mobility to surface waters.

5.4.1 Cropping Systems

Cover crops and crop residues

Cover crops have long been promoted in annual cropping systems as they provide numerous benefits, including soil health, erosion control, salinity control, nutrient recovery, and reductions in nitrogen leaching. The beneficial effects of cover crops scavenging nitrogen from the soil profile following harvest of the main crop and reducing the potential for nitrogen leaching following fall rains and during the spring snowmelt and recharge period are relatively well understood (see Section 4.4).

However, recent research is showing that the aboveground vegetative matter contributed to the cropping system from cover crops and crop residues can be a substantive source of P in runoff to surface waters. Freeze-thaw cycles act to break down vegetative material (e.g., plant cell lysis) and promote mobilization of dissolved P, and to a lesser degree, particle-bound P, and allow for transport of these P sources during snowmelt and rainfall events to surface waters via runoff and leaching (Fig. 5.2).

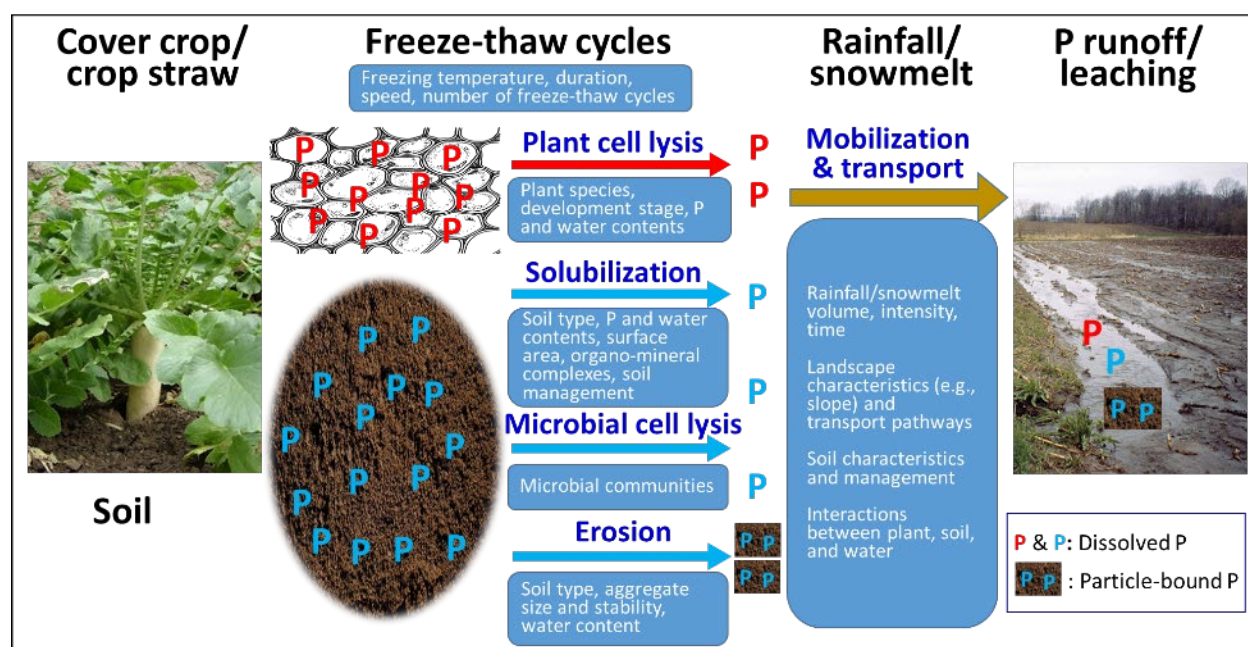


Figure 5.2: Freeze-thaw effects on P mobilization and transport processes (Liu et al. 2019)

The complexity of the various cropping systems, other components of agricultural management systems (e.g., tillage, drainage management) and variable soil-landscape conditions poses a challenge in understanding the dynamics of P transport and loading. Understanding the benefits and costs of incorporating cover crops and maintaining surface crop residues across the RRB requires an understanding of the complexities and variability associated with how the broad range of potential cover crops interact with these systems and conditions. Understanding these interactions is confounded by a lack of research in P loss from cover crops and crop residues in cold climates.

There are a wide range of categories and individual types of cover crops and crop residues that are currently used or considered as potentially agronomically appropriate in the RRB:

- Brassicas such as winter rape, oilseed radish, white radish, and white mustard
- Grasses such as annual ryegrass, perennial ryegrass, cocksfoot, Kentucky bluegrass, meadow fescue, oat, rye, timothy, and winter wheat
- Legumes such as alfalfa, hairy vetch, red clover, and white clover
- Other cover crops such as chicory and phacelia
- Crop residues including stubble from commonly harvested crops (e.g., barley, wheat, canola, oat, soybean, corn, hemp) and associated chaff from harvesting operations

Cover crops and crop residues constitute a sizeable P pool. However, the amount of biomass, plant P concentration and plant P uptake vary by crop type and form (cover crop vs. residue vs. root biomass) (Fig. 5.3). The variability in quantity and quality of P source in vegetative matter provided by cover crops and crop residues must be considered in determining BMPs for cover crops and crop residues, such as species selection and other management practices (i.e., harvest, incorporation).

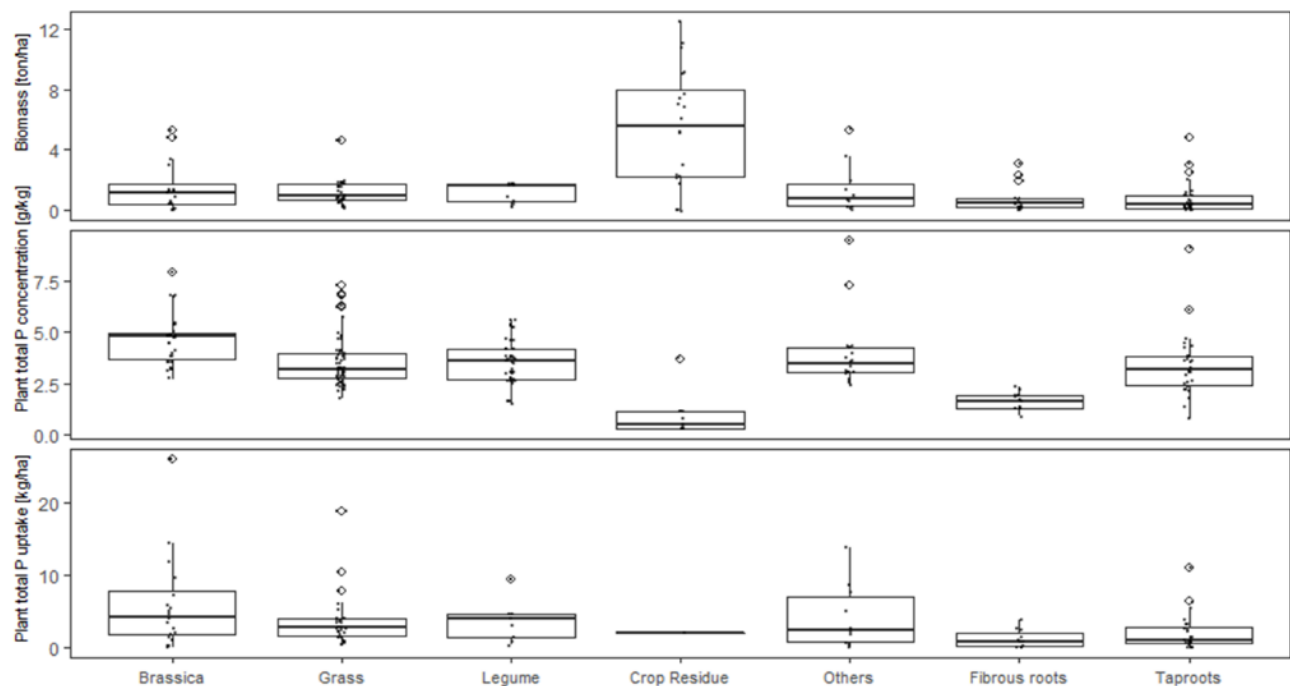


Figure 5.3: P pools of cover crops, crop residues, and roots (Liu et al. 2019)

Based on a review of studies (laboratory simulations and field investigations) conducted in Ontario, Saskatchewan, and Manitoba, a wide range of P release was found (Fig. 5.4). However, in all cases cover crops (and riparian vegetation) provided a significant P release as expressed as a % of plant total P. Generally, P in crop residues is less vulnerable to loss than P in cover crops due to lower P concentrations and lower water content in residues. The review indicated that up to 4 kg P/ha was released from cover crops.

Water-extractable P (WEP) provides a measure of P in plant materials that is potentially available for transport and loss. Water-extractable P varies with crop type and increases with increasing FTC intensity (lower temperature) and FTC frequency (number of cycles). As illustrated in Fig. 5.5,

regardless of crop type, crop residue and root biomass, the amount of WEP was higher when there was at least one FTC relative to no FTC. For cover crops, WEP increased when there were multiple FTCs when compared to a single FTC.

While understanding P dynamics in cover crops and crop residues in relation to other aspects of the cropping management system is complex, a systems approach must be considered in determining appropriate BMPs. The implementation of cover crops and management of crop residues are intimately associated with other aspects of the cropping system (i.e., crop rotation) and other aspects of the management system (i.e., tillage system). So, to reduce P loss and loading from cover crops and crop residues, BMPs must be appropriate to crop rotations and tillage system and must also consider the effectiveness in reducing losses and loads in conjunction with these other aspects of the cropping management system.

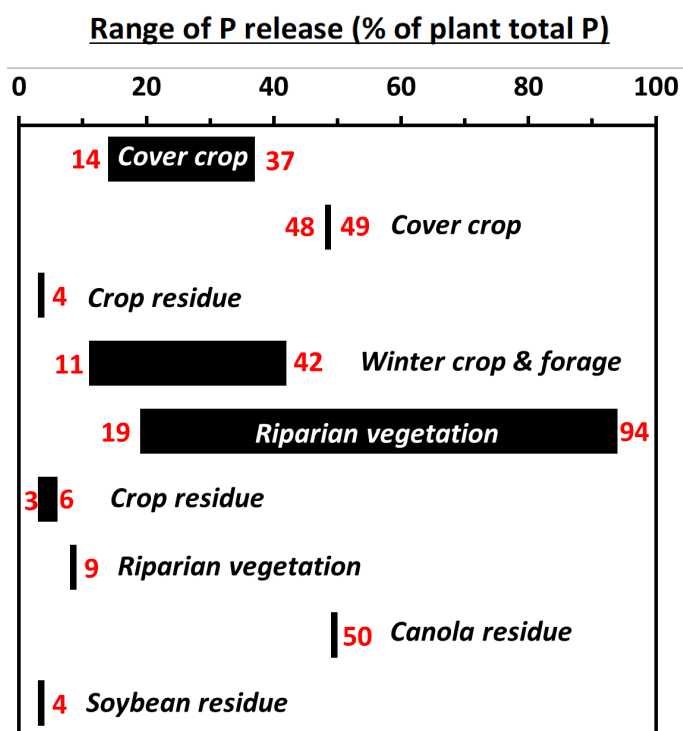


Figure 5.4: P release from plant materials following FTCs (adapted from Liu et al. 2019)

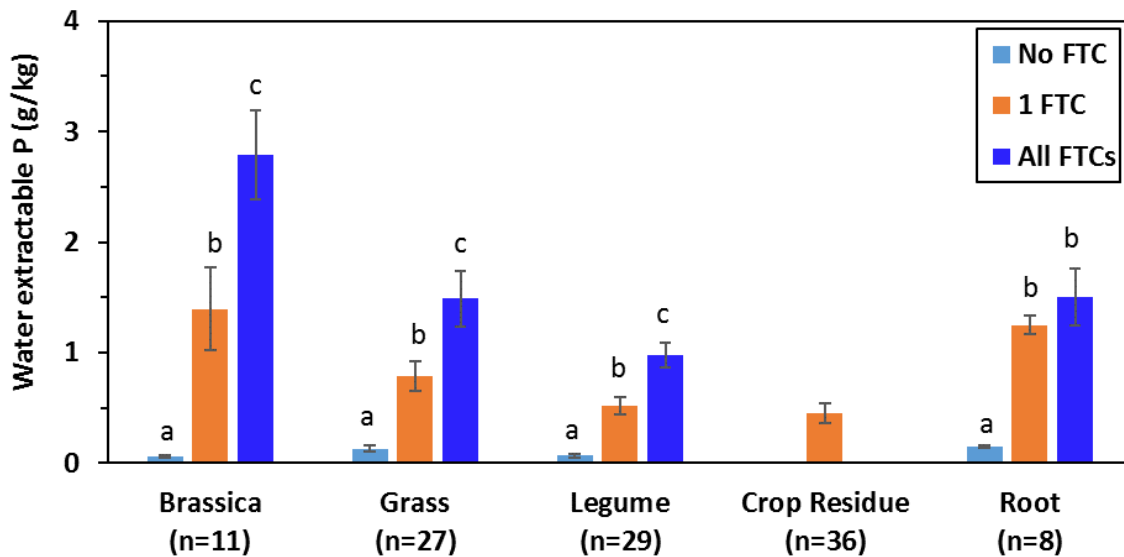


Figure 5.5: Water extractable P from various sources (Liu et al. 2019)

Some key findings of a review of the impacts of cover crops and crop residues on P loss under different tillage and cropping systems (Liu et al. 2019) are as follows:

- Denser crop residues in no-till systems have been found to reduce total P load through reductions in water and sediment runoff; however, they can increase DRP load.
 - For example, a study in Wisconsin demonstrated that under a no-till system denser residues associated with corn silage increased total P enrichment in sediments in rainfall-runoff but not in snowmelt-runoff over an 18-month period when compared to grain corn (Panuska 2010). In this study, DRP loss increased by 21% under the denser residue associated with silage.
- Conservation tillage can increase P loss in snowmelt runoff and also year-round P loss as compared to conventional tillage because conservation tillage can lead to more snow accumulation and greater contribution of P loss from crop residues.
 - A study in Minnesota (Hansen 2000) demonstrated increases in runoff by 46% to 281%, sediment by 88% to 250%, total P by 200% to 250%, and DRP by 143% to 286%.
 - Studies in Manitoba (Tiessen 2010; Liu et al. 2014) have found that conservation tillage increased DRP losses due to both direct P loss from crop residues and buildup of P on the soil surface as well as generally increasing runoff volume associated with greater snow accumulation. In these studies, annual runoff increased by -37% to 2,200%, annual sediment by -93% to -46%, annual total P by 42% to 3,980% and annual total dissolved P (TDP) by 62% to 4,078%. The extremely high percentage in P loss occurred in one year when the P loss from the conventional tillage treatment was extremely low (0.01 kg total P /ha and 0.009 kg total dissolved P /ha).
 - Similarly, a study in Finland (Puustinen 2005) found that conservation tillage resulted in increased DRP losses while it reduced losses of sediments and particle-bound P.

- Cover crops have been found to increase total P loss during the non-growing seasons, with results being variable among crop species.
- When evaluations of cropping systems have been completed examining year-round impacts on P loading, results have been found to be variable. At least some of the variation is attributable to landscape and climatic characteristics.
 - For example, an erosive soil in Oregon under a wheat-pea rotation (Douglas 1998) was found to have reductions in runoff, sediment and total P (-90% to -44%) when compared to fallow, while a 10-year evaluation in a flat landscape in Saskatchewan under green manure (Schneider et al. 2019) demonstrated decreases in runoff (-19%) and sediment loss (-44%) but increases in DRP (33% to 71%) when compared to fallow.

While cover crops can be a substantive source of P due to P release from vegetative materials following FTCs, soils can be an important sink for this released P. A study in Ontario (Lozier 2017) shows that a small proportion of the P released from plants was found in runoff in cropped soils. Regardless, the contribution of cover crops and crop residues to P load cannot be neglected.

An important trade-off that must be considered (and better understood) in determining potential BMPs, is the beneficial effects cover crops and crop residues can have on runoff, sediment loss, and total P reduction vs. the adverse effects associated with higher DRP loss and loading. Further evaluation would aid in this understanding.

As discussed above, BMPs for cover crops in cold climates for P loss and load reduction must consider cover crop type (i.e., the pool of P they provide) and the management of vegetative biomass they contribute (e.g., harvest and removal, incorporation). Therefore, a suite of potential BMPs for P loss from winter crop cover in cold climates may include the following:

- Selecting cover crops that are hardy in cold environments
- Selecting cover crops that contain low P concentrations in aboveground biomass
- Harvesting and removing cover crops and crop residues from the field in the fall in order to remove the P source the additional vegetative material provides (this may reduce the level of overall benefit the cover crop provides)
- Rotational tillage to incorporate residues following harvest and removal of the bulk of aboveground biomass

Vegetative buffers

Vegetative buffers and water retention structures have been promoted as an effective means to reduce runoff, erosion, sedimentation, and nutrient loading into surface waters, including streams and drainage ditches. Additionally, these vegetation features provide a physical buffer between field operations and surface waters and serve as a setback for varying benefits (e.g., prevent pesticide application close to water, farm safety factor), enhance terrestrial and aquatic habitat, and protect streambanks. While the impacts of vegetative buffers on erosion and runoff (and associated sediment and P load) are addressed in Section 5.3, vegetative buffers can be a source of P to surface waters during snowmelt runoff. Additionally, riparian vegetative buffer areas (and other similar vegetative features) are not effective in filtering dissolved P from snowmelt runoff.

Roadside drainage ditches have the potential to add substantive amounts of P from vegetation on an annual basis and, as such, these waterways should be considered a significant source of P for streams and lakes. A back-of-the-envelope estimate suggests multiple tonnes of P could be contributed from roadside drainage ditches annually from a single watershed (Lobb 2019). To reduce nutrient delivery into surface waters, the vegetation in these areas of the landscape must be managed. Vegetation harvest may provide an effective means to reduce the pool (source) of P these landscape features provide.

A potential philosophy is to expand the current concept of growing crops. Currently, the growing of crops is primarily confined to within agricultural field boundaries. This leaves a large portion of the landscape and watershed with vegetation that is not currently managed. An expansion of the concept of growing crops could be made to consider the landscape and watershed scale. In other words, communities should broaden their view of crop management to include non-traditional forms of vegetation that are common across the agricultural landscape of the RRB, such as riparian areas of streams, drainage ditches, and other surface drains and wetlands. Harvest, removal, and use of these other vegetation forms that may contribute to P losses and loading will be beneficial to reducing P loading from the landscape. Examples of these non-traditional practices occur along the Red River Floodway, a large, grassed flood protection structure around Winnipeg, Manitoba and along the TransCanada Highway, a major transportation corridor in Manitoba.

Healthy Crops

Another area of potential improvement in management of vegetation is within the traditional agricultural field crop context. Growing more uniform crops within fields with variable soil-landscape conditions and growing crops with a higher degree of stability from year-to-year in the face of weather variations and extreme conditions will result in a more productive cropping system. While productive crops produce more P-bearing vegetative material, including crop residues, healthy crops provide other benefits. For example, healthy crops can result in the following:

- Improved soil health with better infiltration, less compaction, better aggregate stability, and higher soil organic matter
- Reduced runoff and improved soil moisture conditions, which in turn improve crop productivity and P-use efficiencies
- Improved interception of rainfall and trapping of snow
- Increased use of soil water

This is another area that poses a conundrum. The trade-off between an increased P pool from vegetative material (crop residues remaining after harvest) from healthier crops and the beneficial effects healthier crops provide, such as reduced runoff and improved water and nutrient use efficiency, needs to be studied and better understood to support informed beneficial management decisions.

5.4.2 Integrated Cropping and Livestock Systems

The inclusion of livestock into the agricultural production system has numerous benefits:

- Increased diversity in the agricultural system (improved compared to straight cropping system)
- Creates opportunities for perennial forages and rangeland to persist in selected portions of the landscape
- Creates food from crops that may not be suitable for human consumption
- Manure enhances the soil and adds nutrients and carbon back into the system

Additionally, grazing animals create an opportunity for improved water quality within an agricultural production system. The addition of grazing animals allows for farming in diverse landscapes, with the inclusion of natural and managed features such as wetlands, grasslands, and trees, which act to alter the agricultural landscape relative to what has become more typical of a monoculture-type cropping system. Based on modeling work in 21 small watersheds (ranging in size from approximately 200 to 2,000 km²) in Manitoba (Fasching et al. 2019), water quality improvements for TDP and total dissolved N (TDN) were linked with decreasing percent cropland area (Fig. 5.6). Additionally, as non-cropland area increases to above 30% to 40% of the watershed, P concentrations in runoff decrease with increases in flow (Q, normalized to mm per day) (Fig. 5.6). This example demonstrates the challenge associated with assessing the effectiveness of a BMP in isolation from broader considerations of other aspects of the production system and the sum of the parts.

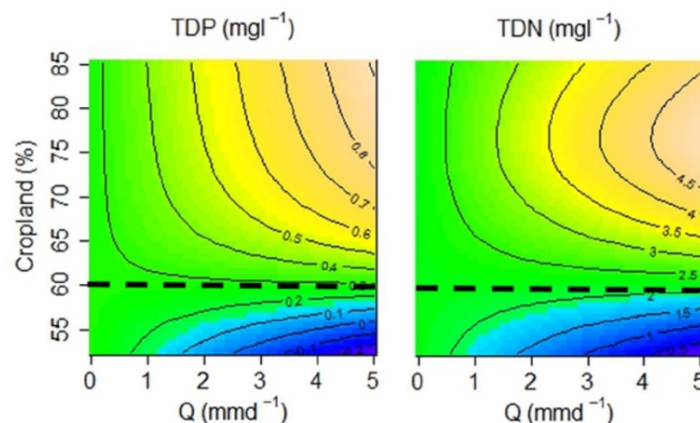


Figure 5.6: Water quality for TDP and TDN relative to percent cropland (Fasching et al. 2019)

Livestock integrated into cropping systems provide an opportunity to utilize aboveground biomass through harvest and removal for feeding (hay) or direct removal by grazing. Winter in-field feeding is a practice that is beneficial due to reduced costs associated with feed preparation, transport, and manure handling when compared to confined winter feeding and may result in improved soil fertility. Field feeding provides a mechanism to “harvest” and remove aboveground biomass including cover crops. However, elevated concentrations of P in snowmelt runoff have been observed following bale grazing in Saskatchewan (Smith et al. 2011), which is likely attributable to uneaten feed, bedding, urine, and dung left on the frozen soil or snow surface. P losses have been found to be similar for bale grazing and confined feeding without capture or runoff. Capture and treatment of runoff may be used to reduce P loading from watersheds, and is more cost-effective for higher-density, lower-volume designs. The potential to reduce runoff and

nutrient export from overwintering using new management practices needs to be determined. For example, there may be potential to reduce nutrient losses and loading through changes in management of crop residues prior to overwintering. Trade-offs associated with field feeding, including during overwintering, need to be better understood.

Livestock integrated into the agricultural system also provide the potential opportunity for using harvested vegetation from non-traditional agricultural cropping (see Section 5.4.1). For example, bale grazing on bales harvested from vegetated buffer strips may provide a means to utilize non-traditional feed sources in some circumstances. However, the suitability of harvested vegetation from these non-traditional sources (e.g., drainage ditches, wetlands, etc.) would have to be evaluated.

Surface residue management may also be an important factor in managing P loss and loading following manure applications. Research in Wisconsin (Grande 2005) found that denser residue cover associated with harvests of corn grain and high-cut corn silage decreased total P load in all of 12 years and DRP load in 9 of 12 years as compared with harvest of low-cut silage for both manured and unmanured treatments. This result was determined to be largely due to a reduction in runoff and sediment load with a denser residue cover. However, the overall impact of residues on P loss is dependent on climate conditions, so caution is required in applying these results to the RRB. Relative to Wisconsin, the longer and harsher winter conditions in the colder climates of the RRB result in annual P loss being dominated by dissolved P in snowmelt. Therefore, the benefits to P loss reduction from manured fields from denser residues reported from the Wisconsin study may not be realized in the RRB.

Vegetative buffer strips provide some benefit in integrated livestock systems, including physical setback from surface waters. Buffer strips have been shown to reduce P loss in rainfall runoff events. For example, as reported by Gitau et al. (2005) and shown in Fig. 5.7, buffer strips can reduce P loss by over 20%. However, this conclusion was not based on cold climate conditions. As noted previously, vegetative buffer strips in cold climates can be a source of P. However, vegetative buffers may provide a net benefit in integrated livestock systems considering reductions in runoff, sediment trapping, and physical separation from open water, in addition to the other benefits they provide.

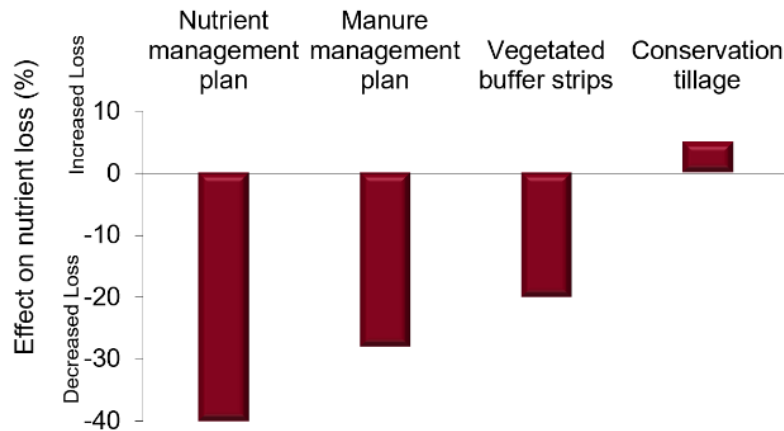


Figure 5.7: BMP effectiveness for reducing nutrient losses (Gitau et al. 2005 from Modderman 2019)

Setbacks from surface water bodies, water courses, and other means of water conveyances (e.g., drainage ditches, field surface drains, tile inlets) should be adhered to as required through regulations (e.g., Manitoba, Minnesota, South Dakota). While these setback distances do not require a vegetated area, vegetation and setback areas are complementary practices and permanent vegetative cover should be considered to establish setbacks in integrated livestock systems. Additionally, harvesting of vegetation in these setback areas by mechanical harvesting or managed grazing may complement this practice in reducing the potential for P loss.

5.5 BMPs FOR STRUCTURAL MANAGEMENT

As discussed in Section 4.5, the flat terrain within the RRB lake plain has been substantially altered by artificial drainage, with nearly the entire area altered by surface drainage. The emergence of tile drainage in the 1990s also rapidly increased the number of acres drained in the last decade. Structural practices are predominantly designed to manage water and to counteract some of the negative impacts artificial drainage has had on water flow (stream discharge volumes and peak flow) and water quality.

The primary structural practices which may be used for P load reduction and/or provide other environmental benefits include tile drainage (with and without control), treatment of tile drainage discharge, water retention on the land using small dams, reservoirs and retention ponds, wetland restoration and constructed wetlands, and ditch network improvements and control. For integrated livestock and cropping systems, the primary structural practices to reduce P losses include runoff containment systems and proper manure storage.

Determining the feasibility, effectiveness, and suitability of structural management BMPs requires consideration of regional and site-specific environmental factors including landscape, soil, and climate. For example, controlled tile drainage is only feasible in flat landscapes while most water retention practices are generally better suited to regions that have some relief and topographic variability.

As with other BMP considerations, trade-offs often need to be considered with structural practices. Practices that are beneficial to P load reduction are sometimes not the best solution for

N load reduction and vice versa. As previously discussed, other environmental benefits provided by these practices need to be considered to support decision-making.

5.5.1 Cropping Systems

Subsurface Drainage

Tile drainage is a structural practice that is increasingly being implemented throughout the RRB as producers attempt to address excess soil moisture, which limits soil trafficability in the spring, field uniformity and crop productivity following heavy rainfalls. Tile drainage influences the water balance and shifts a portion of the water export from agricultural fields from surface water runoff to subsurface flow.

Following rainfall events or snowmelt, water ultimately partitions into runoff or infiltration components. Runoff generally enters surface drainage ditches or other surface water courses, while infiltration flows through the vadose zone via matrix flow or preferential flow and may reach the underlying water table. Tile drainage intercepts shallow groundwater and discharges this flow into the surface drainage network. Generally, P is lost through runoff in particulate or dissolved forms, due to its decreased mobility in the soil environment. While leaching losses of P are generally low, the incorporation of tile drainage creates a potential pathway for loss via interception of P entering preferential flow paths during rainfall runoff events (Fig. 5.8). This is of particular importance in cracking clay soils and can result in a “short-circuiting” of P entry into surface water via tile discharge (much of the research on this topic has been conducted in warmer climates such as Ohio; more discussion below). Cracking clay (i.e., smectitic) soils are tiled within the RRB, particularly in the U.S. portion. However, evaluations of water quality of tile drainage effluent in North Dakota at 18 tile discharges in 2008 (Johnson 2010) and at 8 tiled fields from 2009 to 2013 (Scherer and Johnson 2014) demonstrated that the concentrations P in tile drainage water was substantially less than that of surface water. The net loss and loading of P into surface water is generally lower under tile drainage systems due to the reduction in surface water runoff.

Differences in the impact tile drainage has on the shift in water balance in cold regions and warmer regions, on which much of the scientific literature including BMPs are based, must not be neglected. Very little water runs from tiles across much of the RRB during winter months and into early spring (typically November through March) due to frozen soils and tiles being decoupled from the surface. For example, the following values were recorded in tile-drained clay soil in Manitoba (Kokulan et al. 2019):

- 80% of the volume of drainage from the field was surface water runoff.
- 96% of SRP load was contained in surface runoff.
- 96% of TP load was contained in surface runoff.

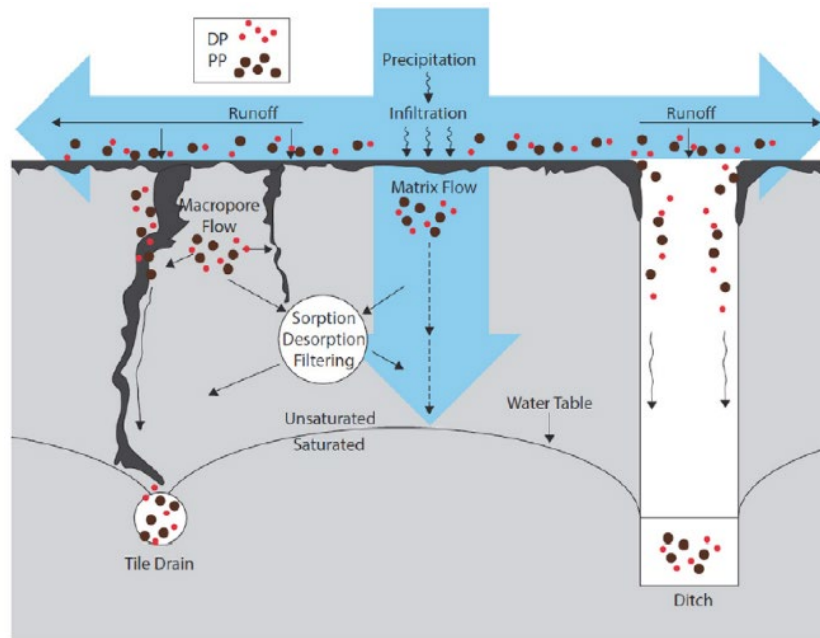


Figure 5.8: Non-point source drainage pathways for P (adapted from Radcliffe et al. 2015)

The researchers found SRP and TP concentrations to be higher in surface runoff than tile flow, indicating that preferential flow is not always an important mechanism in clay soils. A couple of important observations can be made based on research in Manitoba (Kokulan et al. 2019; Kokulan et al. 2018):

- Fields largely wet from top down and surface runoff often precedes tile flow, due to a combination of frozen soils, snowmelt and runoff, and clay soils with low permeability.
- Regarding preferential flow, simultaneous responses are rare in Manitoba (surface drainage flow typically happens before tile flow), indicating that rapid connectivity to tiles is not occurring.

So, research in the cold climate of the RRB is suggesting that the potential pathway of P loss to tile through preferential flow paths in cracking clay soils may not be as significant an issue as in warmer climates such as Ohio. For preferential flow to be of importance to P loss, a combination of heavy rainfalls, non-frozen soil conditions and surficial P must be present. Heavy summer rainfalls resulting in these events have historically been limited in the RRB but could increase in frequency due to the effects of climate change.

In Minnesota, subsurface drainage on sandy loam soils under traditional tillage systems is being evaluated at the Discovery Farms demonstration sites in Norman County and Wilkin County. Annual precipitation is strongly correlated with annual tile flow discharge. Annual tile flow at the Norman site is generally low (averages 0.59 inches), while at the Wilkin site the average annual flow is 2.91 inches but can exceed 5 inches. A significant portion of the annual tile flow occurs in the spring after the soils have thawed, with June having the highest contribution: April and May – 12% at Norman, 27% at Wilkin; June – 51% at Norman, 40% at Wilkin. During the remainder of the growing season, July through August, 13% of annual flow occurs at Norman while 4% occurs at

Wilkin. During the fall period of September and October 15% of the annual flow occurs at Norman and 20% at Wilkin. Tile discharge varies tremendously from one year to another according to precipitation and crop. Discharge as a percent of precipitation varies at Norman from 0.4% to 8%, while it ranges from 2% to 23% at Wilkin. Discharge after dry years tends to be low. The vast majority (96%) of discharge occurs under non-frozen conditions. Annual soil loss through tile averages 1.9 lb/ac at Norman and 2.7 lb/ac at Wilkin. Annual TP loss through tile averages <0.01 lb/ac at Norman and 0.01 lb/ac at Wilkin.

Another study site in Minnesota at Clay County has been used to evaluate P in tile discharge on a system with a drain spacing of 55 feet. Subsurface drainage represents 68% of annual flow while surface runoff accounts for the remaining 32%. Subsurface drainage discharge ranges from 1 to 4 inches per year, representing 7% of the precipitation on average. Surface runoff accounts for 92% of the total phosphorus loss, while subsurface loss accounts for the remaining 8%. Annual subsurface P losses ranged from 0.01 to 0.04 lb/ac over 5 years (2011 to 2015; no subsurface flow occurred in 2012) under crops including corn (3 years), sugar beets, and edible beans.

The interaction between nutrient management and tile water quality is important to consider given the following factors:

- Soil P content – tile discharge P concentrations generally increase with increasing STP.
- Timing of P application – P should be applied when tiles are not running as there are often high concentrations in tile discharge following P application. P should not be applied late in the fall preceding wet conditions; rather, earlier fall application is favorable as P has more time to be bound by the soil.
- P application placement – P should be placed in subsurface banding to reduce the opportunity for P entry into surface cracks and loss to tile through preferential flow. Application of P and N via subsurface banding reduced nutrient loss in drainage by 60% over a simulated growing season, with reductions in both clay and silt loam soils and with more prevalence in frozen soil (Grant et al. 2019).
- Tillage – studies have shown increases in preferential flow in no-till systems (Lam et al. 2016), attributable to the lack of soil disturbance, which promotes macropore network development. However, differences were found in TP concentrations not SRP, indicating differences in P losses are attributable to particulate forms. Tillage is a practice that has some promise in interrupting the preferential flow pathway that is understood to be largely responsible for P entry into tile drainage systems. However, the benefit of tillage may be limited if P is subsurface banded (Lam et al. 2016).

The variability across the RRB is pertinent to the discussion of tile drainage and the associated environmental benefits and trade-offs. For example, heterogenous conditions across the RRB include landscape (slope), soil (permeability), and climate gradients.

Under the current climate, tiles will likely do little to modify runoff pathways or surface water runoff chemistry in the RRB. Therefore, tile drainage will likely will not exacerbate P problem but could elevate nitrate loss. However, if storm distribution and intensity changes in future (e.g., more frequent, intense summer rainfalls), tiles could play a more active role in influencing P dynamics. Regardless, 4R strategies can be used to minimize P loss to tiles.

Tile drainage provides some opportunity to manage water discharge and water quality. Tile drainage shifts the non-point source challenge of nutrient loss via surface water (edge-of-field) to one-point source whereby nutrients are exported from the end-of-pipe. This allows for easy capture of tile discharge for treatment prior to entry into the surface water network or for storage and reuse. Additionally, tile drainage can be controlled, which can be used to conserve water and limit discharge.

Controlled Subsurface Drainage

As discussed in Section 4.5, controlled drainage can be used to reduce tile discharge in fields through installation of gated control structures within the subsurface drainage system. Controlled drainage is only feasible on very flat landscapes, typically those with less than 1% slope. Controlled drainage typically reduces total discharge; however, the impacts to P losses in cold climates are not well understood.

At the Red River Valley Drainage Water Management Project site in Wilkin County, Minnesota, conventional and controlled tile drainage are being evaluated for impacts on discharge volume and water quality. Controlled drainage reduced drainage volume by 1.2 inches (84% of conventional discharge) under soybeans in 2017 (conventional – 7.7 inches; controlled – 6.5 inches) and 1 inch (71% of conventional discharge) under corn in 2018 (conventional – 3.4 inches; controlled – 2.4 inches). Total P load was higher in the controlled drainage system in 2017 (conventional – 0.04 lb/ac; controlled – 0.2 lb/ac) while loads were very similar in 2018 (conventional – 0.05 lb/ac; controlled – 0.06 lb/ac). It is unclear what is causing the increased P loads under the controlled system. So, while controlled drainage is a proven technology that can be used in flat landscapes to reduce the volume of discharge, additional knowledge needs to be gained on the benefits it may provide for P load reduction.

Subsurface Drainage Discharge Treatment

Bioreactors provide one option for treatment of tile drainage discharge. The first-generation bioreactor was a horizontal flow, wood-chip based system targeting nitrate treatment for subsurface drainage at the edge of field. Now, second generation bioreactors are being evaluated, including their ability to treat P in drainage discharge. These systems are vertical flow and are placed at the side of ditches. They incorporate a heat source and P-adsorbing material, such as crushed concrete, limestone or steel slag. Mean P load reductions in second-generation bioreactors in a 2-year evaluation in Minnesota showed positive results in 2016 with reductions of 47.5% with crushed concrete, 33.9% with limestone and 44% with steel slag. Results were not favorable in 2017 with increased P loads of 13.7% with crushed concrete, 1.2% with limestone and 4.3% with steel slag. Increased P loads were attributable to P sorbing materials releasing P through desorption. In an evaluation in 2018 P sorbing material use was discontinued. At this point in time, bioreactors do not appear to provide the potential to manage P loads in tile drainage discharge.

Small Dams, Retention Ponds, and Reservoirs Dams

There are various types of dams that can be used to reduce and/or slow flow into surface waters, including dry dams, which are infrequently used for flood control, upper basin dams, and small dams.

Small dams and reservoirs have been shown to effectively provide protection to downstream flooding and can be cost effective relative to large dams for this purpose. However, they can also be effective at reducing nutrient concentrations in runoff leaving agricultural fields. In a small dam and reservoir network on the South Tobacco Creek along the Manitoba Escarpment, researchers found 9% to 19% reduction in snowmelt runoff, 13% to 25% reduction in rainfall runoff and 48% to 83% sediment retention (Yarotski 1996). In the same watershed, Tiessen et al. (2011) found an average annual P reduction of 9% to 12%. Researchers found greater removal of dissolved nutrients than particulate and noted that small reservoirs were less effective during snowmelt.

At a research site in Morden, Manitoba, researchers are evaluating the effectiveness of the use of surface water drainage retention ponds in reducing nutrient concentration of runoff. These ponds include an enhanced ditch and a pond created using a large berm in a natural surface drainage course. Substantial reductions in nutrient concentrations and load were found in 2016 and 2017 (Fig. 5.9; Vanrobaeys, unpublished). Concentration reductions were as follows: TDP (51% in 2016 and 42% in 2017), TP (38% in 2016 and 33% in 2017) and TSS (97% in 2016 and 45% in 2017). Flow and load reductions were as follows: water volume (80% in 2016 and 64% in 2017), TDP (93% in 2016 and 78% in 2017), TP (93% in 2016 and 71% in 2017) and TSS (99% in 2016 and 71% in 2017).

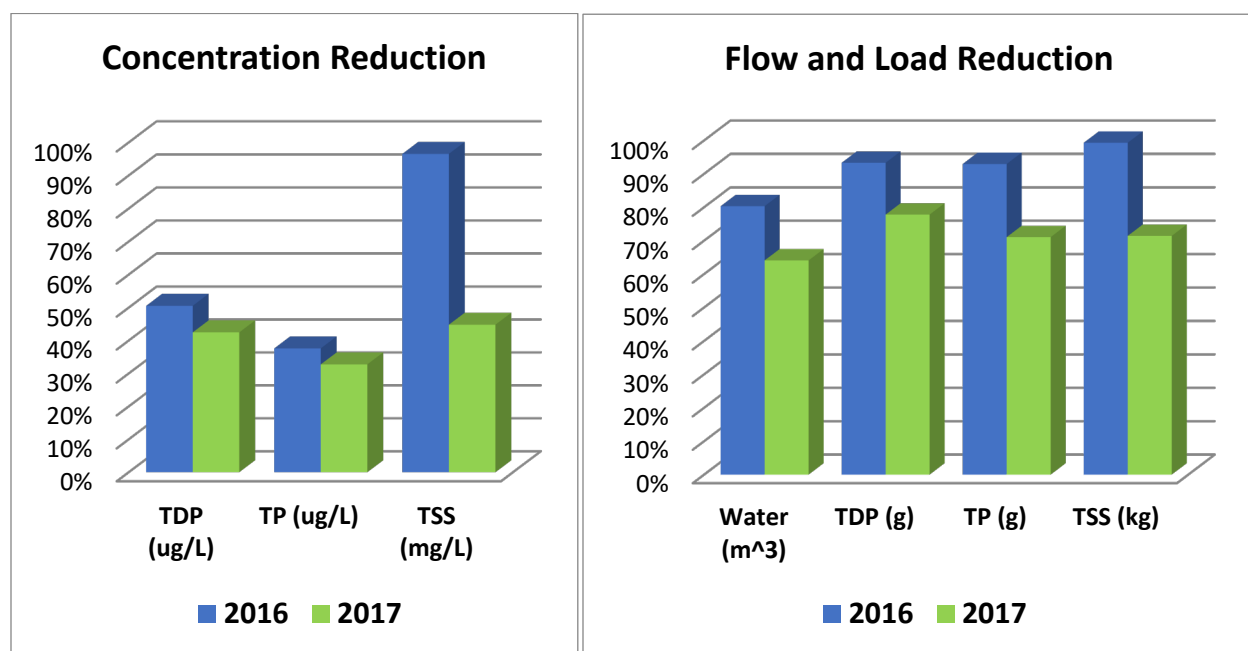


Figure 5.9: Reductions in P concentration and load by water retention ponds at Morden, MB (Vanrobaeys, unpublished)

Nutrient removal mechanisms for P in small dams and reservoirs include (1) sediment-bound nutrients being removed through sedimentation, (2) sorption to suspended or benthic sediments (P), either adsorbed or co-precipitated with Ca or Mg, or binding with Fe or Al oxides, and (3) uptake of dissolved P by aquatic plants and organisms and potential re-release through plant material decay. Systems have variable capacity to retain P (Galuschik 2015). As one of the primary mechanisms through which small dams and reservoirs reduce P is by retaining sediment and

associated P, buildup of P and remobilization is a consideration in these systems (low oxygen, changing pH, variable EPC).

Small dams and reservoirs can provide other benefits, such as wildlife habitat, diversity in the landscape, and the potential to reuse water for irrigation.

Small dams and retention ponds work best on lands that have some natural topographic relief. Upland acres and sloped or rolling topography are better for retention placement than flat, former lakebed areas.

Drainage ditch system improvement and management

Improvements to the drainage ditch system and improved management of these systems are practices that can reduce or restrict flows and keep sediment from running off fields.

Drainage restriction can be accomplished by various means such as ditch blocking, or blocking water at the edge of the field, and culvert resizing, which provide a low-cost alternative to more complex structures. For example, culvert resizing to smaller culverts can be implemented to restrict flow and create temporary storage by keeping water on the field. These practices may provide benefits to P loading by reducing sediment and particulate P leaving the field with runoff water. However, P-rich sediment buildup at the edge of the field can become a source of P in subsequent events. For example, retention of water on the field has the potential for P release under anoxic conditions through reductive dissolution of Fe phosphates in acid soils and dissolution of Ca and Mg phosphates in alkaline soils.

Retention of water in the ditches has challenges with respect to P. There is the potential for nutrient contribution from drainage ditch vegetation. Therefore, vegetation would have to be managed to minimize the potential for vegetation to contribute P.

At a ditch research facility at Lamberton, Minnesota, a treatment ditch effectively controlled flow (66% reduction in 2017 and 60% reduction in 2018); however, results for dissolved (ortho) P load was variable with a 47% increase in 2017 and a 67% reduction in 2018. There are two possible explanations for this variability:

- The release of phosphorus in fall 2017 was due to ditch vegetation behaving as a source of phosphorus where P was released from dead vegetative material following mobilization because of freeze-thaw cycles.
- P buildup in the controlled system ditch bottom sediment and release was due to a P concentration gradient between the sediments and overlying water.

Other practices recommended for nutrient reduction related to ditches included improved grade control (laser ditching) and systematic culvert sizing. While ditches can be used to reduce flows and trap sediment, additional research could provide insight into their effects on P loss reduction with improved vegetative management to reduce dissolved P losses and consideration of management of sediment buildup.

Constructed and restored Wetlands

Wetlands provide water retention on the landscape, and the loss of wetlands has contributed to nutrient mobilization and loss of nutrient sinks. Wetlands function similar to small reservoirs;

however, they are more biologically active in summer. Wetland drainage efficiency affects nutrient export, and nutrient removal efficiency depends on hydraulic residence time. Wetlands can become a source of nutrients if they spill over and become hydrologically connected to other surface waters. With respect to P, P-rich sediment buildup can provide a source of P for remobilization and wetland vegetation can also be a source of P. Wetlands provide numerous other benefits, including providing habitat benefits and diversity in the landscape.

Restored wetlands are typically fewer and larger than original wetlands. In order to drain a field in Manitoba, restored wetlands are typically larger than the original wetlands that were individually scattered throughout the field. Farms are easier to manage in this case. Wetlands can be expensive to reconstruct and, in some cases, can require conversion of agricultural land. However, land suitable for restoration or reconstruction of wetlands is often not considered prime agricultural land.

An evaluation of three wetland types was conducted at the Lamberton site in Minnesota in 2010 and 2011. The three types included (1) surface flow, a design which replicates natural wetlands; (2) vertical flow, where treatment water is removed from the subsurface of the wetland using drainage pipes after it flows vertically down through the filter media; and (3) horizontal flow, a design where water flows horizontally through media (typically gravel and sand) that provides filtration. While DRP concentrations were similar across the three wetland types, TP concentrations decreased from surface flow design > vertical flow design > horizontal flow design. Ortho-P decreased when water was stored in the wetland.

Wetlands, like small dams and retention ponds, work best on land that has some natural topographic relief and are more suited to undulating or rolling topography.

Soil redistribution

Redistributing eroded soil from low-lying receiving areas to upland, farmable areas was included as a potential structural management practice to reduce P loss and loading while improving productivity of areas in which soil is being redistributed. Based on evaluations in Manitoba's pothole region, Dr. David Lobb has concluded that this practice can provide payback within 3½ years based on restored productivity (Lobb 2019). No findings from research or evaluations were provided for quantifying the benefit in potential reduction in P loss and loading.

5.5.2 Integrated Cropping and Livestock Systems

As discussed in Section 4.5.2, catastrophic releases following large storms and intentional releases from manure storage facilities can have devastating impacts on surface water quality and aquatic life. However, these events are rare. Manure storage siting should follow regulations and guidelines including setbacks from natural surface water and groundwater features and wells, and avoidance of surface water conveyances. Storages should be engineered and have 6 to 9 months of storage to reduce the potential for cleanout emergencies, spills, and other unintended releases. Liquid storage systems should be aboveground concrete structures or synthetic or clay-lined earthen structures.

Solid manure should be stored in pits or stockpiled on concrete or clay pads. Runoff should be contained by low sidewalls or gutters. This runoff should be collected, stored, and land-applied or

treated. In some situations, collecting or treating runoff may be more difficult and expensive than covering the stockpile.

Confined livestock feeding and wintering sites can be a major nutrient source. Holding ponds can be used to capture and contain this low volume, high nutrient runoff from these sites.

Considerations for design include choice of site, pond capacity relative to site hydrology, planning for extreme events, and liner durability in cold climates with freeze-thaw cycles. Clean water should be diverted around these sites to manage runoff volume. Treatment could be used to reduce nutrient content of retained water, and water could potentially be used for irrigation with or without treatment depending on water quality and irrigation suitability criteria.

6 BMP STACKING

BMP stacking refers to the ability of BMPs to be combined in the same field or area and is an important consideration to achieve desired results. As previously discussed, some BMPs only benefit N load reduction, some only P load reduction, and some benefit load reduction of both nutrient constituents. In some cases, while a BMP may be beneficial to load reduction of one nutrient constituent, it may actually increase loading of the other constituent. Stacking can be used to package BMPs to enhance outcomes, be it increased load reduction of either N or P, or both. Stacking can also be used to offset limitations or challenges of another BMP, such as applying one BMP to target N or P load reduction and another to avoid increasing loading of the other.

The suitability of stacking and combining BMPs was evaluated by Christianson et al. (2018). The most cost-effective practices (such as in-field nutrient management practices) were generally stackable with a wide range of erosion control or structural practices. Nutrient management practices were not as compatible with certain vegetative practices, including perennial crops or animal grazing systems, but could be combined with other vegetative practices, including cover crops or filter strips. In-field BMPs that are effective during the growing season can often be combined with in-field BMPs that are effective during the non-growing season. An example of this is combining contour farming with cover crops. Another option for stacking BMPs is to combine in-field BMPs with edge-of-field BMPs. An example of this is stacking conservation tillage with bioreactors in fields that are tile drained.

Many vegetative BMPs can be stacked with other vegetative BMPs, and similarly, many structural practices can be stacked with other structural BMPs. For example, cover crops can be stacked with filter strips, and controlled drainage can be stacked with bioreactors.

While cover crops are beneficial in reducing sediment loss and N loss, they can result in higher DP losses following freeze-thaw cycles. However, if coupled with vegetation removal or low P cover crop types, DP losses may be reduced or offset.

A summary of stacking for selected BMPs is found in Table 6.1, including an indication of the direction of impact in nutrient load reduction for N and P, general comments on applicability, and challenges and limitations.

Table 6.1: Stacking of BMPs in the Red River Basin

BMP	Reduction in Nutrient Load		Stacking and Integration
	N	P	
Nutrient Management Practices			
Nutrient Management	Y	Y	Can be stacked/integrated with all other BMPs
Soil/Manure Testing to Determine Application Rates	Y	Y	Can be stacked/integrated with all other BMPs
Spring Nutrient Application (instead of fall)	Y	Y	Can be stacked/integrated with all other BMPs
Variable Rate Application	?	?	Can be stacked with most other BMPs
Inhibitors/Slow Release Fertilizers	Y	?	
Incorporation/Injection/Banding	Y	Y	Can be stacked/integrated with all other BMPs
Manure Application on Non-frozen Ground	Y	Y	Can be stacked/integrated with other manure BMPs
Erosion Control Practices			
Contour Farming	?	Y	Can be integrated with conservation tillage systems
Conservation Tillage	Y	?	Can be integrated with many nutrient management BMPs
Windbreak/Shelterbelt/Living Snow Fence	?	?	
Riparian Grazing Management (manage grazing timing and stocking rates in riparian areas)	Y	Y	Can be stacked/integrated with other livestock BMPs
Streambank and Shoreline Protection	?	Y	Can be stacked with vegetation removal where feasible
Feedlot Siting/Relocation	Y	Y	Can be stacked with wastewater & feedlot runoff control
Vegetative Management Practices			
Conservation Crop Rotation	Y	?	Can be stacked with crop and livestock BMPs
Cover Crop	Y	?	Can be stacked with crop and livestock BMPs
Filter Strip (grass)	?	?	
Grass Waterway	?	?	
Pasture/Hayland Planting (conversion to perennial cover)	Y	?	Can be integrated with annual cropping
Feedlot/Wastewater Filter Strip	?	?	Should be stacked with feedlot runoff control
Vegetation Removal (buffer, ditches, cover crop)	?	?	Stacked with cover crop, filter strips, grass waterway
Strategic Tillage/Crop Residue Incorporation (chop, spread, harrow, rotational till)	?	?	Can be stacked with conservation tillage
Extended/Winter Grazing (in-field feeding management)	N	N	Should be stacked with edge-of-field nutrient capture practices and planned grazing management systems
Structural Management Practices			
Drainage Water Management (Controlled drainage)	?	?	Can be stacked with water treatment (bioreactor), saturated buffer, constructed wetlands, ponds and reservoirs, drainage water recycling, and nutrient BMPs
Drainage Water Recycling	Y	Y	Requires integration with drainage water management, and ponds and reservoirs
Bioreactor	?	?	Can be stacked with drainage water management
Culvert Resizing	Y	Y	
Two-Stage Ditch	?	?	Can be stacked and integrated with constructed wetlands and vegetation removal
Wetland Restoration	Y	Y	May be stacked with drainage water recycling (may require regulatory approval) and vegetation removal
Water and Sediment Control Basin	Y	Y	May be stacked with drainage water recycling, vegetation removal, upland vegetative BMPs
Small Dams, Ponds, Reservoirs	Y	Y	May be stacked with drainage water recycling (may require regulatory approval) and vegetation removal
Wastewater & Feedlot Runoff Control	Y	Y	Should be integrated with feedlots and in-field feeding management
Nutrient-Rich Sediment Removal (water retention areas)	?	?	Could be stacked with two-stage ditch, water and sediment control basin, small dams, ponds, reservoirs to address sediment buildup in these features

7 RESEARCH GAPS

Given the magnitude of reductions in N and P loadings needed to the Red River and Lake Winnipeg, research is vital to improve our understanding of N and P loading sources and pathways, identify critical source areas and priority watersheds, improve the effectiveness of existing BMPs, and develop innovative BMPs more effective at reducing N and P losses, particularly during snowmelt runoff events. Some of the most pressing research needs related to an improved understanding of N and P loading sources and pathways include the study of the magnitude of N and P transport to surface waters by wind erosion, documenting the role that legacy P and total, dissolved and particulate P transport to Lake Winnipeg plays in eutrophication, and identifying the impact on N loadings to the Red River from expanded adoption of subsurface tile drainage coupled with climate change. Research/demonstration farms should be established in the highest priority areas representing diverse combinations of climate, soil, and landscape where suites of BMPs can be researched, tested, and evaluated for their effectiveness at reducing N and P losses. Research is needed to improve the effectiveness of existing BMPs through development of stacked synergistic practices that combine protection during the growing and non-growing season through integration of in-field and edge-of-field practices as well as other approaches described in Table 6.1. Finally, research is needed to develop innovative new BMPs that have greater effectiveness. Examples of this include more effective bioreactors that can remove both N and P, cover crops that have limited P uptake but are effective at controlling soil erosion, or tillage practices that increase random roughness of soil and reduce crop residue cover to control wind and water erosion while reducing soluble P losses during snowmelt runoff. In addition, research should focus on developing integrated systems that protect the soil, reduce erosion, and minimize nutrient export from croplands in cold climates. The agriculture community will need clear direction on integrated systems that work for both erosion and nutrient control.

Research gaps were identified at the Workshop by presenters and during discussion groups. Identified research gaps are summarized in Table 7.1 according to the BMP category and by nutrient constituent (N only, P only, or both N and P).

Table 7.1: Research Gaps to Understanding of Nitrogen and Phosphorus Load Reduction in the Red River Basin

Nutrient Constituent	Research Gaps
Nutrient Management Practices	
N & P	<p>Cropping Systems</p> <ul style="list-style-type: none">• Specific frozen soil BMP effectiveness studies• Identification of noncontributing areas (e.g., LiDAR usage) and siting/placement/targeting of BMPs as appropriate <p>Integrated Cropping and Livestock Systems</p> <ul style="list-style-type: none">• Impacts of grazing density on nutrient loss/load• Accounting for valuing contribution and uneven distribution
N only	<p>Cropping Systems</p> <ul style="list-style-type: none">• Evaluation of N losses in colder regions lacking tile drainage during snowmelt in relation to freeze/thaw cycles and frozen soils. Interactions between N losses during these conditions and management practices that include different rates and placements of fertilizer and manure• N availability in manure. A study of Minnesota soybean growers shows N rate is overestimated in manure crediting• Elevated residual N indicates over-fertilization. What is the exact threshold?• Research on Y-drop and dribble sidedress• Putting on too late• Waseca 25-year study—put on splits later• Amount of inter-seeding• Slow release nitrogen• Integration of manure & strip• Are deeper N soil tests (like sugar beets) effective from both crop production and water quality standpoints?• Cover crop role function -> soil stabilizer -> N/P release during freeze/thaw• Residual soil nitrogen target research, also residual N in corn stubble• Effect of N loading due to increasing tile <p>Integrated Cropping and Livestock Systems</p> <ul style="list-style-type: none">• Depends what kind of system— manure, beef, dairy, swine• Cover crops & manure• Composting• Nitrate leaching under grazed pasture/cover crops, especially sandy soils
P only	<p>Cropping Systems</p> <ul style="list-style-type: none">• Soil test P recommendation for new varieties• Develop soil test P recommendations based on 0–5 cm soil sample for stratified soils (conservation till, perennial)• Importance of 0 to 5 cm vs. 0 to 15 cm P for “pop-up” effect• Stratification—can crops use near surface P, response to deeper and less frequent application of P• Estimated crop P removal/rates are high; more accurate numbers needed for nutrient reduction strategies• How much P is enough and in what form after a long history of input?• Better understanding of factors leading to 80% of P in spring flood• Alternative P forms (e.g., coated product, struvite) <p>Integrated Cropping and Livestock Systems</p> <ul style="list-style-type: none">• Influence of buffer species selection on P releases• Buffer management-grazing, haying effects on P
Erosion Control Practices	
N & P	<p>Cropping Systems</p> <ul style="list-style-type: none">• More comprehensive assessment of combined effects of wind, water, and tillage erosion on flat Red River plain• Interactions between sediment and P in runoff and in streamflow are needed.• BMPs such as tillage practices that reduce soil loss but reduce the amount of crop residue are needed• Cropping practices that require less tillage and provide more crop residue cover and longer cover to reduce wind and water erosion and reduce runoff• How crops affect runoff and nutrient concentration in the path of runoff• No-till management may limit frost due to snow cover and may have lower runoff• Confirming value and optimizing design of windbreaks• No-till single seed coated with fertilizer row-crop planter

Nutrient Constituent	Research Gaps
	<ul style="list-style-type: none"> No-till planting into short, legume with corn, soybean, wheat, etc. Cover crop research into high soil disturbance crops (e.g., sugar beets) Integrated soil erosion assessments and modelling Research on social adaptation/change with different BMPs How to increase organic matter and residue management on specialty crops Integrating no-till into dry bean production systems Development of dry bean varieties that can be strip cut Potato rotation research (to increase residues/improve residue management) More research on strip tillage—incorporation of strip tillage into beets, all crops; region and soil-landscape suitability; influence of climate change More comprehensive assessments of the combined effects of wind, water, and tillage erosion, particularly on the Red River Plain Nutrient loads from no-till vs conventional tillage— ↑P concentration in no-till but less runoff. Water yield? Surface protection/cover impacts on infiltration and interaction with freeze/thaw Soil organic matter and increased “tradeoffs” soil water holding capacity + vegetative release or manure Water yield in changing climate The impact of wind erosion on water quality in rivers is unknown <p>Integrated Cropping and Livestock Systems</p> <ul style="list-style-type: none"> Influences of stock density on erosion and runoff Influences of buffer management (i.e., grazing, haying) on erosion and runoff
Vegetative Management Practices	
N & P	<ul style="list-style-type: none"> Cropping systems Understanding the potential of crops to affect runoff and affect nutrient concentrations in the path of runoff, and the net impact on nutrient loads Understanding of the interactions between sediments and phosphorus in runoff and in streamflow; dynamics of PP-DP Cover crop and buffer species selection for soluble nutrient reduction Comprehensive net benefit analysis of vegetation in water use (↓ runoff vs. nutrient loss FTCs) Soil interception of P released from vegetation Utilizing ash as a soil amendment. What is the nutrient content and agronomical benefit and chemical characteristics? Soluble P from plants may impact lake/stream/river quality, but is the P in sediment more dangerous downstream due to legacy impacts? Do we need to reduce sediment with residue and increase organic P? Integrated cropping and livestock systems Impacts of grazing and grazing management on nutrient loading Understanding these interactions is confounded by a lack of research in P loss from cover crops and crop residues in cold climates.
N only	<p>Cropping Systems</p> <ul style="list-style-type: none"> Varied root cover crop preferential flow ID contributing areas and prioritization N movement in sandy soils related to water table, rotation, and application When cover crop N becomes available Right cover crop for the right soil Cost/benefit for each practice <p>Integrated Cropping and Livestock Systems</p> <ul style="list-style-type: none"> Nitrate leaching under grazing Grazing management and stock density/time
P only	<p>Cropping Systems</p> <ul style="list-style-type: none"> Understanding the potential of crop residue management to increase interception of plant P by the soil and decrease available P at soil surface. A study is needed to evaluate all of the aspects of impacts of cover crops simultaneously Cover crop establishment in cold climates and cover crop impacts on measured P loss in runoff (not WEP). Which P forms are more/less detrimental to water quality (particulate or dissolved)? P mobility in soluble form Do buffer strips ↑ soluble P (species selection) Determine site-specific conditions/situations for buffer strips Do grassed waterways ↑ soluble P (species selection) Do grassed waterways work in hilly areas with ↑ slope? P release from native prairie (cold climate/freeze-thaw cycle effects)

Nutrient Constituent	Research Gaps
	<ul style="list-style-type: none">• Impacts of different cover crop species on P loads into surface water (and soil health benefit)• Cover crop species selection influence on P releases (low P cover crops)• Net gains DP vs. PP in no-till/ cover crop systems• Plant-soil water interaction• Partitioning source between vegetation, soils• P budgets removal vs. losses• Residue management practices—grazing, haying, tillage• Optimizing ditch vegetation harvest (timing and frequency [one or two harvests])• What effect does healthy soil have on P cycle?• New filter strip designs (i.e., convert concentrated flow to diffuse)• Potential of crop residue management (chopping, spreading, tillage) to increase the interception of plant P by the soil—decrease available P at the soil surface during runoff events• What level of soil mineral sediment is needed in surface water to optimally reduce soluble P? <p>Integrated Cropping and Livestock Systems</p> <ul style="list-style-type: none">• Potential of crop residue management (grazing, haying) to increase the interception of plant P by the soil—decrease available P at the soil surface during runoff events
Structural Management Practices	
N & P	<p>Cropping Systems</p> <ul style="list-style-type: none">• We need a verdict on tile drainage – this is a big debate. Does it reduce N and soluble P or not?• Water yield in drained landscapes— water balance• Drainage water recycling• Nutrient removal efficiency in impoundment design—tradeoff
N only	<p>Cropping Systems</p> <ul style="list-style-type: none">• Bioreactors—useful life/longevity, maintenance requirements (media change), scale limitation (scale to standard field size?), cold climate limitation (temperature, snowmelt, heating requirements)• Can controlled drainage work on the flatter central part of the RRB?• Effectiveness and suitability of saturated buffers• Management is maximizing denitrification in wetlands and reservoirs• Can we use beavers to build dams near roads to reduce runoff?• What is the right N level? It is not zero—is there a beneficial level we need to maintain?
P only	<p>Cropping Systems</p> <ul style="list-style-type: none">• Mobilization of P under reducing conditions in sediment collecting BMPs (retention ponds, wetlands, marshes [e.g., Netley Marsh])• Does controlled drainage result in enhanced P loss, including P mobilization from reducing conditions?• Conditions/soil-landscapes where tile drains will exacerbate P problems and where they will reduce P losses/loading• P dynamics in relation to other chemicals, pH change• How to design and manage? Where are the hotspots?• Can we treat or filter tile water to reduce soluble P (e.g., tile infiltration)?

8 SUMMARY AND RECOMMENDED NEXT STEPS

8.1 SUMMARY

The Red River Basin/Cold Climate Agricultural Nutrients BMP Workshop (the Workshop) was an important step in moving towards achieving additional reductions in nutrient loading into the Red River from agricultural activities across the Red River Basin. The workshop was attended by a broad cross section of university researchers and extension staff, state/provincial and federal government researchers and water resource managers, and industry professionals involved with BMPs in agricultural landscapes. The purpose of the workshop was to review and explore the available research on nutrient reduction BMP effectiveness in cold climates to develop consensus recommendations on BMP effectiveness.

The workshop discussions and presentations were organized according to the following BMP categories:

1. Nutrient management BMPs for nitrogen and phosphorus load reduction
2. Vegetative practices BMPs for nitrogen and phosphorus load reduction
3. Erosion and runoff control BMPs for nitrogen and phosphorus load reduction
4. Structural management BMPs for nitrogen and phosphorus load reduction

There are numerous and considerable challenges in determining the effectiveness and suitability of BMPs for nutrient load reduction in the RRB. Some of the key challenges include the following:

- Lack of research, knowledge, and understanding of processes resulting in nutrient loading in the cold climate environment of the RRB
- Numerous sources of variability operating over different scales, including existing environmental factors, changing temperature, precipitation, frequency and intensity of storm events, jurisdictional regulation, policy and market conditions, agricultural management systems, economics, and access to equipment and technology
- Scale applicability of BMPs – some BMPs are generally applicable at the regional scale while some are suitable and effective at the local scale or field level or even specific areas within a field
- Trade-offs – many BMPs are beneficial for reducing N loading or P loading but not necessarily both. In some cases, BMPs that effectively reduce loading of one constituent may increase the loading of another. The impact BMPs have on other aspects of the environment also need consideration, including soil health, natural habitat, flood reduction, and greenhouse gas emissions

This variability necessitates numerous small measures employed throughout the RRB, as determined to be appropriate, to achieve the objective of nutrient load reduction into the Red River. In other words, success will be achieved by using silver buckshot, as there is no one silver bullet to reducing nutrient loss resulting from agricultural activities across the RRB. Despite the challenges, progress can be achieved through building on existing knowledge (short-term action on known knowns) and addressing key gaps in knowledge (known unknowns). Adaptive management will be important to employ in the planning and implementation framework in order

to respond and adapt to changes in conditions in the future (known unknowns and unknown unknowns), including changing climate and weather; state, provincial and federal policies; economics; and the evolution of the agricultural management system.

This report synthesizes information presented and discussed at the Workshop and information presented in advance of the Workshop, including pre-Workshop webinars and map outputs on various pertinent factors across the RRB. The culmination of this synthesis is presented in the summary tables for nitrogen (Table 8.1) and phosphorus (Table 8.2). For each BMP considered, these summary tables indicate the following:

- Level of consensus or agreement reached by the Workshop participants
- Effectiveness of the practice in nutrient load reduction
- Limitations and research gaps

Additional synthesis of information from the Workshop includes a summary of the potential for stacking of BMPs in Table 6.1 and a more detailed summary of research gaps for BMPs in Table 7.1.

Further, a draft framework to address the regional effectiveness of BMPs is presented in Appendix C. This includes a discussion of the following:

- BMP suitability zones across the Basin (Appendix C.1), delineated based on climate, soil, and landscape factors
- Regional targeting of BMPs (Appendix C.1) culminating in tabular summaries identifying the effectiveness of individual BMPs within each BMP suitability zone for nitrogen (Table C.2) and phosphorus (Table C.3).

The information presented and discussed at the Workshop and disseminated in this report provides a foundation for next steps in achieving nutrient load reductions in the Red River caused by agricultural activities in the RRB.

Table 8.1 Summary Table for BMPs for Nitrogen Load Reduction

Category	Practice	CRP #	Beneficial Management Practice (BMP)	Workshop Consensus (level of agreement) ¹	Effectiveness for N Reduction ²	Limitations and Research Gaps
Nutrient Management Practices	590		Nutrient Management	Strong	High	N rate cannot be reduced below agronomic crop requirements without reducing crop yield. Science-based thresholds for residual soil N should be established
			Soil/Manure Testing to Determine Application Rates	Strong	High	
			Spring Nutrient Application (instead of fall)	Strong	High	Addressing limitations in some cropping systems and in some areas or years with a small spring operation window
			Variable Rate Application	Weak	Uncertain	Need research to show it reduces edge-of-field losses
			Inhibitors/Slow Release Fertilizers/Split Application	Weak	High	Lack of research linking to edge-of-field losses of N
			Incorporation/Injection/Banding	Strong	High	Limited applicability in no-till systems
			Manure Application on Non-frozen Ground	Strong	High	Jurisdictional regulations may be required to change practice in US; may require costly storage upgrades
Erosion Control Practices	330		Contour Farming	Strong	Uncertain	May be effective if particulate NH ₄ ⁺ is the dominant form. More suited to steeper landscapes.
	329		Conservation Tillage	Strong	High	Currently a limited practice in fine and very fine textured soils in flat, poorly drained landscapes
	380	CP5A CP16B CP17A	Windbreak/Shelterbelt/Living Snow Fence	Weak	Uncertain	
	472/382		Riparian Grazing Management (manage grazing timing and stocking rates in riparian areas)	Strong	High	Effective in eroded or unstable sites
	580		Streambank and Shoreline Protection	Strong	Uncertain	Impact on N losses uncertain
			Feedlot Siting/Relocation	Strong	High	
Vegetative Management Practices	328		Conservation Crop Rotation	Weak	High	
	340		Cover Crop	Strong	High	Establishment of cover crop is a challenge if planted after harvest in October or November. Seeding cover crops into an established crop needs more research.
	393	CP21	Filter Strip (grass)	Weak	Uncertain	May be effective if particulate NH ₄ ⁺ is the dominant form. Impact of vegetation harvesting, and potential trade-offs needs investigation.
	412		Grass Waterway	Weak	Uncertain	Impact on N losses uncertain
	512		Pasture/Hayland Planting (conversion to perennial cover)	Weak	High	Effectiveness at reducing N loadings not well studied

Category	Practice	CRP #	Beneficial Management Practice (BMP)	Workshop Consensus (level of agreement) ¹	Effectiveness for N Reduction ²	Limitations and Research Gaps
	635		Feedlot/Wastewater Filter Strip	Weak	Uncertain	
			Vegetation Removal (buffer areas, ditches, cover crop)	Weak	Uncertain	
			Strategic Tillage/Crop Residue Incorporation (chop, spread, harrow, rotational till)	Weak	Uncertain	Relative impacts of random roughness vs. residue cover on erosion control should be studied
			Extended/Winter Grazing (in-field feeding management)	Strong	Not effective	Practice will increase N losses in spring. May be comparable to an untreated confined operation. Needs to be combined with edge-of-field treatment to reduce the volume of runoff (e.g., water retention ponds).
Structural Management Practices	554		Drainage Water Management (controlled drainage)	Strong	Uncertain	Effectiveness for nutrient retention should be compared in spring vs. summer months (i.e., limited potential to capture and retain snowmelt water)
			Drainage Water Recycling	Strong	High	Site limitations (favorable soil-landscape conditions); other water quality concerns (e.g., salts); requires means of irrigation or sub-irrigation
			Bioreactor	Strong	Uncertain	Research is needed to develop bioreactors that can simultaneously remove N and P, especially during spring when temperatures are cold and retention time is small
		80	Culvert Resizing	Strong	High	Impacts on taking land out of production; siting is critical. Tools to identify optimal locations should be evaluated in RRB
		115	Two-Stage Ditch	Weak	Uncertain	Effectiveness at removing N uncertain
	657	CP27	Wetland Restoration (depression/ponded)	Strong	High	Siting tools and cost-benefit needs more investigation in RRB
		CP28				
		CP23	Wetland Restoration (riparian/floodplain)	Strong	High	Siting tools and cost-benefit needs more investigation in RRB
	638		Water and Sediment Control Basin	Strong	High	Lack of permanent storage may limit efficacy
			Small Dams/Ponds/Reservoirs	Strong	High	Siting tools and cost-benefit needs more investigation in RRB; sedimentation can limit effectiveness and lifespan.
	784		Wastewater and Feedlot Runoff Control	Strong	High	May be limited to applicability in Red River valley (lake plain) where cattle feedlots and cow-calf operations are not common
			Nutrient-Rich Sediment Removal (water retention areas)	Weak	Uncertain	Scientific basis is sound; cost-benefit studies required; requires vegetation re-establishment
Notes: 1. Workshop consensus - level of agreement achieved by workshop participants on the effectiveness of BMPs to reduce or limit N loading to the Red River (i.e., if practice is already implemented in portions or all of RRB it may not lead to further reduction but it's important to note it is effective and should continue to be practiced to maintain the reduction or adopted more widely to increase reduction). Categories include: Strong - broad agreement across workshop participants; Weak - lack of agreement across workshop participants (more discussion and/or research may be required) 2. Effectiveness - degree of effectiveness of BMP in reducing or limiting N loading to the Red River. Categories include: High - the implementation of the BMP will be highly effective in reducing N loading; Not effective - the implementation of the standalone BMP has not been shown to reduce N loading; Uncertain - more research is needed to determine BMP effectiveness.						

1 Table 8.2 Summary Table for BMPs for Phosphorus Load Reduction

Category	Practice	CRP #	Beneficial Management Practice (BMP)	Workshop consensus (level of agreement) ¹	Effectiveness For P Reduction ²	Limitations and Research Gaps
Nutrient Management Practices	590		Nutrient Management	Strong	High	Specifics on implementation (e.g., sufficiency application, maintain low levels of soil P and apply to crop requirements) and relationship to reduced losses at edge of field
			Soil/Manure Testing to Determine Application Rates	Strong	High	Soil testing 0-5 cm vs. standard 0-15 cm warrants additional research due to near-surface P stratification
			Spring Nutrient Application (instead of fall)	Strong	High	Addressing limitations in some cropping systems and in some areas or years with a small spring operation window
			Variable Rate Application	Weak	Uncertain	Need research to show it reduces edge-of-field losses; requires specialized equipment
			Inhibitors/Slow Release Fertilizers/Split Application	Not discussed	Uncertain	
			Incorporation/Injection/Banding	Strong	High	
			Manure Application on Non-frozen Ground	Strong	High	Jurisdictional regulations may be required to change practice in US; may require costly storage upgrades
Erosion Control Practices	330		Contour Farming	Strong	Uncertain	May be effective if particulate P is the dominant form; may reduce the efficiency of tillage operations; may be supported by technology (GPS, autosteer). More suited to steeper landscapes.
	329		Conservation Tillage	Weak	Uncertain	May be effective if particulate P is the dominant form; currently a limited practice in fine and very fine textured soils in flat landscapes
	380	CP5A CP16B CP17A	Windbreak/Shelterbelt/Living Snow Fence	Weak	Uncertain	Reduces wind erosion losses of soil bound P
	472/382		Riparian Grazing Management (manage grazing timing and stocking rates in riparian areas)	Strong	High	Ungrazed vegetation can be a source of soluble P in snowmelt runoff
	580		Streambank and Shoreline Protection	Strong	High	May be effective in eroded or unstable sites
			Feedlot Siting/Relocation	Strong	High	
Vegetative Management Practices	328		Conservation Crop Rotation	Weak	Uncertain	May be effective if particulate P is the dominant form. Limited efficacy during snowmelt. May act as a source instead of sink outside the growing season (when vegetation is senescing or dormant).
	340		Cover Crop	Weak	Uncertain	May be effective if particulate P is the dominant form. Limited efficiency during snowmelt. May act as a source instead of sink outside the growing season (when vegetation is senescing or dormant). Species of cover crop (P content) should be studied.
	393	CP21	Filter Strip (grass)	Weak	Uncertain	May be effective if particulate P is the dominant form. Limited efficiency during snowmelt. May act as a source instead of sink outside the growing season (when vegetation is senescing or dormant). Impact of vegetation harvesting, and potential trade-offs needs investigation.
	412		Grass Waterway	Weak	Uncertain	May be effective if particulate P is the dominant form. Limited efficiency during snowmelt. May act as a source instead of sink outside the growing season (when vegetation is senescing or dormant).
	512		Pasture/Hayland Planting (conversion to perennial cover)	Weak	Uncertain	May be effective if particulate P is the dominant form. Limited efficiency during snowmelt. May act as a source instead of sink outside the growing season (when vegetation is senescing or dormant). Livestock may increase risks of erosion or nutrient losses.
	635		Feedlot/Wastewater Filter Strip	Weak	Uncertain	May be effective if particulate P is the dominant form. Limited efficiency during snowmelt. May act as a source instead of sink outside the growing season (when vegetation is senescing or dormant).

Category	Practice	CRP #	Beneficial Management Practice (BMP)	Workshop consensus (level of agreement) ¹	Effectiveness For P Reduction ²	Limitations and Research Gaps
			Vegetation removal (buffer areas, ditches, cover crop)	Strong	High	More research is required to determine appropriate approaches; equipment limitations for harvesting in challenging landscape areas
			Strategic Tillage/Crop Residue Incorporation (chop, spread, harrow, rotational till)	Weak	Uncertain	May mitigate stratification and P buildup near the surface. Trade-offs with erosion and particulate P needs investigation.
			Extended/Winter Grazing (in-field feeding management)	Strong	Not effective	Practice will increase P losses in spring. May be comparable to an untreated confined operation. Needs to be combined with edge-of-field treatment to reduce the volume of runoff (e.g., water retention ponds).
Structural Management Practices	554		Drainage Water Management (controlled drainage)	Strong	Low	Likely only effective for nutrient reduction in summer during high ET periods and typically minimal surface runoff
			Drainage Water Recycling	Strong	High	Site limitations (favourable soil-landscape conditions); other water quality concerns (e.g., salts); requires means of irrigation or sub-irrigation
			Bioreactor	Weak	Uncertain	Requires concentrated drainage flow (e.g., tile discharge); currently small-scale application only; incorporation of P-absorbing material is required and more research is required into the feasibility and cost-effectiveness of this technology.
		80	Culvert Resizing	Strong	High	Impacts on taking land out of production during wet periods, siting is critical. Tools to identify optimal locations should be evaluated in RRB.
		115	Two-Stage Ditch	Weak	Uncertain	May be effective if particulate P is the dominant form. Limited efficiency during snowmelt. May act as a source instead of sink outside the growing season (when vegetation is senescing or dormant).
	657	CP27 CP28	Wetland Restoration (depression/ponded)	Strong	High	Siting tools and cost-benefit needs more investigation in RRB; may require complex design.
	657	CP23	Wetland Restoration (riparian/floodplain)	Strong	High	Siting tools and cost-benefit needs more investigation in RRB; buildup of P-rich sediment may be a concern; may require complex design.
	638		Water and Sediment Control Basin	Strong	High	May be effective if particulate P is the dominant form. Lack of permanent storage may limit efficacy.
			Small Dams/Ponds/Reservoirs	Strong	High	Siting tools and cost-benefit needs more investigation in RRB; sedimentation can limit effectiveness and lifespan.
	784		Wastewater and Feedlot Runoff Control	Strong	High	May be limited applicability in Red River valley (lake plain) where cattle feedlots and cow-calf operations are not common
			Nutrient-Rich Sediment Removal (water retention areas)	Weak	Uncertain	Scientific basis is sound; cost-benefit studies required; requires vegetation re-establishment.
Notes: 1. Workshop consensus: level of agreement achieved by workshop participants on the effectiveness of BMPs to reduce or limit P loading to the Red River (i.e., if practice is already implemented in portions or all of RRB it may not lead to further reduction but it is important to note it is effective and should continue to be practiced to maintain the reduction or adopted more widely to increase reduction). Categories include (1) Strong—broad agreement across workshop participants, and (2) Weak—lack of agreement across workshop participants (more discussion and/or research may be required) 2. Effectiveness: degree of effectiveness of BMP in reducing or limiting P loading to the Red River. Categories include (1) High—the implementation of the BMP will be highly effective in reducing P loading, (2) Not Effective—the implementation of the standalone BMP has not been shown to reduce P loading, and (3) Uncertain— more research is needed to determine BMP effectiveness.						

8.2 RECOMMENDED NEXT STEPS

To build on the work that has been accomplished and documented in this report, next steps are required to continue to move forward in achieving nutrient load reduction to the Red River resulting from agricultural activities in the RRB. Prior to implementing BMPs, Committee and Workshop participants should consider taking the following steps:

1. Confirm BMP effectiveness rankings provided in this report and prioritize through broad consensus BMPs for implementation planning discussions.
2. Establish research priorities to address key knowledge gaps.
3. Discuss policy and regulation for jurisdictions across the RRB, and identify policy and regulatory priorities for governing agencies to consider to aid in achieving objectives.
4. Evaluate the cost of implementation.
5. Develop strategies to move towards implementation.

To implement BMPs, it is recommended that the Committee organize and coordinate another workshop to address the issue of BMP implementation. This should involve the research and extension community; however, the agricultural community across the RRB needs to be a primary player. The workshop should focus on those BMPs for which there is broad consensus amongst the research and extension community and those that will be most effective at reducing nitrogen and phosphorus loading into the Red River.

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APPENDICES

APPENDIX A – WORKSHOP AGENDA



**Red River Basin/Cold Climate Agricultural Nutrients BMP Workshop
April 16-17, 2019
University of Minnesota-Crookston
Crookston, MN**

Tuesday, April 16, 2019

8:00 – 8:15 Welcome and Introductions – Mike Ell, North Dakota Department of Health and Rebecca Power, University of Wisconsin-Madison Division of Extension

8:15 – 8:30 Workshop Objectives and Purpose

Setting the Stage in the Red River Basin

8:30 – 8:40 Review setting the stage webinar presentations

Webinar 1 – Basin Geology • Basin Soils and Soil Nutrients

<https://youtu.be/Rk-sIRZzPRM>

Webinar 2 – Basin Hydrology • Basin and Field Scale Nutrient Trends

<https://youtu.be/67bhrafNh5g>

8:40 – 9:00 Cropping and Livestock Management Systems in the Basin – Mitchell Timmerman, Manitoba Agriculture, and Dave Franzen, North Dakota State University

9:00 – 9:20 Other Natural Resource Concerns in the Basin – Brian Wiebe, Manitoba Sustainable Development, and Keith Weston, Red River Retention Authority

9:20 – 9:30 Questions and Discussion

9:30 – 9:45 Introduce Working Session Format – Rebecca Power, University of Wisconsin Division of Extension

9:45 – 10:00 Break

Nutrient Management BMPs

10:00 – 11:00 Nutrient Management BMPs for Cropping Systems – Jay Goos, North Dakota State University, and Lindsay Pease, University of Minnesota

11:00 – 12:00 Nutrient Management BMPs for N and P for Integrated Livestock Systems - Chryseis Modderman, University of Minnesota Extension, and Henry Wilson, Agriculture and Agri-Food Canada

12:00 – 12:45 Lunch

Nutrient Transport Reduction BMPs

12:45 – 1:45 Field Erosion Pathways and BMPs for N and P Reduction – Dave Franzen, North Dakota State University, and David Lobb, University of Manitoba

1:45 – 2:45 Field Runoff Pathways and BMPs for N and P Reduction – Jeppe Kjaersgaard, Minnesota Department of Agriculture, and Henry Wilson, Agriculture and Agri-Food Canada

2:45 – 3:00 Break

3:00 – 4:15 Breakout Sessions with Facilitated Discussion

4:15 – 5:15 Report Out

Wednesday, April 17, 2019

8:00 – 8:15 Recap of Day 1 and Introduce Day 2 (start at 8:00)

Vegetative BMPs

8:15 – 9:00 Vegetative BMPs and Nitrogen Reduction – Jay Furrer, NRCS

9:00 – 9:45 Vegetative BMPs and Phosphorus Reduction – David Lobb, University of Manitoba, and Jian Liu, University of Saskatchewan

9:45 – 10:00 Questions and Discussion

10:00 – 10:15 Break

Structural BMPs

10:15 – 10:35 Partitioning field runoff and nutrient transport between surface and sub-surface pathways with tile drainage - Merrin Macrae, University of Waterloo

10:35 - 10:55 Nutrient reduction BMPs to treat tile drainage discharge – Gary Feyereisen, USDA-ARS

10:55 – 11:15 Drainage water management and subsurface irrigation to reduce nutrient runoff – Xinhua Jia, North Dakota State University

11:15 – 11:35 Water retention structures and nutrient removal efficiency – Jane Elliott, Environment and Climate Change Canada

11:45 – 12:30 Lunch

Integrating BMPs and Addressing Multiple Natural Resource Concerns

12:30 – 1:00 Integrating/Stacking BMPs in a Systems Approach to Maximize Nutrient Reduction – Roger Wolf, Iowa Soybean Association

1:00 – 1:30 Integrating BMPs for Multiple Natural Resource Benefits – Hank Venema, Strategic Community Consultants

1:30 – 2:45 Breakout Sessions with Facilitated Discussion

2:45 – 3:00 Break

3:00 – 4:00 Report Out

4:00 – 4:15 Wrap Up and Next Steps

COOPERATING AGENCIES AND ORGANIZATIONS

Agriculture and Agri-Food Canada • Environment and Climate Change Canada • USDA Natural Resources Conservation Service • North Dakota State University • North Dakota State University Extension • University of Manitoba • South Dakota State University Extension • International Plant Nutrition Institute • Manitoba Agriculture • Manitoba Sustainable Development • Minnesota Board of Soil and Water Resources • Minnesota Department of Agriculture • University of Wisconsin Division of Extension • North Central Region Water Network • North Dakota Association of Soil Conservation Districts • North Dakota Department of Agriculture • North Dakota Soybean Council • Barr Engineering • Pembina Valley Conservation District • Red River Basin Commission

THANK YOU TO OUR WORKSHOP SPONSORS



**Red River
Joint Water
Resource
District**



Northwest Regional Sustainable
Development Partnership

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APPENDIX B – LIST OF ATTENDEES

The following is a list of workshop attendees and their affiliation, ordered by affiliation.

Name	Affiliation
Henry Wilson	Agriculture and Agri-Food Canada
Jason Vanrobaeys	Agriculture and Agri-Food Canada
Steve Sager	Agriculture and Agri-Food Canada
David Whetter	AgriEarth Consulting Ltd.
John Breker	AGVISE Laboratories
Todd Cymbaluk	American Crystal Sugar
Dale W. Finnesgaard	Barr Engineering Co./North Dakota Soybean Council
Jamie Beyer	Bois de Sioux Watershed District
Colin Gluting	Cooks Creek Conservation District
Armand Belanger	East Interlake Conservation District
Arthur Friesen	Environment and Climate Change Canada
Jane Elliott	Environment and Climate Change Canada
Ute Holweger	Environment and Climate Change Canada
Justin Parks	Grand Forks County Soil Conservation District
Steven Commerford	Independent Crop Consultant
Charles Fritz	International Water Institute
Grit May	International Water Institute
Roger Wolf	Iowa Soybean Association
Heather Donoho	Kittson County Soil and Water Conservation District
Jeremy Benson	Kittson County Soil and Water Conservation District
Justin Muller	Kittson County Soil and Water Conservation District
Chelsea Lobson	Lake Winnipeg Foundation
Marla Riekman	Manitoba Agriculture
M.D. Timmerman	Manitoba Agriculture
Brian Wiebe	Manitoba Sustainable Development
Cassie McLean	Manitoba Sustainable Development
Nicole Armstrong	Manitoba Sustainable Development
Pete Waller	Minnesota Board of Water and Soil Resources
Henry Van Offelen	Minnesota Board of Water and Soil Resources
Jeppe Kjaersgaard	Minnesota Department of Agriculture
Riley Maanum	Minnesota Farm Bureau
Dave Wall	Minnesota Pollution Control Agency
Jim Courneya	Minnesota Pollution Control Agency
Jim Ziegler	Minnesota Pollution Control Agency
Keith Bartholomay	North Dakota Association of Conservation Districts
Mike Ell	North Dakota Department of Health, Division of Water Quality
Greg Sandness	North Dakota Dept. of Health - Water Quality Division
Kendall Nichols	North Dakota Soybean Council
David Franzen	North Dakota State University
Francis Casey	North Dakota State University
Miranda Meehan	North Dakota State University
Kari Helgoe	North Dakota State University
Marie Hvidsten	North Dakota State University
Mary Keena	North Dakota State University
R. Jay Goos	North Dakota State University

Name	Affiliation
Anitha Chirumamilla	North Dakota State University
Naeem Kalwar	North Dakota State University
Tom Scherer	North Dakota State University
Xinhua Jia	North Dakota State University
Heidi Reitmeier	Northwest Research and Outreach Center
Matthew Sorvig	Pennington County Soil and Water Conversation District
Jillian Fejszes	Pheasants Forever
H. Joy Kennedy	Province of Manitoba
Gonzalo Agrimbau	Red River Basin Commission
Steve Strang	Red River Basin Commission
Ted Preister	Red River Basin Commission
Keith Weston	Red River Retention Authority
Lonnie Leake	Research - Dakota Resource Council
Jennifer Klostreich	Richland County ND, 319 Watershed Program
Sandeep Kumar	South Dakota State University
David Kringen	South Dakota State University
Arun Bawa	South Dakota State University
John McMaine	South Dakota State University
Hank Venema	Strategic Community Consulting
Julius Wangler	Three Rivers Soil Conservation of Walsh County
Rochelle Nustad	U.S. Geological Survey
David Lobb	University of Manitoba
David Mulla	University of Minnesota
Jeff Strock	University of Minnesota
Lindsay Pease	University of Minnesota
Karen Terry	University of Minnesota Extension
Lisa Loegering	University of Minnesota Extension
Linda Kingery	University of Minnesota Extension
Ben Anderson	University of Minnesota Extension
Chryseis Modderman	University of Minnesota Extension
Jian Liu	University of Saskatchewan
Merrin Macrae	University of Waterloo
Anne Nardi	University of Wisconsin-Madison Division of Extension
Rebecca Power	University of Wisconsin-Madison Division of Extension
Jay Fuhrer	USDA Natural Resources Conservation Service
Rita Sveen	USDA Natural Resources Conservation Service
Ted Alme	USDA Natural Resources Conservation Service
Michael Steinhauer	USDA Natural Resources Conservation Service
Debra Walchuk	USDA Natural Resources Conservation Service
Kevin Gietzen	USDA Natural Resources Conservation Service
Evan Freeman	Walsh County Soil Conservation District
Sarah Johnston	Walsh County Soil Conservation District
Steve Sodeman	Watsonwan County Soil and Water Conservation District
Matt Olson	Wild Rice Soil Conservation District
Blake Carlson	WSN Engineering

APPENDIX C – REGIONAL EFFECTIVENESS OF BMPs

C.1 BMP SUITABILITY ZONES

The Red River Basin has diverse climatic factors, land uses, land cover, soil characteristics, and landscape features. In addition, the cropping systems and nutrient management systems vary considerably. This diversity affects water quality and water quantity. Mean annual precipitation (Fig. 2.2) varies from less than 20 inches (494 mm) in the northwestern part of the RRB to 30 inches (757 mm) in the southeastern part of the RRB. Average annual temperature (Fig. 2.2) varies from 35 °F (1.5 °C) in the northern part of the RRB to 44 °F (6.5 °C) in the southern part. Thus, on the basis of combinations for precipitation and temperature, the RRB can be divided into four regions with colder/dryer, cooler/dry, warm/wetter, and warmer/wetter climates (Fig. 2.3).

Landscapes in the Red River Basin range from flat to steep (10°) in slope (Fig. 2.4), and from nearly impermeable, poorly drained soils to permeable, well-drained soils with infiltration rates of up to 16 inches/hr (Fig. 2.7). The attributes flatter or steeper, and poorly drained or well-drained can be combined with climatic factor combinations (e.g., colder/dryer) to create twenty BMP Suitability Zones in the Red River Basin (Fig. C.1). Poorly drained and well-drained are based on hydrologic soil groups (D, C) or (A, B). Flatter or steeper are somewhat subjective, but flatter generally means <2%, while steeper means >6%. Rolling landscape is between these two. BMP Suitability Zones are units having relatively homogeneous climate, soil, and landscape characteristics. BMP Suitability Zones can be associated with a specific set of management practices (see Section C.2.5) to minimize the impact of land use activities on soil and water resource quality.

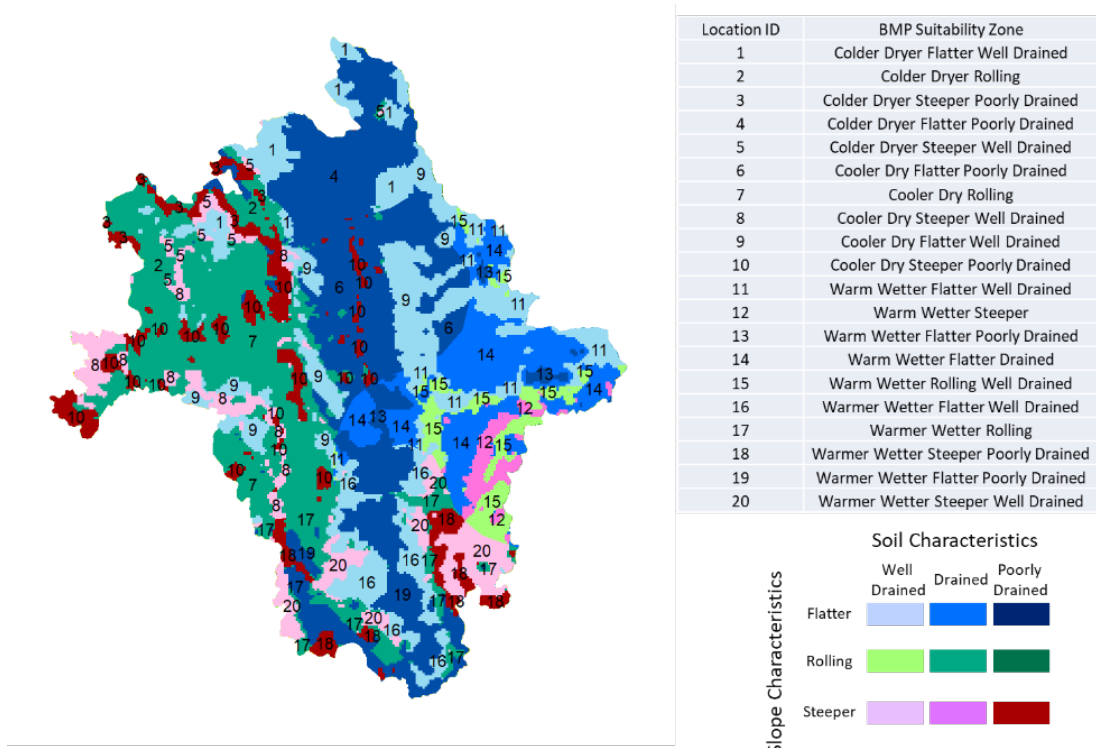


Figure C.1: BMP Suitability Zones for the Red River Basin

BMP Suitability Zones have a wide set of contrasting conditions that affect the effectiveness of agricultural BMPs. For example, zones that are flatter and poorly drained will likely have improved crop production with structural practices such as subsurface drainage or controlled drainage that optimize removal of excess water. At the same time, warmer regions with this combination of conditions will likely have reduced export of nitrogen if the subsurface drainage systems are treated using woodchip bioreactors. In contrast, zones that are steeper and well drained will likely have issues with concentrated runoff and erosion, which can be controlled using contour or conservation tillage. Nutrient losses associated with runoff and erosion from steeper and well-drained landscapes can be controlled using cover crops, especially in warmer and wetter portions of the Red River Basin. Additional detail concerning specific BMPs and their suitability in each of these zones is discussed in Section C.2.5.

C.2 REGIONAL TARGETING AND EFFECTIVENESS OF BMPs

Management practices are available to control losses of N and P arising from the combination of climatic, soil and landscape characteristics, and land use/land cover factors. Four broad categories of management discussed in Sections 4 and 5 of this report included nutrient management, erosion control practices, vegetative practices, and structural practices. The selection and effectiveness of an appropriate management practice at reducing N and P export to surface waters depends on site-specific conditions accounted for partially by BMP Suitability Zones (Fig. E.1), stakeholder attitudes and education, and by economic factors. Some BMPs work best in flatter lands, others in steeper landscapes. Some BMPs work best in warmer climate, others in colder climate. Some BMPs work best in well-drained soils, others in poorly drained soils. Some BMPs work best in cropland, others in livestock management systems.

C.2.1 N and P Loadings to Land from Fertilizer and Manure

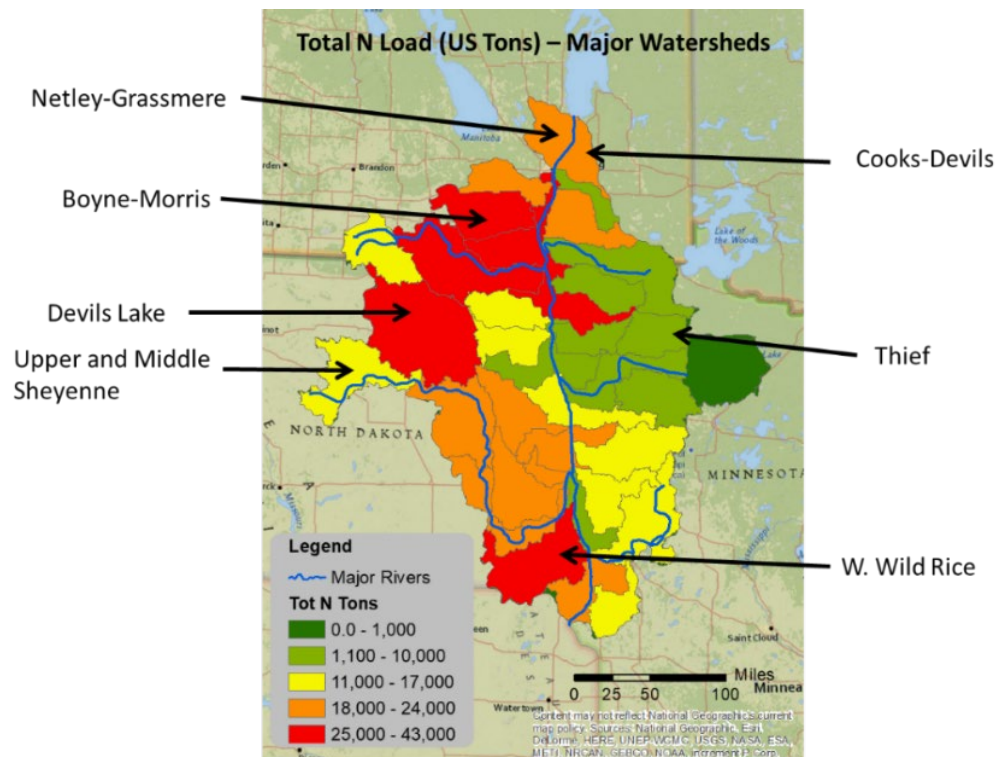
Other important factors should be considered when selecting BMPs and targeting them to the right location to reduce N and P losses. These include total amounts of N and P applied within watersheds from fertilizer and manure, water quality monitoring data at the mouths of watersheds within the Red River Basin, and cropping systems. Nitrogen and phosphorus amounts applied to land from fertilizer and manure vary across the RRB (Jenkinson and Benoy 2015). BMPs should first be targeted to hotspots in the RRB where N and P amounts applied to land from fertilizer and manure are greatest and the risk of transport to surface waters is also large (Fig. 2.15).

C.2.2 N and P Loadings from Water Quality Modeling at Mouths of Watersheds

These hotspots correspond closely with elevated N and P loadings estimated from SPARROW modeling at the mouths of major watersheds (Fig. E.2). Largest N and P loadings occur in the Western Wild Rice, Devils Lake, Tamarac (Middle Red), Boyne-Morris, and the Cooks-Devils and Netley-Grassmere (Lower Red) watersheds. These watersheds should be a priority for implementation of BMPs to reduce N and P loadings to the Red River Basin.

Each major watershed (Fig. 2.1) differs in N and P applications to land from fertilizer and manure (Figs. C.2 and C.3). The largest loadings of N and P application to agricultural land from fertilizer and manure occur in four major watersheds (Fig. C.3). The Middle Red (including the Tamarac),

A-9 | Page



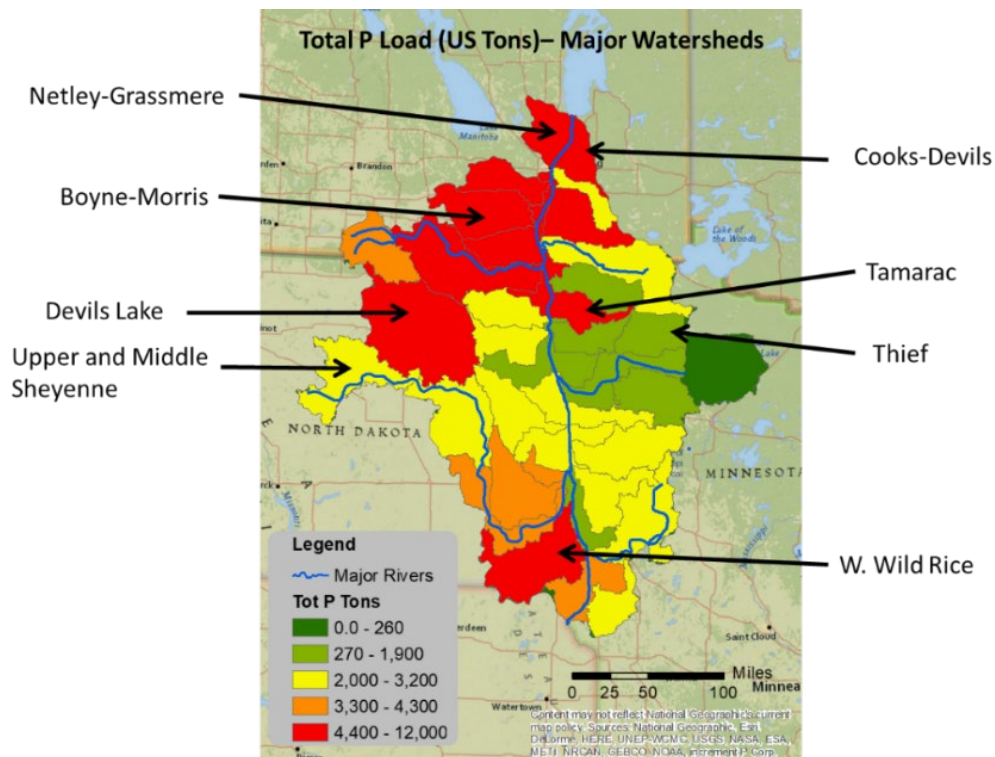


Figure C.2: Red River Basin Major Watershed N (top) and P (bottom) Loadings at Mouth of Watershed based on SPARROW modeling (Jenkinson and Benoy 2015)

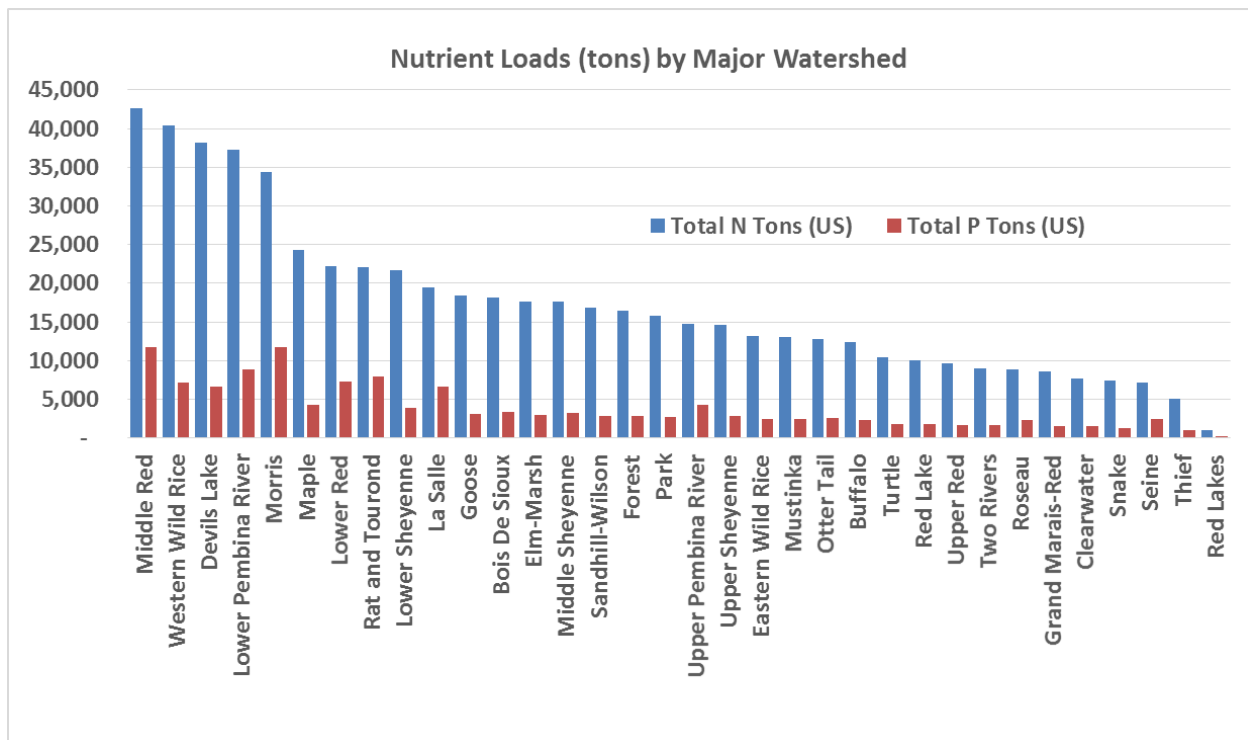


Figure C.3: N and P Loadings to Agricultural Land from Fertilizer and Manure in Individual Major Watersheds Based on SPARROW Modeling (Jenkinson and Benoy 2015)

C.2.3 BMP Suitability Zone Characteristics

BMP Suitability Zones were introduced in Section C.1 of this report. Each zone has a unique combination of climate (precipitation and temperature), soil characteristics (high or low permeability), and landscape slope characteristics (flatter, rolling, or steeper). These three factors, combined with the magnitude of total N and P applications to agricultural land from fertilizer and manure, as well as the specific cropping and integrated animal systems in place, can be used to identify the general suitability for nutrient management, erosion control, vegetative, and structural BMPs.

BMP Suitability Zones differ dramatically in the magnitudes of N and P applications to agricultural land from fertilizer and manure (Fig. C.1). Largest N and P loadings to agricultural land occur in the Colder Dryer Flatter Poorly Drained (BMP Suitability Zone 4), Cooler Dry Rolling Drained (Zone 7), Cooler Dry Flatter Poorly Drained (Zone 6), and Warmer Wetter Flatter Poorly Drained (Zone 19) BMP Suitability Zones. These zones should have the highest priority for implementation of BMPs to reduce nutrient loadings to the Red River Basin. Moderate N and P loadings occur in the Colder Dryer Rolling Drained (Zone 2), Warmer Wetter Flatter Well Drained (Zone 16), Warm Wetter Flatter Drained (Zone 14), Colder Dryer Flatter Well Drained (Zone 1), Cooler Dry Flatter Well Drained (Zone 9), Warmer Wetter Rolling Drained (Zone 17), Cooler Dry Steeper Poorly Drained (Zone 10), and Warmer Wetter Steeper Well Drained (Zone 20) BMP Suitability Zones. All the remaining BMP Suitability Zones have low N and P loadings to agricultural land, and should

be low priority for BMP implementation. Specific BMPs might still be high priority (e.g., BMPs around winter feeding sites).

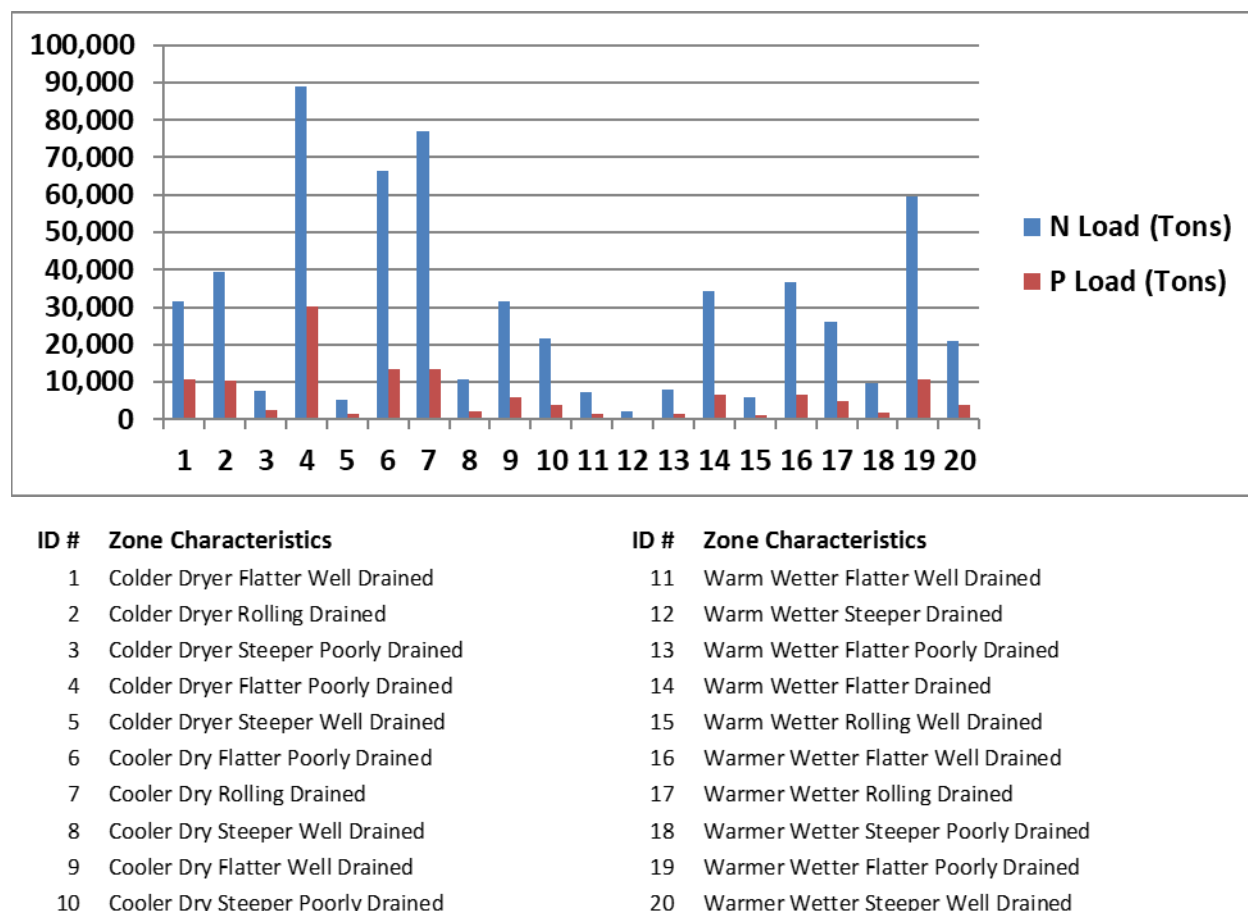
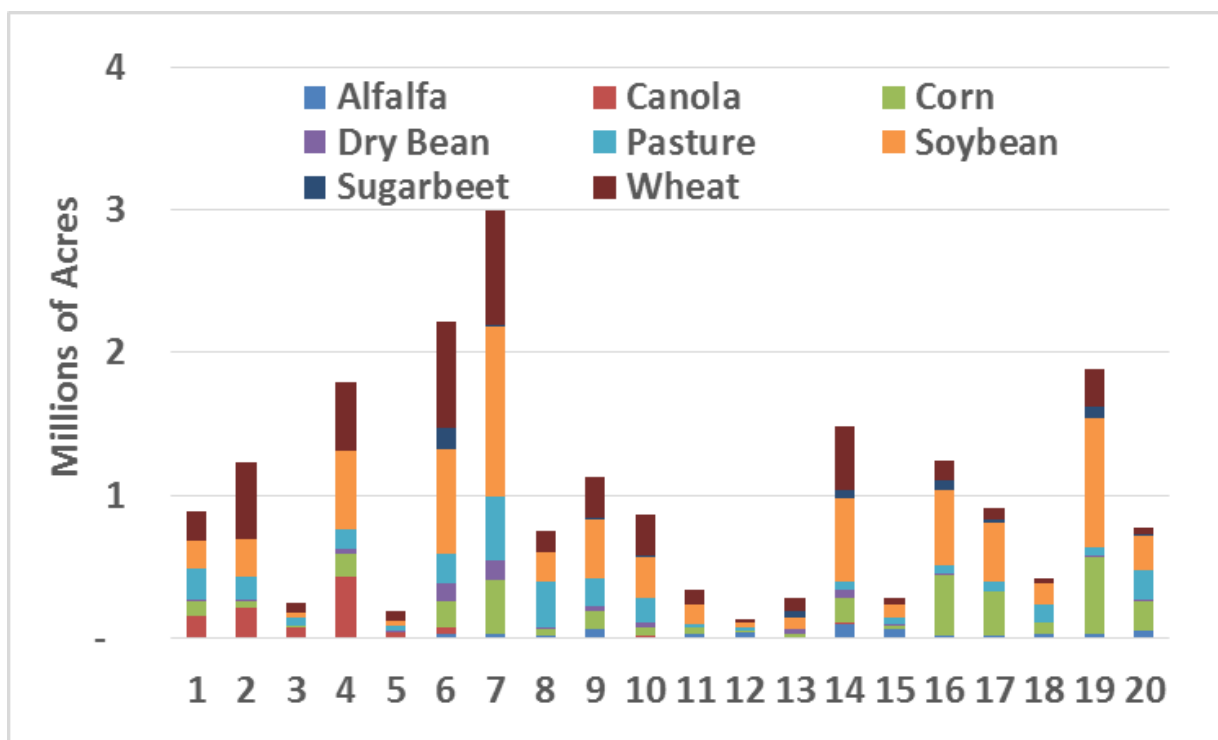


Figure C.4: Load of N or P from Fertilizer and Manure Applied to Agricultural Land Within Individual Red River Basin BMP Suitability Zones (adapted from data provided by Jenkinson and Benoy 2015)

N and P applications in BMP Suitability Zones (Fig. C.4) are primarily used to supply nutrients to agricultural crops. N and P are typically applied as fertilizer or manure on land that will be planted to major crops that require supplemental N and P such as wheat, corn, and canola. Soybeans and alfalfa fix N from the atmosphere and are normally not fertilized with either N or P. Not surprisingly, BMP Suitability Zones in Fig. C.5 that receive the highest applications of N and P (e.g., Zones 4, 6, 7, and 19) also have the highest acreages of wheat, corn, and canola.



ID # Zone Characteristics

- 1 Colder Dryer Flatter Well Drained
- 2 Colder Dryer Rolling Drained
- 3 Colder Dryer Steeper Poorly Drained
- 4 Colder Dryer Flatter Poorly Drained
- 5 Colder Dryer Steeper Well Drained
- 6 Cooler Dry Flatter Poorly Drained
- 7 Cooler Dry Rolling Drained
- 8 Cooler Dry Steeper Well Drained
- 9 Cooler Dry Flatter Well Drained
- 10 Cooler Dry Steeper Poorly Drained

ID # Zone Characteristics

- 11 Warm Wetter Flatter Well Drained
- 12 Warm Wetter Steeper Drained
- 13 Warm Wetter Flatter Poorly Drained
- 14 Warm Wetter Flatter Drained
- 15 Warm Wetter Rolling Well Drained
- 16 Warmer Wetter Flatter Well Drained
- 17 Warmer Wetter Rolling Drained
- 18 Warmer Wetter Steeper Poorly Drained
- 19 Warmer Wetter Flatter Poorly Drained
- 20 Warmer Wetter Steeper Well Drained

Figure C.5: Major Agricultural Crop Acreages in Red River Basin BMP Suitability Zones (adapted from data provided by Jenkinson and Benoy 2015)

C.2.4 Distribution of BMP Suitability Zones Across Major Watersheds

Each major watershed shown in Figures 2.1 and C.3 is composed of multiple BMP Suitability Zones. This information, along with information on N and P application loads (Fig. C.4) and crop acreages (Fig. C.5) in each BMP Zone can be used to identify where to target BMPs within each watershed based on differences in soil and landscape characteristics. Three examples are provided for Red River Basin watersheds showing how to target BMPs in this fashion. Referring back to Fig. C.3, the watershed with the largest applications of N and P from fertilizer and manure is the Middle Red watershed. The Middle Red watershed is primarily composed of BMP Suitability Zones 6, 4, and 9, the Cooler Dry Flatter Poorly Drained (41% of watershed area), Colder Dryer Flatter Poorly Drained (29% of area), and Cooler Dry Flatter Well Drained (16% of area) Zones,

respectively (Table C.1). These differ primarily in whether or not they are poorly or well-drained soils, with more subtle variations in temperature and precipitation. Also, they differ in N and P applications to land from fertilizer and manure (Fig. C.5), with Zone 4 (flatter poorly drained) having the highest applications, followed by Zone 6 and then Zone 9. It would make sense to start with targeted BMPs in Suitability Zones 4 and 6, with a lower priority in Zone 9.

The Western Wild Rice watershed is primarily composed of Warmer Wetter Flatter Poorly Drained (32% of area), Warmer Wetter Flatter Well Drained (26% of area), Warmer Wetter Steeper Well Drained (19% of area), and Warmer Wetter Rolling Drained (16% of area) BMP Suitability Zones 19, 16, 20, and 17, respectively (Table C.2). Differences among BMP Suitability Zones in the Western Wild Rice watershed are primarily due to slope (flatter or steeper) and soil drainage (poorly or well-drained). N and P applications to land from fertilizer and manure also differ among these Zones (Fig. C.4). BMP Suitability Zone 19 (flatter poorly drained) has the highest N and P loadings, followed by lower loadings in Zones 16 and 17 (well drained). The lowest loadings occur in the steeper well-drained Zone 20. In contrast with the BMP Suitability Zones in the Middle Red watershed, Zones in the Western Wild Rice watershed have warmer temperatures and higher precipitation.

As a third example, the Morris watershed (or Boyne-Morris) is primarily composed of BMP Suitability Zones 4 (53% of watershed area), 1 (20% of area), 2 (14% of area) and 3 (10% of area), corresponding, respectively, to the Colder Flatter Dryer Poorly Drained, Colder Flatter Dryer Well Drained, Colder Dryer Rolling Well Drained, and Colder Dryer Steeper Well Drained Zones (Table C.1). These all have colder temperatures and lower precipitation than the Middle Red watershed, but differ among themselves in whether the landscapes are flatter, rolling or steeper, and in whether the soils are poorly or well drained. N and P applications to land from fertilizer and manure (Fig. C.4) are highest in BMP Suitability Zone 4 (Colder Dryer Flatter Poorly Drained). Suitability Zones 1 and 2 have moderate N and P loadings from fertilizer and manure, while Zone 3 has low N and P loadings. BMPs in the Morris watershed should be targeted to Zone 4. Site specific assessments in the other zones might warrant high priority for some sites.

Table C.1: Composition of Major Watersheds in the Red River Basin as Percent of Watershed Area in Different BMP Suitability Zones

Watershed Name	BMP Suitability Zone																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bois De Sioux																19	21	6	51	3
Buffalo												7		6	4	23	1	22	3	17
Clearwater											21	15		40	23					
Devils Lake		18			2		65	2	2	10										
Eastern Wild Rice												23		30	12	10	7		9	9
Elm-Marsh							4		2	5	5		11	6	5	15			45	1
Forest						42	37	4	10	7										
Goose						9	57	1	10	10			4	9						
Grand Marais-Red						49	2		14	10	4		8	12						
La Salle	32	0		67	0															
Lower Pembina River	12	35	13	2	9	13	3	2	5	5										
Lower Red	35	2		53	1	8			2											
Lower Sheyenne							23	5	1	1	1					11	10	11	20	18
Maple							33			1						14	26		21	4
Middle Red	3	6	1	29		41			16	4										
Middle Sheyenne							45	23	26	5										
Morris	20	14	10	53	2															
Mustinka																23	11	2	64	
Otter Tail												5		1	19	3	6	17	4	46
Park						38	27	2	11	21										
Rat and Tourond	28			36		21			14						1					
Red Lake						1			4		15		13	55	12					
Red Lakes											20	3	8	55	14					
Roseau				2		35	1		7		25		3	23	4					
Sandhill-Wilson						8	1		7	2	4	2	10	59	7					
Seine				32		25			44											
Snake						48			52											
Thief						16			2		25			57						
Turtle						32	19		29	20										
Two Rivers						37	1		57	3	1			1						
Upper Pembina River	8	72	13	1	7															
Upper Red																25	6	4	63	2
Upper Sheyenne							37	36		27										
Western Wild Rice																26	16	6	32	19

C.2.5 Effectiveness of BMPs at Reducing N and P Losses in Different BMP Suitability Zones

The effectiveness of BMPs in reducing N and P losses from agricultural fields and loading to surface waters are discussed below.

Nitrogen

Table C.2 provides a summary for the effectiveness at reducing nitrogen losses from agricultural land for a wide range of nutrient management, erosion control, vegetative management, and structural management practices mentioned in Section 4 of this report.

Nutrient management practices for cropping and integrated animal production systems are widely applicable across the entire Red River Basin. However, these practices will be more effective at reducing N pollution in watersheds (Fig. C.3) and BMP Suitability Zones (Fig. C.4) with the largest loadings of N to land. BMP Suitability Zones 4, 6, 7, and 19 (Fig. C.3 and C.4), in particular, have high N loadings from fertilizer, with manure loadings being highest in Zone 4 (Fig. C.6). BMP Suitability Zones 1, 2, 9, 10, 14, 16, 17 and 20 have moderate N loadings from fertilizer, with moderate applications of manure in Zones 1, 2, 6, 7, 9, 14, 16, 17, 18, 19 and 20. Corn acreage is particularly amenable to improved N fertilizer management (soil testing, sidedress N, VRN) in comparison with wheat acreage. BMP Suitability Zones with the highest acreage of corn include Zones 7, 16, 17 and 19 (Fig. C.5).

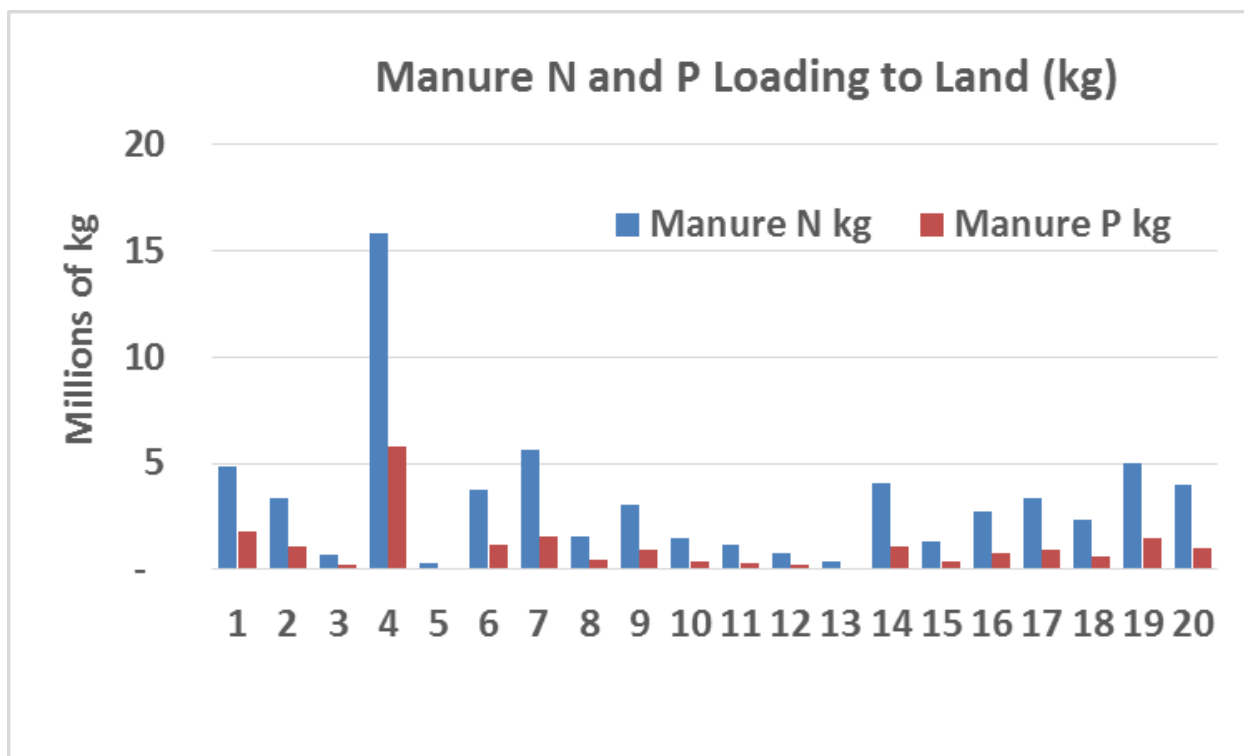


Figure C.6: Manure N and P Loading to Land (kg) in Different BMP Suitability Zones
(adapted from data provided by Jenkinson and Benoy 2015).

Practices such as contour farming and conservation tillage to control soil loss by tillage and water erosion are more effective in steep landscapes than flatter landscapes. Wind erosion is a severe problem throughout the Red River Basin. Wind erosion control practices such as windbreaks or orienting crop rows perpendicular to the prevailing wind direction are more effective in flat landscapes, particularly those having dryer soils with high calcium carbonate content. BMPs to control impacts of animal agriculture on erosion and runoff are best targeted to areas having high concentrations of feedlots or grazing activities. These areas correspond to BMP Suitability Zones with high or moderate applications of manure to land (Fig. C.6). BMPs to exclude animals from watering in streams and producing streambank erosion are best targeted to zones with high or moderate manure applications and dense stream networks.

Vegetative practices such as cover crops, filter strips, and grass waterways to control N losses are most effective in BMP Suitability Zones that are warmer, wetter, steeper, and well drained. These practices are least effective in colder, dryer, flatter, and poorly drained zones, where establishment of cover crops is challenging. However, cover crops may have other benefits in colder, dryer, flatter, and poorly drained Zones, such as improving soil health. Practices such as conservation crop rotation, pasture and hayland plantings, and feedlot filter strips to control N losses from land applied manure are most effective in areas with a high concentration of animal agriculture, particularly if those areas are warmer, steeper, and well drained.

Structural practices include those designed to be implemented with artificial drainage, those designed to store and/or treat water at the edge of field, and those that control nutrient losses from animal feedlots. Drainage-related structural practices are generally limited to flatter, poorly drained landscapes. Controlled drainage practices are restricted to the flatter landscapes with subsurface tile drainage. Bioreactors are even more restricted than controlled drainage to flatter, warmer landscapes with subsurface tile drainage.

The Red River Basin can be divided into landscapes with runoff that reaches the mainstem of the Red River at the early, middle, or late stages of flood flow. Culvert resizing was originally developed as a structural practice to reduce peak flows during snowmelt runoff events (Solstad et al. 2007). Culvert size could be increased in flatter, poorly drained areas near the mainstem and decreased in areas farther away from the mainstem to decouple peak flows from the early, middle, or late contributing areas.

Structural practices to store and/or treat water include wetlands, water, and sediment control basins and small dams, ponds, and reservoirs. Wetlands are most effective at removing N in BMP Suitability Zones that are warmer, wetter, flatter, and poorly drained. Their effectiveness decreases as the climate becomes colder and dryer, or steeper and well drained. The effectiveness of water and sediment control basins is similar to wetlands, and these structures are not well suited for steeper, well-drained landscapes. In steeper landscapes, water retention is often achieved using small dams, ponds, and reservoirs. A summary is provided in Table C.2.

Phosphorus

Table C.3 summarizes the effectiveness at reducing P losses from agricultural land for a wide range of nutrient management, erosion control, vegetative management, and structural management practices discussed in Section 5 of this report.

Similar to the discussion for N, nutrient management practices for P in cropping and integrated livestock production systems are broadly applicable across the entire Red River Basin. However, these practices will be more effective at reducing P loss and loading in watersheds (Fig. C.3) and BMP Suitability Zones (Fig. C.4) with the largest loadings of P to land. BMP Suitability Zones 1, 2, 4, 6, 7, and 19 (Figs. C.3 and C.4), in particular, have high P loadings from fertilizer, with manure loadings being highest in Zone 4 (Fig. C.6). BMP Suitability Zones 9, 10, 14, 16, 17 and 20 have moderate P loadings from fertilizer, with moderate applications of manure in Zones 1, 2, 6, 7, 9, 14, 16, 17, 18, 19, and 20.

Management practices to control tillage and water erosion are more effective in steeper undulating and rolling landscapes. These include contour farming and conservation tillage. BMP suitability zones ranked as high for contour farming and conservation tillage for P load reduction include 2, 7, and 20. Management practices to control wind erosion, such as windbreaks and shelterbelts, will have more impact in areas of reduced cover such as in the flatter landscapes of the Red River Valley where more intensive tillage systems predominate. BMP suitability zones indicated as having high potential for P reduction by controlling wind erosion include 2, 4, 8, 11, 13, 15, 16, and 17. As discussed for N, BMPs to control impacts of animal agriculture on erosion and runoff are best targeted to areas having high concentrations of feedlots or grazing activities, while BMPs to exclude animals from watering in streams and producing streambank erosion are best targeted to zones with high or moderate manure applications and dense stream networks. Feedlot siting is particularly important where there are high loadings from P in areas of steeper landscapes prone to higher rates of runoff.

As indicated for N, vegetative practices such as cover crops, filter strips, and grass waterways to control sediment losses are most effective in BMP Suitability Zones that are warmer, wetter, and steeper, and they are least effective in colder, dryer, flatter, and poorly drained areas. However, to be effective for P load reduction, research is showing that these practices may not be effective in reducing soluble or total P loss from agricultural fields. These practices must consider the potential for these areas to contribute P through P mobilization from senesced vegetation following FTCs. Therefore, harvest and removal of vegetation may be required for these BMPs to be considered beneficial for P load reduction. Therefore, the rankings for vegetative BMPs of cover crops, filter strips and grass waterways, and feedlot/wastewater filter strips in Table C.3 should be considered in conjunction with cover crop species selection (for cover crops) and vegetation removal. In-field feeding management is identified as a BMP ranked as high in areas of high concentrations of manure P; however, in areas of steeper slopes, nutrient losses can be as high as confined feeding operations without runoff capture.

Structural practices in areas of cropping with the highest potential to reduce P loading include those that reduce or slow water runoff from agricultural fields and sediment loss into surface water courses, such as wetlands (restored or constructed), water and sediment control basins, and small dams, ponds, and reservoirs. As discussed for N, wetlands are most effective in areas that are warmer, wetter, flatter, and poorly drained. Effectiveness of water and sediment control basins is similar to wetlands, and, in steeper landscapes, water retention is often achieved using small dams, ponds, and reservoirs. However, the buildup of P-rich sediment in these designed features is a concern as over time these may become significant sources of P if the nutrient is remobilized. Therefore, removal of P-rich sediment and re-application of this sediment should be considered a

potential BMP. Further, soluble P is still a consideration with these BMPs if it is not taken up by vegetation that is subsequently removed from the landscape.

Drainage water management, particularly controlled drainage, is more suitable to flatter and poorly drained landscapes. These practices may not have a substantive impact on P load in the RRB due to the dominance of snowmelt runoff component of annual runoff, when soils are frozen and tiles are decoupled from the surface. However, in combination with 4R nutrient management and more productive cropping, improved nutrient use across a tile-drained field may be beneficial to P management over the long-term. The effects of drainage water management and controlled drainage on N must also be considered.

Table C.2: Agricultural BMP Effectiveness for Nitrogen Reduction in BMP Suitability Zones of the Red River Basin

Minnesota NRCS Standard #	CRP Practice #	Conservation Practices	1: Colder Dryer Flatter Well Drained Zone	2: Colder Dryer Rolling Drained Zone	3: Colder Dryer Steeper Poorly Drained Zone	4: Colder Dryer Flatter Poorly Drained Zone	5: Colder Dryer Steeper Well Drained Zone	6: Cooler Dry Flatter Poorly Drained Zone	7: Cooler Dry Rolling Drained Zone	8: Cooler Dry Steeper Well Drained Zone	9: Cooler Dry Flatter Well Drained Zone	10: Cooler Dry Steeper Poorly Drained Zone	11: Warm Wetter Flatter Well Drained Zone	12: Warm Wetter Steeper Drained Zone	13: Warm Wetter Flatter Poorly Drained Zone	14: Warm Wetter Flatter Drained Zone	15: Warm Wetter Rolling Well Drained Zone	16: Warmer Wetter Flatter Well Drained Zone	17: Warmer Wetter Rolling Drained Zone	18: Warmer Wetter Steeper Poorly Drained Zone	19: Warmer Wetter Flatter Poorly Drained Zone	20: Warmer Wetter Steeper Well Drained Zone
Nutrient Management Practices																						
590		Nutrient Management ⁱ	M	M	L	H	L	H	H	L	M	H	L	L	L	M	L	M	M	L	H	M
		Soil/Manure Testing	H	H	L	H	L	H	H	L	H	H	L	L	L	H	L	M	H	L	H	M
		Spring Application or Fall Application if Soil Temp < 50 °F	H	H	M	H	M	H	H	M	H	H	M	M	M	M	M	M	M	M	H	M
		Sidedress (VRN) Application	M	M	L	M	L	M	M	M	M	M	M	L	L	M	M	M	M	M	H	M
		Incorporation/Inject-ion/Banding	H	H	M	H	M	H	H	M	H	H	M	M	M	H	M	H	M	M	H	M
		Nitrification Inhibitor, ESN or Urea Inhibitor	H	H	M	M	M	M	M	M	H	H	M	M	M	M	M	M	M	M	M	M
634		Manure Hauling	H	H	L	H	L	H	H	M	H	L	M	L	L	H	M	M	H	M	H	M
Erosion Control Practices																						
330		Contour Farming	L	M	H	L	H	L	M	H	L	M	L	H	L	L	M	L	M	H	L	H
329		Conservation Tillage (no-till, strip-till, mulch-till, ridge-till) ⁱⁱ	M	M	M	M	H	M	H	H	M	M	M	H	M	M	H	M	H	M	M	H
380	CP5A CP16B CP17A	Windbreak/Shelterbelt/ Living Snow Fence	H	L	L	M	L	H	L	L	H	M	H	M	H	M	H	H	L	L	H	L
614		Watering Facility	H	H	L	H	L	H	H	M	H	M	M	L	L	H	M	M	H	M	H	H
472/382		Use Exclusion/Fencing	H	H	L	H	L	H	H	H	H	M	M	L	L	H	M	M	H	M	H	H
580		Streambank & Shoreline Protection (structural and/or vegetative practice)	M	L	L	H	L	L	L	M	M	L	M	L	L	H	L	M	L	L	H	L
		Proper Feedlot Siting or Relocation	H	H	L	H	L	H	H	M	H	M	M	L	L	H	M	M	H	M	H	H
Vegetative Management Practices																						
328		Conservation Crop Rotation ⁱⁱⁱ	M	M	L	M	L	M	M	M	M	H	M	L	L	M	H	M	H	M	M	H
340		Cover Crop	L	M	M	L	M	M	M	M	L	M	M	H	M	M	H	M	M	M	M	H
393	CP21	Filter Strip (grass) ^{iv}	L	M	L	L	M	L	M	H	M	L	M	M	L	M	H	H	M	M	L	M
412		Grass Waterway	L	M	L	L	L	L	M	M	L	M	L	H	L	L	M	L	M	H	L	H
512		Pasture & Hayland Planting	L	H	L	L	L	M	H	H	L	L	M	L	L	M	H	M	H	L	H	H
635		Feedlot/Wastewater Filter Strip	H	H	L	H	L	H	H	M	H	L	M	L	L	H	H	M	H	L	H	H
Structural Management Practices																						
554		Drainage Water Management ^v	L	L	L	M	L	M	L	L	M	L	M	L	H	H	L	H	L	L	H	L
		Controlled Drainage	L	L	L	M	L	M	L	L	M	L	M	L	H	L	L	H	L	L	H	L
	156	Woodchip Bioreactor	L	L	L	L	L	M	L	L	L	L	M	L	H	H	L	H	L	L	H	L
	80	Culvert Resizing	L	L	M	H	L	H	L	L	L	M	L	L	M	H	L	H	L	L	H	L
	115	Two-Stage Ditch	L	L	L	L	L	M	L	L	L	L	M	L	H	M	L	H	L	L	H	L
657	CP27 CP28	Wetland Restoration - (depression/ponded)	L	M	L	M	L	L	M	L	L	L	L	L	M	M	L	L	L	L	M	L
657	CP23	Wetland Restoration - (riparian/ floodplain)	L	M	L	L	L	L	M	L	L	M	M	L	M	M	L	M	L	M	M	L
638		Water and Sediment Control Basin	L	M	M	L	M	L	M	M	L	M	L	M	L	L	M	L	M	M	M	M
		Small Dams, Ponds, Reservoirs	M	H	M	L	H	L	L	M	L	M	L	M	L	L	M	L	M	M	L	M
367		Waste Facility Cover	H	H	L	H	L	H	H	M	H	M	M	L	L	H	M	M	M	M	H	H
784		Wastewater & Feedlot Runoff Control ^{vi}	H	H	L	H	L	H	H	M	H	M	M	L	L	H	M	M	H	M	H	H
Notes:																						
i. Includes crop nutrient management, manure management, and feedlot waste utilization																						
ii. Refers to NRCS Standards 329A-329C (Residue Management), which include no-till, strip-till, mulch-till, and ridge-till																						
iii. Refers to at least a third resource-conserving and regionally appropriate crop in addition to an existing 2-crop rotation. (This exceeds minimum requirements for this NRCS practice standard.)																						
iv. Effectiveness depends on complementary upland practices (which may be true for several other practices in this table as well)																						
v. Refers to a range of “conservation drainage” practices, some currently in MN-NRCS Standard 554 Drainage Water Management and others not. Examples include blind inlets, rock inlets, French drains, and tile spacing and depth.																						
vi. Includes Milkhouse Waste Management																						

Table C.3: Agricultural BMP Effectiveness for Phosphorus Reduction in BMP Suitability Zones of the Red River Basin

Minnesota NRCS Standard #	CRP Practice #	Conservation Practices	1: Colder Drier Flatter Well Drained Zone	2: Colder Drier Rolling Drained Zone	3: Colder Drier Steeper Poorly Drained Zone	4: Colder Drier Flatter Poorly Drained Zone	5: Colder Drier Steeper Well Drained Zone	6: Cooler Dry Flatter Poorly Drained Zone	7: Cooler Dry Rolling Drained Zone	8: Cooler Dry Steeper Well Drained Zone	9: Cooler Dry Flatter Well Drained Zone	10: Cooler Dry Steeper Poorly Drained Zone	11: Warm Wetter Flatter Well Drained Zone	12: Warm Wetter Steeper Drained Zone	13: Warm Wetter Flatter Poorly Drained Zone	14: Warm Wetter Flatter Drained Zone	15: Warm Wetter Rolling Well Drained Zone	16: Warmer Wetter Flatter Well Drained Zone	17: Warmer Wetter Rolling Drained Zone	18: Warmer Wetter Steeper Poorly Drained Zone	19: Warmer Wetter Flatter Poorly Drained Zone	20: Warmer Wetter Steeper Well Drained Zone
Nutrient Management Practices																						
590		Nutrient Management ⁱ	H	H	H	H	L	H	H	L	M	M	L	L	M	M	L	H	H	M	H	M
		Soil/Manure Testing	H	H	H	H	L	H	H	L	M	M	L	L	M	M	L	H	H	M	H	M
		Spring Application or Fall Application if Soil Temp < 50F	H	H	M	H	M	H	H	M	M	M	L	L	M	M	L	H	M	M	H	M
		Variable rate P application	H	M	L	H	L	M	M	L	H	M	L	L	L	M	L	H	H	H	H	H
		Incorporation/Inject-ion/Banding	H	H	M	H	M	H	H	M	M	M	L	L	M	M	L	H	M	M	H	M
634		Manure Hauling	H	H	L	H	M	H	H	L	M	L	L	L	L	H	L	M	H	M	H	H
		Manure application on non-frozen ground	H	H	H	H	M	H	H	M	M	M	L	M	M	M	M	H	H	M	H	M
Erosion Control Practices																						
330		Contour Farming	M	H	L	H	L	M	H	L	M	L	H	L	L	M	L	M	H	L	H	H
329		Conservation Tillage (no-till, strip-till, mulch-till, ridge-till) ⁱⁱ	M	H	M	M	M	M	H	M	M	H	L	M	L	M	M	M	M	M	M	H
380	CP5A CP16B CP17A	Windbreak /Shelterbelt / Living Snow Fence	L	H	L	H	L	L	L	H	M	M	H	L	H	L	H	H	H	M	M	L
614		Watering Facility	H	H	H	H	H	L	L	L	M	H	M	M	H	H	M	M	H	L	H	M
472/382		Use Exclusion/Fencing	H	H	H	H	H	L	L	L	M	H	M	M	H	H	M	M	H	L	H	H
580		Streambank & Shoreline Protection (structural and/or vegetative practice)	L	L	L	M	L	L	L	L	L	H	M	L	H	L	L	M	M	L	H	M
		Proper Feedlot Siting or Relocation	M	H	H	H	M	H	H	M	M	H	L	M	M	M	M	M	H	H	H	H
Vegetative Management Practices																						
328		Conservation Crop Rotation ⁱⁱⁱ	L	M	M	L	M	L	M	M	L	M	L	L	L	L	L	L	L	M	L	M
340		Cover Crop		L	H		H		L	H		H		H			H		H	H		H
393	CP21	Filter Strip (grass) ^{iv}	L	M	H	L	H	L	M	H	L	H	L	H	L	L	H	L	H	H	L	H
412		Grass Waterway	L	M	H	L	H	L	M	H	L	H	L	H	L	L	H	L	H	H	L	H
512		Pasture & Hayland Planting	L	M	L	L	M	H	L	M	L	L	H	H	L	H	H	H	L	H	L	M
635		Feedlot/Wastewater Filter Strip	L	M	H	H	M	M	M	M	L	H	L	H	M	L	M	L	M	H	M	H
		Cover Crop Type (low P)	L	M	H	L	H	L	M	H	L	H	L	H	L	L	H	L	H	H	L	H
		Vegetation Removal (buffer, ditches, cover crop)	L	M	H	L	H	L	M	H	L	H	L	H	L	L	H	L	H	H	L	H
		Crop Residue Incorporation (chop, spread, harrow, rotational till)	L	M	H	L	H	L	M	H	L	H	L	H	L	L	H	L	H	H	L	H
		In-Field Feeding Management	H	H	L	H	L	H	H	L	H	L	M	L	M	H	L	H	M	L	H	L
Structural Management Practices																						
554		Drainage Water Management ^v	L			M		M			L		M		H	M		M			H	
		Controlled Drainage	L			M		M			L		M		H	M		M			H	
		Drainage Water Recycling	M	M	H	H	M	M	L	L	L	M										
	80	Culvert Resizing	L	L	M	H	L	H	L	L	L	M	L	L	M	H	L	H	L	L	H	L
	115	Two-Stage Ditch	L	L	L	L	L	M	L	L	L	L	M	L	H	M	L	H	L	L	H	L
657	CP27 CP28	Wetland Restoration (depression/ponded)	L	H	H	L	M	L	H	M	L	H	L	M	L	L	M	L	M	H	L	M
657	CP23	Wetland Restoration (riparian/floodplain)	L	M	L	L	L	L	M	L	L	M	M	L	M	M	L	M	L	M	M	L
638		Water and Sediment Control Basin	L	H	H	L	M	L	H	M	L	H	L	M	L	L	M	L	M	H	L	M
		Small Dams, Ponds, Reservoirs	L	H	H	L	M	L	H	M	L	H	L	M	L	L	M	L	M	H	L	M
784		Wastewater & Feedlot Runoff Control ^{vi}	H	H	L	H	L	H	H	M	H	M	M	L	L	H	M	M	H	M	H	H
		P-Rich Sediment Removal (retention areas)	L	H	H	L	M	L	H	M	L	H	L	M	L	L	M	L	M	H	L	M
Notes:																						
i. Includes crop nutrient management, manure management, and feedlot waste utilization																						
ii. Refers to NRCS Standards 329A-329C (Residue Management) which includes no-till, strip-till, mulch-till, and ridge-till																						
iii. Refers to at least a third resource-conserving and regionally appropriate crop in addition to an existing 2-crop rotation. (This exceeds minimum requirements for this NRCS practice standard.)																						
iv. Effectiveness depends on complementary upland practices (which may be true for several other practices in this table as well)																						
v. Refers to a range of “conservation drainage” practices, some currently in MN-NRCS Standard 554 Drainage Water Management and others not. Examples include blind inlets, rock inlets, French drains, and tile spacing and depth.																						
vi. Includes Milkhouse Waste Management																						

