DEPARTMENT OF AGRICULTURE

Agricultural BMP Handbook for Minnesota

2017

CLEAN WATER LAND & LEGACY AMENDMENT

DEPARTMENT OF AGRICULTURE

To the reader,

The Minnesota Department of Agriculture (MDA) is pleased to present to you this 2017 update of the Agricultural BMP Handbook for Minnesota. The original 2012 publication was developed as a literature review of empirical research on the effectiveness of 30 Best Management Practices (BMPs) implemented in Minnesota, and was co-authored with Emmons & Olivier Resources, Inc. The Ag BMP Handbook included the following information for each practice:

- Definition
- Effectiveness estimates based on existing scientific literature
- Costs and other economic considerations

The Ag BMP Handbook is a living document that is updated to reference ongoing and current research (including research gaps) pertaining to the effectiveness of conservation practices in reducing sediment, pesticide, and nutrient losses. It is not intended to be a standards manual or replace the Natural Resource Conservation Service (NRCS) Field Office Technical Guide (FOTG).

In 2008, Minnesota adopted the watershed approach to water quality monitoring and assessment. The approach begins with two years of intensive monitoring of lakes and streams to determine their overall health and identify impairments. Following monitoring and data analysis, a Watershed Restoration and Protection Strategy (WRAPS) and Total Maximum Daily Load (TMDL) study are completed to summarize water quality issues and determine reduction goals for impaired or protected water bodies. Comprehensive watershed management plans or One Watershed, One Plan (1W1P) projects refine the broad-scale WRAPS and other regional information into prioritized, targeted, and measurable implementation activities for restoration and protection. Over the past few years, the 2012 Ag BMP Handbook became a frequently referenced resource used by water quality modelers, watershed managers, and researchers to obtain BMP effectiveness estimates for use in the development of computer-based water quality scenario models and tools. A number of factors will contribute to BMP effectiveness including practice design, maintenance, topographic location, and weather. The further incorporation of data variability information into the updated Ag BMP Handbook was identified as a need in order to develop realistic water quality expectations from the implementation of BMPs.

To address this need, the University of Minnesota responded to a 2015 request for proposals to revise the 2012 Ag BMP Handbook and update the inventory of BMPs and include potential barriers to adoption. This 2017 Ag BMP Handbook includes the most current published effectiveness data available for the upper Midwest. We hope this updated Ag BMP Handbook continues to serve as a resource for consultants, agronomists, conservation and watershed professionals, and producers to prioritize best management practices in order to have the greatest impact on pollutant load reductions.

Kind Regards,

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In 2009, the first Legacy Amendment Funding Bill (CHAPTER 172--H.F.No. 1231) was signed into law. The Minnesota Department of Agriculture (MDA) has since received a biannual appropriation for research to quantify agricultural contributions to impaired waters and for the development and evaluation of best management practices to protect and restore water resources while maintaining productivity. The MDA put out a Request for Proposal (RFP) in 2011 to conduct a comprehensive inventory of agricultural Best Management Practices (BMPs) that address current Minnesota water quality impairments including excess nutrients (nitrogen and phosphorus), E. coli bacteria, herbicides, and turbidity. The inventory should address the following factors:

- Definition for each BMP;
- Effectiveness estimates based on existing literature;
- Costs /economic considerations for each BMP;
- Potential barriers to adoption of the BMP.

The development of the Agricultural BMP Handbook for Minnesota was selected as a recipient of the appropriation. The MDA put out a RFP in 2016 to revise and update the 2012 document to include new information or practices not previously incorporated into the Handbook, resulting in this 2017 Revised Handbook.

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Inside This Handbook

Acronyms

ag-BMP Agricultural Best Management Practice for Water Quality
ASABE American Society of Agricultural and Biological Engineers
BMP Agricultural Best Management Practice for Water Quality
BWSR Board of Water and Soil Resources
cfs cubic feet per second
CCPI Cooperative Conservation Partnership Initiative
CRP Conservation Reserve Program
CREP Conservation Reserve Enhancement Program
CSP Conservation Security Program (Conservation Stewardship Program, after 2008 Farm Bill)
CTA Conservation Technical Assistance Program
CWA Clean Water Act
DNR Minnesota Department of Natural Resources
EONR Economic Optimum Nitrogen Rate
EOR Emmons and Olivier Resources, Incorporated
EPA Environmental Protection Agency
EQIP Environmental Quality Incentives Program
FDA Food and Drug Administration
eFOTG Electronic Field Office Technical Guide
GLCA Minnesota Grazing Lands Conservation Initiative
GLRI Great Lakes Restoration Initiative
GPS Global Positioning System
GRP Grassland Reserve Program
HRT Hydraulic Residence (or Retention) Time
HSG Hydrologic Soil Group
IBI Index of Biotic Integrity
IPM Integrated Pest Management
MAWRC Minnesota Agriculture and Water Resources Coalition
MDA Minnesota Department of Agriculture
MIG Managed Intensive Grazing
MPCA Minnesota Pollution Control Agency
MRBI Mississippi River Basin Healthy Watershed Initiative
MRTN Maximum economic net Return
N Nitrogen
NRCS Natural Resources Conservation Service
P Phosphorus
RIM Reinvest in Minnesota
SCS Soil Conservation Service (now the NRCS)
SDR Sediment Delivery Ratio
SRA State Resource Assessment
SWAT Soil and Water Assessment Tool
SWCD Soil and Water Conservation District

TAC	Technical Advisory Committee (Minnesota Department of Agriculture)
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSS	Total Suspended Solids
UAN	Urea and Ammonium Nitrate
USACE	U.S. Army Corps of Engineers
USDA	United States Department of Agriculture
WASCOB	Water and Sediment Control Basin
WD	Watershed District
WEPP	Water Erosion Prediction Project
WHIP	Wildlife Habitat Incentives Program
WMO	Water Management Organization
WRAPS	Watershed Restoration and Protection Strategy
WRP	Wetlands Reserve Program

Glossary

The terms in this glossary are general, informal definitions being provided to guide a better understanding of the content of the overall manual. The USGS maintains a more formal, comprehensive document at ga.water.usgs.gov/edu/dictionary.html.

Anaerobic – lacking oxygen; a biological or chemical process that takes place without oxygen

BMP (Best Management Practice) – procedure to prevent or reduce water pollution

Culvert – a pipe or enclosed structure that allows water to move under a road or other obstruction

Denitrification – the process of removing nitrates from water

Drain tiles – perforated pipes buried in fields to carry excess water away

Ecoregions – Fifteen distinct zones across North America, twelve of which occur in the U. S. based on climate and landforms by the USEPA. Parts of Minnesota are in regions VI, VII, and VIII.

Evapotranspiration – evaporation of water from land and plants

Freeboard – The depth between the top of the effluent and the top of the storage structure.

Hydraulics –structures built to control water, such as dams or culverts

Hydraulic conductivity – the rate at which water moves through a medium

Hydraulic residence (or retention) time – the average length of time that dissolved pollutants remain in the bioreactor.

Hydrology – the science of how water moves through the environment

Hypoxia – reduced dissolved oxygen in water

Impervious – describes a surface through which water cannot move (e.g. concrete)

Leaching - The removal of dissolved nutrients from water

Macro invertebrate – animals with no backbone that can be seen without magnification

Nitrification – the chemical process by which ammonia (NH3) becomes nitrite (NO2-) which then becomes nitrate (NO3). Nitrates in drinking water can cause human health problems.

Pervious – describes a material through which water can drain (e.g. sand)

ppm – parts per million

Return period (event) – A two-year return period event is a precipitation amount (e.g. 2.4 inches of rain or three feet of snow) that has a 50% chance of occurring in any one year. A 100-year return period event is a precipitation amount that has a 1% chance of occurring in any one year.

Rill erosion – Runoff that forms channels in a field

Riparian – river or stream bank

Sidedress – application of fertilizer between rows of crops, near the roots

Soluble – able to dissolve into water

TMDL (Total Maximum Daily Load) – the amount of a pollutant that a water body can receive and still maintain water quality standards

Turbidity – cloudiness in water caused by suspended soil particles

Watershed district – In Minnesota, local government agency that monitors and regulates water bodies and land uses that impact those water bodies. District boundaries are based on natural runoff flows. Subwatersheds are divisions within a watershed.

Water Quality in Agricultural Watersheds

Improving water quality in lakes and streams in agricultural watersheds requires a variety of tools. The purpose of this handbook is to present the findings of a comprehensive inventory of agricultural Best Management Practices (BMPs) that address water quality impairments in Minnesota. This handbook provides water quality practitioners with the information necessary to identify suitable agricultural BMPs (ag-BMPs) for agricultural watersheds in Minnesota.

A note on terminology and organization: In this handbook, the term "BMP" is commonly used as a generic descriptor for all relevant state and federal conservation practices. It is important to note that Minnesota has formally designated statewide and regional nitrogen (N) fertilizer BMPs, as well as statewide pesticide BMPs. These BMPs are scientifically based and are subject to a formal public review process before official designation. The original N loss effectiveness research that went into the development of state N BMPs is cited in the contextual chapters and in the matrices of this document.

Inconsistencies exist in how ag-BMPs are defined, modeled and prescribed throughout the state. Accurate ag-BMP effectiveness information is needed to quantify the benefits to water quality and to determine which practices are best suited to do so. With the vast amount of ag-BMP data available from many disparate sources, it is no surprise that guidance documents differ in reported effectiveness estimates. This document includes the most up-to-date information regarding water quality BMPs in agricultural watersheds that can be used to mitigate pollutants of concern.

The targeted audience of this handbook is project managers, consultants and stakeholders that work to improve water quality in agricultural watersheds. The handbook provides BMP implementers (including SWCDs and watershed districts) and producers with a tool that will enable them to make more informed decisions about which practices to implement based on pollutants treated. This handbook enables water quality practitioners to estimate the level of treatment provided by BMPs so that the appropriate extent or number of BMPs needed can be targeted to the load reductions required to improve water quality. We also anticipate that the handbook will provide common understanding among stakeholders, moving the conversation from one about terminology and effectiveness to one about cost considerations and how to obtain landowner acceptance and support.

Recognizing that some BMPs are new and still evolving because of developing science and technology, this handbook should be revised periodically to reflect new research, technologies and costs as information becomes available, research is completed and knowledge gaps are filled.

Introduction to Agricultural BMPs and Water Quality in Minnesota

Two distinct paths - regulatory and voluntary - both based on improving and preserving water quality, have brought agriculture's impact on water quality to the forefront of discussion in Minnesota.

Since the inception of the Soil Conservation Service (SCS, now the NRCS) in 1935, the agricultural community has been taking an active, field-based approach to improving water quality through conservation practices that reduce soil, fertilizer and pesticide losses. This approach of keeping soil, nutrients and pesticides on the land, instead of in our waterways made both environmental and economic sense and great advances have been made throughout the decades.

Since the Federal Clean Water Act (CWA) was established in 1972, it has been unlawful to discharge any pollutant from a point source (wastewater treatment plants) into navigable waters without a permit; the law has primarily focused on improving the water quality from point sources. The CWA also set in motion processes that have resulted in regulation of stormwater discharges from urban areas in addition to previously regulated discharges.

Minnesota has taken a proactive Watershed Approach to assessing the condition of water bodies throughout the state and plan for improvements, if necessary. Section 303(d) of the CWA requires that states establish total maximum daily loads (TMDLs) of pollutants to water bodies that do not meet water quality standards. The loading limits are to be calculated such that, if achieved, the waterbody would meet the applicable water quality standard. To comply with the CWA, the MPCA assesses the state's waters, lists those water bodies that are impaired (i.e. do not meet water quality standards), and conducts studies to determine the pollutant loading limits for the impaired water bodies.

The Minnesota Water Management Framework was developed in 2014, and lays out the state's approach for implementing watershed-based planning that will sustain a 10-year statewide cycle for locally-led water quality improvement plans. The approach focuses on the watershed's condition as the starting point for water quality assessment, planning, implementation, and measurement of results. This improved approach allows efficient and effective use of public resources in addressing water quality challenges across the state.

In impaired watersheds where the predominant land use classification is agriculture, nutrient management and implementation of agricultural BMPs is often the primary strategy for addressing water quality. The BMP information provided in the Agricultural BMP Handbook can aid strategy development to restore and protect the watershed's water bodies. Farmers, agencies and researchers must work together in order to bridge knowledge gaps and restore Minnesota's waters. The MDA's Minnesota Agricultural Water Quality Certification Program (MAWQCP), a voluntary opportunity for farmers and agricultural landowners to take the lead in implementing conservation practices that protect our water resources, is one avenue that may serve to ensure improved implementation of BMPs. Those producers who implement and maintain approved farm management practices will be certified and in turn obtain regulatory certainty for a period of ten years. Producers who are already certified or actively seeking certification qualify for Financial Assistance Grants for implementing agricultural best management practices. Through this program the

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public receives assurance that certified producers are using BMPS to protect Minnesota's water resources.

Pollutants of Primary Concern in Agricultural Stormwater Runoff

The primary pollutants that are relevant to Minnesota's Water Quality Framework and agriculture are sediment, nutrients (phosphorus [P] and N), bacteria and pesticides. Additionally, biotic impairments exist that may be attributed to any combination of these conventional pollutants, habitat loss, modified hydrology and/or any other factors that prevent establishment of plants and animals expected to be found in a particular water body (see additional discussion of biotic impairments later in this chapter).

Sediment (Turbidity)

The Minnesota Pollution Control Agency names 359 rivers or streams as impaired by sediment and algae. This represents 13.1% of the 2743 impaired rivers and streams (MPCA, 2016) or 5.5% of the 6,564 natural rivers and streams in the state (Minnesota DNR, Lakes, rivers, and wetlands facts. www.dnr.state.mn.us/faq/mnfacts/water.html). Sediment starts as soil erosion, which moves organic and inorganic particles to water bodies during rain events. In streams and rivers, sediment causes turbidity (cloudiness) which, for example, blocks sunlight from aquatic plants and makes it difficult for smallmouth bass to locate food (Brach, 1985). Transparency (with Secchi disks or transparency tubes) and total suspended solids (TSS) laboratory tests are common methods to determine the amount of sediment in water.

Two highly publicized TMDL studies worth noting are the Minnesota River and the South Metro Mississippi River TMDL projects. Lake Pepin is a natural impoundment of the Mississippi River in southeast Minnesota and is impaired for sediment, which is slowly filling in the lake within the Mississippi River. Over the next three centuries the sediment could completely fill in the lake (MPCA, 2007).

The Minnesota River contributes 74% of Lake Pepin's sediment load (MPCA, 2012). It is difficult to quantify the contributions of agriculture on this sediment pollution. However, the Minnesota River Basin is 90% crop land (mostly corn and soy beans) and the study indicates that the river now delivers 10 times as much sediment to Lake Pepin as it did 150 years ago (Engstrom et al., 2009).

The sources of excess sediment to Lake Pepin are primarily eroded stream banks and ravines, bluffs undercut by rivers, and upland agricultural fields (Lenhart et al., 2013). Man-made drainage systems can alter the timing and magnitude of flows, which often exacerbate erosion in downstream streams and ravines. The wind also carries soil from fields and deposits it into water ways.

The South Metro Mississippi River – which has high turbidity – includes parts of several basins: the Upper Mississippi, the Minnesota, Cannon, and Saint Croix Rivers, as well as smaller tributaries (MPCA, 2012). Fifty thousand square miles – most of Minnesota as well as small sections of Wisconsin, South Dakota and Iowa – drain into this reach of the Mississippi. This large area is composed of agricultural fields as well as large-scale, mostly impervious, urban landscapes.

The lag time for seeing positive effects of actions taken to reduce sediment pollution is likely on the order of decades (10 to 50 years). Smaller watersheds would likely show improved conditions more quickly (Cruse et al., 2012).

Nutrients: Phosphorus and Nitrogen

There are 17 rivers and streams in Minnesota impaired by nitrates (less than 1% of impaired rivers). 604 lakes (or 33% of all impaired lakes) show Nutrient/Eutrophication Biological Indicators, which is impairment due to P pollution, according to the Minnesota Pollution Control Agency (MPCA, 2016).

N is applied to agricultural fields as fertilizer or manure. Plants absorb N from the soil primarily in the form of nitrate (NO3-), which is very soluble in water. NO3- that is not utilized by the crop may leach into groundwater during irrigation or precipitation events. In Minnesota, nitrates are a drinking water pollutant and rarely are the primary cause of lake eutrophication although in karst areas with significant groundwater-surface water interactions the drinking water standard of 10 mg/L can be applied to streams. Blann et al. (2009) cite numerous studies detailing increased nitrate export from the Mississippi River Basin over the last half century. This excess nitrate has been linked to the hypoxic zone in the Gulf of Mexico (Rabalais et al., 2001; 2010) and accelerated eutrophication in Lake Winnipeg, Canada (Pip, 2006). N is the limiting nutrient in ocean systems.

Runoff, primarily from pasture and agricultural fields but also from drainage through tiles, accounts for roughly 19% of the state's total 11,732,000 lbs of total P contributions to Minnesota surface waters (MPCA, 2014). Feedlot runoff is also a contributor; statewide, manure accounts for between 70,000 to 242,000 pounds of P per year, depending on the magnitude of runoff.

P also arrives in rivers and lakes bound to sediment (adsorption), especially at high flows, and then settles to the river or lake bed. This bed sediment provides a long-term source of P in the water system.

The lag time for seeing positive benefits of nitrate pollution reduction are on the order of years to decades. Nitrates dissolve into groundwater, which can move very slowly. The groundwater can act as long term storage for pollution that shows up in downstream watersheds many years after its use on agricultural fields (Cruse et al., 2012).

The lag time for P is directly related, and similar, to the lag time for sediment. P is often bound with soil and so can also take 10 to 50 years for the positive benefits of BMPs to show up in a watershed (Cruse et al., 2012).

Pesticides

Pesticides – herbicides, insecticides, fungicides – are vital to crop production. Pesticide use in Minnesota is dominated by herbicides (Table 1). From a water quality perspective, the factors affecting the transport of these pesticides from field to watercourse are adsorption, solubility and persistence. Adsorption is the ability of a chemical to bind onto a larger particle (such as sediment), solubility is the ability of a chemical to mix with water and remain is solution, and persistence is the time it takes for a chemical to degrade in a soil environment. Although research may not be available for all pesticide formulations, knowing the chemical properties of the active ingredient(s) allows for general characterization of environmental risk.

Table 1. Top 10 crop chemicals sold in Minnesota in 2013 (the most current year with data available).

Pesticide	Pounds of Pesticide Sold in Minnesota
Glyphosate	24,862,447
Metam Sodium	6,755,570
Acetochlor	4,733,089
S-Metolachlor	1,864,095
2,4-D	1,498,747
Atrazine	916,446
Dimethenamid-P	746,622
Chlorpyrifos	678,786
Propionic Acid	555,301
Dicamba	432,238

Applicators are legally required to follow the requirements specified on the product label. Many commonly used pesticides, such as atrazine and chlorpyrifos, specify minimum setback distances from water bodies and have provisions regarding maximum wind speed at the time of application. These requirements are designed to prevent and/or minimize off target movement of pesticides. In addition, the MDA has developed product specific BMPs for certain herbicides and insecticides including the following active ingredients: acetochlor, alachlor (no longer registered for use), atrazine, chlorpyrifos, metolachlor, and metribuzin.

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These pesticides have been identified as posing additional risk to groundwater and/or surface water in Minnesota due to widespread use and chemical properties. The BMPs developed by MDA should be followed to minimize movement from the point of application and to ensure the long-term access to these products for pest control.

Monitoring conducted by MDA has found frequent detection of pesticides, and/or pesticide breakdown products in Minnesota water resources, however, concentrations rarely exceed established human health or aquatic life based water quality reference values. There are currently no pesticide violations for drinking water standards in Minnesota. There are 13 pesticide impairments for legacy pesticides including DDT (5), dieldrin (5) and toxaphene (3), and five pesticide impairments for currently registered pesticides including acetochlor (1) and chlorpyrifos (4) in Minnesota rivers/streams on the proposed 2016 MPCA Impaired Waters List. The MDA will continue to monitor for pesticides, and will develop and promote BMPs to minimize their effect on water resources.

Bacteria

Bacteria impairments are defined by testing for E. coli in water bodies. E. coli testing is not a direct measurement of impairment of a water body but an indicator of fecal contamination. Previously, fecal coliform testing was used to determine impairment. This results in some water bodies being listed for E. coli and some impairments listed for fecal coliform; regardless of the listing, the cause is the same, fecal contamination.

Bacteria in agricultural regions results almost exclusively from manure; wildlife droppings and improperly installed or maintained septic systems contribute as well. When spread on fields as fertilizer, bacteria-laden manure can be carried by precipitation runoff through drain tiles or overland to surface waters. Spills or runoff from manure storage facilities also contaminate surface water. Animals grazing in or next to natural water ways can also directly contaminate the water (Cruse et al., 2012).

The Minnesota Pollution Control Agency has identified 611 rivers and streams with elevated E. coli or fecal coliform counts, which represents 23.6% of all MPCA identified impaired rivers and streams and 6% of all Minnesota's flowing water bodies (MPCA, 2012b). A 2006 regional study showed portions of the lower Mississippi River contained elevated fecal coliform counts, as were some reaches of the Vermillion and Cannon Rivers (MPCA, 2006).

In general, the effects of BMPs targeting bacteria can often be seen within days or months because bacteria do not persist in the environment (Cruse et al., 2012). In contrast to the rather quick effects of bacteria BMPs, is the persistence of bacteria within instream sediments, potentially dampening the quick effect of the BMP. The impact of legacy bacteria in instream sediments on water quality is still in its infancy.

Biotic Impairments

The MPCA completes bioassessments for fish, aquatic macroinvertebrates, and less commonly aquatic plant assemblages. These bioassessments include the calculation of an index of biotic integrity, or IBI. The MPCA sets thresholds for these IBI scores and places water bodies with IBIs lower than the corresponding threshold on the list of impaired waters.

Biotic TMDLs require that a stressor identification process be followed in order to determine the cause of the biotic impairment. The primary stressors must then be translated into a load-based TMDL. Although some stressors do not naturally fit into a pollutant load-based framework (such as habitat quality and flow regime), EPA Region V in the past has required that biotic TMDLs be based on pollutant loading goals. This had led to the use of translators, in which load-based pollutants are used in place of non-load-based stressors (EPA, 2017). In agricultural regions, these stressors can be sediment, P or pesticides.

Water Quality in Ag Watersheds

Funding Conservation Practices

The Environmental Quality Incentives Program (EQIP) is a NRCS supported, voluntary program that provides financial and technical assistance to agricultural producers to plan and implement conservation practices that improve soil, water, plant, animal, air and related natural resources on agricultural land and non-industrial private forestland (USDA NRCS 2017). EQIP may also help producers meet Federal, State, Tribal, and local environmental regulations. Eligible land includes cropland, rangeland, pastureland, non-industrial private forestland and other farm or ranch lands. Each BMP chapter within this handbook outlines the available EQIP options.

In addition to EQIP there are several additional Minnesota specific programs offered through the MDA to assist with funding the implementation of agricultural BMPs. The MAWQCP was discussed earlier as one potential option. Several alternatives are summarized below.

Agricultural Best Management Practices (AgBMP) Loan Program

This program provides low interest loans to finance BMPs that reduces adverse impacts, restores, or protects water quality. Most practices that benefit surface or ground water quality are eligible; however eligibility is determined on a case by case basis in coordination with local managers of the AgBMP Loan Program. Additional information about the AgBMP Loan Program can be found at: www.mda.state.mn.us/agbmploans or by calling 651-201-6618.

Local managers and participating lenders can be found at: https://app.gisdata.mn.gov/mda-agbmploan/

Agricultural Improvement

This program provides financing for improvements to a farm. These improvements can be for any agricultural purpose including grain handling facilities, machine storage, livestock buildings and improvements, wells and manure systems.

Livestock Equipment Loan Program

This program is designed to finance the purchase of livestock, equipment for housing, confinement, feeding, watering, fencing, milk production and waste management.

Farm Opportunity Loan Program

This program is used to finance machinery or equipment to add value to crops or livestock, adopt best management practices, reduce or improve management of agricultural inputs resulting in environmental improvements, or to increase the production of on-farm energy (no refinancing).

Methane Digester Loan Program

This program is used to finance the purchase and construction of a system designed to produce electricity from manure. It may be used as a match for a Federal loan/grant.

For information on any of these loan programs, the Minnesota Rural Finance Authority (RFA) can be contacted directly at 651-201-6004 or more information is available at www.mda.state.mn.us/agfinance

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Agricultural BMP Inventory

This handbook was created by conducting an inventory of current research on agricultural BMPs that address water quality impairments in Minnesota. The primary focus was on field research containing empirical data conducted in Minnesota and the Upper Midwest. Additional research that does not fit these criteria such as research from elsewhere in the country or modeling studies were included as a supplement to local data when local empirical data was lacking. This distinction is made explicitly throughout the text of the document. The inventory of research focused on BMP definitions, effectiveness estimates based on existing literature, costs and economic considerations, potential barriers to BMP adoption and knowledge gaps.

BMP removal effectiveness

This handbook does not contain a comprehensive table of BMP pollutant removal effectiveness. Instead, pollutant removal tables are located in individual BMP chapters. Because every individual pollutant removal observation contains specific site conditions and caveats, the reader is urged to review the information within the text of each BMP chapter to determine if a removal efficiency is applicable to a particular BMP project.

This being said, compilations of BMP effectiveness are available from a variety of sources nationwide (Appendix B). Although these results are not necessarily from local or regional examples they can be used (with caution) in the interim until local research can be conducted to fill the research gaps identified in this document. The information in the BMP chapters of this report should be used whenever possible to define BMP effectiveness.

Since there is considerable variability in BMP effectiveness, the next chapter of the handbook describes the causes of variability in BMP effectiveness. The degree of variability is also compared amongst BMP types and pollutant types. It was found that dissolved pollutants were removed more variably than particulate pollutants such as sediment and particulate phosphorus (P). Dissolved P removal was the most variable. Many studies have shown that certain BMPs can actually serve as a source of dissolved P at times (Lenhart et al., 2016).

BMP Research Summary

Our BMP research was conducted with the goal that a comprehensive literature review becomes an accessible document in its final form and that this document represents the cutting edge of BMP research with particular attention paid to research conducted in Minnesota and neighboring states. This research was accomplished by:

- Creating a preliminary BMP list
- Creating a preliminary resource list
- Researching all BMPs
- Identifying research gaps
- Receiving additional sources of data
- Compiling all data into BMP chapters

Direction and collaboration with University of Minnesota, government agency staff and the MDA Technical Advisory Committee (TAC) was received throughout the process and external reviews were completed at critical development junctures.

The list of BMPs included in the handbook was based on the 2012 edition using the MN NRCS eFOTG list, our own expertise and through consultation with MDA. This BMP list contained the name, position on the landscape, primary use and description of BMP. The main objective of this step was to develop a common understanding with MDA and other interested stakeholders regarding consistent terminology and extent of this research project.

The chapter updates for the 2017 handbook focused on post-2012 research though some earlier studies were discovered as well. Updates focused on BMPs with substantial new research since 2012 such as nutrient management, bioreactors, two-stage ditches, field borders and filters, subsurface drainage management and cover crops. Saturated buffers was added as a new BMP chapter in the 2017 edition. Other chapters had few changes, such as terraces, which have not been thoroughly-researched in recent decades.

The project team assembled a preliminary list of resources and met with MDA staff and TAC members to discuss additional resources. The bulk of the research information was obtained from (in order of importance):

1. Peer-reviewed research articles
2. Agency technical manuals and guidance (e.g., NRCS)
3. Agency-funded research reports (e.g., EPA 319 research reports)
4. Unpublished research (ongoing studies, gray literature, websites)
5. Other data sources (e.g., SWCD and Watershed District reports and theses)

Discovery Farms - Minnesota

Discovery Farms has been conducting water quality research on working farms in Minnesota since 2010. The Minnesota program was modeled after Wisconsin Discovery Farms which has been active since 2001. A joint partnership between the Minnesota Agricultural Water Resources Center and the Minnesota Department of Agriculture, producers and others has produced a great water quality research framework that is geared toward the impact of different agricultural practices on edge of field water quality. The mission of the Discovery Farms program is to gather water quality information under real-world conditions, providing practical, credible, site-specific information to enable better farm management. The program is designed to collect accurate measurements of sediment, nitrogen (N) and phosphorous (P) movement over the soil surface and through subsurface drainage tiles and to generate a better understanding of the relationship between agricultural land management and water quality. Discovery Farms Minnesota and Wisconsin Discovery Farms have provided much of what we know about the importance of timing of nutrient management in cold climates and will continue to be the basis of agricultural water quality studies in the future. The Discovery Farms framework is now being applied in other states as well with twelve core discovery farms and two special project farms in Minnesota (Figure 1, Table 1). These working farms will provide Minnesota agricultural research over the next 10 years and beyond.

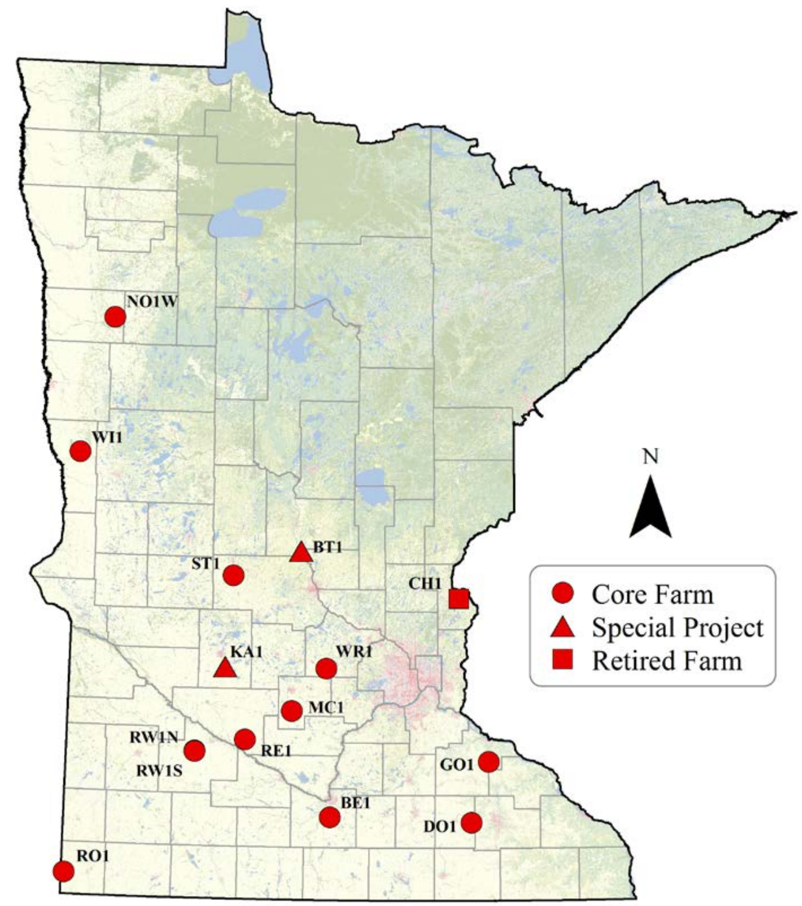

Figure 1. Discovery Farms Minnesota Locations as of July 2017.

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Agricultural BMP Inventory

Table 1. Discovery Farm locations and project information.

County	Farm Enterprise	Start of Project	Monitoring Setup
Goodhue	Swine farrow-to-wean and beef (corn-alfalfa)	Sep-10	Surface runoff (6.3 acres)
Stearns	Dairy (corn-alfalfa)	Mar-11	Surface runoff (28.2 acres) and subsurface tile drainage (24.8 acres)
Chisago	Grain (corn-soybean)	Mar-11 (End Sep-16)	Surface runoff (6.1 acres)
Blue Earth	Swine finishing and grain (corn-soybean)	Jun-11	Surface runoff (14.3 acres) and subsurface tile drainage (26.2 acres)
Wright	Dairy (corn-alfalfa)	Dec-11	Surface runoff and subsurface tile drainage (23.9 acres)
Renville	Grain (corn-soybean-sweet corn-peas)	Dec-11	Subsurface tile drainage (81.0 acres)
Dodge	Swine finishing and grain (corn-soybean)	Oct-12	Surface runoff and subsurface tile drainage (13.9 acres)
Wilkin	Grain (corn-soybean)	Oct-12	Subsurface tile drainage (160.0 acres)
Norman	Grain (sugarbeet-corn-dry bean-soybean-wheat)	Oct-12	Subsurface tile drainage (570.8 acres)
Rock	Beef and grain (corn-soybean-alfalfa)	Oct-13	Surface runoff (25.5 acres)
McLeod	Grain (corn-soybean)	Spring 2017	Surface runoff and subsurface tile drainage (60.6 acres)
Redwood (north)	Grain (corn-soybean)	Spring 2017	Surface runoff and subsurface tile drainage (12.5 acres)
Redwood (south)	Grain (corn-soybean)	Spring 2017	Surface runoff and subsurface tile drainage (10.2 acres)

Gap Analysis

Knowledge gaps identified during research were provided to the TAC for review and comment. Because of the focus in this handbook on local and regional data to assess the pollutant removal capacities of BMPs, the pollutant removal references used in this handbook have been categorized geographically. Tables in Appendix A present the references from Minnesota sources, Upper Midwest (including Minnesota) sources, national sources and all sources. Gaps were then categorized as either research ongoing or information unavailable. Information was gathered from available sources and the state of ongoing research was documented. Information that is unavailable was considered a data gap and is documented for future research consideration in each section.

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BMP Chapters

Individual chapters were developed for each BMP and grouped by BMPs that Avoid, Control and Trap pollutants, a framework used by the NRCS. These chapters serve as a summary of the research findings for each BMP, including definitions, effectiveness and cost considerations and research gaps. These are intended to be used by water quality practitioners during plan development to help inform them and their stakeholders about selecting the appropriate BMPs that achieve the pollutant reductions desired for their watershed. These chapters may also be used as stand-alone products for outreach campaigns, BMP tours, and other training opportunities.

Suites of BMPs and Conservation Farming Systems

The organization of this handbook describes individual BMPs within the context that they have been studied. Many conservation practices are used in series or systems to multiply conservation benefits. The complexities and synergies of conservation systems complicate the study of effectiveness of BMPs but it is becoming clear that conservation systems are more effective than BMPs individually.

Often suites of BMPs are implemented together based on the geographical region of the state. Throughout this document are examples of suites of BMPs that have been studied. In some cases references have been used under multiple BMP chapters with a description of the study and the interaction between BMPs.

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Factors Influencing the Variability of Effectiveness of Agricultural BMPs in Minnesota

Introduction and Background

Agricultural best management practices (BMPs) have a long history of effective use in the upper Midwestern United States and have been well-studied. Many studies were done from the 1930s to the 1980s focusing on sediment loss reduction to conserve soil. Most agricultural conservation practices in use today were designed with sediment and particulate nutrient removal in mind, so their effectiveness tends to be more predictable (Schwab et al., 1981); however, many studies were done in other parts of the country or were done long ago so there is often a lack of data specific to a given practice, climate or region. BMP effectiveness data from The Agricultural BMP Handbook for Minnesota is being used to inform watershed-scale hydrology and nutrient dynamic models and associated BMP-siting tools for watershed planning following Minnesota's Water Management Framework. One problem that arises in BMP planning is the use of overly optimistic treatment efficiency values without recognizing the variability in the effectiveness studies. When scaled up to landscapes or watersheds the uncertainty can affect the ability to assess the success of management programs (Ogle et al., 2003). There has been a history of watershed management programs around the country not achieving established water quality objectives despite the implementation of hundreds or thousands of BMPs. Well-known examples include Chesapeake Bay and the Gulf of Mexico hypoxia problem (Cruse et al., 2012).

How is effectiveness defined?

Effectiveness can be defined as "The degree to which objectives are achieved and the extent to which targeted problems are solved." (businessdictionary.com). When viewed from this larger perspective, design, cost, landowner adoption and long-term maintenance of BMPs influence effectiveness; however, when applied to agricultural management practices, it typically means the rate or percentage of pollutants removed by a certain BMP. The effectiveness is frequently assessed, and often used as the benchmark of success, by the reduction in concentration of a pollutant(s). Yet the total load of pollutant reduction is a better indicator of effectiveness for cumulative benefit over years or decades. For example, a small one acre treatment wetland may have a similar nitrate removal efficiency to a larger 40 acre depressional wetland, yet the latter would remove a much larger total load on an annual basis. Therefore, the effectiveness of BMPs should not be judged solely on the basis of concentration. Reduction in load is also the metric used in Total Maximum Daily Load (TMDLs) calculations, which is used to allocate the maximum amount of a pollutant allowed to enter a waterbody and continue to meet water quality standards.

Effectiveness varies by storm event and spatially across the landscape at different sites. This variability is commonly assessed using the sample variance which is defined as:

$$s^2 = \left(\frac{1}{n-1}\right)\sum_{i=1}^{n}(\eta_i - \bar{\eta})^2$$

where η_i is the removal efficiency defined for the i^{th} event or site as:

$$\eta = \frac{X_{in} - X_{out}}{X_{in}}$$

where x is the mass or concentration of the pollutant and $\bar{\eta}$ is the "average" removal efficiency that can be defined using the arithmetic average or using the total mass in and mass out. For steady flow, as would be found in a wastewater treatment wetland for example, the removal efficiency defined for concentration is equivalent to that defined using mass. However, in most BMPs where nutrient concentration and inflow are driven by storm events the average removal rate cannot be used in total mass removal estimates because variation is much greater. In these settings estimation of variation becomes more important. Other measures of variation include (1) the standard deviation defined as the square root of Eq. 1, (2) the coefficient of variation (c.v.) defined as the ratio of the standard deviation and the average removal efficiency, (3) the inter-quartile range defined as the difference between the upper and lower quartiles of measured η and (4) the range defined as difference between the largest and smallest removal efficiency.

Ideally, the success of a BMP would be determined objectively by whether or not its performance equals or exceeds a design value. In practice, the majority of agricultural BMP installations do not have specific quantitative objectives defined when they are installed or data are not available to compute the effectiveness. In these cases, the determination of success is based on a subjective professional judgment or is assumed successful upon completion of installation.

Review BMP effectiveness variability in Minnesota and the upper Midwest

Although models, equations, and empirical tools are used to predict effectiveness of BMPs, managers ultimately rely on data from field studies as the best indicator of BMP success. Studies are done in a variety of climatic and hydrologic settings in different agricultural production systems and are influenced by economic factors and management practices. Study results may be outdated or sited in varying landscape positions, which can lead to great variability in the study results documenting BMP effectiveness and uncertainty. Each chapter of The Agricultural BMP Handbook for Minnesota (Miller et al., 2012) describes data that influence the effectiveness of pollutant removal by focusing on local studies in Minnesota and nearby Midwestern U.S. states which have similar climate, geology and land-use (Table 1). Data from around the U.S. are included in the appendix, which contains a more comprehensive list of BMP effectiveness studies.

Many studies have been completed on Ag BMP effectiveness over the past century which has led to a large range of effectiveness. An illustrative example is the research done to reduce soil erosion. In 1929, ten farms at substantially different locations were established by an appropriation of the U.S. Congress to control surface erosion and quantify the factors that impact erosion rates (Ayres, 1936). This work was combined with other research to determine the effectiveness of different BMPs, and it has been embedded into the Universal Soil Loss Equation (USLE) and other models. These advances enable managers and landowners to better predict rates of soil and nutrient loss from different agricultural management practices. The original USLE was based on approximately 10,000 plot-years of data. Unfortunately, this type of data set does not exist for many of the BMPs of interest in Minnesota. Greater uncertainty on their effectiveness requires careful consideration of factors affecting their performance.

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Variability of BMP Effectiveness

Factors contributing to uncertainty in agricultural BMP effectiveness

Numerous physical factors play a role in creating variable BMP effectiveness as described in the sections below and outlined in Table 1.

Table 1. Some of the major factors influencing effectiveness of agricultural BMPs and its variability.

Factors affecting variability in BMP	Issues specific to drainage water management
Climatic and hydrologic variation	
Nutrient cycles and transformation	Dissolved pollutants such as nitrate-N and dissolved P are predominant in farm drainage water.
Sediment erosion process and deposition	Sediment is usually found in low concentrations in drainage water.
Hydrologic pathways and storage for total load reduction and downstream benefits	Surface inlets or not? Ability to hold back water or temporarily hold or store it.
Design factors	
Reliability (How well are design guidelines established? Can the design be exactly replicated?)	Subsurface drainage system design is well defined. The benefits of many newer BMPs such as bioreactors or saturated buffers are less well documented.
Longevity, management and maintenance	
Lifespan, operation and maintenance requirements	Lifespan influences effectiveness over years to decades, some BMPs such as woodchip bioreactors have a limited lifespan while controlled drainage structures have high operation and maintenance requirements.
Economic factors	
Cost to be designed and installed Long-term management and maintenance costs; Easement or land purchase costs	Many drainage BMPs such as controlled drainage are only installed when tile drainage systems are being enhanced or newly installed.
Social factors	
Adoption by landowners, suitability to local farm systems, ease of installation, local landowner values	Adoptions of drainage management practices typically have landowner support because they are integrated with farming systems.

Physical factors affecting pollutant removal variation

Climate and hydrologic variation

The climate and hydrologic regime strongly influence rainfall amounts, seasonality of rainfall, the production of surface runoff, groundwater infiltration and other factors involving the flow of water and transport of sediment and pollutants. For example, eastern Minnesota has considerably more rainfall than western Minnesota with annual rainfall levels ranging from 18-35 inches per year moving in an east-west gradient across the state (Figure 1). Perhaps more importantly for the management of sediment and nutrient pollution, the flow path of rainfall, runoff and drainage flow has a great impact on pollutant transport and delivery to water bodies. For example, it is known that subsurface drainage flow has a greater N-to-P ratio than surface runoff (Green et al., 2007). Values for annual average stream flow range from 2.0 to 12.0 inches which is approximately 10 to 40% of total annual average rainfall across the state (Lorenz et al., 2010) (Figure 2). The greatest amounts of surface runoff occur in northeastern Minnesota where there are abundant rock exposures at the ground surface and shallower surface soils; however, little tile drainage exists in that region. In contrast, western Minnesota has a total annual stream flow of only 1.0 to 3.0 inches (Lorenz et al., 2010). In this area, most watersheds with intensive tile drainage have a small percentage of the total load of nutrients carried as surface runoff. In this region BMPs that address subsurface drainage are keys to mitigating nutrient loading, particularly nitrate, as most of the pollutant load is carried through the subsurface drainage pipes.

In addition to rainfall quantities, the flow path of runoff and drainage water strongly influences the relative loading of pollutants (Green et al., 2007). Surface runoff picks up sediment and nutrients, especially particulate P when flowing over bare soil with sufficient velocity. Subsurface tile flow and groundwater both carry dissolved nutrients, specifically nitrate-N, in greater abundance than surface flow, but transport less sediment; therefore, subsurface flow has a greater ratio of N: P compared to surface runoff.

One of the biggest causes of variation in BMP effectiveness is annual and seasonal variability of rainfall and runoff events. The same watershed can fluctuate from a drought to flood stage within the same year. Flow levels strongly influence BMP nutrient removal efficiency as many practices are not as effective at removing dissolved nutrients at higher flows. At high flow levels, many BMPs do not have the capacity to treat the excess runoff or drainage flow, so more untreated water flows through the BMP. Typically, the highest flow levels in Minnesota occur in the time period of April to June when temperatures are also lower, causing a reduction in nitrate removal through denitrification. Drought years can also lead to higher nutrient losses from watersheds in subsequent years due to flushing of nutrients in the wet year. Time lags can complicate interpretation of the data (Cruse et al., 2012).

Flow variability makes pollutant removal rates more unpredictable. When water storage BMPs such as sediment basins or wetlands have more constant flow input, pollutant removal rates are less variable. In situations with flashy, intermittent flow, the flow input, sediment eroded, and nutrient load are more unpredictable. Gully erosion is highly episodic, occurring only at high flow events often separated by months or even years (Harvey et al., 1985). BMPs to control sediment from gullies will appear to have highly variable effectiveness, especially when observed over shorter time scales. In contrast most drainage water management practices have lower variability overall and carry little sediment.

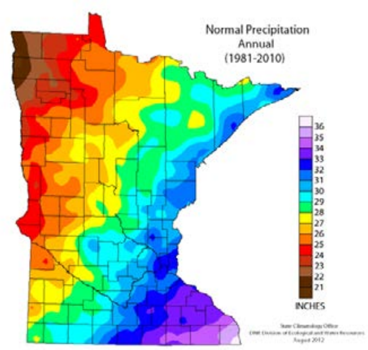

Figure 1. Average annual rainfall in Minnesota. Rainfall increases moving from the west - northwest to east - southeast across the state. (Image from State Climatology Office of Minnesota)

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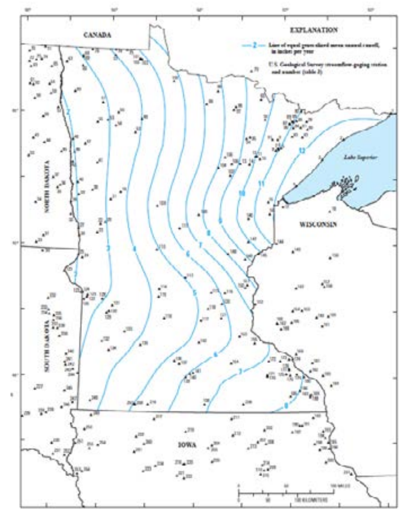

Figure 2. Average annual stream flow in Minnesota in inches of stream flow at the watershed scale. This is equivalent to total inches of runoff and drainage flow to the outlet streams. (Image from Lorenz et al., 2010)

Pollution Variation

An assessment of BMP nutrient removal effectiveness studies with sample size (n) ranging from 17-100 studies from the Agricultural BMP Handbook for Minnesota (Merriman et al., 2009; Miller et al., 2012) was done using the coefficient of variation (c.v.), which is defined as the ratio of the standard deviation and the average removal efficiency, to normalize standard deviation relative to the mean allowing for better comparison across studies. The data were obtained from studies done around the U.S. because there was insufficient sample size from Minnesota alone. For this assessment, physical removal efficiency was considered only, not cost-effectiveness. This assessment showed that removal rates were highly variable between BMP types, making it difficult to find significant differences across BMP types, when grouped using the USDA categories of avoiding, controlling and trapping practices.

BMP effectiveness also varies by pollutant type (Table 2). Particulate and dissolved pollutants are mobilized, transported and retained or deposited via different processes. In general, sediment and particulate P had the highest average removal efficiencies at 65 and 64%, respectively. Total P, which is typically comprised primarily of particulate P, followed at 57%. Nutrients where dissolved forms predominate had lower removal efficiencies averaging from 15 to 53%, with dissolved P lowest at 15%. Dissolved P was the only pollutant examined where negative removal rates were recorded as an average for an entire study, indicating that the BMP was acting as a nutrient source at times.

Table 2. Data used in assessment from agricultural BMP studies around the U.S.

Pollutant	Sample size (n)*	Mean pollutant removal rate (%)	Removal range (%)
Dissolved phosphorus	31	15	-63 - 45
Nitrate-nitrogen (NO_3-)	28	25	22 - 37
Ammonium (NH4+)	17	44	30 - 47
Total nitrogen (N)	55	53	27 - 57
Total phosphorus (TP)	86	57	44 - 78
Particulate phosphorus (P)	17	64	60 - 79
Total sediment	100	65	60 - 86

*Each sample represents one study on pollutant removal efficiency, adapted from data summarized in Merriman et al., 2009 and Miller et al., 2012.

Variability of BMP Effectiveness

Analysis of the same data showed that the c.v. of removal rates for dissolved pollutants (dissolved P and NO_3-) was higher (c.v. of 1.98 and 1.01 respectively) than removal rates for particulate pollutants. Sediment and particulate P had c.v. values of 0.32 to 0.27, respectively (Figure 3), presumably because the process of sediment trapping has been extensively studied and well-established BMP designs are effective.

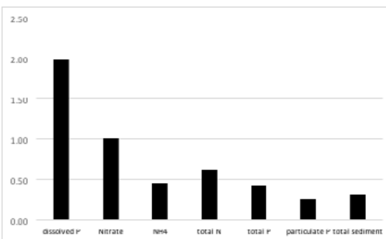

Figure 3. Coefficient of variation (c.v.) of removal rates by BMP by pollutant type, n = 17 to 100. Variation in nutrient removal efficiencies (as measured by the coefficient of variation, cv) is greater in dissolved substances (P and nitrate) to the left of the bar chart. c.v. = standard deviation (σ) divided by the mean (μ). Abbreviations: P = phosphorus, NH4 = ammonium, N = nitrogen.

Soil properties and geomorphic setting

Soil properties strongly affect soil erosion rates and nutrient cycling processes in farmland. For field erosion, this is reflected in the erodibility coefficient (k) values used in the Universal Soil Loss Equation (USLE) and the revised equation (RUSLE). Higher k values indicate that more soil is lost per acre per year given the same rainfall amounts. For example, it is well established that non-cohesive soil types such as sand or loamy sand tends to be more prone to rill and gully erosion than more cohesive soils and tend to have higher k values. Soil structure and aggregate formation, which is harder to measure, helps to resist erosion and pollutant loss as well. Soil carbon strongly affects water retention in soil and supports denitrification. Soils low in organic carbon tend to be more erosion prone and have lower denitrification rates. Minnesota farmland regions have great variability in soil organic matter content. For example, prairie soils and drained wetland soils tend to be high in carbon, while sandy deposits in alluvial areas tend to be low in soil carbon.

Seasonal variation in soil properties also influences erosion and pollutant loading rates. After tillage, soil structure and the bonding effects of plant roots and the chemicals exuded from them are greatly reduced; therefore, farm soil is more erodible in spring before crop growth has begun. The freeze-thaw cycle can reduce soil strength, making soil more erodible in winter and spring. Stream bank and bluff slumping are also more common at this time of year.

Over longer time scales, nutrients can become deficient or in excess in farmland soils and adjacent riparian areas. In some Midwestern watersheds, P levels have accumulated in soils over time leading to increasing downstream loading, a problem that has been particularly critical in the recurrence of algae blooms in Lake Erie (Muenich et al., 2016), but is prevalent throughout the Midwest. High levels of legacy P can mask the benefits of recently installed BMPs making them appear less effective than they otherwise would be.

Landscape position

Landscape position strongly influences the physical processes of nutrient and sediment transport and deposition. The treatment train framework classifies the role of different BMPs according to landscape or hillslope position into avoiding, controlling and trapping categories (Figure 4). Typically, practices placed in series help to improve the effectiveness of downstream BMPs. Avoiding practices, which are typically high in the landscape, help to prevent nutrient and soil loss and hold soil in place. Trapping practices such as wetlands, buffers, and sediment ponds help to remove pollutants at the end of the pipe. For systems of the same size, the effectiveness of these practices vary substantially with their location in the watershed and their position in a treatment train. For example, if a practice is located in the uplands with relatively small drainage areas and runoff flow rates, removal efficiency is larger than that obtained with the same practice located downstream with larger drainage areas. Likewise, if a practice is positioned to be the first practice in a treatment train, some pollutants, such as larger sediment particles, are more easily removed, resulting in a more effective BMP than implementing the same practice at the end of the train. Landscape placement is not merely a two-dimensional factor; the depth of the BMP is also important in many cases, especially when subsurface flow is a large contributor. Variability of the soil in the watershed will also influence effectiveness and determine placement (Ssegane et al., 2015).

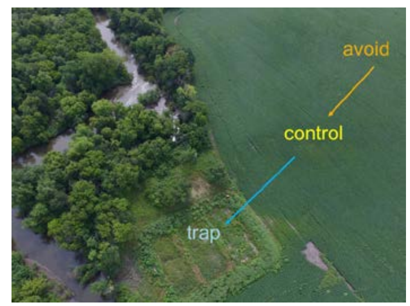

Figure 4. The treatment train concept is based on the idea that applying different management practices across a hillslope in a series will maximize pollutant removal effectiveness. BMPs located in different hillslope positions raise different management issues, have varying maintenance needs, and different prospects for long-term utility or benefit. The NRCS uses the "avoid – control - trap" framework to group BMPs by hillslope position and removal processes. Avoiding practices are located in the field above water bodies. Controlling practices moderate the movement of water and pollutants already in motion downhill and trapping practices capture and store water and pollutants prior to entering the stream or ditch. (Photo by David Hansen)

Treatment train examples

Avoiding practices typically involve nutrient and tillage management practices done by the farmer / landowner such as cover crops and no-till agriculture. Controlling practices moderate the downstream flow of water and nutrients in practices such as grassed swales and controlled drainage. Trapping practices slow down, settle, and trap sediment and pollutants and include riparian buffers, treatment wetlands, and Water and Sediment Control Basins (WASCOBs) to name a few examples from Minnesota. When practices that reduce sediment or pollutant load are combined with practices that regulate and trap outflow there can be synergistic benefits that could increase removal effectiveness in a non-linear way.

Design and cost factors

Design factors

In general, structural BMPs with tightly controlled inlets and water control structures at the outlet have less variability in their removal efficiencies than non-structural BMPs that are unable to regulate the flow. Structural BMPs lend themselves to laboratory studies using smaller prototypes scaled based on principles of similitude and rigorous theoretical modeling. They may have higher initial investment, but longer benefits. Non-structural BMPs do not control or regulate as much, so they are likely to be more variable, especially if they are not properly maintained.

Cost factors

Numerous cost factors may affect BMP selection and design, particularly land and crop prices which strongly influence cost-benefit ratio. While projects with higher pollutant removal may cost more at first, BMP longevity tends to increase. Other design factors that affect performance include complexity of installation and maintenance of BMPs. Landowner adoption is influenced by many factors (Olson, 2013). Overly technical and complex projects tend to be adopted less by farmers and rural landowners.

3. Longevity, management and maintenance

Sustainability and longevity considerations influence how effective BMPs are from a policy perspective. BMPs may be well designed and constructed, but if they are not maintained properly, there may be

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a reduction in their treatment effectiveness. For example, depending on the placement of WASCOBs and other sediment trapping practices, they may fill rapidly with trapped sediment, resulting in a reduction in trapping efficiency. The effectiveness of tile drainage practices may also decline, including bioreactors which may become nutrient saturated or result in decomposed woodchips. Research is currently exploring cost-effective designs to allow easier management of these practices. Practices which include vegetation require an establishment period before reaching optimal conditions since many plant communities do not fully establish within the first two years, limiting the vegetation's role in reducing flow or removing nutrients initially.

Economic factors

Economics often dictate the extent and BMPs installed since land and crop prices strongly affect cost-benefit ratios, as well as the type of crop itself which is often driven by economics. For example, soybean and corn tend to yield different amounts of runoff and nutrient pollution in drainage water. Projects with initially higher pollutant removal may cost more to install. However, BMP longevity may offset high initial cost through longer lifespan. For example, large restored wetlands have high upfront costs but may last for 100 years or more providing great long-term benefit.

Social factors (landowner adoption and continuity in practices over time)

Landowner adoption and continuity in practices over time are key factors influencing BMP effectiveness in the broad sense and are influenced by complex factors (Olson, 2013). Landowner maintenance of BMPs, including practices such as managing water levels in wetlands or controlled drainage structures, or continuing tillage and nutrient management practices after NRCS payments cease, are critical for the continued BMP effectiveness. Vegetation management and species selection will also have an impact on effectiveness. For example, taller vegetation, may be viewed as weedy to many landowners and be mowed; however, above-ground biomass promotes root growth. Regular mowing is likely to impede root development and organic matter accumulation in buffers, subsequently reducing nutrient uptake, and water storage capacity. Furthermore, some landowners may have preferences on the amount of standing water on a property, with the tendency to implement practices which quickly remove standing water. Making adjustments that appeal to landowner values and visual preferences as well as clearly defining expectations of the practice may all help improve the effectiveness of agricultural BMPs.

Application to BMP planning

Recognizing variability more explicitly in watershed management plans ultimately provides for better planning and implementation of agricultural BMPs. Although recognizing variability may appear to reduce "certainty" of BMP projects, it reduces the chance of over selling a practice with unrealistic expectations and should result in better achieved goals. Inclusion of this information in public planning will also improve public expectations. Expectations will better reflect the variability that exists in the real world due to climate, soils, management, design and all the factors discussed in this chapter.

Towards greater certainty in management outcomes

There is a desire for certainty in the implementation of agricultural practices so that farmers are not held responsible for environmental factors beyond their control. While we do not have control over many factors affecting variability including climatic and hydrologic fluctuations, we do have a great deal of control over site selection, BMP design, management, and maintenance. We can learn from previous projects to improve the effectiveness and certainty of BMPs moving forward. Other practices that can reduce uncertainty in BMP performance include standardization of BMP designs to help to reduce variability and placing greater priority on management and maintenance over the BMP lifespan. With tillage and nutrient management practices that require ongoing landowner management, efforts to promote greater long-term acceptance and continuity are needed as demonstrated in the past decade by the huge de-enrollment of farmland in conservation cover through USDA's Conservation Reserve Program.

Future research and information needs

Research data on pollutant removal effectiveness variability is lacking for many of the newer BMPs such as bioreactors and saturated buffers. As discussed earlier in this chapter, more research on practices that address dissolved P removal are strongly needed and for dissolved pollutants more generally (Jarvie et al., 2013). Similarly, information on the change in BMP effectiveness over time is missing for most practices. Data on costs of BMPs and their variability are hard to obtain since they are often not publicly available so more research is needed in this area as well. Furthermore, little is known about combinations of practices or treatment trains as the vast majority of studies are done for individual BMPs. This is because studies are easily designed to assess one or two variables but are much more complex and require more time and space to conduct such multi-BMP studies.

Lastly, landowner adoption/acceptance research is necessary to increase the coverage of BMPs. These issues are difficult to quantify but are critical for the success of agricultural watershed management programs.

Summary

From the 1930s to the 1980s most agricultural BMP studies focused on sediment loss reduction during the soil conservation movement and implementation of programs to reduce erosion. Therefore, most BMPs in use today were designed with sediment and particulate nutrient removal in mind, so there is less variability in their removal efficiencies. Despite the rich legacy of agricultural research in the Upper Midwest there is still a lack of studies documenting pollutant removal effectiveness for BMPs in the specific setting of Minnesota and the upper Midwest. The wide range of physical, ecological, social and economic factors further contribute to variability in pollutant removal effectiveness particularly across landscape and large watershed scales. These factors can skew models that are influencing decisions within Minnesota's Water Management Framework. Variability in BMP removal efficiency is most pronounced in the dissolved forms of N and P, particularly for dissolved P. The high effectiveness variability can lead to unrealistic expectations during the development of restoration strategies and implementations plans. BMPs to manage dissolved pollutants are increasingly being designed, studied and implemented, however. By acknowledging this variability and explicitly recognizing it in watershed-scale plans, government agencies and non-profit watershed management organizations can plan accordingly with realistic expectations. There are steps that can be taken to decrease uncertainty in ag-BMP performance such as focusing on the factors that we do have control over such as site selection, design and management. Those factors which we have little control over (e.g. climate) should be considered in models when predicting effectiveness of BMP implementation across large areas.

Notes: This chapter was adapted from Lenhart et al., 2016. An abbreviated version of this was published in the proceedings of the *2016 10th International Drainage Symposium Conference, 6-9 September 2016, Minneapolis, Minnesota* (pp. 1-8) by the American Society of Agricultural and Biological Engineers.

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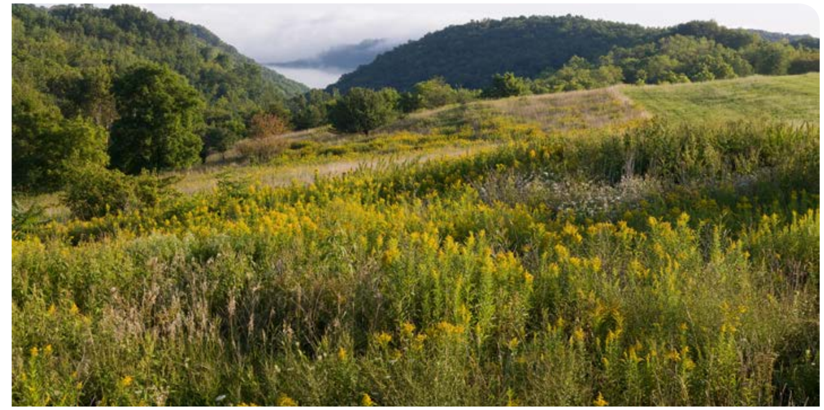
Agricultural BMPs: **Avoiding**

Photo by SRF Consulting Group, Inc.

Conservation Cover (327)



Conservation cover on a hillslope in southeastern Minnesota. Prairie vegetation was established to control soil erosion on steep farmland. (Photo by David Hansen)

Definition and Introduction

Conservation cover is establishing and maintaining permanent vegetative cover to reduce soil erosion and nutrient export to nearby water bodies. Conservation cover is often funded through the Conservation Reserve Program (CRP), Reinvest in Minnesota (RIM), and the Conservation Reserve Enhancement Program (CREP) although other programs also contribute to the implementation of conservation cover. Although these programs have different goals, the end result of each is establishing perennial vegetation on lands that were previously used for row crops.

Water Quality and Other Benefits

Conservation cover reduces erosion and nutrient loss by changing land cover from row crops to perennial vegetation. Christensen et al. (2009) conducted a study in the Minnesota River Basin to assess water quality characteristics and responses to land retirement (conservation cover) in three watersheds. The three watersheds were in row crop agriculture with 1.71%, 2.72%, and 4.32% of the land in conservation cover. They found that total nitrogen (N), suspended sediment, and chlorophyll-a concentrations were reduced with increasing land retirement. In addition, in-stream N concentrations were 15 mg/L, 10.6 mg/L, and 7.9 mg/L and decreased as more land was placed in perennial vegetation. These results indicate that even small changes in the amount of conservation cover may lead to large changes in N concentrations in streams.

In addition to reduced nutrient levels in stream, the fish and index of biotic integrity (IBI) scores also increased as local conservation cover percentages increased. This was most apparent when the conservation cover was located within 50 to 100 meters of the stream (Christensen et al., 2012).

Phosphorus (P) concentration in the three streams was not correlated to land retirement although the effects are not well understood and may be an artifact of the amount of time the land is in retirement before effects on in-stream P concentrations are realized. Another Minnesota

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study (Christensen and Kieta, 2014; Williamson et al., 2014) did calculate a significant correlation between a decreasing total P load in the West Fork Beaver Creek and annual land retirement. Although a significant correlation was not calculated between the mean suspended solids and land retirement, there was less movement of cropland sediment into the creek along stream reaches with retired land.

Other studies on perennial prairie strips have indicated reductions in sediment-, P-, and N-loss from agricultural land with 10% to 20% perennial cover compared to 100% row crop cover. Results from these studies revealed a 35-fold difference in sediment reduction between 100% annual crops and fields with some perennial strips. Fields with only annual crops also had a six- to eight-fold greater N export than those with some perennial vegetation. Furthermore, there was an 11- to 16-fold greater P loss in watersheds with 100% annual crop cover versus watersheds with some perennial strips. Total water runoff was also 1.6 times greater in watersheds with 100% annual crop cover (Asbjornsen et al., 2013).

A study at the University of Minnesota Southwest Experiment Station at Lamberton, Minnesota (Randall et al., 1997) evaluated nitrate losses on drain-tiled conservation cover, row crop, and alfalfa fields. The combined effect of higher volumes and higher concentrations of nitrate on row-crop systems showed nitrate losses of 45 times that of the conservation cover.

While the primary benefits of conservation cover have been reducing surface runoff of soil and nutrients, there is also a benefit to reducing N in tile drainage. Daigh et al., (2015) observed nitrate and soluble reactive phosphorus discharging from tiles draining continuous corn, corn harvested for bioenergy with a winter rye cover crop, and prairie with and without added fertilizer. Tile water from the continuous corn was often above 10 mg nitrate/L, but drainage from the prairie substantially lowered nitrate levels to <1 mg nitrate/L.

Following conversion of perennials back to row crops, the effects of reduced nitrate export are negated within one to two years of growing corn (Huggins et al., 2001). This indicates that although there is some benefit to nitrate export immediately following conversion of perennials to row crops it is short lived. The main benefit is realized when the perennial is in the ground.

In addition to providing water quality improvements, results of conservation cover include improved air quality, enhanced wildlife and pollinator habitat, improved soil quality, and managed plant pests (Lovell and Sullivan, 2006; Bentrup, 2008)(Figure 1). Adjustments can be incorporated during the planning and design of the conservation cover to accomplish these additional benefits.

Figure 1. Conservation cover provides important habitat for game species such as pheasants.

Key Design/Implementation Considerations

Conservation cover (NRCS Code 327) can be applied to any land needing permanent vegetative cover. However, it does not apply to land used for forage production or critical area planting. Seeding species, planting dates, planting methods, and establishment should be directed by a local SWCD or NRCS office to ensure specific site conditions are taken into account. Plant material can be selected to provide additional benefits such as improving air quality, enhancing wildlife habitat, enhancing pollinator habitat, improving soil quality, and managing pests. Local SWCD and NRCS field offices can adjust designs to meet the desired goals.

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Some funding sources allow plant harvest and mowing in their conservation cover practices as long as the soil is not disturbed. If harvesting vegetation in the conservation cover is desired, there are vegetative practices that provide soil conservation and provide crop income such as perennial biofuels that are described in the *Continuous Living Cover Manual* (Green Lands to Blue Waters, 2015).

Cost Information

The two most common programs for conservation cost reimbursements are the CRP and the Environmental Quality Incentives Program (EQIP). Both require participants to follow guidelines carefully to receive funding. They can also be combined with other funds, but funding cannot exceed 100% of the costs of the practice.

Enrolling land in the CRP can offset installation costs and also pay rent for the land taken out of production. Average costs for Minnesota are listed in Table 1. These contracts are 10 to 15 years in duration. The average rental payment for all CRP programs across the United States is $63.65/ac; however, this rental payment will vary by local average rent and soil fertility (Hachfeld et al., 2016). There are also payments for installation, maintenance, sign-up incentives, and other incentives under CRP practices. These payments, however, cannot exceed $50,000 annually (Stubbs, 2014).

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/ Acre	Typical Units Installed	Estimated Total Installation Cost (rounded)
Introduced with Forgone Income	$546.75	50	$27,300
Native Species with Forgone Income	$602.67	50	$30,100
Pollinator Species with Forgone Income	$892.20	1	$890

On the other hand, EQIP has much shorter contracts for conservation practices. These contracts are usually two to three years but have a much higher maximum payment rate. EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

RIM Reserves are also fairly common funding sources for conservation cover in Minnesota. These differ from the above options in their duration. RIM Reserves are permanent conservation easements. Landowners are payed rent for the land, but must continue to pay taxes for and manage that land. Rates vary by county.

Capital expense for installation of Conservation Cover practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category expenses such as the initial site preparation expenses, planting costs, and exclusionary fencing are eligible. In addition, purchase costs of equipment required to maintain the quality of the permanent ground is also eligible for AgBMP loan financing; however, typical operation and maintenance expenses such

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as periodic over-seeding, fuel for management activities, and weed control herbicides are ineligible.

Operation and Maintenance Considerations

Mowing and harvest operations in perennial crop systems, such as orchards, vineyards, berries, and nursery stock, should be done in a manner that minimizes the generation of particulate matter. If the land is enrolled in the CRP, the payment may be reduced up to 25% if the land is harvested, grazed, burned, or disturbed in other ways that are not established in the contract. Some exceptions to this rule include grazing during drought years when forage is limited or if young farmers are beginning their practices. Due to these restrictions, some management activities are limited depending on the funding program and contract.

While short-term contracts are less restrictive, some conservation covers may take several years to reach their full potential. Prairie species direct most of their growth into roots the first couple of years so many species are not apparent above ground until year two or three of the project. As a benefit, the CRP guarantees funding beyond the early establishment of the vegetation.

If wildlife habitat enhancement is a goal, maintenance practices and activities should not disturb conservation cover during the reproductive period for the desired wildlife. Exceptions should be considered for periodic burning or mowing to maintain the health of the plant community.

Maintenance measures must be adequate to control noxious weeds and other invasive species. These measures should be established in the contract with the funding source. In some cases, partial mowing or spot spraying herbicide may be used to control invasive species. Controlling invasive plants is also critical for pollinator habitat as grasses such as reed canary grass or smooth brome can eliminate forb coverage and diversity, which reduces the plants available for pollinators.

To benefit insect food sources for grassland nesting birds, spraying or other control of noxious weeds should be done on a spot basis to protect forbs and legumes that benefit native pollinators and other wildlife.

Legal/Permit Requirements

Local laws must be followed when controlling noxious weeds. Seed from the correct distributors must be used. Contact the local farm service agency, NRCS office, or conservation district for assistance with planning, regulations, and funding requirements. Interested landowners and government agency staff should refer to the CRP and RIM guidance. While these are voluntary programs they do have land-use and management requirements for program participants.

Local/Regional Requirements Design Example

The Minnesota USGS Water Science Center studied the West Fork of Beaver Creek in western Minnesota for the impacts of conservation cover (land retired in CRP) on water quality (Christensen et al., 2009; Williamson et al., 2014). This project carefully documented the benefits of conservation cover on a watershed scale both for water quality and in-stream biota.

In Minnesota, conservation cover design usually consists of a native seed mix specified by BWSR (www.bwsr.state.mn.us/native_vegetation/index.html).

Research Gaps

Recent and ongoing studies in Minnesota have helped fill the research gaps relating to conservation cover, particularly for phosphorus. Current research needs include prioritizing locations within each watershed, selecting vegetative species, and determining the amount of vegetation for each conservation cover to achieve the most effective use of the practice for improving water quality. Research about vegetation selection has been limited and shows mixed results on grassed areas versus a mix of grass and tree species (Asbjornsen et al., 2013).

Research is also needed on long-term management and how changes to plant community composition over time affect functions such as provision of pollinator habitat and retention of nutrients. For example, invasion by invasive species or succession to shrubs or trees may reduce the value to pollinators.

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Links

NRCS Conservation Practice Standard, Conservation Cover, Code 327
efotg.sc.egov.usda.gov/references/public/MN/327mn.pdf

MDA Conservation Practice, Grass Planting
www.mda.state.mn.us/protecting/conservation/practices/grass.aspx

Minnesota Board of Water and Soil Resources, Native Vegetation/Seed Mixes
www.bwsr.state.mn.us/native_vegetation/index.html

Green Lands to Blue Waters, 2015, Integrating Livestock, Continuous Living Cover Manual
greenlandsbluewaters.net/resources2/clc-manual

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Conservation Crop Rotation (328)

Definition and Introduction

The NRCS defines Conservation Crop Rotation as “growing crops in a planned sequence on the same field.” The MDA takes this definition one step further by defining it as “a system for growing several different crops in planned succession on the same field, including at least one soil-conserving crop such as perennial hay.” In Minnesota, this practice usually consists of a corn-soybean-alfalfa rotation or a corn-soybean-small grain rotation. Crop rotations have many benefits to the producer including reduced erosion, improved soil quality, and improved wildlife habitat. NRCS Practice Standard 328 defines what combination of crop types are permitted under the standard, depending on the length of rotation.

Water Quality Benefits

The water quality benefits of a conservation crop rotation occur in two ways. The first is that legumes and low nitrogen (N) input crops can scavenge N remaining in the soil from previously fertilized crops, increasing N use efficiency and reducing potential for N loss via surface or subsurface pathways. The second effect is that a year in a protective crop directly reduces erosion susceptibility because of the increased surface cover. Other benefits include potential yield benefits, improved soil quality, increased carbon sequestration and improved habitat (Olmstead and Brummer, 2008).

Tomer and Liebman (2014) compared N and phosphorus (P) losses between a 2-yr corn-soybean, 3-yr corn-soybean-red clover/small grain, and 4-yr corn-soybean-small grain/alfalfa-alfalfa systems. They found that soil water nitrate concentrations were significantly less at 1.2-m depth under the 4-yr (9.8 mg/L) crop rotation than under the 2- (12.6 mg/L) or 3-yr (14.3 mg/L) rotations. One key finding from the study as that in the 4-yr rotation, the benefit of reduced N movement below the root zone was extended after alfalfa to the following year’s corn crop.

In a Minnesota study of the impact of alternative cropping systems on water quality (Oquist et al., 2007) corn-soybean rotation with in-organic fertilizer was compared to a rotation including corn, soybean, oats and alfalfa and organic practices. This study showed that the alternative cropping system reduced nitrate losses by 59% in 2002 and

62% in 2004. These results are similar to those reported by Kanwar et al. (2005), who reported a 42% reduction in flow-weighted mean nitrate concentration in a 6-yr study in Iowa. It should be noted that the Kanwar et al. (2005) study reported greater subsurface drainage volumes with the alternative cropping system, which they attribute to deeper rooting depths and subsequent macropore development. The results of that Iowa study also showed greater average nitrate loss in kg/ha, which was tied to drainage volume and the fact that alternative cropping systems can release fixed atmospheric N when plant roots (e.g, alfalfa) decay.

A Minnesota study of subsurface drain losses of water and nitrate following conversion of CRP to row crops (Huggins et al., 2001) shows that perennial grasses or alfalfa have substantially less nitrate loss than row crops. A corn-soybean rotation has nitrate losses 4-5 times greater than an alfalfa-corn-corn-soybean rotation and 13-15 times greater than in CRP-corn-corn-soybean rotation. The study also shows that the benefits of perennials on subsurface drainage characteristics can last one to two years following corn.

A six-year (1987-1993) Lamberton, Minnesota study (Randall et al., 1997; Randall et al., 1993) of nitrate in drainage water from both perennials and row crops showed nitrate concentrations 35 and 37 times higher than from alfalfa and CRP systems due primarily to greater evapotranspiration resulting in less drainage and greater uptake and immobilization.

Results of a nine-year study in Indiana showed that a conservation crop rotation can also reduce P losses (Smith et al., 2015). In that study P losses were compared between rotations with, alfalfa, wheat, and oats, corn, and soybeans (not in that order) on two different fields and a traditional corn-soybean rotation. Median soluble P was 75% less than under the conservation crop rotation than the corn-soybean rotation. Total P loads during the growing season were also reduced by about 75% under the conservation crop rotation.

Additional Benefits

An ancillary, but important, additional benefit of conservation crop rotation is the improvement in soil quality. A multi-year study in Missouri, part of the Conservation Effects Assessment Project (CEAP), assessed physical, chemical and nutrient qualities of the soil and assigned soil quality indices based on these measurements. They found that soil quality under a corn-soybean-wheat rotation with red clover cover, had the same soil quality as hay and warm season grass treatments in the 0-2 in soil depth (Veum et al., 2015).

Additional reported benefits of conservation crop rotation include lower fossil fuel inputs and fertilizer N requirements as well as greater economic returns (references in Shipitalo et al., 2013).

Gaudin et al. (2015) evaluated the N use efficiency and impact on yield of adding wheat to both a corn-corn and corn-soybean rotation. They found that, on average, winter wheat improved maize performance by 16.6% under zone-till and 18.8% under conventional tillage. These yield increases were found to be N dependent, where the greatest yield benefit was seen as lower N application rates. The amount of N that maximized corn yields and economic return of N fertilization was found to decrease with wheat in the rotation. In addition, Gaudin et al. (2015) note that including wheat in the crop rotation produced higher corn and soybean yields and decreased fertilizer N requirements for maximum yield.

Gardner and Drinkwater (2009) performed a comprehensive meta-analysis to compare studies examining the role of tillage, rotation, and fertilizer on the fate of N. They found that more diverse rotations increased the amount of N recovered by crops by 17% on average and increased total recovery of N in crops and soil by 30%. The implication of this is that a conservation crop rotation can lead to more efficient use of N by crops, which requires less N input and less N susceptible to leaching. The same study suggests that practices that re-couple carbon and N cycling, such as conservation crop rotation,

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are more important to plant and soil N retention than N-application method or timing of fertilizer application.

Key Design/Implementation Considerations

Minnesota follows the federal guidance when developing conservation crop rotations (see link to standard). In general, the practice should maximize crop diversity as much as possible within site constraints and work with other on farm BMPs.

Cost Information

Cost information is summarized in Table 1 below. EQIP (USDA NRCS 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of Conservation Crop Rotation practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses related to the purchase of equipment for field preparation, planting, and production are eligible when the equipment can help with any of the following; nutrient management, erosion control management, or chemical management. Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, moldboard plows, tractors and weed control herbicides are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/ Acre	Typical Units Installed	Estimated Total Installation Cost (rounded)
Basic Rotation Organic and Non-Organic	$6.29	200	$1,300
Specialty Crops Organic and Non-Organic	$33.52	50	$1,700
Irrigated to Dryland Rotation Organic and Non-Organic	$90.20	200	$18,000

Operation and Maintenance Considerations

The rotation of conservation crops adds diversity to farming operations. As with other vegetative and tillage management practices, maintenance needs are minimal in comparison to that required for structural BMPs.

Legal/Permit Requirements

There are no permitting requirements that apply specifically to conservation crop rotation. However, contact the local farm service agency, NRCS office, or conservation district for assistance with planning, regulations, and funding requirements.

Local/Regional Requirements Design Example

Conservation crop rotation is practiced throughout Minnesota. Many examples are found in steep, sloping land for example in southeastern Minnesota.

Research Gaps

Research in Minnesota does indicate that adoption of conservation cover crop management can lead to reduced pollutant loading. To be more widely adopted, the economic implications of adoption must be better understood.

The effect of conservation crop rotations on soil quality indicators in Minnesota should be investigated to better inform producers and policy-makers on benefits of the practice.

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MDA Conservation Practice, Crop Rotation
www.mda.state.mn.us/en/protecting/conservation/practices/croprotation.aspx

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Contour Buffer Strips (332)

Definition and Introduction

Contour buffer strips are planted in-field and on the contour (perpendicular to the slope) and are regularly spaced between wider crop strips. As an in-field buffer conservation practice, contour buffer strips provide runoff and erosion control close to the source. Contour buffer strips, in contrast to contour strip cropping, are narrower than adjacent crop strips and are planted in permanent vegetation. The vegetation established in the buffer is herbaceous and dense.

Water Quality and Other Benefits

Contour buffer strips slow the flow of water and facilitate infiltration and diffuse flow, which reduces sheet and rill erosion and the transport of sediment and associated contaminants to downstream water bodies. Contour buffer strips can also reduce dissolved pollutants that infiltrate into the shallow groundwater flow through interaction with the buffer root zone.

Many studies in Iowa have compared varying widths of contour buffer strips and different placements of strips on the slopes of crop fields to understand the benefits of buffer strips on water quality and soil health (Zhou et al., 2010; Pérez-Suárez et al., 2014; Mitchell et al., 2015). Results from one study indicated that strips occupying 10% of the watershed and placed at the foot of the slope most effectively reduced runoff. Strips occupying 10% to 20% of the watershed in multiple locations on the contour or foot of the slope were also effective. The buffer strips reduced flow by 37% compared to the row crop fields without buffer strips (Hernandez-Santana et al., 2013).

In Table 1, contaminant reductions are presented from a natural rainfall study in Iowa (Arora et al., 1996). The study investigated having drainage area-to-buffer strip area ratios within or near the strip width specifications of NRCS (2007) standards for contour buffer strips (Code 332).

Table 1. Pollutant Reduction Estimates for Contour Buffer Strips (percentage reduction of pollutants).

Pollutant	Mean	Minimum	Maximum	Standard Deviation	Sample size
Total Sediment	87%	83%	91%	4	3
Herbicide (atrazine, metolachlor, cyanazine)	67%	53%	77%	8	9

Ssegane et al., (2015) measured the reduction of nitrate that had leached into subsurface flow in a study of the potential for contour buffer strips to be used for biofuel production. Both buffers with willows and those with switchgrass reduced leached nitrate by approximately 60%. The average width of the contour buffer was 98 feet (30 meters).

Contour buffer strips can also provide corridors and habitat for various wildlife species. The benefits to wildlife depend on the vegetative cover type. Some wildlife can use the buffer as cover instead of other disturbed areas. Other species use the vegetation for nesting. Furthermore, buffer strips can be beneficial for pollinators and other beneficial insects.

Key Design/Implementation Considerations

Buffers with higher drainage area-to-buffer area ratios are expected to produce lower contaminant retention rates (Dosskey et al., 2002). While many buffers are 10% of the drainage area, variable-width buffers should be considered for variable upland contributing areas. This enhances infiltration and improves removal efficiencies of soluble pollutants, such as pesticides or dissolved nutrients (USDA NRCS, 2000; Helmers et al., 2008). When modeling contour stripcropping, recognize that surface roughness factors (such as Manning's n) change with depth since the density of the vegetation varies with height (Dabney et al., 2006).

Implementing grass barriers at the upstream end of the buffer strip and covering approximately the first 10% of the buffer increases removal rates where drainage areas-to-buffer area ratios are greater than 1:1 (Blanco-Canqui et al., 2004). Dense vegetation at the upstream end of the buffer also spreads the flow through the full length of the buffer. In general, mature stem densities should be greater than 50 stems per square foot for grasses and greater than 30 stems per square foot for legumes (USDA NRCS, 2007).

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NRCS Code 332 recommends the following standards for contour buffer strips:

- Buffer Widths should be:
  - At least 15 feet wide for grass or grass-legume buffers
  - At least 30 feet wide for legume buffers (where legumes make up more than 50% of the buffer)
- Cropped Strip Widths should not exceed:
  - 50% of the slope length used for erosion calculation
  - Widths in Table 2 based on land slope

If wildlife is the goal, the widths of the buffer strips should be 30 feet or wider.

Table 2. Maximum[1] Cropped Strip Widths for Contour Buffer Strip Farming Practice (USDA NRCS 2007)

Land Slope (%)	Cropped Strip Width (ft)
1-2%	180
3-5%	150
6-8%	120
9-15%	105
>16%	90

[1] Maximum cropped strip width is the lesser of 50% of the slope length used for erosion calculation or slope-based values in this table.

Soil type, surface flow pathways, shallow groundwater flow gradients, and subsurface nitrate concentrations should be considered when placing buffers (Ssegane et al., 2015). Soils that are too coarse could cause water to infiltrate too quickly and bypass the buffers. The subsurface flow depth should be measured in order to place the buffer where plant roots can reach the subsurface flow. Plant species with roots long enough to reach this water should be selected. Buffers should also be placed in areas where surface flow is concentrated. Fields with intensive tile drainage may not benefit from contour buffer strips as much as fields with mostly surface runoff due to tile drainage short-circuiting the groundwater interaction with the root zone. In addition, less productive sections of land could be used for buffers to keep the areas with the highest yield in production.

Buffer strips can also be used for bioenergy crops. Due to their high productivity and ability to reach lower groundwater tables, some tree species and grasses are beneficial for bioenergy as well as nitrate reductions.

Cost Information

The cost of contour buffer strips depends on the value of the land taken out of production, buffer installation, plant establishment, and maintenance. In Iowa, assuming a 15-year time horizon, the cost of installation, maintenance, and taking the land out of production to produce 15-foot wide prairie strips ranges from $590 to $865 per acre each year (Tyndall et al., 2013). The cost of single-species contour buffers is lower due to reduced seed costs. If the land is enrolled in the CRP, landowner costs decrease approximately 85%.

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office (Table 3).

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category expenses such as the initial site preparation expenses and planting costs. In addition, purchase costs of equipment required to maintain the quality of the permanent ground is also eligible for AgBMP loan financing; however, typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, and weed control herbicides are ineligible.

Table 3. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Component	Estimated Average Cost/Acre
Introduced Species, Foregone Income	$527.23
Native Species, Foregone Income	$529.14
Wildlife/Pollinator, Foregone Income	$675.24

Operation and Maintenance Considerations

Tillage parallel to buffer strips can establish berms at the upstream edge of the buffers and can result in undesirable runoff patterns. These berms must be prevented through tillage operation or re-spreading the berms (Vieira & Dabney, 2012).

Establishing and maintaining dense, continuous vegetation is one of the most important factors in buffer strip performance (Helmers et al., 2008). Mowing can be an effective tool for handling weed competition during buffer vegetation establishment. Tall vegetation should be maintained more frequently during periods of heavy rainfall. If wildlife habitat is a goal, mowing should be delayed until after the nesting period of song birds and other wildlife. Harvesting or mowing should also be timed appropriately to maintain vegetation at a proper height during critical erosion periods. If vegetation is harvested in the fall, time for regrowth should be factored in before a killing frost occurs.

Avoiding: Contour Buffer Strips

Grass barriers at the upstream end of the buffer strip can trap sediment and prevent the sediment from depositing throughout the entire buffer (Blanco-Canqui et al., 2004). After the sediment builds-up at the grass barriers, it can be more easily re-distributed throughout the row crops than if it had spread throughout the entire buffer strip. Appropriate grass species have stiff stems that remain erect during periods of runoff.

Legal/Permit Requirements

Local laws must be followed when controlling noxious weeds. Seed from the correct distributors must be used. Contact the local farm service agency, NRCS office, or conservation district for assistance with planning, regulations, and EQIP requirements.

Local/Regional Requirements Design Example

While contour buffer strips have been implemented in Minnesota, most research on its effectiveness regionally has been conducted in Iowa. Iowa State University has researched contour buffer strips as part of their *Science-based Trials of Rowcrops Integrated with Prairie Strips* (STRIPS) research program, some of which is referred to in this chapter.

Research Gaps

It is understood that larger particles are trapped more efficiently in buffers, but research is needed to improve the ability to predict aggregate size distribution of eroded soils and the N and phosphorus (P) content of each particle size fraction (Helmers et al., 2008).

The role of contour buffer strips in reducing P load in subsurface flow is still largely unknown. The process of trapping P attached to eroded soil is well understood, but more needs to be learned about the role of plant roots and their interactions with dissolved P in shallow groundwater.

Agroforestry buffer strips could reduce the yield of corn adjacent to the buffers (Senaviratne et al., 2012), but there are numerous actions that can prevent the reduction. More research is needed to understand what designs and strategies can provide the benefits of buffers without reduced corn yields. Potential precautions include using drought tolerant corn varieties, early planting, tree pruning, or barrier construction.

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Links

NRCS Conservation Practice Standard, Contour Stripcropping, Code 332
efotg.sc.egov.usda.gov/references/public/MN/332mn.pdf

NRCS CORE4 Conservation Practices Training Guide: The Common Sense Approach to Natural Resource Conservation.
www.nrcs.usda.gov/technical/ecs/agronomy/core4.pdf

NRCS Conservation Buffers to Reduce Pesticide Losses.
www.in.nrcs.usda.gov/technical/agronomy/newconbuf.pdf

Iowa State University STRIPS (Science-Based Trials of Rowcrops Integrated with Prairie Strips) program
www.nrem.iastate.edu/research/STRIPs

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Avoiding: **Contour Buffer Strips**

Contour Farming (330)

Contour farming in southeastern Minnesota with crops in rows perpendicular to the slope. This slows runoff velocity, reducing the initiation of sheet and rill erosion. (Photo by David Hansen)

Definition and Introduction

Contour farming entails farming along the hillslope contour such that ridges, furrows, and planting are perpendicular to the slope of the land. Contour farming is an erosion control system that shifts the direction of runoff from directly downslope, to across the slope, slowing velocity and reducing the initiation of rill and gully erosion. Stable outlets, such as field borders and grassed waterways, are necessary downstream components of contour farming.

The concept of contour farming had an early beginning in the worldwide history of agricultural production, and in modern history it was one of the first practices promoted by the U.S. Soil Conservation Service (subsequently renamed the Natural Resources Conservation Service) when it was formed in the 1930s. It is particularly common in the steeper parts of Minnesota, especially the southeastern Driftless Area.

Water Quality and Other Benefits

Contour farming increases infiltration of rainwater and reduces sheet and rill erosion, which reduces soil loss and the transport of sediment and associated contaminants to downstream waterbodies. Early U.S. Soil Conservation Service studies showed that contour farming may increase crop yields on hillslopes by retaining topsoil (Hays et al., 1949). Contour farming also provides some benefits for nitrogen (N) and phosphorus (P) load reduction, but it has a sparse record of contaminant concentration reduction as a stand-alone conservation practice. Contour farming improves the performance of downstream buffer-type practices, such as contour buffer strips, terraces, contour stripcropping, cover crop, filter strips, and grassed waterways, as it helps to prevent concentrated flow. Although records are limited for recent field studies on the improvement of water quality as a result of contour farming, recent modeling studies have predicted loss reductions of sediment and nutrients (Merriman et al., 2009). Sediment, organic N, and organic P

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losses could be reduced by 34-53%, 18-36%, and 18-35% respectively, and soluble and total P losses could be reduced by 23 and 27% respectively (Gassman et al., 2006).

Key Design/Implementation Considerations

The NRCS standard (Code 330) recommends for this practice:

- between 0.2 and 5% grade and between 100 and 400 feet long.
- Ridge height minimums of:
  - Two inches for row spacing greater than 10 inches
  - One inch for row spacing of 10 inches or less.

The water quality and soil conservation benefits of contour farming depend largely on integration with other conservation practices on the contour (i.e., contour buffer strips, terraces, and contour stripcropping). In addition, contour farming can be an effective tool to maintain the diffuse flow required to realize water quality benefits from conservation practices, such as riparian forest buffers, field borders, riparian vegetation, filter strips, and grassed waterways.

Cost Information

Contour farming does not typically involve taking land out of production, although it may require consolidation of fields so they may be farmed efficiently. As contour farming is based on a change in operations, costs are low and primarily associated with initial field design.

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

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Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses related to the purchase of equipment for field preparation, planting, and production are eligible when the equipment can help with any of the following: nutrient management, erosion control management, or chemical management. Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, moldboard plows, tractors and weed control herbicides are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Component	Estimated Average Cost/Acre	Typical Units Installed	Estimated Total Installation Cost (rounded)
Contour Farming	$9.07	30	$270

Operation and Maintenance Considerations

Contour farming as a stand-alone practice requires similar operation and maintenance as conventional farming, including routine inspection for erosion and associated repairs. Contour markers used to maintain crop rows at designed grades may need to be replaced or re-established periodically when a marker is lost.

Legal/Permit Requirements

Contact the local farm service agency, NRCS Field Office, or conservation district for assistance with design and meeting EQIP requirements.

Local/Regional Requirements Design Example

There are numerous examples of this practice throughout the state, especially in southeastern Minnesota where more hillslopes are present. However, research and demonstration sites are limited.

Research Gaps

Research regarding pollutant reductions as a result of contour farming as a stand-alone practice is uncommon. Existing studies typically assess contour farming in combination with other conservation practices, and more recent studies typically address pollutant reduction at the watershed scale assuming a certain rate of implementation rather than assessing the practice at the field-scale. In fact, a significant fraction of the contour farming research is now coming from outside the United States, possibly suggesting that in the U.S. contour farming is not often being used as a stand-alone practice.

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NRCS Conservation Practice Standard, Contour Farming, Code 330
efotg.sc.egov.usda.gov/references/public/MN/330mn.pdf

MDA Conservation Practice, Contour Farming
www.mda.state.mn.us/protecting/conservation/practices/contourfarm.aspx

Avoiding: **Contour Farming**

Cover Crops (340)

Rye grass, shown above, is a common cover crop used in Minnesota. Cover crops are widely used in Minnesota to reduce soil erosion during the period when annual row crops are not growing. (Photo by David Hansen)

Definition and Introduction

Cover crops implemented as a BMP refers to the use of grasses, legumes, and forbs planted with annual cash crops to provide seasonal soil cover on cropland when the soil would otherwise be bare. In Minnesota, the cover crop is commonly winter rye (*Secale Cereale* L.), although oats (*Avena sativa*), alfalfa (*Medicago sativa*), buckwheat (*Fagopyrum esculentum*), and other small grains are also used. The short growing season in Minnesota, paired with the use of full season corn and soybean, creates obstacles for adequately establishing cover crops although there is much evidence of cover crops' potential for improving water quality (Carlson & Stockwell, 2013); however, cover crop use is expanding as farmers see the environmental and financial benefits of the practice (SARE/CTIC, 2016).

The MDA categorizes cover crops into five main categories with winter cover crops and catch crops being the most commonly used (MDA, 2016):

- A **winter cover crop** is planted in late summer or fall to provide soil cover over winter and early spring. In Minnesota, winter cover crops are commonly planted after the harvest of crops such as potatoes, silage corn, canning crops, and sugar beets for a range of ecological services, most notably erosion reduction.
- **Catch crops** are planted after harvesting an early season crop (e.g., canning crops) and are primarily used to reduce nutrient leaching. Many southeastern Minnesota growers use cover crops in this way and are collaborating with the MDA on related research and demonstration projects.
- A **smother crop** is a cover crop planted primarily to outcompete weeds. In Minnesota, buckwheat, sorghum-sudangrass, and rye commonly serve this purpose.
- **Green manure** is a cover crop, typically a legume, incorporated into the soil while still green to improve soil fertility. Currently in Minnesota, green manures are used primarily by organic growers.

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- Cover crops can serve as **short-rotation forage crops** when used for grazing or harvested as immature forage or green chop.

Water Quality and Other Benefits

Water quality benefits of cover crops come from three processes. The first is the reduction of erosion from raindrop impact and by slowing surface flow. The second is the potential for the cover crop to take up nutrients that would otherwise be lost from the field through surface or drainage water and the third is increasing soil infiltration.

Minnesota has pioneered cover crop research in northern climates. In a three-year study at Lamberton, Minnesota (Strock, Porter, & Russelle, 2004) subsurface tile drainage discharge was reduced 11% with a cover crop and that nitrate loss was reduced 13% on a corn-soybean cropping system. These results show a much lower reduction than has been reported around the nation, and it has been hypothesized that the reduced effectiveness in Minnesota is due to the short growing season, cold climate, and poor cover crop establishment.

An additional study in southwestern Minnesota (Feyereisen et al., 2006) based on modeling concluded that a rye cover crop planted on September 15 and desiccated on May 15 can reduce nitrate losses on average of 6.6 lbs/ac (7.4kg/ha). Jaynes et al. (2004) showed that a cover crop treatment in Minnesota reduced nitrate load by 64% over the control. In a large soil monolith study in Iowa, Logsdon et al. (2002) showed rye cover crop and oat cover crop both reduced nitrate leaching and they recommended late-summer, interseeded small-grain cover crops to reduce nitrate losses from corn-soybean rotations.

In central Iowa, researchers found a nitrate load reduction of 61% for rye cover crop (Kaspar et al., 2007) additional approaches need to be devised. We compared two cropping system modifications for NO3 concentration and load in subsurface drainage water for a no-till corn (*Zea mays* L.). This effectiveness was reduced slightly after 5-9 years of annual establishment, but these changes may be attributed to changes in fertilizer rates and increased cumulate drainage. The rye cover crop remained effective over the course of the study even with these changes (Kaspar et al., 2012). An oat fall cover crop in the same study was about half as effective at reducing nitrate concentrations, but it still significantly reduced nitrate concentrations in drainage. Kladivko et al. (2014) but adoption rates are low, and the potential impact if cover crops were widely adopted is currently unknown. This paper provides an analysis of potential cover crop adoption and relative benefits to water quality across the five-state region of Ohio, Indiana, Illinois, Iowa, and Minnesota in the upper midwestern MRB. Two agricultural counties were selected in each of the five states, and the potential for fall-planted cover crop adoption was estimated based on cash crop rotation and tillage systems. In these 10 counties, an estimated 34% to 81% of the agricultural land could have cover crops integrated into their corn (*Zea mays* L.). Kladivko et al., (2014) estimated that adopting cover crops on 34% to 81% of agricultural land in the Midwest could reduce nitrate loads to the Mississippi River by approximately 20%.

While preventing soil erosion with cover crops will reduce the loss of phosphorus (P) bound to the soil particles, P dynamics vary based on the cover crop used. Research has suggested that some cover crop varieties, such as legumes, may mobilize P for the following crop in P-limited systems (Maltais-Landry et al., 2015; Horst et al., 2001; Nuruzzaman et al., 2005). A study in Rosemount, Minnesota, concluded that rye cover significantly reduces total P losses during spring rain events (Nater et al., 2012). Studies conducted in central Indiana found concentrations of soluble reactive P in tile drainage were 50% lower from fields with cover crops than those without cover crops (Tank & Willows, 2016).

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Key Design/Implementation Considerations

Cover crops can be used to reduce erosion, hold nutrients, and/or provide forage. A fact sheet published by the MDA summarizes conditions where farmers are deploying cover crops and when they are used (MDA, 2006). This information can be used as a starting point for designing a cover cropping system (Figure 1). Although this figure shows Winter Rye as the primary cover crop, a large variety of cover crops exist including varieties of grasses, legumes, and brassicas. The Midwest Cover Crop Council has developed a decision tool that can inform planting times and species for specific farms in Minnesota. The tool is available at: www.mccc.msu.edu.

When considering cover crops as a practice, it is important to talk to a local extension agent or SWCD office about the best implementation strategy to meet your goals. Although cover crops have been proven to increase cash crop yield, certain factors could impact crop yields such as the cultivar of the cover crop or topography (Kaspar & Bakker, 2015; Muñoz et al., 2014; SARE/CTIC, 2016). The most widely used cover crops in corn-soybean systems in the upper Midwest United States have been winter cereals. However, there have been isolated reports of corn yield reductions following winter rye (*Secale cereale* L.).

Cover Crops are often used on beet fields and have become part of the southern Minnesota Beet Growers cooperative P trading program. It is a precedent-setting program where a co-op provided financial incentives for farmers to use cover crops. For more information, visit: www.smbsc.com.

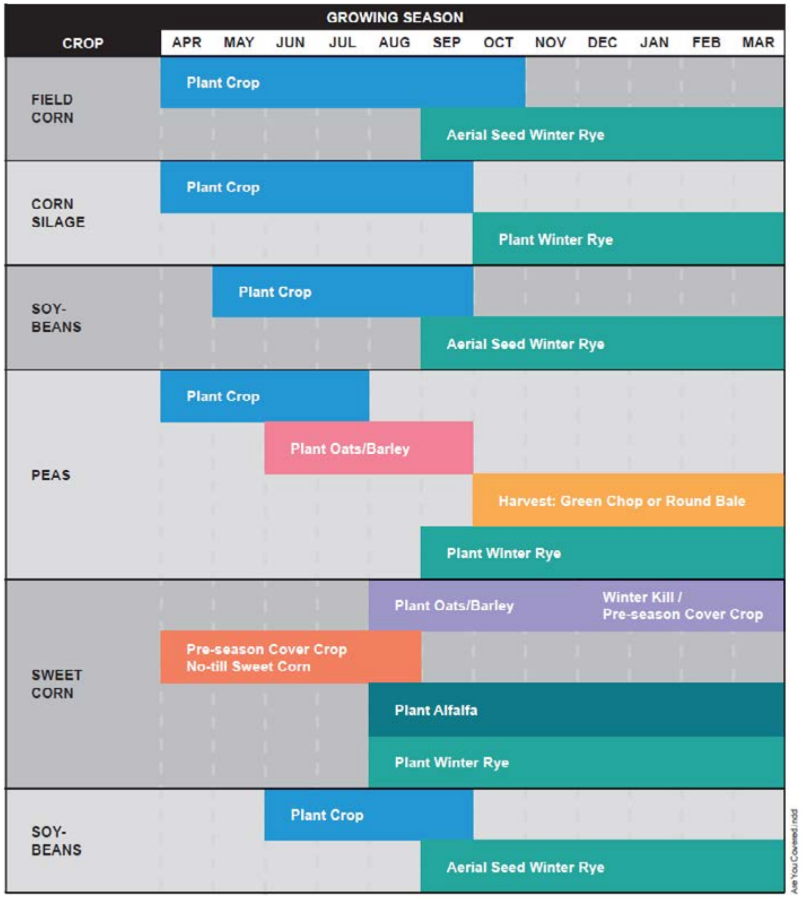

Figure 1. The graph shows cover crop uses and timeline by crop type. It displays some options for pairing cover crops with cash crops such as field corn with aerially seeded winter rye. It also shows common times and strategies for planting and terminating cover crops based on their cash crop pairings. The figure was adapted from an MDA publication (2006).

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Avoiding: Cover Crops

Cost Information

Costs for cover crops typically include seed, planting drills, fuel, herbicide, and spraying. Cash crop yields will vary depending on site topography and practices (Muñoz et al., 2014; Olson, Ebelhar, & Lang, 2014; Kaspar & Bakker, 2015), however their adoption by farmers has remained limited. A challenge to farmer uptake is high spatial and temporal variability in cover crop growth and performance. Since topography plays an important role in spatial processes that ultimately affect plant performance, it could be used to quantify cover crop spatial variability and cover crop contribution to a subsequent cash crop. We assessed the effects of topography and cover crop (red clover).

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses related to the purchase of equipment for field preparation, planting, and production are eligible when the equipment can help with any of the following: nutrient management, erosion control management, or chemical management. Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, moldboard plows, tractors and weed control herbicides are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/Unit	Typical Units Installed	Estimated Total Installation Cost (rounded)
Basic and organic/non-organic	$83.13/acre	40	$3,300
Adaptive Management	$2,630.46 each	1	$2,600
Multiple Species Organic and Non-Organic	$97.55/acre	40	$3,900

Operation and Maintenance Considerations

Operation and maintenance is dependent on the cover species used and field conditions. In Minnesota, it can be difficult to establish cover crops due to the short time between harvest and freezing. Aerial seeding is a practice which allows the cover crop to establish before harvesting the cash crop. One study in southeastern Minnesota concluded that successful establishment of winter rye using this seeding method was dependent on water potential at the soil surface and precipitation within one week following seeding. This is especially important in coarse-textured soils. If there has been no recent rain or no rain is forecasted within a week, alternate seeding methods may need to be considered (Wilson, Baker, & Allan, 2013). Further studies are near completion at the University of Minnesota that evaluate more planting methods and species selection for interseeding cover crops in Minnesota. For information on these projects, visit the MDA Clean Water Fund research project website at: www.mda.state.mn.us/cleanwaterfund/research.

The cover crop is commonly terminated before the cash crop is planted. When the crop is not winterkilled, herbicide application is a common method for termination; however, it is imperative that crop restrictions are considered. Rolling, crimping, and tilling are also used to terminate cover crops. Grazing can be used as part of the termination process but should be combined with other methods and discussed with local SWCD offices.

Other considerations should include asking the local SWCD office about potential pests, diseases, or competition from cover crops. These impacts can be avoided by selecting the proper cover crop species, establishing and terminating the cover crop at the correct time, and allowing the proper number of days between termination and planting.

If the cover crop is grazed or harvested for grain or seed, it may be considered a double crop for insurance purposes.

Legal/Permit Requirements

When terminating cover crops with herbicide, the local weed control guide has legal requirements and suggestions that should be followed. Due to some herbicide carryover and residual activity, some herbicides have time restrictions between application and harvest or between application and planting of the next crop (Stahl, 2017).

Some restrictions may apply when harvesting cover crops as forage. Insurance may be significantly reduced if the cover crop is harvested before November 1st. Check with your local farm service agency and crop insurance agent before harvesting or grazing.

Local/Regional Requirements Design Example

More research is being done to determine other cover crop species that can perform well in Minnesota. Some examples of these species include Kura clover (*Trifolium ambiguum* M. Bieb.), winter camelina (*Camelina sativa* L.), and field pennycress (*Thiaspi arvense* L.) (Ochsner et al., 2010; Gesch et al., 2014; Anderson, 2016). Other work at the University of Minnesota Forever Green Initiative includes the development of varieties of living mulches and more winter-tolerant cover crops for Minnesota.

Research Gaps

Although erosion and P reductions are commonly acknowledged to occur with cover cropped land, there is a lack of research data in Minnesota and the upper Midwest to quantify this reduction.

Although there is ongoing research in Minnesota exploring new cover crop varieties, establishment and termination techniques, management, and water quality benefits, there remains a need to further address these practical or logistical problems. In addition to identifying methods or varieties that will improve growth and establishment in Minnesota's climate, additional research is needed to quantify the benefit to soil and water quality, nutrient management implications, and long-term economic and environmental implications.

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Links

NRCS Conservation Practice Standard, Cover Crops, Code 340
efotg.sc.egov.usda.gov/references/public/MN/340mn.pdf

MDA Conservation Practice, Cover Crops
www.mda.state.mn.us/protecting/conservation/practices/covercrops.aspx

Midwest Cover Crops Council
www.mccc.msu.edu/index.htm

University of Minnesota Forever Green Initiative,
www.forevergreen.umn.edu

University of Notre Dame, Indiana Watershed Initiative
www.indianawatershedinitiative.com/uploads/8/0/9/5/80953414/phosphorus_sheet.pdf

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Grade Stabilization Structure (410)

Full Flow grade stabilization structure. (Photo by NRCS)

Definition and Introduction

A grade control structure is used to control the grade and head cutting in natural or artificial channels by arresting upstream movement of the "knickpoint" though natural or artificial means. NRCS Practice Standard 410 also applies to both grade control structures and side inlet controls. Design of side inlet controls is contained in a separate chapter in this document. Grade control structures are used to prevent the advancement of gullies that result from concentrated flow.

Water Quality and Other Benefits

Grade control structures can improve water quality by reducing erosion and sediment-bound pollutants. Gullies and ravines have been identified as major contributors of sediment to Lake Pepin (Wilcock, 2009). According to Wilcock (2009), erosion rates in ravines in the Le Sueur watershed ranged from 0 to 3.56 tons/acre and may make up about 10% of the total sediment delivery in the Maple River. Gran et al. (2011) found that about 9% of the sediment in the Le Sueur River is attributed to ravines. Gran et al. (2011) only considered fine grained materials (silts and clays), thus it is assumed that sand and gravels either remain in gullies or move in the riverine systems as bedload.

Ephemeral gullies, which are often the target of grade control structures, were defined by Poesen et al. (2003) as channels with concentrated flow less than 1.5 meters deep. Ravines are more permanent channels that connect relatively flat, cropped upland areas to incised channels and ditches below; therefore, they transport sediment generated from up-gradient fields, as well as sediment generated from within the gully due to both geotechnical and fluvial processes. In loess regions of Iowa, gully erosion is considered one of the main sediment sources to streams (Cox et al., 2011). In the Seven Mile Creek watershed of southern Minnesota, ravines and gullies are considered the largest source of sediment to that stream (Lenhart et al., 2016).

Wilson et al. (2008) indicate that drop pipe grade stabilization structures should reduce annual sediment yield from 5.13 ton/acre/year to 0.05 ton/acre/year, or 99%, based on estimates produced using RUSLE. As these authors point out, there is very little research on the effectiveness of grade stabilization structures at the field and watershed scales. Thomas (2009) found in a study of grade control structures in the loess region of western Iowa estimated that 0.98 tons of sediment per structure on average was protected from erosion, based on predictions of sediment loss avoided from headcutting.

Gullies often require farmers to spend substantial time and resources to grade, fill, and manage head-cutting channels. In addition, they often cause difficulties in maintaining roads and trails in parkland where steep terrain was set aside as natural areas; therefore, grade stabilization is often done first for practical reasons to protect farmland, park trails or adjacent infrastructure, with water quality as a secondary benefit.

Key Design/Implementation Considerations

Design criteria for grade stabilization structures are referenced in NRCS Practice Standard 410. Both low-hazard embankment dams and full-flow open structures are specified in NRCS 410. For embankment dams with an effective height of less than 15 ft and with a 10-year frequency, 24-hour storm runoff volume less than 10 acre-feet, the designer may use the design standards from CPS Water and Sediment Control Basin (Code 638). (USDA NRCS, 2016). The grade control structure should be designed to control the peak flow from the 10-year frequency, 24-hour duration storm without overtopping.

Full flow open structures are designed for channels with more regular flow and include drop, chute and box inlet drop spillway types and/or drop boxes to road culverts and may be constructed in natural or constructed channels. Design guidance is contained in the NRCS National Engineering Handbook, Part 650, Chapters 6 and 10 (USDA NRCS, 1984). A Minnesota DNR permit is required if the grade stabilization structure can be classified as a dam. Criteria for dam classification are provided by the Minnesota DNR (2012).

From a wide-scale policy standpoint reduction in gully/ravine erosion can be most cost-effectively accomplished through upland hydrologic management of the contributing area and/or direct vegetative or structural means. A design charrette conducted in 2011 for Scott County, Minnesota determined that the consensus recommendation for two projects in the Blue Earth and Sand Creek basins, was to first address upland hydrology and then implement site specific practices (EOR, 2011). Hydrologic management in the contributing watershed includes practices that reduce the amount and/or rate of water flowing to the gully or ravine. Potential options include:

- Diverting water above the gully using a diversion or terrace
- Retaining more water in the contributing area through tillage practices, vegetation, or structures like infiltration basins

Cost Information

The cost of grade stabilization structures is highly variable depending on the drainage area served, height of drop, armoring requirements, soils, and other site specific factors. The Minnesota 2016 EQIP payments depend on the type of structure and the drainage area. Payments are provided for embankment dams, fabric reinforced vegetated chutes, plunge pools, side inlet structures, drop inlets to culverts, culvert protection, concrete block or rock chutes, and toe walls.

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office

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Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses related to the purchase of materials and labor for the installation of a stabilization structure are eligible when the practice will result in less erosion and improved water quality. Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, and weed control herbicides are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
Fabric Reinforced Vegetated Chute	$2.58/ft^2	360	$930
Concrete Block or Rock Chute	$10.69 /ft^2	720	$7,700
Culvert Outlet Protection, MN TR3	$1,630.00 each	1	$1,630
Plunge pool, Design Note-6	$4,590.00 each	1	$4,590
Aluminum, Steel, or Concrete Toe Wall	$10,710.00 each	1	$10,710
Drop Inlet to Culvert	$4,240.00 each	1	$4,240
Side Inlet Structure	$6,500.00 each	1	$6,500
Embankment Dam – Drainage Area 0 to 5 Acres	$5,940.00 each	1	$5,940
Embankment Dam – Drainage Area 5.1 to 10 Acres	$7,860.00 each	1	$7,860
Embankment Dam – Drainage Area 10.1 to 20 Acres	$11,110.00 each	1	$11,110
Embankment Dam – Drainage Area 20.1 to 40 Acres	$18,060.00 each	1	$18,060
Embankment Dam – Drainage Area 40.1 to 70 Acres	$29,550.00 each	1	$29,550
Embankment Dam – Drainage Area 70.1 to 100 Acres	$31,580.00 each	1	$31,580
Embankment Dam – Drainage Area 100.1 to 200 Acres	$34,960.00 each	1	$34,960
Embankment Dam – Drainage Area > 200 Acres	$41,700.00 each	1	$41,700
Embankment Dam Rehab – Drainage Area 0 to 20 Acres	$7,550.00 each	1	$7,550

Avoiding: **Grade Stabilization Structures**

Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
Embankment Dam Rehab – Drainage Area 20.1 to 70 Acres	$10,300.00 each	1	$10,300
Embankment Dam Rehab – Drainage Area 70.1 to 200 Acres	$16,510.00 each	1	$16,510
Embankment Dam Rehab – Drainage Area > 200 Acres	$22,850.00 each	1	$22,850
Embankment Dam – Earthfill	$10.00/yd^3	2,600	$26,000

Operation and Maintenance Considerations

Grade stabilization structures should be inspected for periodic trash and debris accumulation, particularly in and around piped drop inlet structures.

Local/Regional Design Examples

The study of ravines and gullies sediment sources have been the subject of many studies in relation to the causes of high turbidity in the Minnesota River (Wilcock, 2009; Gran et al., 2011). They were not found to be one of the larger sources of sediment overall but they are a major source of sediment in certain watersheds, such as Seven-Mile Creek near Saint Peter, Minnesota (Lenhart et al., 2016). Since ravines and gullies are often unstable and stabilization is costly, identification and prioritization of gully and ravine locations is critical for implementation of grade stabilization structures.

While the topic of this section is grade control structures, another means to address grade control is through upland hydrologic flow modification. That is, reducing the amount of runoff reaching unstable grade location, such that the location either self-heals or a reduced-size structure can be built.

There is not consensus on the best approach to stabilize a grade in a ravine or gully. Gray and Sotir (1996) present a wide range of stabilization alternatives. Check dams have been the standard NRCS practice for decades in medium-size gullies, while grass swales can help control or prevent minor knickpoint advance. For larger gullies and ravines, there is no single standard approach, and risk of project failure and cost increases greatly.

In the Seven Mile Creek County Park the Nicollet County SWCD and Nicollet County Parks and Trails have implemented a variety of practices to address ravine and gully erosion and excess deposition affecting park resources.

The Scott Watershed Management Organization and Minnesota River Board held a design charrette (EOR, 2011) to identify ways to reduce the erosion from ravines and gullies. The preferred management techniques were hydrologic modification followed by stabilization with wood and/or vegetative plantings within the ravine (Table 2). One of the study areas used in the charrette process was in Blue Earth County. A drawback of addressing individual locations is the difficulty and cost in accessing ravine sites. The preferred or recommended solution for the 1000-acre watershed was to construct water and sediment control basins (WASCOBs) at key locations. The other study site evaluated by the design charrette (EOR, 2011) was in Scott County. In this case as well, the preferred plan focused on hydrologic alteration as a first means of stabilizing ravines and then focusing on structural and vegetative means at individual sites.

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Table 2. Minnesota River Valley Ravine Stabilization Charrette

TECHNIQUES		GROUP CONSENSUS				NOTES
Category	Practice	Favored	Favored In Certain Settings	Further Exploration warranted	Not Preferred	
HYDROLOGY MODIFICATIONS*	Road Detention			●		Need to consider safety and fish passage issues
	Constructed Wetlands		#			Potential to leverage other funding
	Restored & Enhanced Wetlands	Δ				Potential to leverage other funding
	Infiltration Basins	Δ				Reduction and in peak flow and volume
	Detention Basins	Δ				Peak reduction only
	Conservation/ Controlled Drainage			●		Benefits during the most erosive events lessened, but provide additional water quality benefits
	Critical Landcover Alteration		#			Most effective, but very high cost; potential to leverage other funding
	Water & Sediment Control Basins	Δ				(WASCOB)
	Buffer With Depressional Storage		#			Limited benefit with larger (destabilizing) precipitation events

Avoiding: **Grade Stabilization Structures**

TECHNIQUES		GROUP CONSENSUS				
Category	Practice	Favored	Favored In Certain Settings	Further Exploration warranted	Not Preferred	NOTES
STABILIZATION WITHIN RAVINE – VEGETATIVE**	Soil Biotechnical & Bioengineering	Δ				Multitude of practices and techniques
	Stiff Grass Treatments		#			
	Thinning of Canopy		#			Increase in root diversity and density has been seen from solar gain
	Invasive Species Removal		#			Increase in root diversity and density has been seen from solar gain and reduced competition
STABILIZATION WITHIN RAVINE – ENGINEERED STRUCTURES	Side Inlet Control (Ag Drainage)	Δ				Provides stable outlet to ravine
	Bank & Bed Armoring - Rip Rap		#			
	Bank & Bed Armoring - TRM, Geoweb and other Geosynthetics		#			
	Bank & Bed Armoring - Woody debris		#			
	Grade Control - Check Dams**	Δ				Access can be an issue
	Grade Control – Log**		#			Shorter life span in this climate
	Grade Control - Gabions				○	Access can be an issue; gabion basket lifespan is short lived
OTHER	Accelerated Succession of Field Terraces				○	Via gravel augmentation
	Raise Profile & Increase Channel Capacity				○	Via placement of engineered fill; effective but expensive alternative
	Piping			●		Passing flows via pipe/draintile to lower discharge point
	Saturated Bank Toe Dewatering			●		Subsurface drainage to remove destabilizing saturated soils

*Group identified this category as the 1st design option to explore and sequence in rectifying ravine instability

**Group identified this category/practice as the 2nd design option to explore and sequence in rectifying ravine instability

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Research Gaps

As indicated in Gran et al. (2011), implementation of grade control structures requires identification and prioritization of critical locations. Research should be undertaken, preferably at the watershed scale, to prioritize critical locations.

Despite the relatively widespread use of the practice, there is still little research on practice effectiveness at the field and watershed scales (Wilson et al., 2008).

Lenhart et al. (2016) found that the use of alternative grade control structures such as engineered wood jams and other low-tech solutions have not been thoroughly studied but may provide cost-effective solutions with additional ecological benefits.

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Avoiding: **Grade Stabilization Structures**

Access Control/Fencing (472 and 382)

Access control may be needed where cows are grazing adjacent to streams or other sensitive areas. (Photo by David Hansen)

Definition and Introduction

The temporary or permanent exclusion of livestock, people, vehicles and/or equipment from a designated area—often to protect streambanks, wetlands, woods, cropland, wildlife habitat or conservation buffers.

This practice generally refers to permanently excluding animals from coming into contact with water resources. It can also refer to the spatial or temporal limiting of livestock access as a management tool. The practice is typically used in conjunction with stream restoration efforts. While appropriately timed grazing of the riparian zone can provide some benefits to the stream, complete exclusion of livestock is oftentimes preferred, especially on very sandy soils and extremely erosive or frequently flooded areas.

The majority of research suggests that complete exclusion of livestock from streams is highly effective at preventing water pollution. In reality it can be impractical to completely fence off riparian areas due to the cost of fencing and the costs associated with providing an alternative water source for livestock. There may also be situations when it is beneficial to allow livestock to graze in areas for a very brief time in order to manage vegetation (Magner et al., 2008). Also see chapters on riparian buffers and prescribed grazing for additional information.

This practice also refers to the exclusion of vehicles and equipment from sensitive areas during susceptible times of the year or permanently. Furthermore, it can refer to the posting of signs or placement of barriers to prevent people from entering unsafe or susceptible areas. These areas are often under conservation practices or are highly erodible.

Water Quality Benefits

Livestock exclusion has the direct benefit of preventing sediment disruption due to trampling of soil and eliminating pollution associated with animal waste. Animal waste can be directly deposited into

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the stream in cases where livestock have access to the stream. Animal waste can also leach into the stream from riparian areas adjacent to the stream, which may impact the nutrient and bacteria concentration. Soil can become compacted from livestock leading to an increase in runoff due to reduced infiltration rates.

A study in Iowa estimated that livestock access paths and loafing areas accounted for 72% of suspended sediment and 55% total phosphorus (P), released into a stream from a 50 ft wide riparian strip, which accounted for less than 3% of the riparian area. The study concluded that managing these paths and loafing areas, as well as controlling stocking rates, could create great reductions in sediment and P loss (Tufekcioglu et al., 2013).

Research on the impacts of access control on nitrogen (N) losses into water resources is limited in Minnesota, but there are projects on grazing land differing from that of Minnesota which indicate that access control could reduce N losses to water resources in Minnesota. Studies in North Carolina concluded that using exclusion fencing to prevent dairy cows from accessing a stream can reduce N, P, and sediment loss to the stream. In one study, Kjeldahl N, ammonia, total P, and total suspended residue reductions were 41%, 59%, 54%, and 67% respectively following exclusion (Line, 2015). In the other study, nitrate + nitrite, total Kjeldahl N, total P, and sediment loads were reduced by 33%, 78%, 76%, and 82% respectively following exclusion (Line et al., 2000). In Canada, Miller et al. (2014) concluded that livestock grazing along a riverbank and access to the river increase soil compaction and nutrients in the soils near the river. This would lead to lower infiltration, greater potential for nutrient release into water, and more erosion. In Indiana, total Kjeldahl N and ammonium increased threefold where cattle had unrestricted access to a stream but nitrate seemed unaffected by cattle access (Vidon et al., 2008).

As a secondary benefit, livestock exclusion may improve the health and vitality of the riparian plant community. A healthy plant community immediately adjacent to the stream typically translates to greater bank stability and lower stream water temperatures. A well-vegetated riparian zone improves bank stability and filters runoff. Kronvang et al. (2012) and Zaimes et al. (2008) note that riparian buffers with trees and shrubs have lower soil and P losses than grass buffers. However Zaimes and Schultz (2015) found the opposite. Riparian land-use also has a major influence. This study investigated spatial and temporal patterns and geomorphologic processes of stream bank erosion and deposition along a 6.2-mile reach of Bear Creek in north-central Iowa, USA. The channel sub-reaches used were adjacent to a riparian forest buffer, a perennial grass filter and a continuously grazed pasture. Two plots were placed in each sub-reach; one on a north-facing outside bank and one on a south-facing outside bank. They conclude that deep-rooted grass filters have less streambank erosion.

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Although the benefit that livestock exclusion has on reducing nutrient loss to streams varies by study, there is a consensus that controlled grazing access around streams does significantly reduce erosion (Zaimes et al., 2008; Nellesen et al., 2011; Zaimes & Schultz, 2015). Pasture lands may deliver significant sediment and P to streams. In addition to water quality benefits, livestock exclusion can improve stream ecology by eliminating destruction of aquatic habitat and through improved shading of the stream (Magner et al., 2008).

Restricting or minimizing equipment or vehicle access to exposed soils or highly erodible areas can also reduce soil loss to water bodies. While restricting access permanently is impractical in many cases, limiting access during times when soil is saturated or less stable could reduce erosion.

Key Design/Implementation Considerations

While a variety of natural materials can be used for livestock exclusion, including boulders, logs and woody vegetation, fencing is the preferred method.

Options for fencing include wood slats or boards, barbed wire, high tensile wire or electrical fencing.

NRCS Conservation Practice Standard for Fence, Code 382 requires the following:

- Fencing materials, type and design of fence installed shall be of a high quality and durability, with a minimum life expectancy of 20 years. The type and design of fence installed will meet the management objectives and topographic challenges of the site.
- Barbed wire will not be electrified. Fences shall be positioned to facilitate management requirements. The fence design and installation shall follow all federal, State and local laws and regulations.
- Height, size, spacing, and type of materials used will provide the desired control and management of animals and people of concern. Perimeter fences shall have a minimum of four wires.
- Manufactured brace assemblies that are screwed into the ground are acceptable if installed according to the manufacturers' recommendations, and the fiberglass component is guaranteed to last for 20 years without splintering or deteriorating from sunlight and weather.

The fence design and location should also consider:

- Topographic features
- Soil-site characteristics
- Type and amount of vegetation on site
- Safety and management of livestock
- Kind and habits of livestock and wildlife
- Location in relation to reliable watering facilities
- Location in relation to livestock handling facilities
- Development of potential grazing systems
- Human safety and access
- Landscape aesthetics
- Erosion problems (existing and potential)
- Moisture conditions
- Seasonal weather conditions (snow, ice, flood, drought, wind, and fire)
- Stream crossings
- Durability of materials.

Where applicable, cleared rights-of-way may be established, which would facilitate fence construction and maintenance. Fences across gullies or streams may require special bracing, designs or approaches. Fence design and location should consider ease of access for construction, repair and maintenance. Treatment of wood posts with preservatives may not be allowed in organic production systems. Producers should check with their certifying agency regarding requirements.

Cost Information

Access control and fencing along riparian areas is often performed in conjunction with bank or buffer restoration. However, the costs for access control and fencing pertain mostly to the cost and labor of fence installation and maintenance. Other costs could potentially include purchasing and installing signage, setting up alternate grazing areas with water sources to replace the riparian grazing area, and vegetation management in excluded areas (Tables 1 and 2).

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of access control fencing practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses related to the purchase of materials and labor for the installation of access controlled fencing and exclusionary fencing are eligible when the fencing reduces adverse impact of livestock on water quality such as nutrient loading, erosion, sedimentation, bank sloughing, and other wetland habitat disturbances. This practice as a component of a rotational grazing plan is also eligible. In addition, purchase costs of equipment required to maintain the quality of the permanent ground is also eligible for AgBMP loan financing.

Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, and weed control herbicides are ineligible.

Table 1. Estimated average statewide conservation practice costs for access control. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/ Acre	Typical Units Installed	Estimated Total Installation Cost (rounded)
Protection of a designated sensitive area threatened by environmental stressors	$43.92	10	$440

Table 2. Estimated average statewide conservation practice costs for fencing. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/ Foot	Typical Units Installed	Estimated Total Installation Cost (rounded)
Multi Strand Barbed or Smooth Wire	$1.65	1,320	$2,200
Electric, High Tensile	$1.81	1,320	$2,400
Feed or Feeding Area Enclosure	$4.44	1,320	$5,900
Safety	$4.27	450	$1,900
Chainlink	$15.15	1,000	$15,100
High Tensile Electric One Strand	$0.85	1,320	$1,100

Annual average ownership cost by fence type (Mayer et al. 2012)

Fence TypeTotal Cost/Foot/Year
Woven wire $0.33
Barbed wire $0.25
High-tensile nonelectric (8-strand)............$0.16
High-tensile electric (5-strand) $0.12

(Includes depreciation, interest on investment, and maintenance.)

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Operation and Maintenance Considerations

Regular inspection of fences is the key component of the operations of a livestock exclusion fence. Inspections should be conducted at a regular interval and after storm events to insure proper function of the fence. Maintenance generally consists of minor repairs.

Research Gaps

Although complete livestock exclusion is a common BMP, controlled or rotational grazing practices have started to show that some grazing can be beneficial under certain conditions. All aspects of livestock exclusion need further study to identify design and benefits to water quality. In particular, the impacts of grazing streambanks with small livestock need to be further studied to quantify the benefit as a potential nutrient management strategy by removing vegetation prior to the release of nutrients during decomposition.

Legal/Permit Requirements

Any barriers that restrict flow of water in the 100-year floodplain need approval or a permit for floodplain management. Any access restrictions near roadways or trails where people may be walk or driving near a hazard should have clear barriers to improve safety and minimize the risk for liability.

Local/Regional Requirements Design Example

Access restriction is used throughout Minnesota particularly in southwestern Minnesota and the Driftless Area where grazing if more common. Few research studies have been conducted in recent years to determine nutrient and sediment reductions from access control and fencing in Minnesota.

The Minnesota Pollution Control Agency now gives priority to feedlot permits if the farmer also applies for agricultural water quality certification through the MDA's Minnesota Agricultural Water Quality Certification Program.

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NRCS Conservation Practice Standard, Fencing, Code 382
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NRCS Conservation Practice Standard, Access Control, Code 472
efotg.sc.egov.usda.gov/references/public/MN/472_MN_Access_Control.pdf

MDA Conservation Practice, Livestock Exclusion/Access Control
www.mda.state.mn.us/protecting/conservation/practices/exclusion.aspx

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Nutrient Management (590)

Definition and Introduction

Nutrient management is the management of the application rate, timing, source, and placement of fertilizers, manure, and other soil amendments. The nutrients that have the greatest impact on water quality are nitrogen (N) and phosphorus (P). Among all BMPs, nutrient management BMPs are one of the most effective ways to improve water quality. Nutrient Management is one of the basic BMPs used on farms state-wide.

An excess of either N or P, or both, can adversely affect the aquatic system, driving new water quality standards and efforts to prevent further impairment of water bodies. N applied in agricultural fields poses a potential threat to human health when excessive levels of the nitrate form of N find their way into drinking water sources. Agricultural fertilizers are also a major contributor of nitrates in the Gulf of Mexico where they contribute to seasonal hypoxia.

In Minnesota, cold weather makes nutrient management challenging due to a non-growing season with limited evapotranspiration rate, frozen soil with little infiltration, and melting snow in spring. The combination of cold weather and unpredictable spring precipitation makes nutrient management even more complex. Following nutrient mangement BMPs can help farmers overcome these challenges. A series of very useful fact sheets developed by the University of Minnesota Extension covers nutrient management and should be reviewed for more details on how to implement nutrient management on Minnesota farms. It can be found at www.extension.umn.edu/nutrient-management. The University of Minnesota Extension is also a partner in the corn N rate calculator to help determine the maximum return to N available at cnrc.agron.iastate.edu. The Minnesota Department of Agriculture has developed the Minnesota Nitrogen Fertilizer Management Plan (MDA, 2015), which discusses recommendations for preventing or minimizing the impacts of N fertilizer on groundwater based on the University of Minnesota Extension recommendations.

Water Quality and Other Benefits

Nutrient application can be managed in four key ways by optimizing application rate, application timing, source of nutrient, and placement of the application, referred to as the 4Rs (Right Rate, Right Timing, Right Source, Right Placement), which are based on the same overarching principles used in the Minnesota Nitrogen Fertilizer Management Plan (NFMP) (MDA, 2015). The benefits of nutrient management have been described and studied in this manner and are presented by management area in this chapter. Nutrient management is often related to all four of the key areas, so the discussion overlaps between sections. Nutrient management recommendations, particularly for N, also vary geographically across the state because of differences in soil type, geological parent material, climate, and topography. The MDA (www.mda.state.mn.us/nitrogenbmps) presents regional and specialized N BMPs.

In Minnesota, management of nutrients must take into consideration the pathways that nutrients follow if they leave the farm field. About 67% of nitrogen that enters the Mississippi River north of its confluence with the Ohio River is agricultural in origin (Petrolia & Gowda, 2006), and tile drainage is the major pathway for that nitrate. Petrolia and Gowda (2006) found that nutrient management on tile-drained land was the most cost-effective means of achieving nitrate reduction goals. They compared nutrient management (defined as spring-applied N at 112 lbs/ac), land retirement, plugging tile but continuing to farm, and plugging tile and retiring it. They also found that it was more cost-effective to achieve reduction goals by using a targeted approach, where watersheds were required to meet the reduction goals, as opposed to a uniform approach where all operators would be required to meet the reduction goal. King et al. (2015) provide a comprehensive review of P transport in subsurface drainage systems as described later in this chapter.

An important aspect of nutrient management is developing a nutrient management plan. Shepard (2005) compared nutrient application rates of producers who had developed nutrient management plans to those without and found that those with plans applied N at an average rate of 124 lb/ac versus 168 lb/ac for those without plans.

Nutrient management strategies depend on the types of crops being grown. One potential important part of nutrient management for achieving water quality goals is building in rotations of small grains, perennials, forage or cover crops. This is discussed in the Conservation Crop Rotation and Cover Crops chapters of this handbook.

Water Quality Goals

The State of Minnesota developed a comprehensive nutrient reduction strategy (NRS) for surface water in 2014 (MPCA, 2014). That document presents N and P reduction targets to meet nitrate, eutrophication, turbidity, and dissolved oxygen water quality standards statewide. These reductions vary by region, depending on baseline loading and the standard for a particular area. Figure 1 shows priority loading areas (i.e., highest contributing areas) of the state for both P and N.

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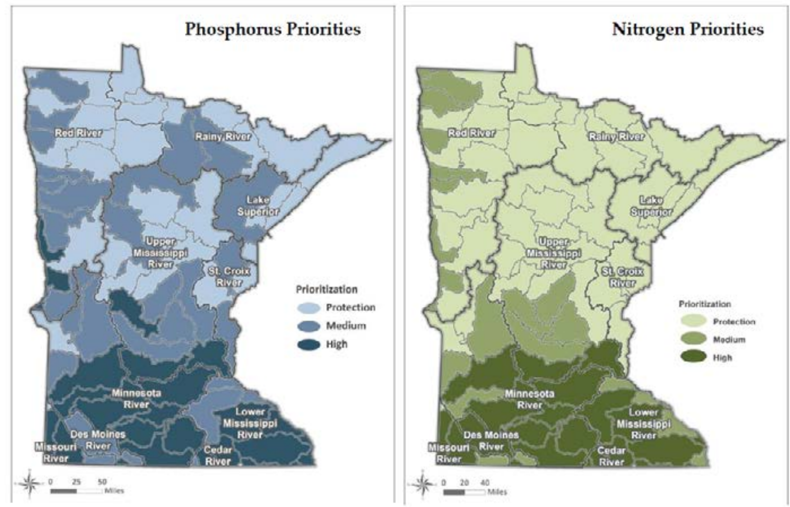

Figure 1. Modeled phosphorus and nitrogen loading from HUC8 major watersheds. (images from MPCA, 2014)

According to the MPCA (2014), agriculture contributes about 29% of the statewide P and 73% of the N load in the state's surface water in a typical year, which is similar to the 67% estimated by Petrolia and Gowda (2006). In order to achieve the goals and milestones presented in the NRS by the year 2025, the reductions to baseline loads presented in Table 1 below would have to be made (Anderson et al., 2016).

Table 1. Nitrogen and phosphorus load reduction percentages from baseline load (2003 baseline for Red River, 1980-1996 for Mississippi River). Adapted from MPCA (2014).

Watershed	Percent Reduction	
	Nitrogen	Phosphorus
Mississippi River Major Basin	22	26
Red River Basin	14	10

Nutrient management is one part of a comprehensive nutrient management reduction strategy. Downstream nutrient reduction targets are likely to be met only if nutrient management in addition to nutrient reduction practices is undertaken (McLellan et al., 2015; MPCA, 2014). In fact, improved fertilizer management alone would only result in an estimated 12.7% reduction in N load delivered. The MPCA 2014 study found that reducing fertilizer application to the University of Minnesota-recommended rates could reduce N load by a predicted 16% and P by 17%. Switching fall application to spring with rate reductions could reduce N loads by 26% while P incorporation into the subsurface could reduce its load by 24%. Specific recommendations based on the 4Rs are presented below for P and N. However, general guidelines presented in the Minnesota NFMP (MDA, 2015) for N include:

- Adjust the fertilizer rate according to University of Minnesota Extension fertilizer guidelines
- Do not apply fertilizer above recommended rates and include any N in starter program and contribution from phosphate fertilizer such as MAP and DAP

Avoiding: **Nutrient Management**

- Take credit for previous legume crop or manure used in the rotation
- Plan fertilizer application to achieve high efficiency and minimize loss
- Develop a comprehensive record-keeping system for field-specific information

For a complete overview of current nutrient best management practices, please see visit www.extension.umn.edu/nutrient-management.

If manure is used, the following guidelines are recommended by University of Minnesota Extension:

- Test manure for nutrient content.
- Calibrate manure application equipment.
- Apply manure uniformly.
- Avoid manure application on sloping, frozen soils.
- Manure injection is preferable to broadcasting, especially on steep sloping soils.

Rate

The amount of nutrient applied (recommended nutrient application rates) are calculated based on many different factors. Crop nutrient budgeting, recent yields, soil productivity, climatic conditions, level of management, nutrient costs, and expected return are all factors used in selecting an application rate. Good resources utilizing these factors are on the University of Minnesota Crop Calculators page and Fertilizer Recommendations page. Discussions regarding 'Right' rate for P and N are presented below.

Phosphorus

The amount of P lost through subsurface pathways is tied directly to P application rate, regardless of P source or P application method (King et al., 2015). P reacts slowly and is slowly released from fertilizer into the soil. Therefore knowing the P fertilizer application history and management practices are essential to understanding the accumulated available P. In soils of the north central region of the U.S. total P typically range between 300 and 1000 ppm (Mallarino and Bundy, 2008). For corn, there is no economic advantage of adding P to the fields when the P soil test is 20 ppm and higher for Bray test and 16 ppm or higher for Olsen test (U of M Extension, 1997).

Nitrogen

Minnesota, like much of the Midwest, has adopted a MRTN, or Maximum Return to N approach to N application guidelines for corn. This approach provides recommendations that account for price per bushel of corn, price per pound of N fertilizer, cropping history (e.g., corn after soybean), and also accounts for soil type (Rehm et al., 2006; Sawyer et al., 2006).

For N, rotating in legume crops such as soybean or alfalfa adds N to the soil and reduces the amount of N fertilizer needed (see crop rotations chapter). Nangia et al. (2008) indicated that nitrate loss response to application rate may be more pronounced if the crop is corn only as opposed to a corn-soybean rotation. Other factors that influence the nutrient application rate are soil type, tillage method, and fertilizer application methods (Baker et al., 1975; Fawecett, n.d.).

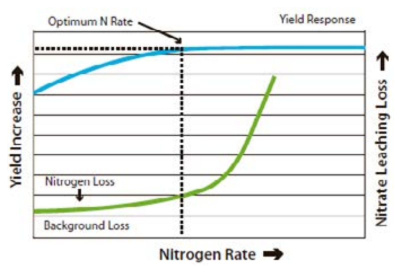

Figure 2. Importance of using optimum N rate for greatest profit and minimal nitrate-N loss (U of M Extension, www.extension.umn.edu/agriculture/nutrient-management/nitrogen/validating-n-rates-for-corn-on-farm-fields-in-southern-minnesota/index.html)

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Optimum N rate is the minimum amount of N fertilizer that produces maximum profit. Thorp et al. (2007) estimated through a calibrated modeling exercise in Iowa that an 18% reduction in N loss could be seen over a 45-year simulation if the optimum N rate was applied. Using the optimum N rate makes N leaching loss minimal under normal conditions (Figure 2). Traditionally the economic optimum N rate (EONR) has been used for this calculation. However, it has not been modified to reflect environmental costs resulting from increased nitrate loss to water systems mainly due to lack of cost information and societal decisions on where to divide those costs. Preplant and in-season soil and plant diagnostic tests are also useful tools to help improve N application rates (Sawyer and Randall, 2008). In an early study of N losses in tiled fields in Iowa, Baker and Johnson (1981) found that reduced N application resulted in a 45% reduction in nitrate loss from the field. Christianson and Harmel (2015) reviewed nearly 1,000 plot years of data to better understand the effects of fertilizer type, timing, rate, and location on water quality in artificially drained landscapes. They noted a relationship between N application rate and dissolved N load. Approximately 20% of applied N was lost via drainage (Christianson and Harmel, 2015).

The rate of loss to groundwater is high in very coarse-textured soils (Rubin et al. 2016) especially with irrigation. Nitrate leaching is best handled by a split application to reduce groundwater contamination. Struffert et al. (2016) found that a 9% rate of nitrate-nitrogen leaching was achieved in a corn field with a 20% reduction in N rate application below the economically optimum rate. This highlighted the difficulties in reducing nitrate leaching in irrigated corn agriculture in sandy soils.

As indicated in McLellan et al. (2015), water quality goals in the Midwest are likely to be achieved only if a combination of nutrient reduction and nutrient management practices are implemented. Nangia et al. (2008) calibrated the ADAPT model using measured data for a site near Saint Peter, Minnesota, and ran the calibrated model for a 50-year period. They found that decreasing fall applied N from 180 kg/ha to 123 kg/ha (161 to 110 lb/ac) (a 32% reduction) resulted in a decreased nitrate loss of 13% (50.4 kg/ha - 45 to 39 lb/ac to 43.7 kg/ha). The lowest nitrate losses corresponded with reduced rates of N fertilizer applied during spring (Nangia et al., 2008).

Timing

The timing of nutrient application is a critical component of nutrient management and is one of the "Four R's." N and P applied in the field are subject to leaching or runoff after precipitation prior to being utilized by the plant. Generally speaking, the most effective time to reduce N loss is to apply N during the maximum N demand period of a crops growth. (Randall & Sawyer, 2008). Examples include using split applications where appropriate, avoiding N application in the fall, and fertigation in irrigated production systems. Although not as mobile as N, P should not be applied prior to rainfall or on frozen ground conditions.

The timing of P application is not critical for the predominant crops and soils in the north central U.S. due to its low mobility. However, the risk of P loss from recent application is higher if the application is made prior to an intense rainfall, to water-saturated or snow-covered soils, to sloping ground, or to flood-prone areas. An Iowa study showed a runoff event 10-15 days after application of manure had 50% less dissolved P compared to runoff 24 hours after application (Mallarino & Bundy, 2008). A more recent study in Wisconsin presented similar results. Liquid-dairy or solid-beef manure applied on frozen and snow-covered ground less than one week prior to runoff events contributed to significantly higher N and P concentrations in the runoff despite relatively lower application rates (Komiskey et al., 2011).

Recommended N application depends on geographic location and type of fertilizer. MDA (2015) provides guidance, reprinted in Table 2, regarding timing.

Avoiding: **Nutrient Management**

Table 2. Summary of the major nitrogen timing and source recommendations for corn by region.

Minnesota Recommended Application Timing for Corn			
Nitrogen BMP Region	Fall*	Spring Preplant	Split or Sidedress
Southeast	Not Recommended	Highly Recommended: AA or Urea	Highly Recommended: AA, Urea, or UAN
		Acceptable with Risks: Preplant with UAN or ESN	
South-Central	Acceptable with Risks: AA or Urea with N-Serve	Highly Recommended: AA or Urea	Highly Recommended: Split Applications of AA, Urea, or UAN
	Not Recommended: Fall Application of Urea or UAN	Acceptable with Risks: Preplant with UAN or ESN	
Coarse-Textured Soils	Not Recommended	Acceptable with Risk: AA or Urea with N-Serve, Single Sidedress w/o N-Serve, or Single Preplant with ESN	Highly Recommended: Use Split Applications, N-Serve with Early Sidedress
Southwest/ West-Central	Recommended: Fall Application of AA or Urea	Recommended: Urea, AA, or UAN	Recommended: Sidedress Prior to V7 Growth Stage
	Acceptable with Risk: Late Fall ESN or use of N-Serve or Agrotain		
	Not Recommended: Fall UAN or Any Fertilizer Containing Nitrate		
Northwest	Recommended: Fall Application of AA or Urea	Recommended: Urea, AA, or UAN	Recommended: Sidedress Prior to V7 Growth Stage
	Acceptable with Risk: Late Fall ESN or Use of N-Serve or Agrotain		
	Not Recommended: Fall UAN or Any Fertilizer Containing Nitrate		

*Only after six inch soil temperatures fall below 50 °F
Note: AA=Anhydrous Ammonia, ESN=Environmentally Smart Nitrogen, UAN=Urea Ammonium Nitrate Solution

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Fall vs Spring Application

Many U.S. corn growers in the northern part of the Corn Belt prefer to apply N in the fall because they usually have more time and fields are in better condition (Randall et al., 2003). The price of fertilizer is also lower in fall. Also, anhydrous ammonia in fall is acceptable except in course-textured soils or in southeast Minnesota if the soil temperature is below 50°F and trending downward. A number of studies show that fall N application is associated with more N loss to surface water. This is especially true in coarse soils where subsurface water may percolate rapidly through the bottom of the root zone. In poorly drained soils, however, losses to tile drainage and denitrification are likely more important sources of loss. Surface runoff losses are possible in poorly drained soils particularly if N is not incorporated or injected into the soil.

Early spring planting is desirable for higher crop yields as soon as soil is tillable. Therefore, if farmers wish to have an interval between spring N fertilizer application and pre-emergence herbicide application, time for spring fertilizer application is very limited. An extended rainy season and risk of soil compaction can also restrict spring N fertilizer application. Randall et al. (2003) demonstrated a 36% reduction of N loss from tile drainage when N was applied in spring compared to the fall application. On average a 15% reduction of leaching loss in drainage water with spring N application was observed in Minnesota compared to a late-October application when soil temperature was at or below 50°F. However, Christianson and Harmel (2015) report that these N reductions due to differences in timing of application may be overshadowed by differences in precipitation; their analysis of nearly 1,000 site years of data across the Midwest showed no difference in dissolved N load for four different timings. One key recommendation of the Minnesota Nutrient Reduction Strategy is to shift from fall to spring application. This agrees with the research of Nangia et al. (2008), who showed that spring application led to lower nitrate losses than fall application of N.

P loss is also correlated with application timing, in relation to both stage of crop growth or planting and how soon after application precipitation occurs. In general, greater risk of loss is associated with autumn and winter application as opposed to spring and summer (King et al., 2015).

Split Application

Split application is recommended in all areas of Minnesota (MDA, 2015). Split application for N is highly recommended for irrigated corn fields (Brach, n.d.), if ridge-till or no-till planting systems are used on irrigated sandy soils (U of M Extension, www.extension.umn.edu/agriculture/nutrient-management/), or southeast and south-central Minnesota. It involves a pre-plant N fertilizer application and side dress application, which is typically made four to six weeks after planting crops. Side dress application provides N just prior to high demand of N uptake and reduces the risk of N loss. Split application also reduces the risk of yield loss by having late side dress application due to weather or labor and equipment shortage (Fawecett, n.d.). For urea and ammonium nitrate (UAN), split application seems to be suitable as it reduces the risk of N loss when conditions are wet prior to the V10 corn growth stage. However, there is little consistency in recent studies to support the benefit of split application over spring pre-plant anhydrous ammonia from a water quality or economic perspective on medium and fine-textured Corn Belt soils (Jaynes & Colvin, 2006; Randall & Sawyer, 2008). Nitrate-N losses with split application for the corn-soybean rotation were lower during the corn year, but tended to be higher during the following soybean year (Randall & Mulla, 2001). Overall, data to support the benefit of split application is not sufficient and more research is necessary to determine techniques of application, including the ideal proportion of pre-plant N vs. side dress N, N sources, placement methods, in-season diagnostic tools to determine optimum N rate for sidedress, and timing of sidedress (Randall et al., 1993; Randall & Sawyer, 2008). In their review, Christenson & Harmel (2015) found no significant improvement in water quality due to split N

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application. Recent studies in course-textured soils by Rubin et al. (2016) and Struffert et al. (2016) do show reduced N loading from split application.

Nutrient Source

The best source of N is different for fall and spring application in terms of yield and impact on water quality. On Nicollet and Webster glacial till soil in southern Minnesota, anhydrous ammonia and urea were compared between fall and spring application. The best N recovery was observed for anhydrous ammonia and urea applied in spring, followed by fall anhydrous ammonia application; fall applied urea had the least recovery. The effect of nitrification inhibitor, N-Serve, was minimal in this study. A 17-year study completed in Iowa showed similar results. Thoma et al. (2005) found that nitrate levels in the soil were higher from urea than from manure treatments in an experiment performed at Lamberton, Minnesota. Thoma et al. (2005) also found that N loss in surface runoff was less from manure compared with urea, likely due to slow but continuous release of manure organic N that was taken up by the crop more efficiently.

Rate and timing of manure application depends on the ratio of ammonium-N to organic N. ammonium-N is readily available during the first year of application, so manure with high ammonia N should be applied in spring. Manure with greater organic N can be fall-applied with less potential for nitrate loss and to improve long-term soil nutrient holding capacity. When late fall-applied dairy manure slurry was compared with spring-applied urea for four years in Minnesota, no difference in nitrate loss was observed to subsurface drainage for continuous corn (Randall & Sawyer, 2008).

For manure application, the amount and form (organic, inorganic, or soluble) of total P varies depending on the animals' species, age, diet, and manure storage method. For example, total P is 80-100 pounds of P2O5 per ton for some poultry manures and 5-10 pounds of P2O5 per ton or less for liquid swine manure from lagoons or solid cattle manure. For liquid swine manure, 80% of the P is inorganic and soluble, therefore P reactions and availability are similar to that of fertilizer P. For solid manure from beef and dairy cattle, inorganic P can be less than 50% and the rest is the more stable organic form, which is not immediately available for crops during the first year of application (Mallarino & Bundy, 2008). In a field study in Minnesota, liquid swine manure was applied at doubled rate of recommendation based on soil test and the yield of corn did not increase, but dissolved P load in spring runoff almost doubled (Gessel et al., 2004).

It is notable that manure application, annually or less frequently, is known to reduce soil erosion and the amount of runoff from the field. At several locations in Minnesota, Iowa, and Wisconsin where manure was applied annually on agricultural fields, runoff was reduced 2% to 62% and soil erosion was decreased 15% to 65 % compared to the sites without manure application (Gilley & Risse, 2000). These reductions can be observed for both solid and liquid manure (Gessel et al., 2004) and the degree of reduction is found to depend on manure characteristics, application rates, incorporation, and the time between application and the first rainfall (Gilley & Risse, 2000; Mallarino & Bundy, 2008). Application of manure is further discussed in this chapter under the sections of timing and method.

P may be applied in organic (manure) or inorganic (fertilizer) forms. Research suggests that losses of P through subsurface pathways may be dependent upon the form of P applied, with losses of P from organic sources being greater than inorganic sources (King et al., 2015). King et al. reference two studies that found that losses of P in drainage water were two times greater on plots receiving manure compared with plots receiving like or greater amounts of P as superphosphate and phosphogypsum. This finding is consistent with field work done by Thoma et al. (2005) at Lamberton, Minnesota, who found significantly higher soil P levels in plots treated with manure than in plots treated with triple superphosphate.

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Annual and biannual applications of P are similarly effective for most crops of the region. For biannual application, the instantaneous application rate of P is higher and it may result in increased P loss in the short term. However, there is little evidence showing that application of the same amount of P at a higher rate at longer interval with care and appropriate methods results in more long-term potential for P runoff loss compared to more frequent application at lower P rate. Infrequent N-based applications of manure may be a good strategy as it reduces the use of fertilizer and helps to meet the full N need for crops such as corn grown in rotation (Mallarino & Bundy, 2008).

Placement Method

Careful placement of fertilizer can reduce the risk of N loss for ridged crop, such as ridge-till corn and potatoes. Placing N fertilizers in a band in ridges reduces N loss due to leaching and may improve N use efficiency (Fawecett, n.d.). This method is also effective for no-till planting systems (U of M Extension, www.extension.umn.edu/agriculture/nutrient-management/fertilizer-management/fertilizer-management-for-corn/). One experiment showed effectiveness of dripping N solution and immediately covering it with ridging. In this case, ridge-placed N had higher yield of corn, N use efficiency and reduced leaching from the root zone (Dolan et al., 1993). For fertilizer placement on corn residue, one study showed that there was no difference in runoff concentrations when ammonium, nitrates and phosphates were placed above or below corn residue (Baker & Laflen, 1982).

Incorporation

Liquid N fertilizer can be lost into air by volatilization at higher temperatures. Incorporating liquid N fertilizer is recommended and it can be done by tillage in systems utilizing full width tillage or injection for fields with residue such as no-till planting system (Baker & Laflen, 1983). Two studies showed that incorporation by injection or tillage reduced the concentration of nutrients in runoff and there was no significant difference from the results from the unfertilized plots (Baker & Laflen, 1982; Baker & Laflen, 1983). Banding or knifing are other ways to incorporate N fertilizers into soil. For UAN solution application to heavy crop residue, banding or dribble application is effective since these application methods limit the contact with urease enzyme, slowing the conversion of urea to ammonia, and extending the time urea remains on the surface until being incorporated through precipitation. Banding slows nitrification of ammonia fertilizers reducing risk of nitrate accumulation in soil and leaching of nitrate, especially for early applications. Banding distance from seeds and type of N fertilizer have to be chosen carefully following professional recommendations to minimize evaporation and the amount of N taken up or immobilized by micro-organisms (U of M Extension, www.extension.umn.edu/agriculture/nutrient-management/fertilizer-management/fertilizer-management-for-corn/).

For liquid manure with high inorganic, soluble P content, incorporation or injection are highly recommended methods that reduce P losses. P losses from simulated rainfall studies in Iowa show a 25% reduction for manure applied fields when the manure was incorporated. (Tabbara, 2003)

Recommended methods for reducing P in runoff are incorporation of applied P, deep banding of P fertilizer, or injection of liquid manure. If soil test P is in an optimum range, all maintenance P can be applied as starter or corrective application in banding (Fawecett, n.d.).

Grande et al. (2005) compared the effect of residue cover and manure application on no-till corn fields in Wisconsin. Manure application increased dissolved reactive P concentration in runoff in spring by two to five times, but dissolved reactive P load did not differ from plots without manure application due to lowered runoff volumes. Unincorporated manure applied on no-till fields in spring lowered total P loss by 84% by increasing infiltration and reducing erosion by 77-90%. A few studies show that application of manure with high organic matter content has a larger influence on reducing sediments

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and runoff volume than employing different tillage systems. Incorporation of manure may lower dissolved reactive P losses, but it can increase total P due to increased soil erosion. Combining manure application and conservation tillage system has a great potential to reduce dissolved and total P load in runoff (Bundy et al., 2001; Grand et al., 2005). When ridge till was compared to moldboard plow, ridge till incorporation of manure resulted in lower particulate and total P load in runoff and dissolved P load was similar. Interestingly, annual particulate and total P load in runoff were similar or less from manure treated plots than plots without manure (Ginting et al., 1998).

Other Management Techniques

Controlled Release Fertilizer and Nitrification Inhibitors

The effectiveness of controlled release fertilizer and N fertilizer application with nitrification inhibitors has recently been evaluated. Controlled release fertilizer comes in various forms including sulfur coated urea and polymer coated urea, among others. Stable-U is an experimental urea-calcium formulation designed to slowly release N. No yield difference was reported when controlled release fertilizer with half the amount of N in traditional fertilizer was compared to traditional fertilizer (Fawecett, n.d.). Depending on the cost of controlled release fertilizer, its use may have economic as well as water quality benefits.

Nitrification inhibitor is used with urea or anhydrous ammonia to delay the conversion of ammonium to nitrate after being applied to the field. The active life span of the inhibitor is determined by the timing of application, soil pH and soil temperature. N-Serve is the most commonly used nitrification inhibitor in the U.S with Nitrapyrin as its active ingredient. In Minnesota, when N-Serve is applied in late October after soil temperature at 6-inch depth is at about 50 °F, inhibition stays active until May. Warm soil temperatures and high-pH values shorten activation times (Randall and Sawyer, 2008). Randall et al. (2003) reported that using a nitrification inhibitor, Nitrapyrin, for late fall N application or applying N in the spring as a preplant or split (preplant plus sidedress) treatment can improve corn production (yield and profit) while reducing nitrate losses to subsurface drainage waters. The loss of nitrate in subsurface drainage from a corn-soybean rotation was reduced by 10-18% with addition of Nitrapyrin, by 14-17% with spring preplant-applied ammonia (Randall et al., 2003; Randall & Vetsch, 2005), by 13% with N split-applied between April (40%) and June (60%) when compared to late fall-applied N as anhydrous ammonia (Randall et al., 2003). The application of nitrification inhibitor in spring has not shown any reduction in N lost via drainage nor any increase in yield or profitability (Randall & Sawyer, 2008). Using nitrification inhibitor with fall N fertilizer application is similar to changing the timing of N fertilizer application from fall to spring. However, when spring conditions are wet, spring application tends to give substantially greater yield than fall application with nitrification inhibitor. In other words, fall application with nitrification inhibitor can be economically more risky than a spring preplant application of ammonia (Randall & Sawyer, 2008).

Precision Agriculture

For both N and P fertilizer, variable rate fertilizer application is a tool to improve nutrient use efficiency and reduce nutrient loss. This method recognizes the variation in soil type, organic matter content, and water and nutrient holding capacity throughout a field. By using GPS grid sampling and flow meters, localized nutrient needs are determined to match the soil productivity potential or crop needs (Redulla et al., 1996, Mulla, 2015). Besides all the scientific challenges to determine the optimal amount of nutrients, it is also important to understand that farmers are in general not comfortable reducing the fertilizer rate based on N credits (Legg et al., 1993).

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Key Design/Implementation Considerations

The nutrient management BMPs one chooses depends on soil type, crop, form of fertilizer, and other conservation practices such as cover crop and conservation tillage. Because the best nutrient management practice needs to be tailored to each field, there is no one size fits all design. The following links provide detailed information on creating a nutrient management plan that reduces water pollution and improves plant nutrient uptake.

NRCS Conservation Practice Standard, Nutrient Management, Code 590
efotg.sc.egov.usda.gov/references/public/MN/590mn.pdf

MDA Conservation Practice, Nutrient Management
www.mda.state.mn.us/protecting/conservation/practices/nutrientmgmt

BMPs for Nitrogen Fertilizer Use in Minnesota-MDA
www.mda.state.mn.us/protecting/bmps/nitrogenbmps

The Minnesota Phosphorus Index-University of Minnesota Extension: overview of P management and how to use P Index in Minnesota
www.extension.umn.edu/distribution/cropsystems/DC8423.html

Cost Information

The cost of nutrient management consists of soil sampling and testing for nutrient availability as well as calculation of fertilizer and/or manure need based on information such as soil productivity, crop nutrient budgeting, and recent proven yields. In 2006, University of Minnesota Extension estimated that 56% of farmers in Minnesota could save more than $10/acre and 86% could save more than $6/acre, after assessing about 700 nutrient management plans prepared by farmers (MDA). Nutrient management is covered under the EQIP according to the Table 2 below.

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses related to the purchase of equipment that assist with hauling, loading, storage, field preparation of application or application of nutrients that help management equipment that assist in applying for field preparation are eligible when the equipment can help with any amount of nutrient management. This also includes initial site assessments, soil tests, and technological equipment such as GPS and variable rate technologies. Typical operation and maintenance expenses such as fuel for management activities, repairs, tractors, and periodic soil and site testing are ineligible.

Table 2. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
Basic NM* (Non-Organic/Organic)	$3.43/acre	40	$140
Small Farm NM (Non-Organic/Organic)	$161.69 each	1	$160
Basic NM with Manure and/or Compost (Non-Organic/Organic)	$5.78/acre	40	$230
Adaptive NM	$1,879.05 each	1	$1,900

*NM = Nutrient Management

Operation and Maintenance Consideration

Operation and maintenance of nutrient management depends on the history of nutrient management, soil conditions, and type of crop. The outcome of crop yield and reduction in nutrient runoff is also significantly influenced by weather. It is important to evaluate both short and long term outcomes when evaluating current and new management practices.

Legal/Permit Requirements

The determination of the most appropriate nutrient management practices are up to the discretion of the individual farmer / landowner. In some cases there are regulations related to management of manure especially in concentrated animal feeding operations (CAFOs) as well as handling and storage of pesticides and fertilizers. The National Pollutant Discharge Elimination System (NPDES) permit may apply in some situations where bio-solids or waste materials are applied as fertilizer.

Local/Regional Requirements Design Example

Since nutrient management is an individual farmer choice and varies from year-to-year and site to site no local examples are given here.

Research Gaps

Although much research has been conducted in Minnesota and the Upper Midwest on nutrient management, more research is needed in many areas to better understand optimum nutrient rate, application timing, and most effective methods to reduce nutrient runoff while increasing productivity. The following lists are examples of areas where more research is needed.

Nitrogen Rate

- Research to better quantify the relationship between adequate N rate increments and nitrate loss in subsurface drainage.
- Research to better understand reasons for variation in optimal N rate across the Upper Mississippi River sub-basin.
- Research to further develop and refine management tools including soil N tests, plant tests, and plant sensors so that optimum N rate is more accurately determined while reducing the risk of under- or over-fertilization (Sawyer & Randall, 2008).

Split application of Nitrogen

- More study is needed to find the benefit of split application from both economic and environmental perspectives. Recent studies show mixed results depending on factors such as crop type and tillage systems.
- Research to determine whether lower N rates can be used for split application to reduce N loss for pre-plant application while maintaining crop yield (Randall & Sawyer, 2008).

Phosphorus Management

- Research to evaluate impact of P placement methods on both short and long term P loss.
- Research to evaluate the relationship between the proportion of soluble P in animal manures and P loss in surface runoff shortly after a surface application (Mallarino & Bundy, 2008).
- Research to assess soluble P sources, transport and delivery to water bodies.
- Cost effectiveness of Alum use for liquid manure application.
- Research to validate and calibrate P Index in each state.

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Links

NRCS Conservation Practice Standard, Nutrient Management, Code 590 efotg.sc.egov.usda.gov/references/public/MN/590mn.pdf

MDA Conservation Practice, Nutrient Management www.mda.state.mn.us/protecting/conservation/practices/nutrientmgmt.aspx

Phosphorus Loss Assessment by University of Minnesota
www.mnpi.umn.edu

The MN Phosphorus Index: Assessing Risk of Phosphorus Loss from Cropland by University of Minnesota Extension
www.extension.umn.edu/distribution/cropsystems/DC8423.html

Fertilizer management for Corn Planted in Ridge-Till or No-Till Systems by University of Minnesota Extension
www.extension.umn.edu/distribution/cropsystems/DC6074.html

BMP for Nitrogen Use in Minnesota by University of Minnesota Extension
www.extension.umn.edu/distribution/cropsystems/DC8560.pdf

BMP for Nitrogen Use in Minnesota – MDA
www.mda.state.mn.us/protecting/bmps/nitrogenbmps

Agronomic and Environmental Management of Phosphorus by University of Minnesota Extension
www.extension.umn.edu/nutrient-management/Docs/FO-6797-B-1.pdf

National Water Program: P Index
www.usawaterquality.org/themes/animal/research/p_index.html

USDA CSREES 2005 National Water Quality Conference: P Indexes in Four Midwestern States
www.usawaterquality.org/conferences/2005/posters/poster_Abstracts/Pest_Poster_Abstracts/Benning.pdf

4Rs Right for Nutrient Stewardship
www.ia.nrcs.usda.gov/technical/4Rs.html

USDA NRCS NIFA-Conservation Effects Assessment Project (CEAP) Watershed Assessment Studies: Conservation Practice Implementation and Adoption to Protect Water Quality
www.soil.ncsu.edu/publications/NIFACEAP/Factsheet_2.pdf

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Pest Management (595)

Definition and Introduction

Pest management is defined as utilizing environmentally sensitive prevention, avoidance, monitoring and suppression strategies to manage weeds, insects, diseases, animals and other organisms (including invasive and non-invasive species), that directly or indirectly cause damage or annoyance. Integrated Pest Management (IPM), considered a part of Pest Management by the NRCS, is environmentally and economically focused pest control to minimize costs and impacts on non-target species. Integrated pest management utilizes multiple pest control tactics (such as cultural, biological, chemical, and physical) to minimize total inputs and environmental impacts while maximizing the return in yield.

Integrated Pest Management is a set of strategies based on monitoring, economic thresholds and preventative tactics to determine if and when pest treatment is needed. Preventative tactics include strategies to prevent, avoid and suppress pest populations. A cornerstone of IPM is regular monitoring to identify and determine the extent of emerging pest threats. Careful monitoring of pest populations and life cycles enables more judicious and targeted use of pesticides for specific pests. This approach is more effective and economical than non-selective pest management and may result in a lower frequency of pesticide applications.

Selecting integrated strategies to prevent or treat pests requires knowledge of pest and crop ecology. Prevention is the attempt to keep pests from infesting a site in the first place, avoidance is the use of cultural practices to avoid the impacts of pests that already exist in the field and suppression is the use of physical, biological or chemical control (pesticides) to reduce existing pest populations in a field. This is called the PAMS approach (Prevent, Avoid, Monitor, and Suppress):
www.ipmcenters.org/Docs/PAMS.pdf

Examples of cultural controls include crop rotation, pest-resistant crop varieties and timing of field operations to avoid or better manage pest outbreaks. Conservation tactics such as field borders or buffers near crops can be designed to provide habitat for natural predators. Examples of mechanical controls include weed cultivators, rotary hoes and techniques such as flame-weeding. Biological controls involve the timed release of natural predators: an example is the use of parasitic wasps on soybean aphids (blog-crop-news.extension.umn.edu/2015/07/parasitic-wasps-attacking-minnesota.html) (Andow et al., 1987).

Water Quality Benefits

The water quality benefits of pest management can be derived from the reduced introduction, transport or persistence of pesticides into the environment.

There have been several studies of pesticide impacts on water quality in Minnesota. See the MDA annual monitoring report for example. Studies of Atrazine and Alachlor losses in draintile near Waseca, Minnesota showed that over a five-year period Atrazine was detected in 97% of the samples and Alachlor was detected in only 2% of the samples. Concentration of Atrazine was prevalent for more than four years following the last application but no contamination from similar use of Alachlor was apparent. The effect of tillage systems was negligible on Atrazine losses (Buhler et al., 1993).

A 2001 field study in Scott County, Minnesota on Alachlor and Cyanazine compares broadcast application to banding over two years. The results showed that conservation tillage reduced the runoff loss of herbicides by reducing runoff volume and not the herbicide concentration in runoff. Herbicide banding reduced the concentration and loss of Alachlor and Cyanazine by 43% and 17%, respectively (Hansen et al., 2001).

While not directly related to water quality, utilizing biological control within an IPM plan can benefit water quality by reducing the need for chemical control. Studies of biological pest control worldwide were summarized by Bale et al. (2008). They documented over 5,000 introductions of non-native, biological control agents over the past 120 years across 196 countries. There were very few environmental problems yet quantitative documentation of pest control benefits was lacking. Natural predators have been documented to successfully limit population growth of Soybean aphid, Aphis glycines, numerous times (Desneux et al., 2006; Fox et al., 2005). Gardiner et al. (2009) performed a study across 26 locations throughout the Midwest and determined that natural predators of soybean aphid are able to suppress populations of the pest as well. However, the abundance of the natural enemies is largely dependent on the surrounding landscape, with adjacent grasslands or forest increasing abundance in comparison to largely agricultural areas. Similarly, physical control methods such as reduced tillage or mowing practices to reduce pest populations have been used for years but do not have well documented pest control benefits in Minnesota.

Key Design/Implementation Considerations

The NRCS has basic criteria that pest management must be particularly vigilant within 300 feet of water bodies or 50 feet of wells and sinkholes. The Minnesota Pesticide Control Act, Minnesota Groundwater Protection Act and the Minnesota Noxious Weed Law must all be followed. (See also Legal/Permit Requirements.)

The solubility, persistence and adsorption of chemicals can greatly affect the transport method of the chemical and should drive the type of BMPs used to prevent the spread of pesticides. See recommendations from manufacturer and web links from MDA below.

Cost Information

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office (Table 1).

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses related to the proper storage of the pesticides and purchase of the chemical application equipment are eligible. This includes structures such as mixing aprons and spill containment and collection systems. Equipment that controls and permits application at appropriate agronomic rates, reduces loss to the environment, or reduces over all use is eligible. This also includes technological practices such as GPS, variable rate, and infestation assessment technologies. Typical operation and maintenance expenses such as fuel for management activities, tractors, herbicides, and other consumables are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/Unit	Typical Units Installed	Estimated Total Installation Cost (rounded)
Basic IPM* Field Crops, 1RC	$16.09/acre	40	$640
Basic IPM Field Crops, greater than 1RC	$21.75/acre	40	$870
Basic IPM Fruit/Veg, 1RC	$90.52/acre	10	$910
Basic IPM Fruit/Veg, greater than 1RC	$116.65/acre	10	$1,200
Basic IPM Orchard, 1RC	$116.65/acre	10	$1,200
Basic IPM Orchard, greater than 1RC	$178.49/acre	10	$1,800
Advanced IPM orchard, All RCs	$278.93/acre	10	$2,800
IPM Small Farms, 1RC	$548.18 each	1	$550
IPM Small Farms, greater than 1RC	$713.96 each	1	$710

IPM = Integrated Pest Management

Operation and Maintenance Considerations

Time should be spent monitoring equipment to make sure it is working properly both for safety and efficiency of pesticide use.

Legal/Permit Requirements

The NRCS codes list special considerations to protect water resources in cases where it is applied near waterbodies, wells, drinking water management areas, watersheds with streams impaired for pesticides, areas that are especially sensitive to groundwater contamination such as the karst region of southeast Minnesota and areas that are sensitive to high pesticide loss rates.

Local/Regional Requirements Design Example

Pest management considerations vary from site to site so that each the strategies used will be unique for each farm. One Minnesota case study involving the experience of a farmer wanting to do IPM is described in Radcliffe's IPM World Textbook online: ipmworld.umn.edu/jones-private-crop

Research Gaps

The effects of pest management and integrated pest management on water quality impacts through reduced pesticide run-off or leaching through tiled fields are not well known in Minnesota or nationally. Studies of pesticide mobility in non-drain tile water is also lacking.

Avoiding: **Pest Management**

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Links

MDA Conservation Practice, Pest Management
www.mda.state.mn.us/en/protecting/conservation/practices/pestmgmt.aspx

MDA Water Quality and Pesticide Fact sheets
www.mda.state.mn.us/protecting/bmps/herbicidebmps/bmpdocs.aspx

Water quality best management practices for all insecticides
www.mda.state.mn.us/sitecore/shell/Controls/Rich%20Text%20Editor/~/media/Files/protecting/bmps/insecticidesbmps.pdf

MDA annual monitoring report on pesticides and water quality www.mda.state.mn.us/~/media/Files/chemicals/maace/wqm2014rpt.pdf

Other sources of information

New York State Integrated Pest Management Program, the Year in Review
nysipm.cornell.edu/%5C/publications/water_qual/default.asp

Water quality best management practices for chlorpyrifos
www.mda.state.mn.us/protecting/bmps/~/media/Files/protecting/bmps/chlorpyrifosbmps.pdf

Water quality best management practices for potato fungicides
www.mda.state.mn.us/protecting/bmps/~/media/Files/protecting/bmps/potatofungibmps.pdf

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Subsurface Drainage (606) Tile Design

Definition and Introduction

Subsurface soil drainage systems are often referred to as "tile" systems because they were historically built of clay tile; however, they have also been made of wood, concrete and plastic (Figure 1). As of 2010, 20-30% of agricultural land in Minnesota has been tile drained, but this has increased since that estimate. Tile system design has traditionally been singularly focused on controlling the near surface water table for agronomic benefit. While there are usually no regulations or standards to the effect, some recent tile systems have been designed with intent to reduce adverse environmental impacts. Tile design refers to the arrangement of subsurface drainage pipe depth and density to achieve adequate and uniform drainage for crop growth while considering the water quality benefits of reducing outflow. Generally, the wider the tile spacing, the less water is removed, if depth is held constant. Similarly, the deeper the tile is placed, the more water is removed, if spacing is held constant.

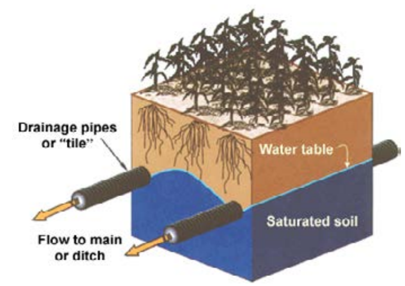

Figure 1. Sketch of a tile drainage system in an agricultural field. (Image from Busman & Sands, 2002)

Water Quality and Other Benefits

The primary mechanism for nutrient loss in tile systems is through seepage of dissolved nutrients (nitrate and phosphorus [P]) into sub-surface drainage systems. Nitrate is the most abundant nutrient of concern in tile drainage systems. Numerous researchers have found that nitrate concentrations in drainage water vary little with respect to system design. Therefore, the primary opportunity for water quality improvement is through flow reduction. For a given flow reduction, a commensurate reduction in nitrate exiting the system via subsurface drainage is expected. Kladivko et al. (2004) showed that drainage spacing had no impact on nitrate concentration but did have a significant impact on water yield. Nangia et al. (2010) and Skaggs and Chescheir (2003) indicate that designs promoting more anaerobic (i.e., wetter) conditions will increase denitrification to some degree, thereby reducing nitrate concentrations in tile water. The reduction in nitrate load associated with reduction in tile drainage volume likely overshadows that reduction associated with increased denitrification. Therefore, for purposes of determining nitrate load reduction resulting from system design, it is conservative to assume that load is reduced solely through flow reduction.

Yuan et al. (2011) found in a modeling study that the greatest flow reductions occur between 4-foot and 3-foot tile drain depth and only small changes occurred between 3- and 2-foot depth in a Ohio study (Yuan et al., 2011). The limited research data in Minnesota suggests that a volume reduction of 20% would be expected when comparing standard drainage depth of 4-foot versus a 3-foot depth, while maintaining the same drainage coefficient (Sands et al., 2008). Sands et al. (2008) reported that, on average, 17% of annual precipitation exited as subsurface drainage at Waseca, Minnesota, though that value ranged from 8.3% to 18.8%, with the bulk of it occurring April through June. A simple estimate with substantial uncertainty of nitrate load reduction can be estimated by multiplying the annual precipitation by 17% to determine the annual drainage volume, which can then be multiplied by volume reduction (e.g., 20% if moving from 4-ft depth to 3-ft depth) and the average nitrate concentration, which is commonly in the 10–20 mg/L range (Randall & Mulla, 2001). Improved estimates of nitrate load can be achieved by using local flow monitoring data, such as from the Minnesota Discovery Farm network. Sands et al. (2003) also showed for a two-year study in southern Minnesota that annual runoff and nitrate losses were reduced by 40 and 47%, respectively when drains were placed at 3-foot instead of 4-foot depth.

Recent research by King et al. (2015) and Smith et al. (2015) indicate that tile drainage is also contributing to P load in agricultural watersheds. King et al. (2015) examined the effects of tile drainage on the hydrology and nutrient loading of a small headwaters stream in central Ohio, finding that tile drainage accounted for 47% of the total discharge, 48% of the dissolved P, and 40% of the total P. Their findings suggest that tile drainage is an important transport path for P in small tile-drained watersheds. However studies from Ohio may not be directly transferable to Minnesota. There are several factors impacting tile drain P concentrations including P content of the soil, soil type, tillage practices, presence of surface inlets, the presence of cracks in the soil that extends from the surface down to the tile, whether manure is applied and how.

Smith et al. (2015) found that tile drainage transported 49% of soluble P and 48% of total P losses in research fields located in the Saint Joseph watershed of northeastern, Indiana, a tributary to Lake Erie. Their findings suggested the need to manage tile drainage water for addressing algal blooms occurring in downstream rivers and lakes. In regards to tile design, shallow drains typically have greater P concentrations than deeper drains. However, deeper drains have a greater discharge volume which leads to a greater load of P discharge from tile. If surface inlets are incorporated in the drainage system, these concentrations of P will yield a higher portion of particulate P due to the direct access of surface runoff into the drainage system unless there is an opportunity for particulates to settle before entering the drainage system. Therefore, in order to reduce the loss of P through tile drainage when designing a tile system, practices should disconnect fast flow pathways from the surface to the drainage, or implement drainage water management, and/or add end-of-tile treatments (King et al., 2015).

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Key Design/Implementation Considerations

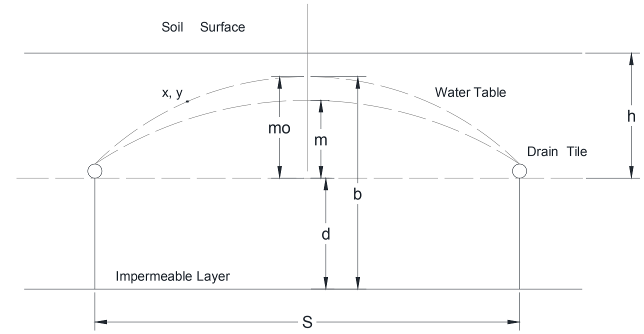

Figure 2. Cross sectional depiction of tile drainage system.

Two key parameters in tile system design are tile spacing (S) and depth (h). Tile spacing and depth will determine the drainage coefficient, or amount of water removed from the soil profile in inches per day. The Hooghoudt equation, indicated below, is a steady state equation for determining drain spacing, given the soil's saturated hydraulic conductivity, ks, the height of the water table above the drains, m0, the depth below the drains to an impermeable layer, d, and the drainage coefficient, q (Figure 2). It can be used to calculate the depth of water reaching the tile lines, sometimes referred to as drainage intensity. The drainage coefficient is the amount of water in inches over the drainage area per day that a tile system can remove from a field. See ASABE standard EP480 (ASABE, 2008) for full equation to correct for effective depth to impermeable layer. Any consistent set of units can be used.

$$S^2 = \frac{4\,k_s\,m_0(2d + m_0)}{q}$$

A typical design approach would be to assume a drainage coefficient and tile depth and solve for spacing. Typical recommended drainage coefficients for mineral soils are 0.25 to 0.50 inches/day for Minnesota (depending on the crop). Typical tile installation depth can range from 3-4 feet though currently three feet is more common.

Another approach assumes the same drainage coefficient with a shallower tile depth and solves for spacing which should provide a reduction in annual drainage volume.

Lastly, a reduced drainage coefficient combined with shallower placement depth could be used to provide even greater water quality benefits by reducing the total outflow of pollutants. The producer or operator should understand the agronomic impacts of such a decision.

If the tile outlet is located in a ditch where the vegetation is burned or mowed, the last several feet of the tile system can be made of corrugated steel pipe to prevent damage during ditch maintenance operations. Marking the outlet with a flag can minimize accidental damage to the outlet during e.g. ditch clean out operations or mowing. The amount of fine soil particles entering the tile lines can be reduced by using narrow slit tiles or wrapping the tile in a textile fabric.

Simplified tools for calculating appropriate pipe size, spacing and depth are provided at the University of Minnesota Extension drainage website.

Avoiding: **Subsurface Drainage Tile Design**

Cost Information

The cost of reduced drainage intensity is correlated with a reduction in the amount of tile installed. Likewise, shallower placement while maintaining a drainage coefficient would result in reduced spacing, thus increasing installation cost. The costs of new tile drainage systems varies greatly, but may run between $500/acre (Hofstrand, 2010) for tile and installation for uncomplicated systems with few connections to over $1000/acre for more complex systems or more difficult installation conditions.

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete related conservation practices (Table 1). NRCS does not cost share tile installation. The EQIP percentages vary from year to year, by applicant, and by region. EQIP does not cost share on the installation of tile drainage in general, but some components of the drainage system could receive cost share when they assist in the installation of other conservation practices. For more information regarding cost share and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or installation of subsurface drainage systems may be eligible when used for soil erosion, infiltration, manage the nutrient discharge, or reduce downstream impacts due to volume or velocity.

Typical operation and maintenance expenses of the subsurface drainage system is ineligible. Subsurface drainage systems that are designed to increase speed of water removal, such as conventional pattern tiling, without concurrent water quality BMPs are ineligible.

Table 1. Estimated average statewide conservation practice costs for practices associated with tile drainage. The NRCS does not cost share costs for installing practice #606. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/ Foot	Typical Units Installed	Estimated Total Installation Cost (rounded)
Structural Practice Support Drain	$4.09	1,000	$4,100
Waste Storage Facility Perimeter Drain, 9 or less feet deep	$22.89	920	$21,100
Waste Storage Facility Perimeter Drain, greater than 9 feet deep	$31.87	920	$29,300
Secondary Main Retrofit for Drainage Water Management	$7.65	3,135	$24,000

Operation and Maintenance Considerations

There are few operation and maintenance considerations beyond that of conventional drainage for shallower drainage depths or reduced densities discussed above although shallower drains may be at greater risk of root intrusion by the crops. Also, shallower drains may be more susceptible to crushing by heavy equipment, such as sprayers with narrow wheels.

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Typically new plastic pipe is installed to replace aging systems that have filled in with sediment or to increase drainage system capacity although new tile drainage is expanding in parts of the state such as northwestern Minnesota. Maintenance recommendations from Hofstrand (2010) include; regular inspection to make sure tiles are not blocked or crushed as indicated by ponding in the fields or reduced flow at the outlet; cleaning ditches to ensure an open outlet and surface inlets which may be damaged by runoff or equipment, or sealed by trash. Holes that have developed over subsurface drains should be repaired or large amounts of soil may wash into the system. Protecting drain outlets from gully erosion may be necessary to prevent downstream damage to streams or ditches. Lastly, rodent access to the tile lines should be prevented by installing and maintaining rodent guards.

Local/Regional Design Examples

The Bois de Sioux and Two Rivers Watershed Districts in Minnesota have required that permitted tile installations design to a 0.25 inch/day drainage coefficient if they do not have controlled drainage outflow (Bois de Sioux Watershed permit application). The cumulative hydrologic effects of this requirement have not been studied to date.

Research Gaps

While there is fairly good understanding of the impact of selecting different drainage depth or spacing on an individual farm operation, the cumulative impacts of many operations within a watershed are less well understood. An analysis performed in the Bois de Sioux or Two Rivers Watershed Districts of the cumulative effect of adopting a reduced drainage coefficient, while also taking into consideration agronomic impacts, would be valuable.

The decision to adopt a reduced drainage coefficient or shallower tile depth in the absence of regulation is solely the prerogative of an operator, who also bears the financial implications of that decision.

An economic analysis to determine the benefit to society through improved water quality would provide potential basis for creating an incentive payment for operators to adopt this practice.

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Avoiding: **Subsurface Drainage Tile Design**

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Links

University of Minnesota Extension
www.extension.umn.edu/agriculture/water/planning/online-calculator/

NRCS Conservation Practice Standard, Subsurface Drain, Code 606
efotg.sc.egov.usda.gov/references/public/MN/606mnCPS2017.pdf

Agricultural BMPs: **Controlling**

Alternative Tile Intakes (Underground Outlet) (620)

Alternative tile intakes shown within a farm field to reduce sedimentation of subsurface tile drainage lines. A close-up on the tile riser.

Definition and Introduction

Isolated surface depressions in agricultural fields are commonly drained with subsurface tile that have surface intakes that outlet to underground drainage pipe systems. Open intakes that are flush with the surface of the ground can provide a direct conduit for sediment and nutrients to enter the tile system, which lead to ditches, streams, and rivers. Alternative tile intakes increase sediment trapping efficiency through increased settling time and/or filtering. They can also reduce the velocity of flow into the tile inlet.

Alternative tile Intakes include:

- **Perforated risers**, such as the Hickenbottom riser.
- **Gravel (rock) inlets**, with gravel to the ground surface, or with a layer of soil covering the gravel (blind inlet).
- Dense **pattern tile** within the isolated surface depression with a capacity equal to the open tile inlet it replaces.
- Other variations of the above include a slotted riser and addition of a vegetated buffer surrounding the inlet.

Water Quality Effects

Water quality benefits of alternative tile intakes are primarily associated with the temporary ponding of water and settling of particles before reaching a waterbody. The removal efficiency by this process is highly dependent on the size distribution of the influent sediment. Although a body of research on alternative tile intakes has been amassed in Minnesota, the vast majority is conducted in laboratories or simulations (Table 1).

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There is a wide range of reported performance:

- Perforated riser sediment trapping efficiency is approximately 70 – 95%
- Gravel inlet sediment trapping efficiency of 70 – 95% during temporary ponding (Wilson et al., 1999).
- Particulate phosphorus (P) removal is closely tied to sediment trapping. However, soluble P concentration may increase, depending on the amount of residue present.
- Potentially reduces flow rates into the tile system with increased ponding in fields.

Table 1. Water quality impacts of different alternative intake studies in Minnesota.

Source	Type	Site Description	Drainage Area (Ac)	Soil Type	Type of Study	# of Years	# of Events	Sediment	Total P	Sediment Bound P	Soluble Reactive P
								Percent Reduction Reported (%)			
Oolman and Wilson (2003)	Flush Pipe	Vernon Ctr	2.7	Silty Clay Loam	Simulation	400		50.4			
Oolman and Wilson (2003)	Slotted Pipe	Vernon Ctr	2.7	Silty Clay Loam	Simulation	400		31			
Oolman and Wilson (2003)	Slot-free Pipe	Vernon Ctr	2.7	Silty Clay Loam	Simulation	400		29.2			
Oolman and Wilson (2003)	Grass Buffer	Vernon Ctr	2.7	Silty Clay Loam	Simulation	400		35.5			
Oolman and Wilson (2003)	No-till Flush Pipe	Vernon Ctr	2.7	Silty Clay Loam	Simulation	400		6.7			
Oolman and Wilson (2003)	Flush Pipe	Martin Co	7.4	Clay Loam	Simulation	400		29.5			
Oolman and Wilson (2003)	Slotted Pipe	Martin Co	7.4	Clay Loam	Simulation	400		16.5			
Oolman and Wilson (2003)	Slot-free Pipe	Martin Co	7.4	Clay Loam	Simulation	400		9.4			
Oolman and Wilson (2003)	Grass Buffer	Martin Co	7.4	Clay Loam	Simulation	400		28.3			
Oolman and Wilson (2003)	No-till	Martin Co	7.4	Clay Loam	Simulation	400		5.1	66.6		
Wilson et al. (1999)	Slotted Pipe	Lab	12	no data	Lab Prototype	N/A	15	91.5	65.9		
Wilson et al. (1999)	Flush Pipe	Lab	12	no data	Lab Prototype	N/A	15	83.1	66.6		
Wilson et al. (1999)	Gravel #7 (d50 = 10.9mm)	Lab	12	no data	Lab Prototype	N/A	3	95.2	81.6		
Wilson et al. (1999)	Gravel #67 (d50 = 11.5mm)	Lab	12	no data	Lab Prototype	N/A	5	93.4	88.1		
Wilson et al. (1999)	Gravel #6 (d50 = 15.4mm)	Lab	12	no data	Lab Prototype	N/A	12	90.2	82.4		
Ranaivoson (2004)	Gravel	LeSueur	14.8	Clay loam, silty clay loam	Field	2	5	20	11	28	
Gieseke (2000)	Gravel	Carver	6.84	Clay loam	Field	2	4	85			
Gieseke (2000)	Gravel	Carver	NA	Clay loam	Simulated Storm	N/A	1	98			
(Feyereisen et al. 2015)	Gravel	Western Minnesota	111	no data	Field	3		88			23
Smith and Livingston (2013)	Sand/ gravel	NE Indiana	10-740	no data	Field	7		79	78		

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Key Design/Implementation Considerations

Perforated Risers

Perforated risers must be farmed around. The minimum diameter should be five inches. Holes in the risers should be large enough to allow more than double the design flow in order to prevent plugging (USDA NRCS, 2016).

Gravel Inlets

Rock and blind inlets have greater longevity if the removal of sediment occurs from deposition in the field and not by the filtering process of flow through the media itself. They also allow for additional subsurface drainage between rainfall events in typically wet depressional areas. Inlet dimensions presented by Gieseke (2000) were 12 feet long, 3 feet wide, and 3 feet deep, using pea gravel with dimensions 0.25 (1/4”) to 0.87 (7/8”) inches. Most design guidance specifies that the gravel be mounded one foot above the surrounding land. Pipe material is 5” muck pipe with 5/8” holes.

Dense Pattern Tile

According to NRCS Interim Standard for Iowa (IA-980) 50 feet of drain tile should be used for each 0.1 acre (4,356 square feet) of pothole or depression (USDA NRCS, 2017b).

Cost Information

Replacing open inlets with alternative tile intakes generally costs less than $500 for each inlet. In recent years, cost-share programs have had funds to compensate installation costs up to 75% with maximum reimbursements up to $200-500 per inlet depending on the district (Table 2).

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more informatio regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses related to the upgrading of an existing inlet to an alternative tile intake or installation of a new alternative tile intake are eligible for funding. Typical operation and maintenance expenses of a drainage system are ineligible.

Table 2. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/ Unit	Typical Units Installed	Estimated Total Installation Cost (rounded)
6-inch corrugated plastic tubing or smaller	$5.44/Foot	500	$2,700
8-inch corrugated plastic tubing	$6.37/Foot	500	$3,200
10-inch corrugated plastic tubing	$8.94/Foot	500	$4,500
12-inch corrugated plastic tubing or larger	$9.90/Foot	500	$4,900
6-inch pipe conduit	$11.25/Foot	500	$5,600
8-12-inch pipe conduit	$12.64/Foot	500	$6,300
15-21-inch pipe conduit	$19.29/Foot	500	$9,600
24-inch pipe conduit	$34.04/Foot	500	$17,000
30-inch pipe conduit	$37.26/Foot	500	$18,600
36-inch pipe conduit or larger	$47.91/Foot	500	$24,000
Intake Riser and short offset outlet	$429.63 each	3	$1,300

Operation and Maintenance Considerations

Gravel inlets can become clogged, reducing drainage capacity and longevity. Site inspection is especially important with these designs to ensure that they are not clogged with sediment or crop residues.

Legal/Permit Requirements

A watershed district permit may be required.

A Drainage Modification request form (1026) may be required from NRCS.

Local/Regional Design Examples

Alternative tile inlets have gained considerable popularity in recent years in Minnesota. There are numerous cost share programs available from SWCDs, WDs, and other conservation-oriented groups. Based on anecdotal information, the majority of these are blind rock inlets. Rock inlets are popular with landowners since they can be farmed over.

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Research Gaps

- Gravel inlet design currently exists as a one size fits all. Key factors in gravel inlet design are contributing area and soil type. Inlet design (both size of gravel filter and size of rock to use) should be based on the preceding.
- The longevity of gravel inlets is still poorly understood. Ranaivoson (2004) concluded that there was a 99% probability that the inlet would last at least 10 years. There are numerous, most likely hundreds, of these types of inlets now in place for many years. A research effort evaluating the effectiveness of a sample would provide valuable information on effectiveness and longevity.
- A survey of alternative tile intakes was performed by Wilson et al. (1999). In that study, one example of dense pattern tile was reported to have failed. However, information from Kandiyohi County suggests that some operators have had good success (Engleby, personal communication). A dense pattern tile type of inlet would provide great filtering capability and would allow an operator to farm over the practice. Additional research should be conducted to determine if this practice is indeed practicable.

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Links

NRCS Conservation Practice Standard, Underground Outlet, Code 620
efotg.sc.egov.usda.gov/references/public/MN/620mn_Underground_Outlet_0916.pdf

Contour Stripcropping (585)

Contour stripcropping in southeastern Minnesota showing alternate strips of corn and erosion-resistant strips or permanent cover such as grasses. (Photo by David Hansen)

Definition and Introduction

Contour stripcropping is contour farming (farming perpendicular to the slope) of erosion-susceptible crops alternating with strips planted in erosion-resistant crops and/or dense cover. As an in-field buffer conservation practice, contour stripcropping provides runoff and erosion control close to the source. Contour stripcropping, in contrast to contour buffer strips, has a 1:1 ratio between the width of the erosion-resistant and erosion-susceptible strips. Erosion-resistant strips are planted in crops or cover which have the ability to trap sediment. Erosion-resistant strips could include close-growing crops such as forages, small grains, or dense grasses that have the ability to trap sediment. Erosion-susceptible strips include row crops, such as corn or soybeans.

Water Quality and Other Benefits

Contour stripcropping increases infiltration of rainwater and reduces sheet and rill erosion, thereby reducing soil loss and the transport of sediment and associated contaminants to downstream waterbodies. Contour stripcropping also reduces soil erosion from wind and protects growing crops from wind-associated damage.

Key Design/Implementation Considerations

For contour stripcropping, alternating erosion-resistant and erosion-susceptible strips are equal in width to the maximum extent possible. As a result of farming on the contour, erosion-resistant strips will be wider on flatter portions of a field and narrower on steeper portions in order to keep cropped strips of uniform width for tilling and planting. Strip widths should also be a multiple of the width of farming equipment. Contour stripcropping may require consolidation of fields so that they may be farmed efficiently.

When modeling contour stripcropping, recognize that surface roughness factors (such as Manning's n) change with depth since the density of the vegetation varies with height (Dabney et al., 2006).

The NRCS standard (Code 585) recommended for this practice (USDA NRCS, 2016) specifies the following:

- **Row grades** should be no greater than 2% and, where ponding is a concern, no less than 0.2%.
- **Strip widths** should be greater than 25 feet wide.

Cost Information

Since contour farming is based on a change in operations, costs are low and primarily associated with initial field design. Out-of-pocket expenses are minimal. Biofuels could also be grown as one of the strip crops as more biofuel processing plants are constructed around the state in order to make these crops more profitable. This could provide added income in some situations. There are also programs available for financial assistance including EQIP, the State Cost-Share Program, and other local programs.

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses related to the purchase of equipment for field preparation, planting, and production are eligible when the equipment can help with any of the following; nutrient management, erosion control management, or chemical management. Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, moldboard plows, tractors and weed control herbicides are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/Acre	Typical Units Installed	Estimated Total Installation Cost (rounded)
Stripcropping	$1.71	80	$140

Operation and Maintenance Considerations

Implementing grass barriers at the upstream end of the erosion-resistant strip, covering approximately the first 10% of the strip, can be an effective mechanism for trapping sediment, reducing deposition throughout the erosion-resistant strip (Blanco-Canqui et al., 2004). After sediment builds up, it can be more easily redistributed throughout the row crop strip if it has not been able to spread throughout the erosion resistant-strip. Grasses eligible for barriers would have stiff stems that remain erect throughout runoff periods.

Erosion-susceptible strips should include species tolerant to herbicides used on the crop strips or protected in some way.

Research Gaps

Although national and international studies are available (see appendices), current research from Minnesota or the Upper Midwest is lacking since the utility of the practice was established decades ago, early in the soil conservation movement (Hays & Bell, 1949). There is a need to better understand the efficiency of contour stripcropping at pollutant removal in Minnesota due to the current climate, soil and crop systems. Most of the research in the past 20-30 years was modeled using the Revised Universal Soil Loss Equation (RUSLE) (Foster, 2005). Cost-benefit analyses would address changes in productivity and herbicide application or other operations associated with contour strip-cropping.

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Local/Regional Requirements Design Example

Contour stripcropping is more common in areas with steeper terrain. Examples of contour stripcropping are common in the Driftless area in southeastern Minnesota and in northwestern Wisconsin. There are other sites scattered throughout Minnesota.

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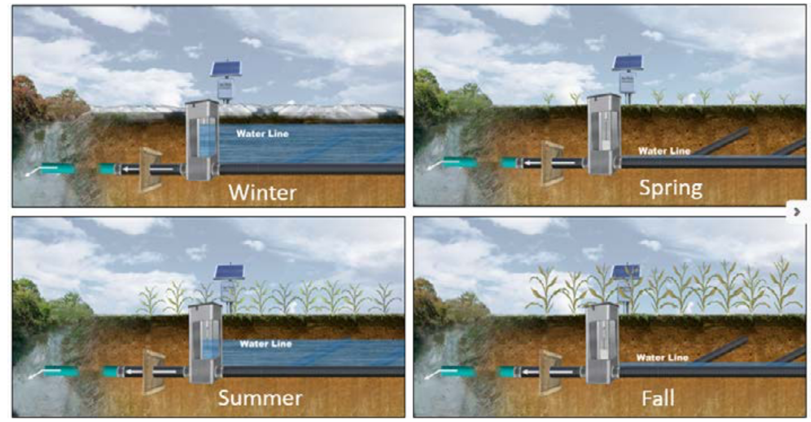
Links

NRCS Conservation Practice Standard, Stripcropping, Code 585
efotg.sc.egov.usda.gov/references/public/MN/585_MN_Stripcropping_2016.pdf

MDA Conservation Practice, Stripcropping
www.mda.state.mn.us/protecting/conservation/practices/contourstrip.aspx

Drainage Water Management (554)

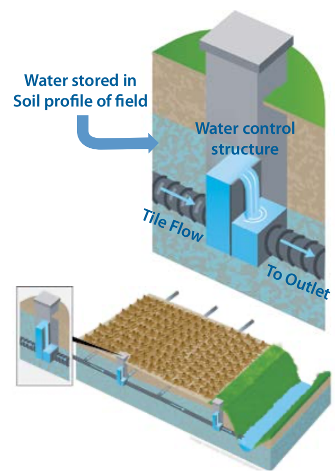


Controlled drainage allows producers to control the water by raising or lowering the outlet, making water available to crops when needed. This is effective at managing flow and reducing nitrate losses. (Image from Ecosystem Service Exchange)

Definition and Introduction

Drainage water management sometimes referred to as controlled drainage is a practice used to control or manipulate the ground water elevation in a tile drained field. Since the term drainage water management is increasingly being used for other practices and programs, the term controlled drainage will be used in this chapter. Controlled drainage is a practice where water is periodically held back within the root zone by adjusting the outlet elevation of the subsurface drainage system. The outlet elevation is typically adjusted using a drainage control structure, in which stacks of boards or stand pipes of different lengths are inserted to raise or lower the outlet elevation. Controlled drainage may be implemented as part of a new system or as part of a system retrofit, provided the layout of the existing system is conducive for controlled drainage.

Figure 1. Controlled drainage during the non-growing season can retain water in the soil profile when drainage is not needed. (Images from transformingdrainage.org)



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Water Quality Effects

Water quality benefits attributed to controlled drainage result primarily from reductions in water yield volume. In other words, most studies (see Skaggs et al., 2012 and Ross et al., 2016) indicated that controlled drainage has little effect on nitrate concentration in tile drainage water so any reduction in loading is derived from a water volume reduction. Feset et al., (2010) conducted a field study in Minnesota comparing freely drained fields with those with controlled drainage. This study showed reductions in nitrate-nitrogen, total phosphorus (P), and ortho-P load losses of 61%, 50% and 63% respectively.

The effects of controlled drainage on the water balance of a system vary greatly depending on climate, soil, and management of the system. In general, controlled drainage reduces the volume of subsurface drainage, particularly during relatively dry years (Tan et al., 2002), increases the average soil moisture content of the soil profile, but does result in somewhat higher surface runoff rates. Controlled drainage may reduce subsurface drainage rates by as much as 15% (Singh et al., 2007) and 40% (Luo et al., 2010) and 50% (Thorp et al., 2008) compared to conventional drainage. Both the Singh et al. and Luo et al. studies were conducted on Webster silty clay loam soils. The greater reduction in the Luo et al. study is likely due to a different management scheme on the outlet control structure. The Singh et al. study assumed no control (4-foot tile depth) in March, April, September and October and 60 cm the rest of the year. The Luo et al. study maintained a 15 cm depth from November through March, 120 cm in April, and 60-cm from May 1 to November. Thus, the Luo study provided more opportunity to store water. The reduction in drainage volume is generally considered to be a close approximation to the reduction in nitrate export.

More recently a Conservation Innovation Grant, which the University of Minnesota was part of, provided more Minnesota-specific data. Results from a 5-state NIRC CIG project indicate that nitrate reductions from 20 to 60% can be achieved, depending on precipitation and climate (ADMC, 2011). Skaggs et al. 2012 summarized drainage water management studies at 12 to 20 sites. Average annual drainage volumes were reduced from 18% to over 85%. Similarly, annual nitrate-nitrogen loads reduction ranged from 18% to 79%. Most recently Ross et al. (2016) found that drainage water management was highly effective a reducing drainage water discharge and nutrient losses from drain tiles in a synthesis of studies. Tile discharge volumes were reduced on average 46%, while tile nitrate loads were reduced by 48%. Total P and dissolved reactive P loads were reduced more at a slightly higher rate at 55% and 57% total load reduction based on four and three studies, respectively.

Key Design/Implementation Considerations

Topography is one key consideration. Generally, controlled drainage is better suited to flatter topography, since fewer water control structures are needed. Cooke et al. (2008) suggest that the practice is best suited to slopes less than 1%, but may be considered for fields with slopes of up to 2%. The advent of new, inexpensive intermediate control structures that require no active management may change this guidance.

Key operational parameters are the date at which the water level are raised or lowered and the degree to which they are raised. The date the water level is raised should occur sometime after spring planting. Ale et al. (2009) recommend from 0 to 20 days depending on antecedent moisture conditions. The wetter it is, the longer the delay. The date to remove the stop logs is approximately 85 days after planting or about one and a half months before crop maturity. In wet years the water elevation should be lowered earlier in the spring. Stop logs may again be installed after harvest until about 4-6 weeks before planting. If flood mitigation is an objective, as is often the case in the Red River Valley, the outlet elevation may be left lower in the fall to increase water storage capacity in the soil following snowmelt and high spring water levels.

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Cost Information

The final report from the Conservation Innovation Grant, which the University of Minnesota was part of, provides information on cost of installation (ADMC, 2011). The basic assumption is that each control structure will control 20 acres. ADMC indicated that new installation cost would start at $65/ac for a 6-in main and increase to $88/ac for a retrofit on a 12-in main for installation and equipment.

According to Nistor and Lowenberg-DeBoer (2007), in order for controlled drainage to be profitable, a producer must sustain a 4% yield increase if no subsidies are considered and a 2% increase when subsidies are provided. As can be seen from Table 1 the EQIP subsidy payments only account for a fraction of totatl costs for drainage water management. Decision-makers may want to consider adjusting subsidy rates such that farmers reach a break-even point

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or installation of subsurface drainage systems may be eligible when used for soil erosion control, to manage the nutrient discharge from a field, provide storage capacity, water reuse, or reduce downstream impacts including velocity and volume of flow.

Typical operation and maintenance expenses such as fuel for management activities and increasing drainage flow with no water quality improvements are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/Acre	Typical Units Installed	Estimated Total Installation Cost (rounded)
Drainage Water Management	$10.53	50	$530

Operation and Maintenance Considerations

As stated above, the key operation consideration is when and by how much to adjust the outlet elevation. The following operation schedule is the recommended strategy for the Hayfield, Minnesota site of the CIG project (ADMC, 2011).

Table 2. Recommended operation schedule (ADMC, 2011).

Dates	Depth of Stoplogs Below Surface (in)
November - March	6
April	48
May – mid-September	24
Mid-September – October	48

Control structures should be checked for debris when the stoplog height is adjusted.

Legal/Permit Requirements

New systems may be subject to the same requirements as conventional drainage systems.

Local/Regional Design Examples

The most studied sites are those that were part of the 2010 CIG project including the Minnesota projects at Dundas, Hayfield, Wilmont, and Windom. MDA has a demonstration project in Clay County, Minnesota as well. The University of Minnesota also has long-term research being done at the Southwest Research and Outreach Center in Lamberton, Minnesota.

Research Gaps

Controlled drainage is still a relatively new practice in the upper Midwest and specifically, in Minnesota. Longer-term data at different sites will help to better define controlled drainage effectiveness in different soils and climatic variability.

As the effects of controlled drainage in response to year-to-year climate differences are better understood, the ability to manage a controlled drainage system to mimic a natural system may be of interest. While there is ongoing debate regarding the role of tile drainage water in flooding and water quality issues, the ability to manage an agricultural production system in a manner similar to a natural system may provide an opportunity for increased environmental stewardship while maintaining economic viability.

One of the perceived drawbacks of controlled drainage in Minnesota is that there is very little if any drainage from the soil profile late in the growing season, thus, the system is only 'working' in the spring. The use of sub-irrigation in drainage systems to supply water to crops later in the summer is being studied by Jeff Strock at the University of Minnesota's Southwest Research and Outreach Center (Gunderson, 2015). Drainage ditches could be retrofitted with water control structures such that ditch water elevation could be raised in mid- to late summer to irrigate fields. There are a host of challenges with this method, both from a policy and legal standpoint and a technical standpoint, but may be worth future consideration.

Operational methods are still being optimized for controlled drainage. More research is needed to determine operational strategies given annual differences in precipitation and soil moisture. Automated or remote control operation may provide enough ease of operation and enough precision of management to make the practice efficacious.

The study by Thorp et al. (2008) indicated that plant uptake of N may be more efficient under controlled drainage. Field studies are necessary to confirm this result. If confirmed, less N application may be required.

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Links

Controlled Drainage
Transforming Drainage.org

Controlling: Drainage Water Management

Culvert Sizing/Road Retention/Culvert Downsizing

Definition and Introduction

There are tens of thousands of miles of natural watercourses and public and private drainage ditches in Minnesota, as well as untold miles of roadside ditches. Drainage management continues to be improved and expanded. Current design methods and regulatory requirements often result in channel and culverts having large capacities to prevent upstream flooding. However, the increased pipe sizes upstream allow water to flow more quickly and at higher volumes to downstream locations. The runoff can result in flooding and unequal levels of protection along the length of drainage ways. The practice of culvert sizing is the downsizing of pipes that cross minor roads or berms to help manage runoff timing and peak flows within a drainage network.

The purpose of culvert sizing is to reduce or prevent flood damage downstream by using distributed temporary storage and the metering of runoff, without causing a significant increase in the risk of flood damage where runoff is temporarily stored. Culvert sizing not only reduces downstream flood peaks, it also provides a more uniform level of flood protection within a drainage system. Other possible benefits of this practice include reduced field and channel erosion while short-term ponding of runoff may provide a water quality benefit.

The principle of road retention is the same as culvert sizing, but the storage amount and storage time tends to higher. The objective of culvert sizing is to store water for no longer than 24-48 hours, while road retention might store water for several days or weeks. Culvert sizing is discussed in the chapter as a method to address water quality through retention/detention which will address flows in addition to quality and may not be intended to restore natural hydrology (Hacker, 2015). While it may help with water quantity and water quality in minor waterways, it can negatively impact the environment in other ways. To reduce these impacts, the practice should not be applied to natural stream channels or where sediment is carried. McEnroe and Gonzalez (2006) stated that storage effects are less likely to be significant for large culverts than for small culverts.

Water Quality and Other Benefits

The water quality effects of culvert sizing have not been documented although flood reduction benefits have been thoroughly assessed by modeling. It seems reasonable to assume, that some water quality benefits may be expected if peak flows are reduced and storage time is increased.

Solstad et al. (2007) examined the implementation of culvert sizing in a modeling study in the Red River Basin. They found that the 10-year, 24-hour peak flow could be reduced by 41% at a one square mile drainage area, 33% at eight square miles and 11% at 28 square miles. Percentage reduction were even greater for less frequent (i.e. greater magnitude) events. These results were based on 24-hour detention time. The Red River of the North Basin Technical and Scientific Advisory Committee (BTSAC, 2014) assessed the benefits of culvert sizing as part of a surface drainage water management strategy. They found that culvert sizing can affect the timing of runoff delivery in the Red River Basin by reducing the peak from runoff traveling long distance from the upper watershed, thus reducing downstream peak flows in the main river channel.

Reductions in peak flows would lead to reductions in the sediment transport capacity of streams and rivers and would also reduce the erosive capability of those stream and rivers. There is no research to quantify benefits at this time (Solstad et al., 2007). Alternatively, sedimentation and channel stabilization must also be considered upstream. The Minnesota DNR recommends that only ditches that see periodic flows and where there are minimal sediment loads should be considered for downsizing (Zytkovicz & Murtada, 2013).

Key Design/Implementation Considerations

Culvert downsizing provides short-term temporary storage within channels and on adjacent lands upstream of road crossings. It is most applicable for small drainage areas up to approximately 5-20 square miles (Hacker, 2015). The Minnesota DNR suggests that the upper limit ford drainage area should be approximately one square mile. Larger perennial streams or intermittent streams that support substantial aquatic life should be avoided.

The primary hydraulic design standards currently used for culverts and bridges are based on risk assessment at individual crossings to minimize adverse impacts of road overtopping and potential upstream flood damages.

Culvert sizing takes an opposite design approach. The culvert is expected to have an effect on stage and temporary storage and the resultant peak flow reduction is a desired outcome. The goal is to reduce the peak flow as much as possible without causing significant damage. This is achieved by providing short-term storage of water in the channel and on the land upstream from the road crossing.

Guiding Principles

- Risks to highways and developed upstream properties should not exceed current standards.
- Benefits of drainage should be equitable throughout the drainage system.
- The responsibility to temporarily store excess water on cropland should be uniformly distributed throughout the drainage system.
- Detention of water on cropland for most rainfall events should be no longer than 24 to 48 hours to avoid crop damage.
- The drainage system should detain water in excess of downstream channel capacity.

Road retention structures require design by an engineer or hydrologist with a strong background in hydrology and hydraulics because of the potential for flooding impacts on adjacent properties and roads.

Cost Information

According to the Area II Minnesota River Basin Projects, Inc. (Area II Minnesota River Basin Project, 2017), the cost of replacing an existing culvert with a slightly smaller culvert may be slightly lower. However, if the culvert replacement is performed in conjunction with raising the road level to achieve greater storage, then the project may have a greater cost.

Also, according to Area II, the cost of a flowage easement is about $200/acre for non-cropped areas and $400/acre for cropland with encouragement to site projects where cropland can be avoided (Area2.org). The objective of culvert downsizing is to avoid easement costs. There is no information about costs for culvert sizing in EQIP payment schedules because the practice is not recognized by the NRCS. Culvert replacement costs vary greatly depending on the size of pipe, material of the pipe, road/embankment height, width, and construction requirements.

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or installation of practice utilizing appropriate culvert sizing may be eligible when used for soil erosion control, manage nutrient discharge from a field, reduce adverse downstream impacts such as sloughing and bank erosion. Typical operation and maintenance expenses such as fuel for management activities, periodic inspection and cleaning, or replacement with no water quality improvements are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Conservation Code	Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
396 – Aquatic Organism Passage	Earthen Dam Removal Fill Height 8 Foot or Less	$16.33/Cubic Yard	500	$8,200
396 – Aquatic Organism Passage	Earthen Dam Removal Fill Height Greater than 8 Feet	$10.11/Cubic Yard	2,500	$25,300
396 – Aquatic Organism Passage	Blockage Removal, remote access	$517.71 each	1	$520
396 – Aquatic Organism Passage	Blockage Removal, road access	$423.70 each	1	$420
396 – Aquatic Organism Passage	Corrugated Metal Pipe Culvert, Less Than or Equal to 96 inch Diameter	$4.81/Diameter Inch Foot	5,760	$27,700
396 – Aquatic Organism Passage	Corrugated Metal Pipe Culvert, Greater Than 96 inch Diameter	$5.12/Diameter Inch Foot	7,200	$36,900

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Controlling: **Culvert Sizing/Road Retention**

Conservation Code	Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
396 – Aquatic Organism Passage	Bottomless Culvert	$11.40/Cubic Foot	3,485	$39,700
396 – Aquatic Organism Passage	Concrete Box Culvert	$21.41/Cubic Foot	1,440	$30,800
396 – Aquatic Organism Passage	Bridge	$689.04/Foot	30	$20,700
396 – Aquatic Organism Passage	Bridge: Timber Decking, Timber Supports, Timber Pilings	$29.19/Cubic Foot	2,800	$81,700
396 – Aquatic Organism Passage	Multi Plate Full Invert Culvert, Area Greater Than 124 sq. ft.	$10.70/Cubic Foot	9,780	$104,600
396 – Aquatic Organism Passage	Multi Plate Full Invert Culvert, Area 124 sq. ft. or Less	$15.39/Cubic Foot	5,100	$78,500
578 – Stream Crossing	Rock Surfaced Stream Crossing	$1.86/Square Foot	2,000	$3,700
578 – Stream Crossing	Culvert installation, <25' Diameter, Single culvert	$57.20/Foot	36	$2,100
578 – Stream Crossing	Culvert installation, <25', Double culverts	$72.29/Foot	36	$2,600
578 – Stream Crossing	Culvert installation, >25' Diameter, Single culvert	$72.19/Foot	36	$2,600
578 – Stream Crossing	Culvert installation, >25' Diameter, Double culverts	$102.29/Foot	36	$3,700
587 – Structure for Water Control	Inline or Inlet Flashboard Riser, Metal	$3.74/Diameter Inch Foot	1,800	$6,700
587 – Structure for Water Control	Inline Flashboard Riser, Commercial	$5.03/Diameter Inch Foot	1,000	$5,000
587 – Structure for Water Control	Culvert less than 30 inches High Density Polyethylene Pipe	$2.30/Diameter Inch Foot	960	$2,200
587 – Structure for Water Control	Culvert less than 30 inches Corrugated Metal Pipe	$2.51/Diameter Inch Foot	960	$2,400

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Conservation Code	Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
587 – Structure for Water Control	Flap gate structure	$483.17/Foot	2	$970
587 – Structure for Water Control	Rock Checks for Water Surface Profile	$65.38/Ton	87	$5,700
587 – Structure for Water Control	Aquaculture Pond Outlet Structure Only	$2,217.39/Foot	7	$15,500
587 – Structure for Water Control	Outlet Structure and External Harvest Kettle for an Existing Aquaculture Pond	$3,956.36/Foot	7	$27,700
587 – Structure for Water Control	Drainage Water Management Structure	$1,967.78/Each	1	$2,000

Operation and Maintenance Considerations

Culverts should be inspected by the owner to ensure that they are working as designed and are not experiencing blockage by debris or beaver activity.

Sedimentation of the upstream area is likely to occur depending on the sediment load, creating the need for increased maintenance observations. Impacts to the road bed and culvert should be monitored after periods of upstream flooding.

Legal/Permit Requirements

Culverts should be properly designed to meet local, county, and state requirements. These limitations are often set by the owner. These requirements could include restrictions on the probability of overtopping a public roadway and minimum and maximum water velocities to prevent clogging and scour. Limitations on the size of the embankment and storage volumes are set by the state and federal Dam Safety Regulations. If the owner of the culvert or road negatively impacts an upstream landowner a signed agreement should be in place before the culvert is installed. Some ditches have county or state authorities responsible for them. If ditch is classified as a public water the Minnesota Department of Natural Resources has permit limitations and for ditches classified as county ditches the County's Soil and Water Conservation District or Ditch Authority may also have restrictions.

Aquatic life (fish, invertebrates) passage issues may be raised by the Minnesota DNR if the culvert is on a public water or the stream is likely to be supporting aquatic life of significance.

Local/Regional Design Examples

The Upper Cedar River Surface Water Management Plan (UCR, 2009) was developed in response to chronic flooding problems. The goal of the study was to determine the level of storage necessary to reduce the 100-year flood in Austin, Minnesota by 20%. Flow reductions would be achieved by restricting flow at existing road crossings. The road crossings proposed for restriction in the report are fairly large (e.g., 6' by 10' box culvert downsized to 4' diameter Reinforced Concrete Pipe). The conceptual approach taken in the report appears to have guided efforts by the Cedar River Watershed District.

The Area II Joint Powers Area in southwest Minnesota has been using road retentions as a flood control tool since 1989 (Area II, 2017). No information was available regarding effectiveness.

The strategy has been widely recommended for the Red River basin in particular due to the dominance of flooding over other management issues there. (Solstad et al., 2007 and BTSAC, 2014). In the Red River the percentage of small streams and ditches that are intermittent is much greater than in eastern Minnesota. There are less likely to be aquatic life impacts on small intermittent, channelized streams than on perennial streams fed by groundwater, for example.

Research Gaps

There is little research regarding how culvert down-sizing affects water quality, positively or negatively. This is a lesser used BMP and few examples can be found on the intentional design of a culvert retention system.

References

Area II Minnesota River Basin Project | 2017. Road Retentions: A Low Cost Alternative for Flood Control. Retrieved from area2.org/index.php/road-retentions on May 18, 2017.

BTSAC (Red River of the North Basin Technical and Scientific Advisory Committee) | 2014. Water Management Options for Surface Drainage, Briefing Paper #3. Fargo, North Dakota: International Water Institute.

Hacker, B. | 2015. Concerns about culvert sizing / road retention/ culvert downsizing. Minnesota DNR white paper. Mankato, MN.

McEnroe, B. M., & Gonzalez, S. A. | 2006. Storage effects at culverts. Kansas Department of Transportation. Report No. K-TRAN: KU-04-3R.

Solstad, J. A. Kean, & Anderson, C. | 2007. Culvert Sizing for Flood Damage Reduction. Red River Basin Flood Damage Reduction Work Group. Technical Paper No. 15. www.rrwmb.org/files/FDRW/TP15.pdf

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USDA NRCS | 2017. Environmental Quality Incentives Program – NRCS Minnesota. [Accessed May 11, 2017.] www.nrcs.usda.gov/wps/portal/nrcs/detail/mn/programs/financial/eqip/

Zytkovicz, K., & Murtada, S. | 2013. Reducing localized impacts to river systems through proper geomorphic sizing of on-channel and floodplain openings at road/river intersections. Saint Paul, Minnesota: Minnesota Department of Natural Resources.

Links

Area2.org road retention projects:
http://area2.org/index.php/road-retentions

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Grassed Waterways (412)

Grassed waterway in southeastern Minnesota. (Photo by David Hansen)

Definition and Introduction

Grassed waterways are vegetated channels through fields that provide a means for concentrated flows to drain from a field without causing erosion. They can be installed on most fields but are especially effective in controlling gully erosion on steep slopes. Grassed waterways are commonly used to convey runoff from terraces and diversions but are an important BMP wherever concentrated flows occur.

Water Quality and Other Benefits

The water quality benefits of grassed waterways improve water quality by preventing gully erosion. Additionally, the vegetative component can provide filtering and volume reduction although few studies have focused on this (Helmers et al., 2008). Because of the vast differences in grassed waterway design based on specific site conditions it would be difficult to make generalizations as to the effectiveness of this practice. This being said, the literature does show that grassed waterways have a positive effect on water quality by reducing peak discharge and sediment yield and to a lesser extent phosphorus (P) and nitrogen (N). For example Schueler (1992) found grassed waterways reduced sediment load by 70%, P by 30% and N by 25%.

Figure 1. Runoff reduction by grassed waterways of various lengths as predicted by a calibrated WEPP model in Iowa. (Reproduced from Dermisis et al., 2010)

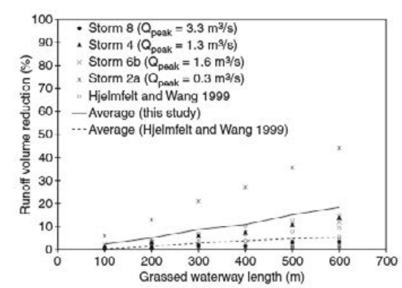
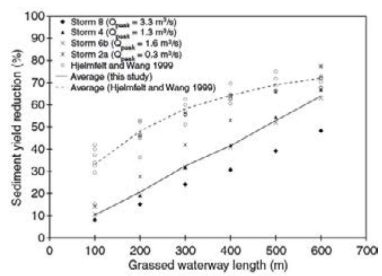


Figure 2. Sediment reduction by grassed waterways of various lengths in calibrated WEPP model in Iowa. (Reproduced from Dermisis et al., 2010)



Grassed waterways have been evaluated in reducing transport of 2,4-D (herbicide) through surface runoff. They found that an 80-foot-long grassed waterway with a watershed area ratio of 0.25 reduced suspended sediment concentrations by 94% to 98% and 70% of the 2,4-D load. Another two-year study showed reductions of 86% to 96% of Trifluralin under the same conditions in Iowa (Arora et al., 2003)

Key Design/Implementation Considerations

The NRCS lists important design considerations regarding capacity on the conservation practice standard. In general, the channel should be able to pass the 10-year, 24-hour storm without surpassing maximum permissible velocities based on soil texture and channel vegetation condition. Otherwise gully erosion may be initiated. When designed for pollutant removal, make grassed waterways as large as possible in both width and length, but continue to follow the design guidance from the NRCS. Slopes should be less than 10%. Beyond 10% slopes, Water and Sediment Control Basins (WASCOBS) or grade control structures are sometimes used if there is a high risk for channel down-cutting.

Cost Information

Grassed waterways have been found to be a cost-effective BMP strategy at the watershed scale (Rabotyagov et al., 2010). Although they are not designed to store water, they can reduce runoff volume by increasing infiltration (Figure 1).

Costs include grading of the waterway and seeding for vegetative cover. There are many funding programs available for this practice including the AgBMP Loan Program, Conservation Reserve Program, Conservation Stewardship Program, Reinvest in Minnesota, State Cost-Share Program, Carbon Credit Programs, Environmental Quality Incentives Program (EQIP), and other local programs (Table 1).

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact your local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or installation of a grassed waterway drainage systems may be eligible when used for soil erosion projects, including cost such as design, site preparation, and initial seeding.

Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, weed control herbicides, and increasing drainage flow with no water quality improvements are ineligible.

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Operation and Maintenance Considerations

Maintenance of grassed waterways is important as sediment can accumulate and cause short circuiting of the system by providing preferential flow paths. Areas that erode following heavy rains will need to be filled and reseeded quickly to prevent further erosion. Vegetation can be mowed or periodically grazed to help maintain capacity and vegetation vigor, and also prevent the establishment of woody vegetation. After mowing, it is recommended that vegetation be removed or harvested to reduce the potential downstream release of nutrients during decomposition (Ippolito et al., 2014). Heavy equipment traffic on the waterway can lead to compaction, which may reduce infiltration rates and hinder vegetation growth.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/Foot	Typical Units Installed	Estimated Total Installation Cost (rounded)
Grassed Waterway with checks less than 200 acre drainage area	$4.20	1,000	$4,200
Grassed Waterway with checks between 200 and 600 acre drainage area	$5.32	1,200	$6,400
Grassed Waterway with checks greater than 600 acre drainage area	$8.39	1,500	$12,600
Waterway drainage area less than 100 acres	$3.13	750	$2,300
Waterway drainage area between 100 and 200 acres	$3.92	1,000	$3,900
Waterway drainage area between 200 and 600 acres	$4.93	1,200	$5,900
Waterway drainage area greater than 600 acres	$7.91	1,500	$11,900

Research Gaps

Little research has been conducted specifically on grassed waterways in the upper Midwest. None of the pollutant removal aspects of grassed waterways have been evaluated in Minnesota.

Grassed waterways can trap particulate N and/or promote denitrification in subsurface flow or shallow drains (Zhou et al., 2014; Tomer et al., 2015) 10% PFS, 10% PFS with strips, and 20% PFS with strips. More studies are needed on the implementation issues and benefits of grassed waterways.

Local/Regional Requirements Design Example

Many grassed waterways have been installed in Minnesota. Numerous SWCD websites describe design and early successes during floods in the first years of implementation. The case study in southeastern Iowa represented in Figures 1 and 2 demonstrates the importance of grass waterways in steep terrain with highly erodible soils (wind-blown silty loess). A grassed waterway was installed by Martin SWCD prior to discharge into the Kittelson Wetland just off County Road 7, five miles southwest of Trimont, Minnesota. The grassed waterway stopped the gully erosion, reducing sediment load to the restored wetland.

References

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Dermisis, D., Abaci, O., Thanos Papanicolaou, A. N., & Wilson, C. G. |2010. Evaluating grassed waterway efficiency in southeastern Iowa using WEPP. *Soil Use Management*, *26*, 183–192.

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Rabotyagov, S., Campbell, T., Jha, M., Gassman, P. W., Arnold, J., Kurkalova, L., Secchi, S., Feng, H., & Kling, C. L. | 2010. Least-cost control of agricultural nutrient contributions to the Gulf of Mexico hypoxic zone. *Ecological Applications*, *20*(6), 1542-1555.

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Links

MDA Conservation Practice, Grassed Waterways
www.mda.state.mn.us/protecting/conservation/practices/waterway.aspx

NRCS Conservation Practice Standard, Grassed Waterways, Code 412
efotg.sc.egov.usda.gov/references/public/MN/412mn.pdf

NRCS National Engineering Handbook, Section 650
directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17766.wba

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Irrigation Management (442 and 449)

Irrigation on a Minnesota farm. (Photo by David Hansen)

Definition and Introduction

According to Kenny et al. (2009) irrigation accounted for about 6% (89.1 billion gallons) of Minnesota's total 2005 water use. Amongst consumptive water uses, irrigation accounted for 21.9% of Minnesota's total water use in 2015 (Minnesota DNR, 2017). Of that total, 89% came from groundwater sources. Irrigation accounted for 25% of the total groundwater withdrawal in 2005 (Kenny et al., 2009). In 2015, the Minnesota DNR reported 101 billion gallons of irrigation use (Minnesota DNR, 2017). According to the Minnesota DNR MPARS permitting data, there is just over 710,000 acres of actively permitted irrigation in Minnesota for major crops. This metric does not include irrigation permits for sod, nursery, wild rice, or pasture irrigation or irrigation where no permit is required, such as home gardens.

Irrigation management is controlling the rate, volume and timing of irrigation such that water is applied efficiently, minimizing the environmental impacts. Irrigation management can be applied to any irrigation operation. Irrigation management may have one or several objectives:

- Manage soil moisture to achieve a desired crop yield.
- Optimize use of available water supplies.
- Minimize irrigation induced soil erosion.
- Decrease non-point source pollution of surface and groundwater resources.
- Manage salts in the crop root zone.
- Manage air, soil, or plant micro-climate.
- Proper and safe chemigation or fertigation.
- Improve air quality by managing soil moisture to reduce particulate matter movement.
- Reduce energy use.

Water Quality Effects

Irrigation rates in excess of the soil's infiltration capacity lead to surface runoff. Surface runoff may contain soluble nutrients such as nitrate and pesticides. Additionally, surface runoff many cause erosion, transporting sediment and sediment-bound nutrients like P.

Irrigated areas in Minnesota are typically defined as valleys that are composed of coarse outwash materials with low water holding capacity, high infiltration rates, and good internal drainage. As a result, on these soil types, supplemental irrigation is almost always required to profitably produce food, fuel and fiber crops. These outwash areas tend to be confined to the central and west-central part of the state; however, there are isolated pockets of irrigated, coarse textured soils in the eastern and southern part of Minnesota. If not managed properly, excessive leaching in sandy soils can lead to groundwater pollution with soluble nutrients like nitrogen (N) and pesticides.

Several studies in the upper Midwest have been conducted quantifying irrigation management factors that influence the leaching of N in the form of nitrate from fertilizer and manure. In a long-term study in southeastern North Dakota, Derby et al. (2009) found that soil N concentration in the fall was the most important variable explaining N concentration in leachate, but also that over-application of irrigation water can lead to greater nitrate leaching. The irrigated Svendrup and Verndale sandy loam soils of Staples, Minnesota have hosted several N loss and N-balance studies over the years. Gerwing et al. (1979) studied nitrate movement, and observed that high N rates resulted in increased nitrate moving into the aquifer. One-time N applications resulted in 70% loss of the applied N in corn. Results indicated that optimum N rates split four times throughout the growing season resulted in almost no N movement towards the aquifer. Sexton et al. (1996) studied the influence of variable water deficits in irrigation scheduling, N rate and N source on yield and N loss. Sexton observed that when N rates were 95% of optimal and variable water deficient was used, N losses were reduced by 46%.

The irrigated Estherville sandy loam soils (that have since been reclassified as Arvilla sandy loam) of Westport, Minnesota have had extensive study on the fate of N and tend to define much of the irrigated soils in the Bonanza Valley of west central Minnesota (Minnesota DNR, 2016). Dylla et al. (1980) used drainage lysimeters to estimate water use by corn at about 35-60 cm per growing season after plant emergence. In subsequent years using drainage lysimeters, Timmons and Dylla (1981) observed that completely refilling the soil profile (5cm) through irrigation once the soil moisture level reached 50% depletion resulted in 36% more N leaching than if irrigation volume left room in the soil profile (2.5cm) to store rainfall. Walters and Malzer (1990b) also used the drainage lysimeters to show that proper N rates and conservative irrigation water management were better at preventing leaching than nitrification inhibitors alone. Fernandez et al. (2016) found that in corn crops within irrigated sandy soils, applying high rates of N for the optimum economic yield is best done by splitting the fertilizer application to avoid excessive loss of nitrate in the soil.

Key Design/Implementation Considerations

Irrigation water management requires knowledge of a crop's consumptive use given climate and soil in relation to the water content of the soil.

There are numerous technical guides available to develop an irrigation management strategy. Some of the prominent ones are:

- USDA NRCS National Engineering Handbook. Part 623, Section 15.
- USDA NRCS National Engineering Handbook. Part 652. Irrigation Guide.
- USDA NRCS National Engineering Handbook. Part 650, Chapter 15, Irrigation.
- NRCS Practice Standard 449, Irrigation Water Management.

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- NRCS Practice Standard 442, Irrigation System, Sprinkler.
- University of Minnesota Extension Publication FO-03875, Irrigation Water Management Considerations for Sandy Soils in Minnesota.
- University of Wisconsin Extension Publication A3600-02, Methods to Monitor Soil Moisture (Panuska et al., 2015).
- FAO Paper No. 56 Crop evapotranspiration (Allen et al., 1998).
- ASCE, Manual 70. Evaporation, Evapotranspiration and Irrigation Use Requirements

The traditional approach to irrigation management is to schedule irrigation using a moisture accounting method or checkbook method as described in Steele et al. 2010. The soil water content is depleted to its maximum allowable depletion (MAD) level, which triggers an irrigation event to bring the soil water content back to near field capacity, which is repeated until the crop reaches maturity (Wright, 2008). Additional inputs (rainfall) and withdrawals (e.g. evapotranspiration) are monitored to track the water balance. See Figure 1 for an example from Westport, Minnesota.

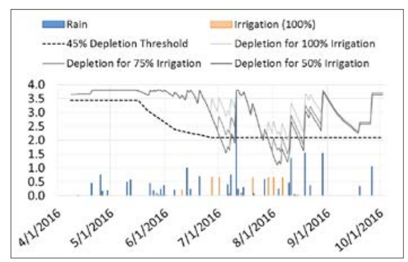

Figure 1. Soil water depletion during a 2016 minimum irrigation study at the Rosholt Farm, Westport, Minnesota. Corn plots were irrigated at 100%, 75% and 50% of full water requirement. The soil is able to hold 3.8 inches of water in the three-foot root zone and the curves show how much water remains in the soil after crop water consumption. Also shown is a 45% depletion threshold and the timing of rainfall and irrigation. Data by J. Stamper, graphic by J. Kjaersgaard.

A more recent approach to managing irrigation water, is to integrate soil moisture sensors as a means to determine when to irrigate. Soil moisture sensors fall into two primary categories, soil water tension sensors and volumetric soil water sensors. Both can be used to determine depletion based irrigation triggers through the use of a soil moisture characteristic curve. Panuska et al. (2015) provides an overview of the instrumentation and practical considerations regarding monitoring soil moisture.

Cost Information

The cost of implementing this practice is extremely variable and depends on any new equipment or technology bought to support its implementation.

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or installation of improvements to an existing irrigation system may be eligible when practices reduce water usage, increase energy efficiency, better control nutrient and chemical application rates, or reduce soil erosion. Examples of eligible costs include high efficiency pumps, control systems, weather stations, discharge heads and devices that reduce evaporation losses.

Typical operation and maintenance expenses for the irrigation system are not eligible. Installation of a new irrigation system is ineligible.

Controlling: Irrigation Management

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
Renovation of Existing Sprinkler System	$8.15/Foot	1,300	$10,600
Variable Rate Irrigation System Retrofit	$4,312.50 each	1	$4,300
Fertigation Retrofit, 80 gph Pump	$4,269.16 each	1	$4,300
Fertigation Retrofit, 30 gph Pump	$3,490.22 each	1	$3,500
Basic Irrigation Water Management, less than or equal to 30 acres	$33.52/Acre	30	$1,000
Basic Irrigation Water Management, greater than 30 acres	$12.25/Acre	125	$1,500
Intermediate Irrigation Water Management, less than or equal to 30 acres	$55.87/Acre	30	$1,700
Intermediate Irrigation Water Management, greater than 30 acres	$16.46/Acre	125	$2,100
Advanced Irrigation Water Management, less than or equal to 30 acres	$100.44/Acre	30	$3,000
Advanced Irrigation Water Management, greater than 30 acres	$26.79/Acre	125	$3,300
Soil Moisture Sensors	$1,388.70 each	2	$2,800
Soil Moisture Sensors with Data Recorder	$2,006.59 each	2	$4,000
Irrigation Water Management for seasonal high tunnels or small scale specialty crops	$285.96 each	1	$290

Operation and Maintenance Considerations

Like any mechanized system, there is wear on irrigation systems as they age. From an agronomic and water conservation standpoint, one of the greatest improvements to application efficiency can be had by conducting uniformity tests to assure that the irrigation system is applying water at the intended rate and location in the field. Instructional videos and software for conducting uniformity testing are available through the University of Minnesota Extension (www.extension.umn.edu/agriculture/irrigation/irrigation-management/#uniformity).

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Legal/Permit Requirements

A new irrigation system may require a water withdrawal permit from the Minnesota Department of Natural Resources if more than ten thousand gallons of water per day or more than one million gallons of water per year are used for irrigation. Information is available at this link: www.dnr.state.mn.us/waters/watermgmt_section/appropriations/permits.html

Irrigators who wish to apply N fertilizers or approved pesticides through irrigation systems need a permit through the Minnesota Department of Agriculture. This process is known as "chemigation" (or fertigation if only fertilizer is being applied), and is commonly used by growers to optimize the timing and amount of N fertilizer application to their crops. There are also University of Minnesota Extension resources for the inspection, maintenance, and permitting requirements for irrigators that wish to apply N fertilizer through an irrigation system (www.extension.umn.edu/agriculture/irrigation/chemigation).

Local/Regional Design Examples

East Otter Tail Soil and Water Conservation District and the Minnesota Department of Agriculture have partnered to increase educational outreach and technical assistance to producers in central Minnesota, an area of sandy textured soils and shallow groundwater aquifers, to promote proper irrigation and N fertilizer management (Newville, 2012). Since the initial 2012 forum report by Newville and Stuewe, extensive work has been conducted to develop a network of agricultural weather stations called the Central MN Ag Weather Network with a website (agweathernetwork.com) that organizes and presents the data in a format that is useful to farmers. The Network calculates crop water use estimates for major crops via the Standardized American Society of Civil Engineers (ASCE) Penman-Monteith Evapotranspiration (ET) equation from a series of weather stations in the central sands of Minnesota. The SWCD offers one-on-one training and works with individual farmers to schedule proper irrigation management. For growers outside of this weather station network, the Biometeorology Group at the University of Minnesota is currently working to develop a real-time, high spatial resolution output of estimated crop ET (www.biometeorology.umn.edu/research/etool). Weekly in-season potential ET forecasts are available through the project.

Research Gaps

There is a need for increased research on technology aimed at improving irrigation efficiency and understanding the environmental impacts in Minnesota (Newville, 2012). Additional research is needed to quantify the benefits of water conservation practices such as variable rate technologies and deficit irrigation for Minnesota. The development of a state-wide irrigation scheduling tool based on weather station data should be pursued.

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Waste Storage Facility (313)

Definition and Introduction

An impoundment created by excavating earth or a structure constructed to hold and provide treatment to agricultural waste. Waste storage facilities may be used to hold and treat waste directly from animal operations, process wastewater, or contaminated runoff.

Water Quality and Other Benefits

Leaking storage facilities (also termed lagoons) have the potential to negatively impact lakes, rivers, and streams. The Minnesota Pollution Control Agency indicates that the likelihood of leakage is greater in earthen basins than in concrete basins (MPCA, 2001). An MPCA study showed that leaking storage basins can result in elevated nitrogen (N) and phosphorus (P) levels several hundred feet down-gradient of the storage facilities (MPCA, 2001). A study of 28 different waste storage structures in Iowa by Glanville et al. (2001) showed that one site had a significantly greater leakage rate than the regulatory standard of 0.063 inches/day (Minnesota's is 0.0179 inches/day), while 15 (53%) had leakage rates not statistically different than the standard (Glanville et al., 2001). A different study in Iowa by Simpkins et al. (2002) found that half of the 28 earth storage facilities in their study leaked at a rate significantly greater than the standard. About 24 of the 28 sites in the Glanville et al. study would have exceeded Minnesota's standard.

Parker et al. (1999) performed a literature review of different manure storage leaking rates and found that four of the five full-scale storage facilities they examined had leakage rates that would have exceeded Minnesota's standard of 1/56 (0.0179) inches/day.

Negative water quality impacts may be realized in the event of structure failure. A structural failure in above ground storage facilities could lead to large release. Other potential sources of pollution include lagoons leaking or seeping into groundwater or if insufficient freeboard is present such that waste facilities are overtopped.

Key Design/Implementation Considerations

The USDA NRCS National Engineering Handbook (NEH) Part 651 addresses agricultural waste management, including design of lagoons (USDA NRCS, 2009). Conservation Practice Standard Number 313(MN) addresses specific guidelines for waste facility design in Minnesota.

The American Society of Agricultural and Biological Engineers (ASABE) addresses waste facility design in standard ASAE EP393.3 (ASABE, 2009).

Key design considerations should include length of storage and accounting for weather limitations during application or disposal. Other considerations include the equipment available for transfer and/or spreading as well as crop and soil types.

Before field application, mixing or other disturbance of anaerobic manure can release hydrogen sulfide (H2S), a lethal gas (Miner et al., 2000). Andriamanohiarisoamanana et al. (2015) found that mixing intensity, duration and total solids in the manure are the major determinants of H2S concentration. Those authors recommend total solids concentration of either more than 10% or less than 5%. They also advise that agitation intensity should be less than 200 rpm for durations less than 15 minutes and conducted more than four times per day. Ni et al. (2010) found that dilution of swine manure from 6.71 to 3.73% did not have a significant effect on H_2S release but did on ammonia. The diluted manure emitted more ammonia per unit of dry matter than the undiluted manure. This suggests that in order to preserve N content, manure should not be diluted.

Minnesota Rule Chapter 7020.2100 prescribes specific design criteria for construction of liquid manure storage areas. Key elements of the requirements are:

- New or modified storage areas treating 1,000 or more animal units must be designed to provide nine months of storage capacity.
- Seepage is not to exceed 1/56 of an inch/day for non-concrete liners.
- Composite-lined or above-ground storage areas must not exceed 1/560 inch/day.
- Most of the southeast part of the state has a Karst area restriction, which limits the type and extent of waste storage facility because of the increased risk of contaminating groundwater.

Cost Information

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or installation of a waste storage facility at an existing livestock operation may be eligible including all expenses related to its design, permitting, construction, and integration with the existing operation to make it fully functional is typically eligible. This includes the structure, fixtures, pumps, and manure handling and application equipment.

Typical operation and maintenance expenses for the waste storage facility. Cost related to the construction of a new livestock operation is not eligible.

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Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
Earthen Storage Facility, in ground, less than 50,000 ft^3 storage	$0.37/$ft^3$	25,000	$9,300
Earthen Storage Facility, in ground, greater than 50,000 ft^3 storage	$0.28/$ft^3$	168,000	$46,400
Steel or Concrete storage facility less than 25,000 ft^3	$7.16/$ft^3$	13,237	$94,700
Steel or Concrete storage facility 25,000 ft^3 through 100,000 ft^3	$2.74/$ft^3$	73,952	$202,800
Steel or Concrete storage facility greater than 100,000 ft^3	$2.18/$ft^3$	175,034	$380,800
Dry stack, Earthen floor, No wall	$0.54/$ft^2$	4,000	$2,200
Dry stack, Reinforced concrete floor, No wall	$5.08/$ft^2$	4,000	$20,300
Dry stack, Reinforced concrete floor, Wood wall or Modular Block Wall	$7.14/$ft^2$	4,000	$28,600
Dry stack, Reinforced concrete floor, Reinforced concrete wall	$12.47/$ft^2$	4,000	$49,900
Concrete storage tank, buried, less than 5,000 ft^3	$7.28/$ft^3$	3,600	$26,200
Concrete storage tank, buried, greater than or equal to 5,000 and less than 15,000 ft^3	$2.87/$ft^3$	9,420	$27,100
Concrete storage tank, buried, greater than or equal to 15,000 and less than 25,000 ft^3	$2.22/$ft^3$	20,000	$44,300
Concrete storage tank, buried, greater than or equal to 25,000 and less than 50,000 ft^3	$1.79/$ft^3$	28,000	$50,200
Concrete storage tank, buried, greater than or equal to 50,000 and less than 75,000 ft^3	$1.56/$ft^3$	62,000	$96,600
Concrete storage tank, buried, greater than or equal to 75,000 and less than 110,000 ft^3	$1.38/$ft^3$	92,500	$128,000
Concrete storage tank, buried, greater than or equal to 110,000 ft^3	$1.28/$ft^3$	152,600	$195,300
Concrete lined earthen storage facility, reinforced concrete liner	$1.00/$ft^3$	168,302	$167,700

Operation and Maintenance Considerations

Operations and maintenance considerations are provided in NRCS Practice Standard MN-313.

Legal/Permit Requirements

See Minnesota Rules 7020 for more detail. Some of the requirements are listed in Key Design/Implementation Considerations above.

Local/Regional Requirements Design Example

There are numerous examples of waste storage facilities particularly in dairy regions such as southeast and central Minnesota.

Research Gaps

Previous research conducted in Minnesota indicates that older or poorly-lined earthen storage basins have the potential to contribute elevated nitrate and potentially P (MPCA, 2001). There are gaps in understanding the effects leaking manure storage facilities have on water quality in the state, particularly on seepage rates from basins constructed with up-to-date standards, but that have been in existence for over 10-15 years. Freeze thaw, desiccation during low water levels, overland flow, and ground water inflow have the potential to cause liner deterioration over time (Simpkins et al., 2002).

Ham and DeSutter (2000) suggest that rather than specifying a maximum seepage rate (as Minnesota does), guidelines or rules should consider input loading (e.g., swine may have greater total N concentration so should have reduced seepage rate). These authors also state that soil cation exchange capacity (CEC) and other vadose zone properties that affect aquifer vulnerability should be considered when assessing risk. Currently there are few swine lagoons in Minnesota so the maximum seepage-based rate is a reasonable approach; however, should the number of swine lagoons increase in future years, an input-based approach should be considered.

Current design criteria in the Minnesota Rules reflect the potential dangers of untreated animal wastes entering surface or ground waters. Although it is not currently a priority for research in Minnesota, as climate change concerns become more pronounced, a rating system reflecting gaseous emission levels may eventually be desired. Nicholson et al. (2002) present a rating system which includes risk to water and air quality, as well as pathogens.

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Controlling: **Waste Storage Facility**

Conservation Tillage (329 and 345)

Conservation tillage in a soybean field in Minnesota. (Photo by David Hansen)

Definition and Introduction

Conservation tillage is any tillage practice that leaves additional residue on the soil surface for purposes of erosion control and moisture conservation. NRCS Practice 329 is No Till and NRCS Practice 345 is Reduced Till. Conservation tillage is often defined as reducing inversion tillage (e.g., moldboard plow) and leaving at least 30% cover on the soil surface (Lal et al., 2007; NRCS, 2011). Conservation tillage is one of the basic BMPs used on farms state-wide and is considered by the NRCS as one of the "Core 4" practices that have conservation impact and can be implemented on almost every farm. Many different variations of this common practice are implemented; which one is often based on climatic conditions and available equipment.

Since 1994, the USDA has required the use of conservation measures on highly erodible land to remain eligible for program benefits. Conservation tillage is one of the easiest ways to protect erodible land with the least interruption of cropping practices. Crop residue is the most important factor effecting erosion from different tillage systems. The more residue on the land following tillage, the less erosion from the field. As of the year 2000, 37% of all major row crops and small grains are being grown with a conservation tillage system (MWPS, 2000).

Ridge till, mulch till, strip till, and no till are all variations of conservation tillage. Ridge till is the practice of growing crops on pre-formed ridges alternated with furrows protected by crop residue (USDA, 2011). Mulch till refers to tillage methods used to manage the amount and distribution of crop residue in systems where the field is tilled prior to planting (USDA, 2006b). No till and strip till involve planting directly into crop residue that either has not been tilled at all (no till) or has been tilled only in narrow strips (strip till).

Water Quality and Other Benefits

Water quality improvements are due primarily to improved erosion control but conservation tillage can also protect water from nutrient and pesticide losses. Conservation tillage can reduce soil loss up to 90% when compared to conventional tillage although chemical loss reductions are likely lower (MWPS,

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2000). Other benefits include: reduction in wind erosion, improve soil organic matter content, reduce CO_2 losses from the soil, reduce soil particulate emissions, and also to provide food and escape cover for wildlife (USDA NRCS, 2006a).

In a Wisconsin field study, Andraski et al. (2003) found that no till reduced dissolved P loads by 57% and 91% for total P when compared to conventional tillage. A simulated rainfall study in Wisconsin by Bundy et al. (2001) showed that no till produced the lowest TP and sediment concentrations and loads when compared to chisel plow and shallow till under multiple manure management scenarios.

A 1993-1994 study near Morris, Minnesota aimed to evaluate the effectiveness of residue management systems on sediment and nutrient losses. This study was conducted on a 12% slope of Barnes Loam soil and showed an average sediment load reduction of 8.9 ton/ac to 0.4 tons/ac between moldboard plow and ridge till. This equates to a 96% reduction in sediment. P loss reduction was from 2.9 lbs/ac to 1.9 lbs/ac, a 34% reduction. (Moncrief et al., 1996; Ginting et al., 1998)

Many studies have examined the impact of conservation tillage on nitrate leaching and found little impact. Studies have shown both increases and decreases in nitrate leaching and losses under conservation tillage. Long-term studies on continuous corn in Iowa have studied nitrate leaching in drain tile and have shown that although the leaching is similar the first two years, in subsequent years leaching is reduced in no till systems. (Kanwar & Baker, 1993)

Conservation tillage can be an important part of reducing phosphorus losses in runoff because a large portion of the phosphorus is attached to eroded sediment particles. A no till study in Iowa showed an 80-91% reduction in total P loss for soybeans following corn and a 66-77% reduction in P loss for corn following soybeans (Baker & Laflen, 1983). However dissolved P losses have been found to be higher in some fields with conservation tillage than conventional tillage (Christanson et al., 2016).

Andraski et al. (1985) studied tillage effects on P losses in a simulated rainfall study in Wisconsin and found reductions of 81%, 70% and 59% for no-till, chisel plow and till-plant respectively.

Numerous studies have also shown that conservation tillage can improve soil quality. Li et al. (2015) conducted a 12-yr study in southern Alberta, Canada, comparing conservation tillage to conventional tillage. Those authors found a 145% increase in particulate organic matter carbon and nitrogen (N) compared with conventional tillage. They also found 45 to 50% increases in total organic carbon and N under conservation tillage and significant increases in aggregate stability. Pare et al. (2015) found no significant difference in organic matter content when comparing chisel plow and moldboard plow in a long-term study conducted in Quebec. They did find, however, an increased nitrate and phosphorus content in the 0–8 inch depth of soil. The same authors also found that chisel plow improved soil water conductivity, soil macro-aggregate stability and aggregate mean weight diameter. Improved soil structure could reduce the need for artificial drainage in some conditions while increased nutrient content in the soil could lead to reduce fertilizer inputs, potentially offsetting any yield reductions. Dolan et al. (2006) suggest that the positive effects of no till or reduced tillage may only be observed in the upper 20 cm (8 inches) of the soil profile. Soil organic matter may accumulate more in lower soil layer as tillage deposits the material below the plow depth and promotes greater rooting depth.

In contrast to the previous studies presented, a number of studies have shown detrimental water quality impacts of ridge tillage and no-till systems. The effects of tillage and nutrient sources were examined in a single-event simulated rainfall study in the Minnesota River Basin (Zhao et al., 2001). This study indicated that ridge till performed

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worse than moldboard plow for water quality protection but is likely an oversimplification of the annual processes that cause erosion on plowed fields. McIsaac et al. (1993) found that the no till treatment produced the highest flow-weighted mean concentration (34 mg/L) of N of all tillage types examined.

Conservation tillage may be of particular benefit to organic growers. Cultural practices (rotation design) and tillage are common ways to manage weeds in organic operations. Anderson (2014) found that reduced tillage combined with oat/pea cover crop reduced weed biomass by 63% and, as a result, yield 14% more soybean in a study conducted in eastern South Dakota. Leavitt et al. (2011) also found decreased weed biomass but found significant decreases in yield, compared to mechanical tillage, in a no till/cover crop study conducted in Minnesota. The Leavitt et al. (2011) study was conducted using vegetables (e.g., tomato, bell pepper), which are sensitive to early season ground temperatures that are often reduced using cover crops.

Key Design/Implementation Considerations

The choice of tillage system on a farm is one of the most visible and complex choices that a farmer can make. In general, some form of conservation tillage is right for every farm in Minnesota and is the first defense against soil erosion. Soil type, crop type, slope and climate play a pivotal role in which method is the most effective and profitable. Conservation tillage is unique in that it is rarely a stand-alone BMP. Often nutrient management and pest management will need to be modified following conversion to conservation tillage. In general, conservation tillage is most effective on well drained soils and may cause delayed field access on poorly drained soils.

Cost Information

The costs of switching to a conservation tillage system are born from both equipment switching and operating cost and is generally believed to be a cost-effective agricultural BMP to protect water quality while protecting yields. An economic analysis of switching to a conservation tillage practice that leaves 30% residue in the Minnesota River basin was conducted in 1996. (Olson & Senjem, 1996) Although outdated, the same general trends likely apply today. This study looked at the costs of switching to a 30% residue system and also the operating cost of the new system using real-world costs of the time.

Switching costs may include the cost of switching twisted shovels to straight shovels on a chisel plow. This is the most cost effective way to switch to a conservation tillage practice because the only new equipment are the shovels. Changing from chisel plow to one-pass-and-plant requires two different tillage methods, one for corn following soybeans and one for soybeans following corn. A combination implement combining a disk, field cultivator and a drag would be needed for soybeans following corn. Changing from chisel to ridge plow requires both the conversion of a planter and the cost of heavy-duty cultivator.

This study in the Minnesota River basin showed that under most scenarios it is economically beneficial to switch to a high residue system. The conversion from moldboard to chisel plow was the most economically viable and created a substantial savings the first year. Switching from chisel plow to one-pass-and-plant had a payback period of less than three years and conversion to ridge till from chisel plow may take as long as seven years.

EQIP (USDA NRCS 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Controlling: **Conservation Tillage**

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for equipment to implement conservation tillage practices is eligible. This applies to all aspects of production through the year including seed bed preparation, planting, cultivation, and harvest, and may be an entire suite of equipment. This equipment typically incorporates specially designed components that result in additional residue for erosion control, moisture conservation or where one piece of equipment is dependent on the results of the preceding implement in order to be effective. Expenses may be for new, used, or retrofitted implements.

Typical operation and maintenance expenses of the equipment is not eligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Conservation Code	Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
329 – Residue and Tillage Management, No Till	No Till, Strip Till	$20.03/Acre	100	$2,000
329 – Residue and Tillage Management, No Till	No Till Adaptive Management	$3,165.61 each	1	$3,200

Operation and Maintenance Considerations

The effect of conservation tillage on yield is a key consideration before adoption. Pittelkow et al. (2015) reviewed studies comparing crops yields between conventional tillage and no till on a global scale and found that no till reduced yield by 5.7%. However, those yield reductions were minimized when no till was practiced in combination with permanent soil cover and used in a crop rotation. Also, the benefits of no till were best in dry climates because of the moisture conservation benefits of no till. Pittelkow et al. noted that yield decreases associated with no till tend to decrease with time after adoption.

No till soils tend to have fertilizer applied as broadcasted P or manure which is easily lost in surface runoff. Research in Ohio (King et al., 2015) has raised concern about P loss to tile lines in no till systems. Therefore, management and maintenance plans should consider both surface and sub-surface loss concerns. Lighter incorporation of fertilizers on no till soils and regular soil testing for nutrient levels are suggested to address these issues.

Research Gaps

Conservation tillage is one of the most heavily researched agricultural BMP with a good deal of information available from Minnesota. Information on the economics and yield of conservation tillage is widely available as is water quality monitoring of runoff volume, sediment, phosphorus and nitrate yield. Work by Bundy et al. (2001) should be expanded upon to further explore the relationship between common management practices that also achieve the greatest pollutant protection. There has been considerable focus on the water quality impacts of conservation tillage and growing attention on the changes in soil quality (soil organic matter, soil aggregate stability, and nutrient content) due to the growing focus on soil health. Most research on water quality has focused on nitrate but the effect of conservation tillage on dissolved phosphorus losses is currently a knowledge gap. There is a need to identify farm management practices to minimize dissolved P losses in tile drainage in fields with no-till.

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Links

MDA conservation tillage webpage
www.mda.state.mn.us/en/protecting/conservation/practices/constillage.aspx

NRCS Conservation Practice Standard, Mulch Till, Code 345
efotg.sc.egov.usda.gov/references/public/MN/345_MN_Residue_and_Tillage_Management-Reduced_Till_2016.pdf

NRCS Conservation Practice Standard, Residue and Tillage Management, Code 329
efotg.sc.egov.usda.gov/references/public/MN/2016ResidueMgmtNoTill329Standardfinal.pdf

Riparian Herbaceous Cover and Riparian Forest Buffer (390 and 391)

Definition and Introduction

Riparian and channel vegetation is a mix of grasses, forbs, sedges, and other vegetation that serves as an intermediate zone between upland and aquatic environments. Riparian vegetation is often used to stabilize streambanks; however, this practice focuses on using native plantings rather than more intensive streambank protection that falls under NRCS Practice 580. Riparian vegetation can improve water quality by acting as a filter strip that induces sedimentation and anchors soil through its root system. Riparian vegetation can also play an important role in providing habitat, helping to regulate water body temperature through shade and dissipating stream energy.

Water Quality and Other Benefits

If receiving runoff from upland sources, riparian vegetation has similar water quality benefits to vegetative filters. Riparian vegetation can improve water quality by promoting the settling of sediment and associated pollutants, including nitrates. There are multiple pathways for nitrogen (N) removal, including plant uptake, microbial immobilization, soil storage, groundwater mixing, and denitrification, though denitrification, the microbially-aided conversion of nitrate to N gas (N_2), is the dominant pathway for N removal. (Mayer et al., 2007) the vegetated region adjacent to streams and wetlands, are thought to be effective at intercepting and reducing N loads entering water bodies. Riparian buffer width is thought to be positively related to N removal effectiveness by influencing N retention or removal. The literature shows that N removal varies widely by buffer width, hydrological flow path and vegetative cover. Wide buffers (>50 m).

Mayer et al. (2007) found in a meta-analysis of 45 different studies that mean N removal across all studies was 67.5%. From a water quality perspective, riparian vegetation width is a key design consideration. In the same analysis, buffers between 0 and 25 m (82 feet) removed 57.9% of N, those between 26 and 50 m (164 feet) wide removed 71.4%, and buffer widths greater than 50 m (164 feet) removed 85.2% of N. Yamada et al. (2007)

found that significant reductions in nitrate were realized within about two years of riparian buffer establishment.

Hoffman et al. (2009) reviewed the efficiency of riparian buffers in retaining phosphorus (P) in the U.S., Canada, and Europe. P retention was dependent on both chemical and physical characteristics. Chemical characteristics included: iron: P ratio in the soil, content of redox stable sorbents, pH, and alkalinity. Local hydrologic characteristics are important and dictate amount of infiltration, magnitude and duration of flooding, residence time, and sediment deposition. As Hoffman et al. (2009) point out, removal of TP in riparian buffers is mainly controlled by sedimentation processes and typically ranges from 41 to 93%. According to the same study, retention of dissolved reactive P is essentially negligible.

Liu et al. (2008) comprehensively reviewed the effectiveness of various forms of vegetated buffers on sediment trapping including vegetative filter strips, riparian buffers, and grassed waterways. Sediment trapping efficiency was found to be primarily a function of buffer width and slope. Riparian buffers were found to have a sediment trapping efficiency ranging from 54 to 98%.

Vegetation variety can also influence performance. The use of shrubs in addition to grasses and forbs has been investigated for riparian vegetation. Mankin et al. (2007) found average TSS reduction of 99.7%, 91.8% for total P, and 92.1% for total N. Infiltration accounted for much of the reduction.

Key Design/Implementation Considerations

Successful riparian vegetation establishment depends on soil, climate, plants, and position on the streambank or within the watershed. The NRCS (2016) Practice Standard 390 provides basic design criteria and guidance. Successfully establishing riparian vegetation requires careful site preparation and seed mix selection. The Minnesota Soil Bioengineering Handbook (2006) provides a list of species that are suitable for riparian vegetation plantings in Minnesota. If a forest buffer or agroforestry/multi-purpose buffer is desired, design criteria can be found from University of Minnesota and Iowa State University publications (Bongard & Wyatt, 2010). The NRCS Stream Restoration Design Guide (USDA NRCS, 2007) provides extensive technical guidance regarding the role of riparian vegetation in bioengineering techniques.

Riparian forest buffer (NRCS practice 391) establishment requires careful selection of tree and shrub species to fit local soil and water conditions as well as landowner objectives.

A critical aspect of riparian vegetation design is identifying critical areas where wider vegetative buffers and denser grasses may be necessary. Galzki et al. (2011) used digital terrain analysis in GIS to identify gully locations, side inlets, and riparian areas where excessive erosion was taking place. Ssegane et al. (2015) listed considerations for designing effective buffers on a field, which can also be used for riparian buffers. To reduce nitrate in the subsurface flow, the depth of the water table should be determined. Deeper water tables may require deeper-rooted species such as trees to reach the subsurface flow where nitrate may be discharging to the nearby waterway (Ssegane et al., 2015).

Tomer et al. (2008) also provided methods to identify riparian buffer locations to improve water quality. One technique uses a simplistic model to rank each soil type for the capacity of a buffer on it to trap sediment, then a map is developed comparing buffers' ability to trap sediment in different soil types. The other technique is a terrain analysis technique.

Cost Information

The costs for installing riparian and channel vegetation mostly pertain to the seed, cuttings, plugs, or transplants chosen for the site. Some site preparation and maintenance expenses will also be necessary. EQIP (USDA NRCS, 2016) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or installation of buffers may be eligible when used for soil erosion projects and riparian stabilization. To be eligible, the project must provide water quality benefits, not simply wildlife habitat. Eligible cost include expenses such as design, site preparation, landscaping, riparian stabilization structures and devices, exclusionary fencing, initial seeding, and vegetation plantings.

Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, weed control herbicides, and practices with no water quality improvements are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Practice	Component	Estimated Average Cost/Acre	Typical Units Installed	Estimated Total Installation Cost (rounded)
Riparian herbaceous cover	Native species	$136.00	5	$680
Riparian herbaceous cover	Native species with forgone income	$504.00	5	$2,520
Riparian herbaceous cover	Native species, pollinator planting	$524.00	5	$2,620
Riparian herbaceous cover	Native species, pollinator planting with forgone income	$892.00	5	$4,460
Riparian forest buffer	Bare root, hand planted	$2,916.67	3	$8,750
Riparian forest buffer	Cuttings	$4,620.00	1	$4,620
Riparian forest buffer	Seeding	$923.00	10	$9,230
Riparian forest buffer	Small container, hand planted	$3,580.00	3	$10,740
Riparian forest buffer	Small container, machine planted	$2,626.67	3	$7,880

Operation and Maintenance Considerations

Key considerations for operations and maintenance are periodic inspection for erosion and maintenance of desired vegetation species and health. Over time, buffer effectiveness can be reduced by soil compaction from tractor and vehicular traffic. Invasion by reed canary grass (*Phalaris arundinacea*) and other exotics reduces the habitat value for birds and pollinators and provides little root depth. Weed control and controlled burns can be used to maintain grass and prairie vegetation. In addition woody species such as willows (*Salix sp.*), box elder (*Acer negundo*), and cottonwood (*Populus deltoides*) may spread into herbaceous buffers (390) causing maintenance problems. For forested riparian buffers (391) protection of tree seedlings, mowing, and/or

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herbicide application is often required the first few years after planting. See the University of Minnesota Extension Factsheet describing maintenance of forested buffers.

Legal/Permit Requirements

Implementation of riparian and vegetative buffers may be subject to a Minnesota Department of Natural Resources public waters permit (www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/index.html) and/or a National Pollutant Discharge Elimination System (NPDES) construction permit from the Minnesota Pollution Control Agency if the project disturbs more than one acre of land.

In addition, the Minnesota Buffer Law was adopted in 2015 and requires buffer strips or alternative riparian water quality practice(s) along state public waters and publicly administered drainage ditches. The applicable watercourses and water bodies are identified on the Minnesota DNR Buffer Protection Map and implementation guidance is available on the BWSR Buffers webpage. These requirements should be considered when designing streambank stabilization or riparian vegetation practices in the applicable areas.

Local/Regional Design Examples

Many examples of riparian and channel vegetation projects can be found across Minnesota. The University of Minnesota Extension developed a forested riparian buffer system to support trout habitat along Vermillion Creek (Bongard & Wyatt, 2010).

The Iowa State University multi-purpose riparian buffer system is a well-researched design that incorporates grasses, shrubs, and trees to provide stabilization, habitat, fruit or nut crops, and timber/agroforestry benefits (Schultz et al., 1995; Schultz et al., 1997).

The Elm Creek riparian restoration project in southwestern Minnesota (Lenhart et al., 2010) demonstrated riparian restoration practices including seeding of regraded stream banks with native prairie seed mix, and installation of willow cuttings on newly established floodplain benches (see Figure 1).

Figure 1. Riparian vegetation planting along Elm Creek (Lenhart et al., 2010).

Research Gaps

There are few examples of monitoring studies documenting the water quality benefits of riparian vegetation in Minnesota.

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Links

NRCS Conservation Practice Standard, Grassed Waterways, Codes 390 and 391
efotg.sc.egov.usda.gov/references/public/MN/390mn.pdf
efotg.sc.egov.usda.gov/references/public/MN/391mn_Riparian_Forest_Buffer.pdf

MDA Conservation Practice, Grassed Waterways
www.mda.state.mn.us/protecting/conservation/practices/bufferforested.aspx

The MDA's Precision Conservation Initiative
www.mda.state.mn.us/protecting/cleanwaterfund/toolstechnology/precisionconsinit.aspx

Minnesota Department of Natural Resources, public waters permit
www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/index.html

The University of Minnesota Extension Riparian Forest Buffer page.
www.extension.umn.edu/environment/agroforestry/riparian-forest-buffers-series/benefits-of-riparian-forest-buffers

Controlling: **Riparian Cover/Forest Buffer**

Prescribed Grazing (528)

Definition and Introduction

Prescribed Grazing, also called rotational or managed grazing, is the practice of controlled harvest of vegetation with grazing animals. Management of grazing systems can maintain the health of vegetation communities, control forage quality, reduce erosion, improve water quality and watershed function, expand or improve wildlife habitat, and promote economic sustainability. This management includes managing the kind or class and number of grazing animals as well as the distribution, location, duration, timing, and season of grazing. Roche et al. (2015) divided this management into five practices: managing the number of pastures, the number of herds, the duration of grazing, livestock density, and timing of rest.

Rotating grazing animals is a management-intensive system of raising livestock on subdivided pastures called paddocks. Livestock are regularly rotated to fresh paddocks at the right time to prevent overgrazing and optimize grass growth. A rotational grazing system is an alternative to continuous grazing in which a one-pasture system is used that allows livestock unrestricted access to the entire pasture throughout the grazing season.

Animal rotations can vary from a simple rotational grazing system (Figure 1) in which animals move or rotate to a fresh paddock every 3-6 days, to an intensive rotational grazing system (Figure 2) in which animals are moved to a fresh paddock as frequently as every 12 hours. Grazing is started when forage is about eight inches tall and stopped once it is grazed down to about four inches tall (depending on vegetation type). Grazing a given pasture should depend more on the plant height than on consistent durations. The NRCS recommended plant heights for select species are listed in Table 1.

Following the grazing period the paddock (pasture) is rested for approximately 30 days (depending on the weather and productivity of the pasture). This provides a recovery time to maintain forage plants in a healthy and vigorous condition. The primary benefit of rotational grazing to the producer is a more efficient and productive pasture allowing for increased carrying capacity, longer stays on pasture, resulting in less need to feed hay, silage or grain. Typically in Minnesota, cattle are grazed in marginal farmland, wet areas and stream valleys. Uplands are reserved for corn and soybeans (Lenhart et al., 2011).

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Figure 1. Simple Rotational Grazing System (Blanchet et al., 2003)

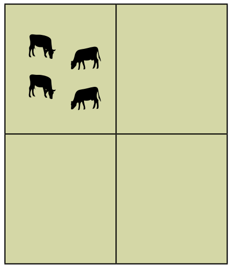

Figure 2. Intensive Rotational Grazing System (Blanchet et al., 2003)

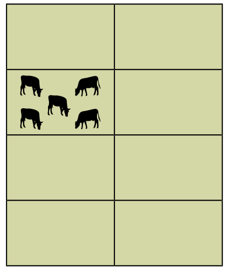

Table 1. Minimum heights of pasture species for initiating and terminating grazing (table is from NRCS Prescribed Grazing Job Sheet 528)

Species	Initial grazing height in early spring (inches)	Minimum and optimum height of vegetative growth (inches)	Minimum stubble height (inches)	Minimum regrowth before killing frost (inches)
Alfalfa	--	Bud Stage	--	6
Creeping foxtail	6	8-10	3	6
Green needlegrass	4-5	8-14	4	6
Inter. Wheatgrass	4-5	8-14	4	6
Ky. Bluegrass	2	4-6	2	4
Orchardgrass	3-4	6-10	3	6
Perennial Ryegrass	3-4	6-10	3	6
Pubescent wheatgrass	4-5	8-14	4	6
Reed canarygrass	4-5	8	4	6
Russian wildrye	4	5-7	3	4
Slender wheatgrass	4-5	6-12	3	6
Smooth Brome	4	8-14	4	6
Tall Fescue	4	6-10	3	6
Tall Wheatgrass	4-5	8-14	4	6
Timothy	4	6-10	4	5
Western Wheatgrass	4	6-10	4	5
Big bluestem	--	10-14	6	6
Indiangrass	--	10-14	6	6
Little bluestem	--	5-7	3	4
Sand bluestem	--	8-14	6	6
Sideoats Gramma	--	4-6	2	4
Switchgrass	--	12-20	8	10

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Water Quality and Other Benefits

The research data in Minnesota directly comparing runoff water quality from continuous and rotational grazed pasture is limited and primarily associated with streams in Southern Minnesota. In one of those studies (Sovell et al., 2000), fecal coliform and turbidity were found to be consistently lower at the rotationally grazed sites than at the continuously grazed sites.

Wagner et al. (2012) found that grazing along the edge of a stream during the dry season instead of the wet season is more important than lowering stocking rates for reducing E. coli runoff into a stream. On the other hand, E. coli tends to survive better in the wet season (spring and summer) while temperatures are warmer. Grazing during early summer when nitrogen (N) demand is higher in plants could reduce nitrate runoff (Sollenberger et al., 2012).

Managing stocking rate can be more important for productivity, nutritive value, and botanical composition for the pasture. A lower stocking rate can potentially reduce erosion along streambanks (Tufekcioglu et al., 2012; Tufekcioglu et al., 2013). Sollenberger et al. (2012) concluded that excluding grazing livestock from riparian areas during the non-growing season when evapotranspiration is lowest will have the greatest benefit to water quality. However, complete exclusion may not be the best option because some grazing can improve biodiversity, rejuvenate forage, and remove some nutrients in vegetation, but timely grazing can improve water quality.

Grazing management was found to be important for reducing compaction and increasing infiltration rates in Iowa. Baharti et al. (2002) found that continuously grazed pasture had less infiltration than that found in corn and soybean fields. In addition to water quality benefits, rotational grazing doubles as a system of perennial grassland management, providing exceptional erosion and runoff control on uplands as well as stream corridors. It offers a productive alternative for marginal, erosion-prone or flood-prone cropland and other environmentally sensitive land, including overgrazed pastures. Rotational grazing also provides built-in manure management. Manure on healthy, well-managed grassland decomposes into the soil rather than running off. Rotating livestock from paddock to paddock allows time for manure to be incorporated into the soil. The manure helps maintain soil fertility for new grass growth, eliminating the need to store, process, haul or spread manure as a soil amendment.

The Minnesota Department of Agriculture (MDA) has a [Rotational Grazing webpage] that describes other practical and environmental benefits of rotational grazing. The MDA webpage also discusses the importance of having a rotational grazing plan and describes key components. Examples include calculating the appropriate number, size and layout of paddocks relative to livestock numbers and forage needs, and determining appropriate locations for livestock watering stations and walkways. [Green Lands Blue Waters] also provides guidance for integrating livestock into farm operations in ways that are beneficial for water quality (see web links).

Key Design/Implementation Considerations

The University of Minnesota Extension Service 2003 Publication "Grazing Systems Planning Guide" identifies the following key considerations for implementation of a rotational grazing system:

Grazing Resource Inventory

- Goals - What are the goals for the grazing system?
- Land and Soils - What land resources are available and what is the productivity of the soils? Are there environmentally sensitive land areas, resources or soil limitations for grazing?
- Livestock - What are the requirements of each livestock heard and how many herds will be grazed? What are the plans for future expansion of the livestock operation?

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- Forages - What are the existing forage species, and what is the health and condition of the pasture? What are the estimated yields and seasonal distribution of those existing forages?
- Water sources - What are the existing water sources, where are the drinking facilities and what condition are they in? Are there other potential water sources and what effort would be required to develop them?
- Fence – What are the types and conditions of the existing fences?

Grazing Plan

- Paddock Design and Layout - How many paddocks, how large are they, and how should they be laid-out to allow for efficient movement of animals?
- Fence Design and Layout - Type of fence, both interior and exterior needed to supplement existing fences.
- Water System Design and Layout - System supply requirements, type and location of drinking facilities.
- Heavy Use Area Planning – Stabilization of heavy use areas, i.e. livestock lanes and areas around water facilities.

Pasture Management Strategy

- Pasture Forage and Livestock Management - Proper grazing management for desired forage species. When to start in spring, when to move from paddock to paddock. Whether seeding is necessary for preferred forage species and how long seedlings need to establish.
- Pasture Soil Fertility Management - Manage livestock to evenly distribute manure (nutrients) throughout pasture and determine need for additional fertilizer.
- Pasture Brush and Weed Control – Determine brush and weed control alternatives (grazing, mechanical, chemical, and other) and when to use each.
- Sacrificial Paddock Management – Management of livestock and pasture during winter, times of drought or wet conditions.

Monitor the grazing system by keeping records of pasture performance to help determine forage availability and help evaluate if management actions are increasing, pasture productivity and natural resource health.

Additional design and implementation guidance for rotational grazing in Minnesota is provided in the MDA publication "Improving and Sustaining Forage Production in Pastures" (Moechnig, 2010). The publication also provides references for additional information on rotational grazing and current contact information for State, Federal (MN), and private grazing specialists.

Cost Information

Rotational grazing costs are low in comparison to other agricultural production practices such as cropping and confined animal operations due to minimal equipment needs. Rotational grazing costs do not typically entail taking land out of production, and often result in gaining production from marginal croplands. Costs for fencing and alternative water systems can be higher than with continuous grazing and tend to increase with increased intensity of the grazing system.

A University of Minnesota extension article describes conversion to rotational grazing from conventional grazing and identifies the fencing costs associated with the implementation of Managed Intensive Grazing (MIG) (Loeffler et al., 2008). The costs ranged from $0 - $11,000 per farm. The average cost for fencing was $2,120 (Table 2). Costs were higher for those without existing pastures. Water equipment costs for the group averaged $627 with the range being from $0 - $5,000. Whole farm labor costs decreased on 15 of the 29 farms, and 26 of those farms reported a decrease or no change in costs after their conversions to MIG.

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EQIP (USDA NRCS, 2016) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or on-site structures and fixtures are eligible when implementing a prescribed grazing plan that results in water quality benefits. Eligible cost include expenses such as site assessment, plan development, site preparation, landscaping, drainage, fencing, water supplies, initial seeding, and vegetation plantings.

Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, weed control herbicides, and practices with no water quality improvements are ineligible.

Table 2. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Component	Estimated Average Cost/Acre	Typical Units Installed	Estimated Total Installation Cost (rounded)
Deferred Grazing, Foregone Income	$53.00	40	$2,120
Pasture Standard	$30.25	40	$1,210

The Minnesota DNR offers cooperative farming agreements and leases to allow grazers on the land for short periods of time to manage the diversity of the public land. Other land managers such as The Nature Conservancy or The Fish and Wildlife Service coordinate similar agreements to provide mutual benefits for livestock farmers to rest their land and conservation managers to improve biodiversity.

Routine maintenance considerations for the rotational grazing operation facilities include standard fence maintenance, pest management, brush and weed control as well as pasture and forage maintenance (i.e. restoration of sacrificial pastures, fertilizer application, seeding to improve forage quality).

Operation and Maintenance Considerations

Operation of a rotational grazing system involves implementation of the grazing and pasture management plans previously described. If temporary fence and watering facilities are used, they are typically setup in advance based on the next week's planned pasture grazing area. Operator needs to make adjustments to the plans based on regular evaluation of grazing monitoring records to ensure efforts are progressing toward the defined goals.

Legal/Permit Requirements

Local laws must be followed when controlling noxious weeds and using seed from the correct distributors. If it is preferred to manage cool-season grasses via burning, a permit must be obtained. Contact the local farm service agency, NRCS office, or conservation district for assistance with planning, regulations, and meeting EQIP requirements.

Local/Regional Requirements Design Example

The Land Stewardship Project documented using a model analysis, significant water quality benefits when a managed year-round cover scenario, which including rotational grazing, was used on working farms to replace intensive row cropping (Boody & Krinka, 2001). In that scenario the Chippewa Study Area of the Minnesota River Basin identified water quality improvements with a 49% sediment reduction, 62% N reduction and a 75% phosphorus (P) reduction, compared to the intensive row cropping scenario.

Another modeling study completed in the Root River Watershed of Southeastern Minnesota produced similar results. Converting row crop acreage to pasture for grazing reduced sediment and P losses at least 85% on targeted areas, especially those with steeper slopes greater than 4% (Wilson et al., 2014).

The Land Stewardship Project website lists many examples of prescribed grazing practices throughout Minnesota where farmers explain the benefits of switching to rotational grazing systems.

Research Gaps

While prescribed grazing has been implemented in many areas around Minnesota, there is still limited research on its measureable impacts on water quality.

More also needs to be understood on how grazing could be used in association with the new Minnesota buffer regulations. Research could guide managers on how and when to graze buffer vegetation to prevent fall nutrient release into water systems from decomposing vegetation.

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Links

MDA Rotational Grazing Practices Website. www.mda.state.mn.us/protecting/conservation/practices/grazing.aspx

MDA Rotational Grazing Informational Website www.mda.state.mn.us/animals/grazing.aspx

NRCS Conservation Practice Standard, Prescribed Grazing, Code 528. efotg.sc.egov.usda.gov/references/public/MN/528mn.pdf

Land Stewardship Project Fact Sheet #3, Grass-Based Beef and Dairy Production – *This innovative system is economically viable and good for the environment*, Updated April 2008. www.landstewardshipproject.org/pdf/factsheets/3_grass_2008.pdf

Land Stewardship Project Fact Sheet #7, How Farms Can Improve Water Quality – Minnesota studies show how working farmland can have a positive impact on water resources, Updated April 2008. www.landstewardshipproject.org/pdf/factsheets/3_grass_2008.pdf

Green Lands to Blue Waters, 2015, Integrating Livestock, Continuous Living Cover Series factsheet greenlandsbluewaters.net/Integrating_Livestock_2015.pdf

Controlling: **Prescribed Grazing**

Streambank and Shoreline Protection (580)

Streambank stabilization project along Elm Creek in Martin County, Minnesota. (Photo by Britta Suppes).

Definition and Introduction

Streambank protection refers to both biological and structural methods of stabilizing streambanks and/or shorelines on rivers, streams, ditches, and other bodies of water. The goals of streambank and shoreline protection include preventing erosion or reducing rates to acceptable levels at key areas, maintaining adequate flow conveyance, or improving habitat, recreational opportunities and aesthetics.

Water Quality Effects

Streambank erosion can contribute substantially to sediment load in rivers (Zaimes et al., 2008; Lenhart et al., 2013; Neal & Anders, 2015), particularly in watersheds with high entrenched or unstable streambanks. Rivers with highly erodible soil materials are particularly prone to erosion as well as stream banks with low vegetation cover.

Gran et al. (2011) estimated that 8% of TSS in the LeSueur River watershed was attributable to channel widening and floodplains, with the majority from channel widening. However, Wilcock et al. (2009) found that only about 4% of TSS could be attributed to net erosion of streambanks in that watershed. Most of the sediment came from large bluffs bordering the river.

A stream protection project along Elm Creek in southern Minnesota combined with floodplain reconnection of a channelized section reduced total sediment loading by an estimated 500-2000 tons per year between 2008-2011 (Lenhart et al., 2010).

The primary benefit of streambank stabilization is reduced erosion and phosphorus (P) loading. It is common to estimate the water quality benefit by estimating the volume voided over a period of time, calculating the mass of soil voided per year based on soil type (i.e., bulk density). This approach is used in eLink (BWSR, 2012) and it represents a reasonable approach for relatively short-term (~10 yrs) estimates of water quality benefit. After enough time, depending on individual site characteristics and hydrology, areas of erosion tend to self heal and stabilize.

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A water quality benefit in terms of reduced sediment concentrations (i.e., turbidity) will be realized but that reduction is difficult to quantify since it depends on the particle size distribution of the soil, mass lost at any given point in time and the hydraulic characteristics of the water body at that time.

For streambank erosion control, grasses have been found to have the greatest benefit on small stream banks due to their dense root network (Trimble, 1997). However, on larger, erodible streambanks, trees play a critical role during large flow events as they have larger diameter roots at depths greater than 12 inches (Rood et al., 2015).

The Bank Erosion Hazard Index (BEHI) is one tool that can be used to estimate the benefit of streambank stabilization projects. It characterizes the types of streambanks in terms of bank heights, slope and soil type that would receive the most benefit from streambank protection (Lenhart & Nieber, 2015). Project benefits can be calculated comparing pre- and post-project annual streambank erosion rates.

Key Design/Implementation Considerations

NRCS' Stream Restoration Design Manual (USDA NRCS, 2011) is an extremely comprehensive manual detailing site assessment, planning, design, construction and operations and maintenance.

For riprap design methods, the reader should additionally consult NRCS (1989).

In the last two decades, emphasis has been placed on natural approaches to streambank protection. This involves first understanding the root cause of any bank instability problem and then attempting to find a solution that is natural in form and function, with vegetation and bioengineering being preferred approaches (Minnesota DNR, 2010).

A decision regarding so-called natural approaches or structural approaches should be made given site specific data in consultation with a qualified design professional. Shields et al. (1995), in a comparison of vegetated, vegetated with toe protection, and hard armor, concluded that providing toe protection might be the most efficient solution when channels are no longer actively downsizing.

Cost Information

EQIP payment rates for streambank protection vary depending on specific stabilization method. Factors to consider when estimating the cost of streambank protection installation include accessibility to the site, any demolition or removal that might be necessary, and filter material (geotextile or gravel) required. Proximity to quarries given the desired quality of rock will also influence the cost.

- **Riprap**: Riprap reimbursement is $7.99/sf according to NRCS (2017).
- **Cable Concrete or precast concrete block:** $118.45/linear foot.
- **Vegetation**: See Riparian and Channel Vegetation chapter, NRCS Practices 390 and 391.
- **Stream barb**: $98.62/cubic yard (cy).
- **Structural toewood with vegetation:** 99.64/linear foot.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or installation of streambank and shoreline protection practices may be eligible when used for soil erosion control and stabilization for natural or man-made waterbodies. To be eligible, the project must provide water quality benefits not just protection of adjacent structures and fixtures. Eligible cost include expenses such as design, site preparation, excavation, landscaping, stabilization structures and devices, exclusionary fencing, initial seeding, and vegetation plantings.

Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, weed control herbicides, and practices with no water quality improvements are ineligible.

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Operation and Maintenance Considerations

Key considerations for operations and maintenance are periodic inspection for erosion and maintenance of desired vegetation species and health.

Legal/Permit Requirements

Implementation of riparian practices and vegetative buffers may be subject to a Minnesota Department of Natural Resources public waters permit (www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/index.html) and/or an NPDES construction permit from the MPCA if the project disturbs more than one acre of land.

In addition, the Minnesota Buffer Law was adopted in 2015 and requires buffer strips or alternative riparian water quality practice(s) along state public waters and publicly administered drainage ditches. The applicable watercourses and water bodies are identified on the Minnesota DNR Buffer Protection Map and implementation guidance is available on the BWSR Buffers webpage. These requirements should be considered when designing streambank stabilization or riparian vegetation practices in the applicable areas.

Local/Regional Design Examples

There are numerous examples of streambank protection throughout the state. Two Minnesota examples include:

The Middle Rice Creek Re-meander Project in Fridley, Minnesota helped restored natural sinuosity to a channelized reach and reduce downstream sediment load by an estimated 100 tons per year to Long Lake (see www.ricecreek.org).

Research Gaps

As indicated in Gran et al. (2011), the driver of changes in streambank erosion and failure is increased streamflow. More research is needed to understand how changes in hydrology affect erosion and sediment transport, particularly streambank erosion and system stability. There is little documentation on how streambank protection projects affect stream erosion rates. There are also knowledge gaps involving the relative role of seepage erosion and flowing water erosion in different settings. The role of tile drainage in accelerating bank erosion is less well-understood than for surface runoff.

Controlling: Streambank and Shoreline Protection

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Terrace (600)

A terrace is an earthen embankment, ridge or ridge-and-channel built across a slope (on the contour) to intercept runoff water and reduce soil erosion. Terraces are usually built in a series parallel to one another, with each terrace collecting excess water from the area above. Terraces can be designed to channel excess water into grass waterways or direct it underground to drainage tile and a stable outlet.

Terraces are generally used in steep-slope applications although they can be used to reduce erosion on moderate slopes as well.

Water Quality and Other Benefits

Terraces are primarily used as a method to reduce slope length to reduce field erosion and gully formation and it is widely accepted that they are effective. Although no recent studies have been done, terraces were intensively studies following the erosion control crisis of the 1930s. In a ten year study near La Crosse, Wisconsin, Hays and Bell (1949) found a 85 to 99% soil loss reduction in comparing terraced versus un-terraced fields in a paired study. It has not been shown but can be inferred that particle-bound contaminants are also reduced by terraces.

In an herbicide-focused field study in Iowa, Mickelson et al. (1998) found that terracing resulted in a small, inconsistent reduction in herbicide concentration over the five events monitored. They hypothesized that the load would have been more significantly reduced than the concentration data due to infiltration in the terrace.

Key Design/Implementation Considerations

Terraces are usually built in locations were gully erosion would form without the use of a structural BMP. They are also used to reshape the land to improve farmability. NRCS conservation practice code 600 describes the criteria for design and implementation in detail. In general, terraced systems are designed to safely pass the 10-year rainfall event.

Cost Information

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for construction of terraces may be eligible when used for soil erosion control, water retention, infiltration, or other water quality benefits. Eligible cost include expenses such as design, site preparation, excavation, landscaping, stabilization structures and devices, inlets and outlets, exclusionary fencing, initial seeding, and vegetation plantings.

Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, weed control herbicides, and practices with no water quality improvements are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Component	Estimated Average Cost/ Foot	Typical Units Installed	Estimated Total Installation Cost (rounded)
Grassed backslope	$5.27	1,500	$7,900
Narrow base greater than 8%	$6.59	1,500	$9,880
Narrow base 8% or less	$4.28	1,500	$6,420
Graded, broadbase, less than 1.5ft average height	$1.99	1,500	$2,980
Graded, broadbase, greater than or equal to 1.5ft average height	$4.91	1,500	$7,360
Graded, narrow base or grass backslope	$1.55	1,500	$2,320
Terrace rehab	$1.53	1,500	$2,300

Operation and Maintenance Considerations

Operation and maintenance should be considered when designing and installing terraces. The NRCS practice standard requires that an operation and maintenance plan shall be prepared for terraces and lists the minimum requirements as:

- Provide periodic inspections, especially immediately following storms with a 10-year or greater return frequency.
- Promptly repair or replace damaged components as necessary.
- Maintain terrace capacity, ridge height, and outlet elevations.
- Remove sediment that has built up in the terrace to maintain a positive channel grade.
- Each inlet for underground outlets must be kept clean and sediment buildup redistributed so that the inlet is in the lowest place. Inlets damaged or cut off by farm machinery must be replaced or repaired immediately.
- Vegetation shall be maintained and trees and brush controlled by chemical or mechanical means.
- Keep machinery away from steep back sloped terraces. Keep equipment operators informed of all potential hazards.

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Controlling: **Terrace**

Two-Stage Ditch (Open Channel) 582)

Two-stage ditch in Mower County, Minnesota. (Photo by Lori Krider)

Definition and Introduction

The extensive artificial drainage network in Minnesota traces its beginnings back to statehood in 1858, in which the state legislature passed its first drainage act (Wilson, 2000). Since that time, thousands of miles of drain tiled and ditches have been constructed to provide soil conditions more suitable for production of row crops. According to the Minnesota Department of Natural Resources (DNR), there are approximately 21,000 miles of channelized streams and ditches in the state (Minnesota DNR, 1980). Of these 21,000 miles, about 17,000 miles are public drainage ditches, which are administered according to Minnesota Statute 103E (Minnesota Board of Soil and Water Resources, 2006). These estimates do not include the numerous ditches governed by private drainage agreements, tile mains in public systems, or private tile that feed public systems.

A two-stage ditch is an alternative to the traditional trapezoidal drainage ditch design that improves stability and ecosystem function. The NRCS design specifications are contained within the Open Channel Practice (582). The two-stage ditch contains an inset channel at the bottom that conveys the channel forming flow and floodplain benches on either side that accommodate less frequent, high-discharge events (Figure 1). The objective of the two-stage ditch is to mimic the form and function of natural systems. Most drainage ditches in Minnesota were designed based on threshold (critical velocity or shear stress) methods at a prescribed flood frequency. These channels are typically over-widened for low flow, meaning that during low flow, there is insufficient velocity to keep the sediment in suspension or saltation (Christner et al., 2004). This results in deposition, which necessitates costly ditch maintenance and clean-out (Jayakaran & Ward, 2007).

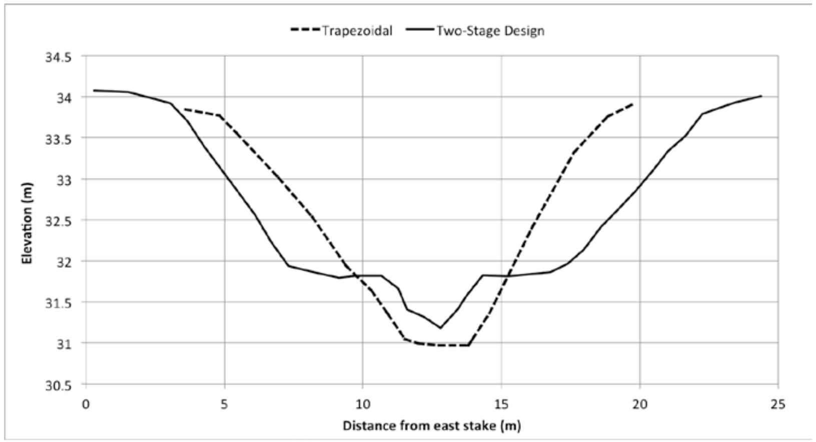

Figure 1. A Typical Conventional (Dashed Line) Drainage Ditch Cross-Section and a Two-Stage Drainage Ditch Cross-Section (Solid Line). Two-stage ditch features are noted in italics (Krider et al., 2016a).

The two stage ditch is termed a self-sustaining design since the low flow inset channel is designed to prevent aggradation or erosion over a sufficiently long-period of time. The low flow channel conveys what is termed the channel forming discharge (~1–1.5 year return period), while the floodplain bench conveys the flood discharge (~ 10 – 50 year return period). The narrow width of the low flow channel allows higher velocities compared to the bottom of the trapezoidal ditch, providing continuous flushing of fine sediment. The side slopes of the ditch are protected from the low flow channel by the floodplain benches, thus preventing undercutting at the toe slope and further bank slope sloughing, indicative of channel instability (Ward et al., 2004). After deposited sediment is removed, the channel will evolve over time to produce its most stable shape, similar to a two-stage system (Hansen et al., 2006, Simon & Hupp, 1986).

Water Quality and Other Benefits

Two stage ditches provide numerous water quality benefits by creating a bench and low flow channel, the design mimics the sediment transport characteristics of natural streams, promoting deposition on the benches and transport of fine sediment in the low flow channel (Powell et al., 2007a). They also support the removal of nitrate-N by denitrification on the benches by increased residence time (Roley et al., 2012). Here, the water comes into direct contact with vegetation, denitrifying soil bacteria and organic matter which is needed for denitrification. Roley et al. (2012) found that when the floodplain was (naturally) inundated for 29 days of the year, it contributed 12% of total nitrate removal and when the floodplain was inundated for 132 days, it contributed 47% of total nitrate removal. The floodplain benches provide also increased area for riparian vegetation to establish, although invasive and noxious species such as smooth brome, wild parsnip, sweet clover, giant ragweed,

stinging nettle are common. Two-stage ditches have benches that support more than twice the amount of biomass compared to the slopes of the traditional drainage ditch (Powell & Bouchard, 2010).

Two-stage ditches can also enhance in-stream habitat for fish and invertebrates by creating a deeper channel at low-flow with a greater variety of depth, velocity, and bed materials. This is thought to create conditions more suitable for the survival needs of stream fish and invertebrates, by reduced sedimentation, increased thermal refugia by shade and deep pools, and increased cover from predators (Krider et al., 2017; Lau et al., 2006). Two-stage ditches allow for the natural sorting of sediment particles with pools of more cohesive soils and riffles of larger sediment, including gravel, which serves as habitat for invertebrate species (Krider et al., 2017).

Two stage ditches also reduce downstream sediment loading. This reduction occurs because the banks are more stable. Undercutting and gravity-driven bank failures are then less frequent, removing ditch instability as a source of sediment to the stream. Over many years two-stage ditches reduce maintenance costs associated with dredging to clean out accumulated sediment. However construction costs are greater in building the generally larger two-stage ditches, and farmland is removed from production. The effectiveness of the ditches to remove nitrogen (N) for cold water of spring runoff has not been established.

Key Design/Implementation Considerations

Design Considerations:

Two-stage ditches are typically sited at watershed scales of two to eight square miles. For Ohio and Indiana projects, the drainage area ranged from 7-13km^2 (2.7-5.0 miles) (Kallio et al., 2010). If they treat smaller areas they are not cost-effective and larger areas cannot effectively treat the larger streamflow volume although they would still accomplish more treatment than a traditional ditch.

It could be argued that as the drainage area increases, the two stage ditch actually provides greater bank stability benefit.

Design specifications attempt to minimize excavation costs and reduce the land loss of adjacent agricultural fields as well as provide maximum stability to the system. A low-flow channel is generally sized to replicate that of natural channels of the surrounding region. This size can be obtained using regional hydraulic geometry curves developed for a similar drainage area, soils, topography, and climate (Kramer, 2011; Krider et al., 2017). If the two-stage ditch is used to replace an existing ditch that have naturally developed benches over time, the observable features of these benches can also be used to size the low-flow channels. The ratio of 3:1 to 5:1 flood width to low-flow channel width is recommended (Ward et al., 2004; Powell et al., 2007a and 2007b). The outside ditch bank slope can typically be designed at 2:1, depending on soil type (Krider et al., 2017). The top width of the ditch can vary to accommodate the benches and channel as well as provide the 2:1 outside bank slope (Krider et al., 2017). Areas of the channel that are within design specification can be left intact (Krider et al., 2017).

The geometry of the low-flow channel is ultimately defined by its channel forming discharge. This discharge typically correspond to a return period event ranging between the one-year to the two-year flow. Because of the infrequent flooding of the benches, nitrate removal is dominated by processes in the low-flow channel. More recent designs, therefore, are considering how to optimize nitrate removal for flows smaller than the channel-forming discharge.

Overall conveyance capacity should be designed based on site specific goals and/or guidance to alleviate flooding, accommodate drain tiles and have stable side slopes given local conditions. Typically the top of the ditch banks are very rarely flooded, usually at greater than a 50-year flood event.

Controlling: **Two-Stage Ditch (Open Channel)**

There are other practical considerations that must be taken into account during the planning and design phases, including the following:

- A two-stage ditch may require additional land on either side of the ditch to accommodate the width of the floodplain benches, making it less feasible for many landowners.
- A hydrologic analysis should be conducted to determine downstream hydrologic impacts to ensure that neighboring landowners will have no negative impacts caused by the project.
- Construction should be planned for low-flow periods to allow equipment access when it is dry, typically during the late summer or fall season.

Unmaintained channelized ditches often naturally evolve to a two-stage channel over time (D'Ambrosio et al., 2015). More recently self-forming two stage ditches are being recommended in Ohio to minimize grading and construction costs. In these cases, a wider ditch bottom is excavated to allow for the formation of benches and a low-flow channel over years (Ohio State Extension, 2017).

Cost Information

The cost to construct a two stage ditch is primarily determined by the following key factors:

- Earthwork. The cost will be substantially reduced if excavated material can be placed onsite rather than transported. Spoil can be applied to the channel in areas where the width needs to be reduced to be within design specifications if it is compacted, seeded and protected from erosion.
- Drain tile outlets and other pipe outlets may need to be replaced if they are cut off during ditch excavation.
- Additional land. If the channel is widened, additional land area may be required, possibly removing some land from production.
- Crop damage. If construction impacts agricultural fields during the growing season the project may be required to pay for any damage to crops.
- Erosion control. Erosion control measures such as geotextile fabric over exposed soil and rip-rap at tile and side inlet outlets may be required after construction.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for land purchases, easements, or installation of two-stage ditch practices may be eligible when used for soil erosion control, stabilization, and downstream water quality benefits. To be eligible, the project must provide water quality benefits not just drainage of fields. Eligible cost include expenses such as design, site preparation, excavation, landscaping, stabilization structures and devices, exclusionary fencing, initial seeding, and vegetation plantings.

Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, weed control herbicides, and practices with no water quality improvements are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Component	Estimated Average Cost/Foot	Typical Units Installed	Estimated Total Installation Cost (rounded)
Two stage ditch	$10.58	1,000	$10,580

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Operation and Maintenance Considerations

Since the basic premise of the two-stage ditch is to create a self-sustaining system, there is expected to be little in the way of operation or maintenance once the ditch reaches equilibrium and vegetation is established. Other features within or adjacent to the ditch may still need to be maintained, including culverts, field road crossings, tile inlets, and side inlets. Excessive woody vegetation along the low flow channel (willows) may be removed if desired as well as beaver dams. Dams or other obstructions within the low flow channel, which divert flow, can create a need for localized repair or maintenance.

Legal/Permit Requirements

Two stage ditches are usually constructed in conjunction with regular ditch maintenance activities or occasionally with development projects (Blue Earth County).

Ditch Improvement - On public drainage systems, modification of a drainage ditch to a two-stage system would likely be an improvement since the conveyance is increased. Therefore, the project must follow Minnesota Statute 103E.215.

A Minnesota Pollution Control Agency - Construction Stormwater Permit: may be required if disturbances are equal to or greater than one acre or if construction may pose a risk to water resources

A Minnesota DNR - Public Waters Permit: may be required if the ditch is a public water.

A U.S. Army Corps of Engineers - Section 404 Permit: required when there are impacts to larger, navigable waters that fall in their jurisdiction, or when there are impacts to wetlands.

Local/Regional Design Examples

Mower County

The site is located in Mower County, Minnesota (Figure 2), located in the Western Lake section of the Central Lowland physiographic province. Total annual average precipitation in this region is 80 cm (31.5 inches). The watershed area is 12.6 km2 (3,102 acres). Land use is predominantly row crop agriculture, the main crops being corn and soybeans.

Construction of the 6,100-foot two-stage channel occurred in October of 2009 at a cost of $197,000. The existing, privately managed, drainage ditch was in need of maintenance because of the following ditch instability issues: 1) seepage induced bank instability; 2) planar failure of ditch side slopes; 3) toe erosion; and 4) tile outlet failures (Kramer, 2011). The original ditch was constructed in the historic drainage way. The design and planning are described in Peterson et al. (2010) and Kramer (2011).

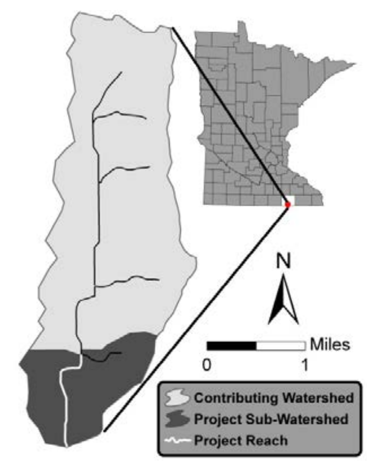

Figure 2. Location of Mullenbach Ditch in Mower County, Minnesota (Kramer, 2011).

Water quality probes allowed for the collection of numerous samples of nitrate concentrations from 2009 through 2013. More than 100 nitrate concentrations were measured from the tile lines, more than 150 concentrations were gathered from the groundwater wells and other surface water sites, and more than 60,000 concentrations were collected from flows above and within the two-stage ditch channel. The two-stage retrofit was estimated to remove between 14 - 34% percent of nitrate within the channel at any given time during the summer months as well as 19 - 23% in the riparian areas along the bench (Kramer, 2011). Difficulties are associated with the quantification of groundwater fluxes between the channel and the adjacent water table.

Pre-construction and numerous post-construction longitudinal and cross sectional surveys concluded it also greatly improved the stability of the ditch as shown by the Pfankuch ("good" overall stability score) and BEHI ("low" bank erosion hazard index score) analyses in 2013 (Krider et al., 2016a). Additionally, there was a 12-fold increase in pool-riffle sequences (from five to 68) by 2013 (Krider et al, 2016a). Although there was a significant increase in the number of fish species from 2009 to 2011 (574 to 1050) the difference was not significant between 2009 and 2013 (574 to 367) due to a lack of insufficient base flow due to summer droughts (Krider et al, 2016b). There was also a significant increase in fish IBI from 2009 to 2013 at one site within the retrofit (38 to 56) but not at the other site within the retrofit (50 to 53) (Krider et al, 2016b). However, four new fish species were collected at the Mullenbach post-construction (Krider et al, 2016b).

Lake of the Woods County

A number of two-stage ditches have been completed in Minnesota in the past 5-10 years. There was documentation of construction success and post-project monitoring for vegetation establishment but there are few estimates of nutrient and sediment load reduction benefits from the projects as described below.

Lake of the Woods SWCD

In Lake of the Woods County, a two-stage ditch was completed on JD-28 in Lake of the Woods County in 2009 called the Bostic and Zippel Creeks Watershed Assessment Project, with funding from Minnesota BWSR. Post-project hydrologic and water-quality monitoring was done but no data has been published. The project was thought to have reduced sediment loading to the Lake of the Woods by reducing channel erosion from the ditch. See http://www.bwsr.state.mn.us/projects/lakeofthewoods.pdf.

Buffalo Red Watershed District

Two lateral ditches in the Whisky Creek ditch system near Barnesville, Minnesota were reconstructed using a two-stage ditch approach in 2004-2005. The two lateral ditches were rebuilt with a wider bottom, flatter side slopes, and a sinuous pilot channel. A second two-stage channel was created when a set-back levee system was installed along a sinuous watercourse called Deerhorn Creek. The projects were successfully installed and functioning as designed though no data on sediment or nutrient removal is available. More recently, the BRWD completed a one-mile-long, two-stage ditch on Whiskey Creek in partnership with Wilkin County. A two-stage channel using natural-channel design was established with a permanent riparian buffer easement and side inlets for sediment control alongside the channel at a cost of $60,000.

Two Rivers Watershed District

A two-stage ditch was constructed in the Two Rivers Watershed District in Spring Brook Township. In this case, the ditch was a high-maintenance system with associated road damage. The ditch was reconfigured with a wider bottom and an inset channel was excavated in the improved ditch bottom. Since construction, maintenance has been required to establish vegetation and repair some areas due to washouts, though no data on sediment or nutrient removal is available. More information is available here: http://files.dnr.state.mn.us/publications/ecological_services/healthy_rivers_color_background.pdf.

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Wild Rice Watershed District

Several miles of a ditch system were filled in and a new meandering channel was designed replacing the old system with at least 300 feet of permanent vegetative cover on each side of the meander belt in 2002. Known as the Dalen Coulee project, it is described in more detail at this link: http://files.dnr.state.mn.us/publications/ecological_services/healthy_rivers_color_background.pdf.

Numerous two-stage ditches have been built in Indiana and Ohio as well (see link below to video made by The Nature Conservancy in conjunction with professors from Notre Dame and The Ohio State University).

Research Gaps

Based on a review of the literature the following research gaps have been identified:

- The engineering design aspects of the two stage ditch have been studied extensively. A key question still remaining is how two-stage ditches impact downstream flows. No negative impact has been reported in the literature. Culverts and other impediments can be used to reduce downstream impacts but they would increase the cost of the BMP. It is unclear if these features are necessary.
- Vegetation in drainage ditches is a key component, helping to stabilize the soil from erosion and aiding in the nutrient uptake process. Invasive species are a continuous issue for water conveyance systems and seeding can have a variable effect. There is not presently an adequate strategy for establishing and maintaining a native vegetation that addresses stability, water quality, and habitat goals.
- One goal of the two-stage ditch is to maintain a balance of aggradation and degradation over some long period of time. It is understood that in some years there may be net deposition and in other years net degradation. It is not clear over what time frame a net zero is expected.
- A topic for consideration for the Drainage Work Group, or other policy group, is the expansion of the definition of the one rod buffer requirement on public drainage systems to include the floodplain bench and flood flow side slope when a two stage ditch is constructed/retrofitted. Doing so would reduce the cost of the two stage ditch considerably.
- One of the key benefits of the two-stage ditch often cited is increased habitat. While two-stage ditches likely improve in-stream conditions for fish and invertebrates (Smiley et al., 2008), there is no conclusive supporting data to suggest that the retrofit will consistently and significantly improve the quality of aquatic life.

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Feedlot Runoff Control
Feedlot/Wastewater Filter Strip (635) and Clean Runoff Water Diversion (362)

Definition and Introduction

Feedlot runoff control is a system of structures and practices that reduce runoff and protect water bodies from nutrients and bacteria. The system is composed of collection, storage, and treatment of livestock manure and feed waste as well as diversion of clean runoff water away from the feed lot area. The system also helps to conserve nutrient-rich manure and enhance livestock health as part of a complete runoff control system that results in clean, dry lots. Best management practices focused on in this section are feedlot/wastewater filter strips and clean runoff water diversions. Manure and agricultural waste storage has a dedicated section in this handbook.

Clean runoff water diversion involves a channel constructed across the slope to prevent rainwater from entering the feedlot area or the farmstead to reduce water pollution.

Feedlot/wastewater filter strips are a strip or area of vegetation that receive and reduce sediment, nutrients, and pathogens in discharge from a setting basin or the feedlot itself. In Minnesota, there are five levels of runoff control, with Level 1 being the strictest and for the largest operation (>1,000 animal units). Levels 2 to 5 involve runoff treatment systems where runoff is treated by a strip of permanent herbaceous vegetation.

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Water Quality and Other Benefits

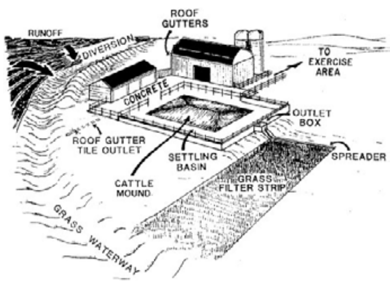

Figure 1. Typical livestock-lot runoff-management system. Adapted from Barnyard Runoff Management, Wisconsin Department of Natural Resources and Department of Agriculture, Trade and Consumer Protection, 1987. Adapted by Leonard Massie, with graphic assistance by Andy Hopfensperger, University of Wisconsin-Madison, Department of Agricultural Engineering.

Installing drip trenches or roof gutters on the livestock building divert rain water around the lot and reduce the volume of runoff from the feedlot. It can also reduce the size of a holding pond or settling basin constructed for manure treatment.

An earthen ridge, terrace, or channel can be constructed across the slope upgrade from the livestock lot or the farmstead to divert clean runoff (see Figure 1). The commonly used earthen channels are grassed waterways with a roughly trapezoidal cross section (University of Illinois Extension, www.wq.illinois.edu/dg/grass.htm). If a diversion terrace is not practical, building a catch basin with a tile outlet above the livestock lot may be an option (University of Missouri Extension, extension.missouri.edu/p/G1504).

Wastewater filter strips reduce runoff, sediments, and contaminants by settling of sediment, infiltration, and dilution (Schmitt et al., 1999). Most sediments settle upgradient of where the filter strip vegetation meets the contributing area (see Figure 2).

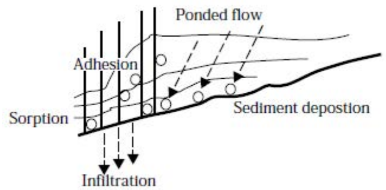

Figure 2. Trapping mechanisms of contaminants in filter strips (USDA)

Sediment is reduced in runoff at much greater extent than dissolved contaminants and reductions of dissolved contaminants are closely related to infiltration (Helmers et al., 2008).

A two year study of filter strips installed on a 4% slope adjacent to a feedlot with 310 head of cattle in west central Minnesota found that 36m (118 ft.) was adequate in treating both nutrients and microorganisms in feedlot runoff from a feedlot of this scale. In this study, the filter strip reduced runoff volume by 67% and total solids by 79%. Total N and P were reduced on average by 84% and 83%, respectively. Both NO_3- N and PO_4- P were reduced an average of 93%. The concentration of NO_3-N in runoff increased; however, due to NO_3-N contribution from the sorghum-sudangrass and the oat buffer strips (Young et al., 1980).

For more information on sediment and contaminant removal by filter strips or buffers in general can be found under the Filter Strips and Contour Buffer Strips sections.

Key Design/Implementation Considerations

Clean Runoff Water Diversion

The USDA NRCS standard (code 362) recommends for this practice (USDA NRCS, 2010):

- A minimum capacity of diversions designed for animal waste management systems shall be for peak discharge from a storm frequency consistent with the hazard involved but not less than a 25-year return period, 24-hour duration storm. Freeboard has to be not less than 0.3 feet.
- Front slopes, back slopes, and cut slopes for farmed diversion should be 5:1 or flatter and designed to fit farm equipment.
- Diversions shall be vegetated according to USDA NRCS Conservation Practice Standard Critical Area Planting (342).

Feedlot/Wastewater Filter Strip

For all levels of control (Levels 2-5), manure solids are settled out and separated from manure liquids prior to the release of the liquids to wastewater filter strips. Filter strips perform well with uniform sheet flows. Gravel beds and woodchip beds constructed across the flow direction can retard and spread flow as well as improving the removal and maintenance.

Each level of control has specific design requirements. In general, the required filtering area increases with the amount of load. The age of vegetation also influences the infiltration capacity and older vegetation seems to have better filtration capacity, consequently improving the removal of soluble contaminants (Schmitt et al., 1999; Udawatta et al., 2002).

The USDA NRCS standard (code 635) recommend for this practice (USDA NRCS, 2009):

- Multiple wastewater filter strips should be established to allow for resting, harvesting vegetation, maintenance, and to minimize the possibility of overloading.
- Use both warm and cool season species in separate areas to ensure the maximum growth and nutrient removal throughout the year.
- Employ inlet control structure to avoid undesirable debris to enter filter strips and to control the rate of inflow.
- Consider storing seasonal wastewater and suspending the application to vegetation during the excessively wet or cold climatic conditions (Soil Temperature < 39°F). When soil temperature is between 39°F and 50°F, application rate should be reduced accordingly.
- Effluent from filter strips can be stored and used for land application or recycled through the wastewater management system.

Cost Information

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or on-site structures and fixtures may be eligible when implementing feedlot runoff control practices that results in water quality benefits. Eligible cost include expenses such as site assessment, design, site preparation, excavation, concrete, roofs, gutters, pumps, conveyances, manure handling and application equipment, landscaping, fencing, treatment systems, storage systems, initial seeding and vegetation plantings.

Typical operation and maintenance expenses such as repairs, fuel for management activities, and practices with no water quality improvements are ineligible.

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Controlling: **Feedlot Runoff Control**

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Component	Estimated Average Cost/Unit	Typical Units Installed	Estimated Total Installation Cost (rounded)
Vegetated treatment area (VTA) downslope from collection point, Fill Present on Site	$0.30/Square Foot	9,000	$2,720
VTA downslope from collection point, Haul in Fill	$0.43/Square Foot	9,000	$3,900
Wastewater pumped uphill to basin with gravity outflow to VTA	$0.70/Square Foot	15,000	$10,540
Mechanical distribution	$9,950.00/Acre	1	$9,950
Earthen	$2.98/Foot	500	$1,490
Reinforced concrete curb with footer	$30.80/Foot	50	$1,540
Reinforced concrete curb, doweled into slab	$9.40/Foot	100	$940
Reinforced concrete channel, flat slab	$89.40/Foot	100	$8,940

Feedlot Runoff Control

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or on-site structures and fixtures may be eligible when implementing feedlot runoff control practices that results in water quality benefits. Eligible cost include expenses such as site assessment, design, site preparation, excavation, concrete, roofs, gutters, pumps, conveyances, manure handling and application equipment, landscaping, fencing, treatment systems, storage systems, initial seeding and vegetation plantings.

Typical operation and maintenance expenses such as repairs, fuel for management activities, and practices with no water quality improvements are ineligible.

Operation and Maintenance Considerations

Clean Runoff Water Diversion

The USDA NRCS standard (code 362) recommends for this practice (USDA NRCS, 2010):

- Periodically inspect, especially after significant storms.
- Maintain diversion capacity, ridge height, and outlet elevations. Routinely clean high sediment yielding area in the drainage.
- Maintain vegetation by hand, chemical and/or mechanical means. Avoid disturbing the area during the nesting season for grassland birds.

Feedlot/Wastewater Filter Strip

Maintenance of the system is as important to maximize water quality effects to keep the proper density and continuity of the buffer (Helmers et al., 2008).

The USDA NRCS standard (code 635) recommends for this practice (USDA NRCS, 2009):

- Inspect and repair treatment strips after storm events to fill in gullies, remove sediment accumulation, re-seed disturbed areas, and take other measures to avoid concentrated flow.
- Periodically grade when deposition is accumulated, and then re-establish the vegetation.
- Periodically de-thatch and/or aerate treatment strips in order to promote aeration.
- Conduct maintenance activities only when the vegetation is dry and moisture content of the surface soil layer will not allow compaction.
- Prevent grazing in wastewater filter strips.

Additional maintenance recommendations by USDA (1999):

- Routinely mow to encourage vigorous sod of filtering vegetation. If the filter strip is removing bacteria or other pathogens, mowing encourages sunlight and air movement to desiccate the entrapped pathogens.
- Routinely weed to maintain the designed width and density of filter strips.

Research Gaps

Little research was found that pertains specifically to clean runoff water diversions. For wastewater filter strips, the coliform reduction efficiency varies case by case and the reason for the variability is not clear. Additional research may be necessary to discover the source of the variability and improve the performance of filter strips.

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Links

USDA NRCS Conservation Practice Standard, Diversion, Code 362
efotg.sc.egov.usda.gov/references/public/MN/362mn.pdf

USDA NRCS Conservation Practice Standard, Vegetated Treatment Area, Code 635
efotg.sc.egov.usda.gov/references/public/MN/635mn.pdf

MDA Conservation Practices Minnesota Conservation Funding Guide, Feedlot Runoff Control System
www.mda.state.mn.us/protecting/conservation/practices/feedlotrunoff.aspx

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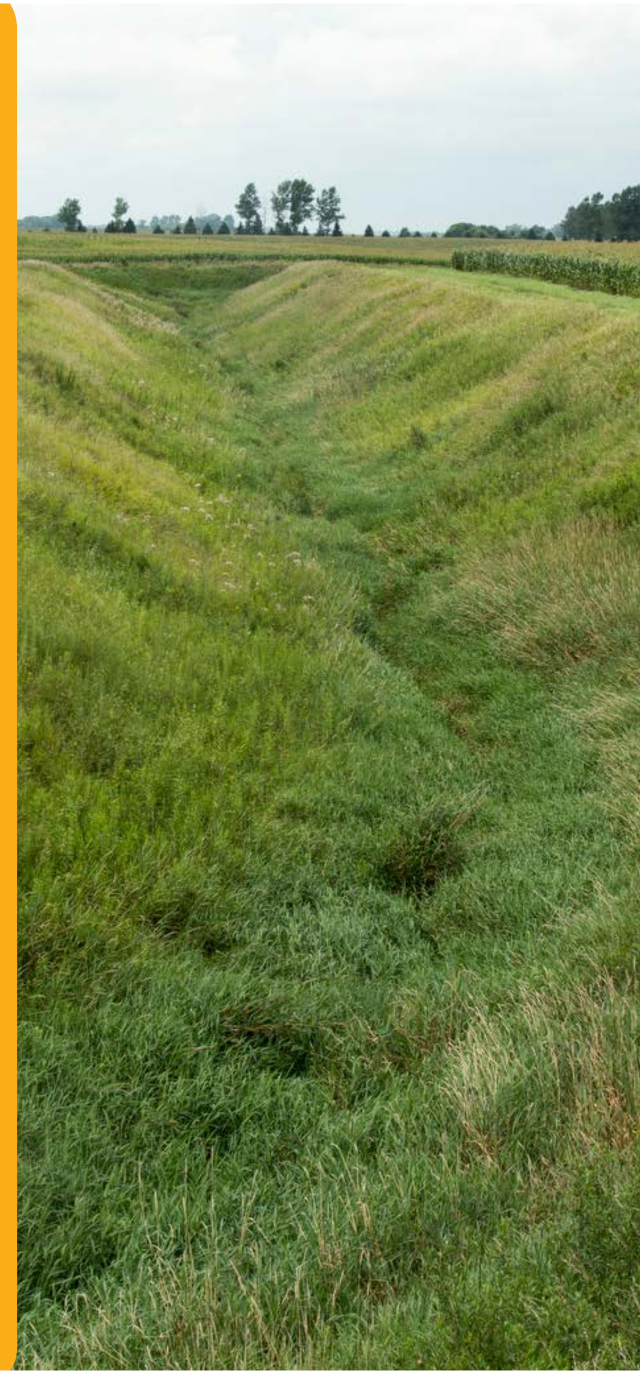
Agricultural BMPs: **Trapping**



Field Borders (386) and Filter Strips (393)

Photo above left: Field border alongside a cornfield (Photo by Nathan Utt). Photo above right: 16 foot filter strip alongside a drainage ditch. (Photo by David Hansen)

Definition and Introduction

Filter strips are an area of vegetation planted between fields and surface waters to reduce sediment, organics, nutrients, pesticides, and other contaminants in runoff. Filter strips are one of the common BMPs used on farms state-wide and is considered by the NRCS as part of the "Core 4" practices that have conservation impact and can be implemented on almost every farm.

Field borders are strips or bands of permanent vegetation established at the edge of or around the perimeter of a cropland field. Field borders and filter strips are summarized together in this chapter because their purpose and design criteria are similar and both established with permanent herbaceous vegetation consisting of a single species or mixture of grasses, legumes and/or other forbs. Both practices, following the appropriate width requirement, could be implemented to be in compliance with the Minnesota buffer law.

Field borders can be used to connect other buffers such as grassed waterways, filter strips, and contour buffer strips providing easy access for maintenance or harvest purpose. Field borders can be strategically located to eliminate sloping end rows, headlands, and other areas which are prone to erosion.

Water Quality and Other Benefits

Field Border

Field borders protect soil from wind and water erosion, reducing deposits of nutrients that are strongly bounded to sediments such as phosphorus. There is little data showing percent erosion reduction or contaminant removal specifically by field borders; however, research on nutrient removal by buffers generally applies to field borders and the nutrient removal benefits of buffers are fairly well established.

Filter Strips

Filter strips reduce runoff, sediments, and contaminants by settling of sediment, infiltration,

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and filtration (Schmitt et al., 1999). Most sediments settle up-gradient of where the filter strip vegetation meets the contributing area (Jin & Romkens, 2001).

Filter strip effectively reduce runoff volume and sediments. Total phosphorus and some insecticides such as Permethrin and Chlorpyrifos are strongly bound to sediments and similarly reduced as sediments (Figures 1 – 3). However, total phosphorus tends to bound with fine particles such as silt and clay, which take longer time to settle than larger sediments, and its reduction is usually less than the total sediment reduction. Dissolved contaminants such as total nitrogen (N), total dissolved P, atrazine, and alachlor (commonly used herbicides) are weakly bound to sediments and its reduction is associated more with infiltration. The reduction of these dissolved contaminants is usually much less than sediment bound P. Reduction efficiencies of both sediment bound and dissolved contaminants increase with width of the filter strip (Figures 1 – 3) (Blanco-Canqui et al., 2004; Helmers et al., 2008; Schmitt et al., 1999).

Recommended width for filter strips depends on sediment load, size, and slope of contributing area. As noted above, filter strips have to be wider to remove finer particles. A Nebraska study by Schmitt et al. (1999) found that doubling width from 7.5 m to 15 m significantly increased infiltration and dilution of runoff; improving the reduction of nitrate + nitrite N from 23 to 38%, and total dissolved P from 24 to 39%. Although TSS was reduced the greatest of any contaminant, it showed the least removal increases (from 77 to 83%) with more width since it is removed via particulate settling. Volume of outflow was also reduced significantly with increased width through infiltration, contributing to the reduction of contaminant masses.

The effects of field length and crop-management factors upstream of filter stips as well as slope, soil texture and pollutant type (sediment vs. dissolved) on pollutant removal are summarized in Figure 1. Using the Vegetated Filter Strip (VFS) model trapping efficiencies are summarized for different conditions represented by Lines 1 thru 7 in Figure 1 (Bentrup, 2008).

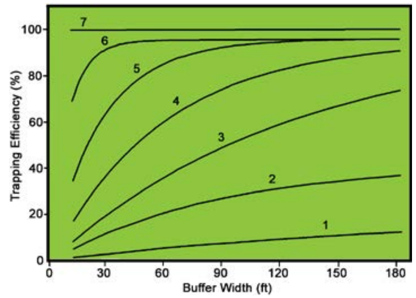

Table A - Conditions Corresponding to Each Line in the Graph

Line Number	Field Length (feet)	C-Factor[1]	Slope (%)	Soil Texture[2]	Pollutant Type
7	650	0.5	2	FSL	Sediment
6	650	0.15	2	SiCL	Sediment
5	650	0.5	2	SiCL	Sediment
4	1300	0.5	2	SiCL	Sediment
3	1300	0.5	2	FSL	Dissolved
2	650	0.5	10	SiCL	Sediment
1	1300	0.5	2	SiCL	Dissolved

1. C-Factor of 0.5 represents plowed and disked row crops with moderate residue returned to the soil surface. C-Factor of 0.15 represents conservation tillage and and no-till with high residue returned to the soil. C-Factor values for other soil cover management conditions can be found on the next page.

2. FSL = Fine Sandy Loam; SiCL = Silty Clay Loam

Figure 1. Trapping efficiency of filter strips predicted by the vegetated filter strip (VFS) model under different soil conditions, slopes and cropping factors.

Two synthesis reports on filter strips or buffer pollutant removal studies, EOR, Inc. (2001) and Ma et al. (2008), were summarized by Nieber et al. (2011) for the Minnesota Department of Transportation. Both studies and the combined graph are shown in Figures 2 and 3. TSS removal in filter strips was much higher than phosphorus, ranging from 65 to 100% across the studies. Phosphorus removal was lower on average ranging from 30% to 84% in the studies synthesis.

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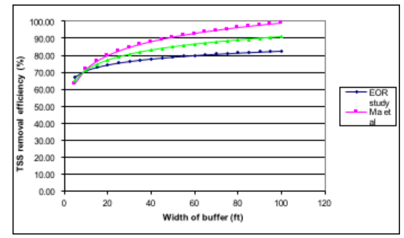

Figure 2. TSS removal by buffer width (Nieber et al., 2011)

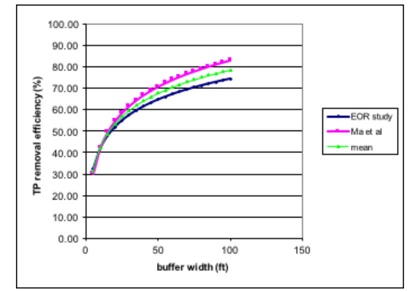

Figure 3. Total Phosphorus removal by buffer width (Nieber et al., 2011)

Table 1. Pollutant reduction estimates in percent for filter strips

Pollutant	Mean	Minimum	Maximum	Number of Entries	Source
Sediment	86	76	91	6	1
Total Phosphorus	65	38	96	4	2, 3
Nitrogen	27	27	27	1	3
Atrazine	58	45	71	6	1
Metolachlor	72	68	78	6	1
Cyanazine	69	59	77	6	1

1 – Arora et al., 1996 2 – Webber et al., 2009 3 – Eghball et al., 2009

Arora et al. (1996) studied filter strip removal of pesticides and sediment in a natural rainfall study in Iowa and found good removals for all substances. Eghball et al. (2009) and Webber et al. (2009) have both studied the phosphorus removal of filter strips in Iowa under natural rainfall conditions (Table 1).

Buffers in general can remove nutrients from shallow groundwater (Helmers et al., 2008), and are particularly valuable on shallow soil (Dabney et al., 2006). Water transported in tile drainage systems beneath a filter strip bypasses the potential treatment of the strip. Kasper et al. (2007) observed no significant nitrate-N removal by gamagrass (Tripsacum dactyloides) strip fields on no-till corn-soybean plots with a tile drainage system in Iowa. They suspect that the removal might have been improved if establishment of gamagrass was longer, or the width of the strip was wider.

Bhattarai et al. (2009) found increased nitrate-N concentrations in a filter strip system (brome grass and annual rye grass) treating runoff from a feedlot with 130 cattle. In this study, subsurface drainage system was installed at a depth of 1.2 m below soil surface right underneath the filter strip. The data suggest that nitrate-N was drained out of the filter strip and possibly to receiving water. They concluded that the presence of subsurface drainage system is harmful to filter strip effectiveness and the buffer is more effective without any drainage system.

In a simulated rainfall experiment in Iowa, Arora et al. (2003) tested pesticide reduction efficiency of filter strips applying 100mg of each pesticide per kilogram

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of soil. Filter strips retained 49.7% of Atrazine, 51.2 % of Metolachlor, and 80.0% of Chlorpyrifos when the drainage area to buffer area ratio was 15:1 and 30:1.

A Wisconsin study showed that 50% of mean annual runoff occurred in February and March when ground was still frozen. Significantly high concentrations of total N and dissolved P were associated with this winter runoff. Vegetated buffers are less effective during the winter months and the alternative BMP to filter strips in winter may have to accompany filter strips to protect water quality year-round (Stuntebeck et al., 2011).

Key Design/Implementation Considerations

Field Borders

The NRCS standard (USDA NRCS 2016, code 386) recommends for this practice:

- Border Widths:
  - To the extent needed to meet the resource needs and producer objectives. Minimum field border widths shall be based on local design criteria specific to the purpose or purposes for installing the practice.
  - Enough to accommodate equipment turning, parking, loading/unloading equipment, and grain harvest operations.
  - Minimum of 30 feet for water quality objectives.
- Plant Species:
  - Adapted species of permanent grass, forbs, and/or shrubs that accomplish the design objective.
  - Permanent grass, legumes, and/or shrubs that have the physical characteristics necessary to control wind and water erosion on the field border area.
  - For shrub cover, plant a minimum of two rows.
  - No plants listed on the noxious weed list of the state.
  - Seedbed preparation, seeding rates, dates, depths, fertility requirements, and planting methods will be consistent with approved local criteria and site conditions.

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Refer to Agronomy Technical Note #31 for seeding specifications and recommendations under the practices Conservation Cover (327), Critical Area Planting (342), and Upland Wildlife Habitat Management (645).

Filter Strips

Filter strips perform well with uniform sheet flows. When the flow is concentrated in some area of strips, the concentrated flow will short-circuit the filter and inversely affect the efficiency of field strips, especially during the time of high flow rate. The combination with other buffer systems such as contour buffer strips can make the flow more evenly distributed for maximum performance (Dabney et al., 2006; Helmers et al., 2008; USDA, 1999). Other conservation measures can be used within a filter strip to improve the removal and maintenance as well (Blanco-Canqui et al., 2004). Shallow trenches and/or vegetative barriers constructed across the flow direction can retard flow and enhance infiltration and absorbance of pollutants. The trenches can be filled with porous or adsorbent material such as crushed limestone or wood products (USDA, 1999).

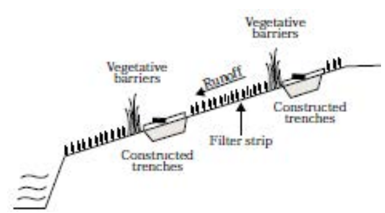

Figure 2. Constructed trenches filled with porous material and vegetative barriers used within a filter strip to enhance performance (USDA, 1999).

The age of vegetation influences the infiltration capacity. Udawatta et al. (2002) observed runoff reduction only from the second year after the establishment of vegetation. When Schmitt et al. (1999) compared different vegetation, 25 year-old mixed grass had better performance in general than 2-year-old vegetation and this is probably due to improved infiltration with more established root system. It seems that when vegetation becomes older, infiltration capacity improves, consequently improving the removal of soluble contaminants.

Filter strips also offer a setback required for manure and agrochemical applications. Grass can be used for haying or grazing unless prohibited by conservation program rules (Helmers et al., 2008; USDA, 1999). Although filter strips shall not be used as a travel lane for equipment or livestock like field borders, the strip area serves as a turning and parking area, facilitating season-long access to fields (USDA NRCS, 2010; MDA).

Filter strips are typically designed and installed with a fixed width. However, it is unlikely that the flow rate distributions entering the upstream edge of strips are uniform. Therefore, when determining widths for sediment delivery the widths shall be based on RUSLE2 estimated soil loss on the contributing area and on the ratio of contributing area size to filter strip area size and the soil hydrologic group at the filter strip location is C or D

The NRCS standard (USDA NRCS 2016, code 393) recommends for this practice:

- Slope of the Area Contributing Runoff to the Filter Strip:
  - 1% or greater.
- Strip Widths:
  - Based on RUSLE2 estimated soil loss.
  - Depends on the ratio of area contributing runoff to filter strip area (< 60:1) vs. percent slope of contributing area and soil losses (< 8.1 tons/acre/year) from the contributing area.
  - Depends on hydrologic soil groups, which show infiltration capacity (Wider for C and D than for A and B).
  - A least 16.5 feet (1 rod) for strips along public drain ditches.
  - A least 50 feet for agricultural lands adjacent to designated public water.
- Plant Species:
  - Able to withstand partial burial from sediment deposition.
  - Tolerant of herbicides used on the area that contributes runoff to the filter strip.
  - Stiff stemmed and a high stem density near the ground surface.
  - Suited to current site conditions and intended uses.
  - Able to achieve adequate density and vigor within an appropriate period to stabilize the site sufficiently to permit suited uses with ordinary management activities.
- Other Requirements:
  - At least 50% of overland flow entering the filter strip from the contributing area shall or shall be converted to uniform sheet flow.
- Other Considerations:
  - Filter strips that may be used in the future to address nutrients carried by subsurface drainage such as saturated buffers should be wide enough for that practice (USDA NRCS code 604). The vegetation selected should be able to effective at removing nutrients from tile drainage water.
  - When a Denitrifying Bioreactor (605) is placed in conjunction with a filter strip area, it is recommended to utilize shallow vegetation directly over the Denitrifying Bioreactor.

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See requirements of the Minnesota Buffer law under **Legal/Permit Requirements** below.

Cost Information

The cost of field borders and filter strips is dependent upon value of the land taken out of production, buffer installation, plant establishment, and maintenance.

EQIP (USDA NRCS, 2016) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for land purchases, easements, or installation of field borders and filter strips may be eligible when used to reduce sediment, organics, nutrients, pesticides, and other contami¬nants in runoff. To be eligible, the project must provide water quality benefits. Eligible cost include expenses such as land or easements, design, site preparation, excavation, landscaping, stabilization structures and devices, exclusionary fencing, initial seeding, vegetation plantings, and equipment to maintain desired vegetation.

Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, weed control herbicides, and practices with no water quality improvements are ineligible.

Table 2. Estimated average statewide conservation practice costs for field borders. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Component	Estimated Average Cost/Acre	Typical Units Installed	Estimated Total Installation Cost (rounded)
Native, forgone income	$710.00	1	$710
Introduced, forgone income	$580.00	1	$580
Pollinator, forgone income	$750.00	1	$750
Organic, forgone income	$650.00	1	$650

Table 3. Estimated average statewide conservation practice costs for filter strips. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Component	Estimated Average Cost/Acre	Typical Units Installed	Estimated Total Installation Cost (rounded)
Native species, forgone income	$530.00	1	$530
Introduced species, forgone income	$500.00	1	$500
Organic, forgone income	$570.00	1	$570
Native species with land shaping, forgone income	$730.00	1	$730
Introduced species with land shaping, forgone income	$700.00	1	$700
Organic with land shaping, forgone income	$770.00	1	$770

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Operation and Maintenance Considerations

Field Borders

The maintenance work recommended by NRCS standard (USDA NRCS 2007, code 386):

- Sediments accumulate along the upper gradient of borders. This sediment has to be removed before it reaches six inches high and diverts runoff flow around the borders. The removal can be done with tillage equipment or other machinery. Re-establishment of vegetation at the contributing area interface may be necessary.
- Mowing is important to encourage a vigorous sod growth.
- Weeding is important to maintain the designed width and density of field border, as well as to prevent the invasion of harmful invasive species and/or noxious weeds such as Canada thistle or teasel
- If the main purpose of field border is to protect soil and water, no burning is allowed.
- If field borders serve as wildlife food and cover, schedule mowing, harvest, and weed control to accommodate reproduction and other requirements of target wildlife. For ground nesting wildlife, any maintenance activities should be avoided during the nesting season.

Filter Strips

The maintenance of filter strips is directly related to its performance. If proper maintenance is not practiced periodically and after storm and tillage events, the runoff flow can be altered to parallel flow bypassing the strips (Dabney et al., 2006). Maintenance of the system is important to maximize water quality effects to maintain the flow direction, the proper density, and continuity of the buffer (Dabney et al., 2006; Helmers et al., 2008). USDA (1999) recommends a list of maintenance work:

- Concentrated flow will be dispersed before it enters the filter strip or addressed by an additional practice. Any concentrated flows moving through the filter strip shall be shaped, graded and vegetated according to NRCS Conservation Practice Standard: Critical Area Planting, (342), Grassed waterway (412) or WASCOB (638) or any other practice that meets the need of the identified resource concern or purpose, or other means shall be used to convert concentrated flow to sheet flow.
- Inspect the filter strip after storm events and repair any gullies that have formed, remove unevenly deposited sediment accumulation that will disrupt sheet flow, reseed disturbed areas and take other measures to prevent concentrated flow through the filter strip.
- Mowing is important to encourage vigorous sod or filtering vegetation. If the filter strip is removing bacteria or other pathogens, mowing encourages sunlight and air movement to desiccate the entrapped pathogens.
- Weeding is important to maintain the designed width and density of filter strips.

Legal/Permit Requirements

There are no legal requirements for field borders though if applying for EQIP funds, NRCS specifications 386 or 393 must be followed.

However, the Minnesota Buffer Law was adopted in 2015 and requires buffer strips or alternative riparian water quality practice(s) along state public waters and publicly administered drainage ditches. The applicable watercourses and water bodies are identified on the Minnesota DNR Buffer Protection Map and implementation guidance is available on the BWSR Buffers webpage. These requirements should be considered when designing riparian management practices in the applicable areas.

Research Gaps

No new research quantifying efficiency of field border erosion control was found. This may be because field borders generally accommodate other conservation practices and it is difficult to isolate its

Trapping: **Field Borders and Filter Strips**

impact on erosion. In order to improve the general understanding on the benefits of having field borders to improve water quality, more research on cost and effect of field border may be necessary.

For filter strips, there are little data on nutrient reduction efficiency studied under unconfined flow-path conditions and more research is necessary on plots similar to actual agricultural setting. Most monitoring studies are short-term and there are few long-term studies to understand maintenance required to keep the maximum effects of buffers (Helmers et al., 2008).

Minnesota BWRS staff suggested that there are few studies comparing different plant types and their benefits for filtering out particulate pollutants. We also lack data on the uptake of phosphorus by different plant types which would be beneficial in designing harvest systems to increase phosphorus removal in filter strips and field borders. Further research on the factors affecting N removal and their relative importance is needed as well.

More information on which filter strips or borders would be best suited to more intensive treatment such as saturated buffers would be helpful.

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Links

BWSR Buffer and Soil Loss Program Implementation www.bwsr.state.mn.us/buffers/

NRCS Conservation Practice Standard, Field Borders, Code 386 efotg.sc.egov.usda.gov/references/public/MN/386mn.pdf

NRCS Conservation Practice Standard, Filter Strips, Code 393 efotg.sc.egov.usda.gov/references/public/MN/393mn.pdf

MDA Conservation Practices Minnesota Conservation Funding Guide, Field Border www.mda.state.mn.us/protecting/conservation/practices/fieldborder.aspx.

MDA Conservation Practices Minnesota Conservation Funding Guide, Grass Filter Strip www.mda.state.mn.us/protecting/conservation/practices/buffergrass.aspx.

Trapping: **Field Borders and Filter Strips**

Sediment Basin (350)

Definition and Introduction

The effects of sedimentation ponds on water quality is well documented, especially in the use of treating urban stormwater and construction runoff. A sediment basin works by detaining sediment or nutrient-laden water for sufficient time to allow for settling of particles. Settling is accomplished by creating a permanent pool of water in contrast with the Waster and Sediment Control Basin (WASCOB). Sediment basins may be used in agricultural or urban locales and are often used to treat water from disturbed areas or construction sites, either on a temporary or a permanent basis.

Water Quality and Other Benefits

The MPCA (2016) reports average TSS removal rates of 84%, total phosphorus (P) rates of 50% and total nitrogen (N) removal of 30% in stormwater ponds and higher reductions if the basins are designed for infiltration (Table 1). Removal efficiencies for agricultural sediment basins are likely to be different than averages reported for urban locations due to differences in influent concentrations.

Table 1. Removal efficiency of stormwater ponds. (From MPCA, 2016)

Practice	TSS (Low-Med-High)	TP (Low-Med-High)	TN	Metals (average of Zn and Cu)	Bacteria	Hydrocarbons
Stormwater Ponds	60-84-90	34-50-73	30	60	70	80

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Simulations of agricultural runoff through sedimentation basins by Edwards et al. (1999) were found to remove 94% of sediment, 76% of N, and 52% of P.

Sediment basins are often designed specifically for sediment and particulate removal and not for dissolved nutrient removal. Therefore, sediment basins are effective at reducing TSS and TP from the effluent. Constructed wetlands, due to the established vegetation, will be more effective at reducing nutrients from the outflow than sediment basins.

Variability in efficiency will vary based on the hydraulic residence time, the dewatering device, the presence of a permanent pool, the turbulence in the basin, and soil particle size. Much of the effectiveness depends on what other practices are implemented with the sediment basin. It is oftentimes recommended to construct a series of erosion control practices with the sediment basin as the last practice in the series.

Key Design/Implementation Considerations

Detailed and extensive design guidance is provided in the MPCA's Stormwater Manual (2016), USDA NRCS (2010), and the NPDES Construction Stormwater Permit (2013). Design considerations should include the drainage area and runoff that will flow through the basin. These factors will determine the basin size needed and the outlet control. If an embankment is to be added, special consideration should be taken to prevent failure.

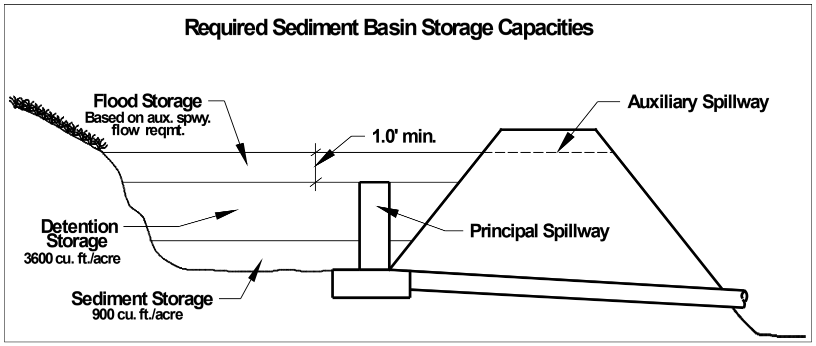

Figure 1. Sediment Basin figure from the NRCS (2010). Storage capacity is divided into sediment storage on the bottom, detention storage in the middle and flood storage on the top of the basin. The principal spillway provides a water outlet at normal flow levels while the auxiliary spillway provides flood protection at high flows.

Cost Information

The Minnesota Department of Transportation average bid prices for 2014 provide a range of excavation costs between $5.29 and $6.90/ cu yd. This does not include installation of inlet and outlet structures.

EQIP (USDA NRCS 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

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Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for construction of sedimentation basins may be eligible when used to prevent erosion, reduce sediment or nutrients in runoff, or prevent downstream adverse impacts. Eligible cost include expenses such as design, site preparation, excavation, construction, landscaping, stabilization structures and devices, water level control structures, inlets and outlets, waterways, exclusionary fencing, initial seeding, and vegetation plantings. To be eligible, the practice must have a water quality benefit, not just habitat improvements.

Typical operation and maintenance expenses such as periodic over-seeding, fuel for management activities, weed control herbicides, periodic clean-out, and practices with no water quality improvements are ineligible.

Table 2. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/Cubic Yard	Typical Units Installed	Estimated Total Installation Cost (rounded)
Excavated basin	$2.57	1,500	$3,900
Embankment earthen basin with pipe	$4.91	500	$2,500

Operation and Maintenance Considerations

The key considerations in operations and maintenance according to the NRCS (2010) are:

- Routine inspection of inlet and outlet for plugging or debris accumulation, as well as emergency or auxiliary spillways,
- Inspection of embankments for excessive erosion or seeping,
- Maintenance of vegetation on embankments, including mowing and removal of trees, brush and invasive species, and
- Periodic sediment removal.

Legal/Permit Requirements

Contact your local SWCD, Watershed District, or the Minnesota Pollution Control Agency (MPCA) to determine if permits are required for construction of a sediment basin. A Dam Safety Permit may be required for large sediment basins if the embankment is greater than six feet or if the impounded storage is greater than 15 acre-feet. If used to treat construction or other disturbed site runoff, an MPCA General Construction permit may be required (see stormwater.pca.state.mn.us/index.php/Construction_stormwater_program).

Local/Regional Design Examples

Generally sediment basins are used less often in rural areas compared to urban settings since they are not subject to the same storm water runoff regulations. However their use is growing. The University of Minnesota, Minnesota Department of Agriculture and Nature Conservancy are investigating the use of sedimentation ponds, termed 'surge ponds,' in combination with woodchip bioreactors in Mower County, Minnesota.

The University of Minnesota's Southwest Outreach and Research Center (SWROC) at Lamberton, Minnesota, is investigating the use of surface flow wetlands, which are similar to sediment basins

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(Strock, 2011). Preliminary results from that research indicate potential nutrient load reductions.

Research Gaps

Historically, sediment basins have been used in urban areas and construction sites. The use of permanent sediment basins to improve water quality in agricultural settings is relatively new. The inflow water quality of agricultural runoff is likely different than that of urban stormwater. Thus, the efficacy of sediment basins for treating agricultural runoff warrants further consideration.

Sedimentation ponds are usually viewed as a last line of defense when addressing water quality problems and have not been traditionally used as a permanent agricultural best management practice. However, as indicated above, research has been undertaken to quantify the benefit that sedimentation can have, particularly when combined with other BMPs that target nutrients, like woodchip bioreactors.

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Grade Stabilization Structure at Side Inlets (410)

Side inlet controlling gully erosion alongside a ditch. (Photo by C. Lenhart)

Definition and Introduction

Side inlet controls are used to convey water from a field to a drainage ditch and are one specific type of grade stabilization structure.

In artificially drained agricultural land, an estimated 21,000 miles of drainage ditches (Minnesota DNR, 1980) convey runoff and tile drainage to receiving bodies of water. Side inlets serve as surface runoff outlets from agricultural land into drainage ditches and are very common wherever surface drainage ditches are present. There could be as many as 70,000 side inlet locations in the drained agricultural areas of the state, extrapolating inventory information from Seven Mile Creek watershed in Nicollet County. These side inlets may contribute about 70,000 tons/year of sediment and concomitant nutrients and pesticides to Minnesota's waters. As a comparison, the Minnesota River at Jordan transports about 675,000 tons/year. Side inlet controls such as culverts and drop pipes can prevent gully erosion, control the rate of flow to ditches, and create sedimentation areas to improve water quality.

In many open ditched systems, spoil banks are created from side-cast material during ditch construction. In many cases, where natural ground topography slopes toward the ditch, the spoil bank forms a berm, which will impound water if an inlet through or under the ditch is not provided (Figure 1).

Figure 1. Reduced conveyance due to side inlet failure.

Concentrated flow at these locations can cause bank failure or weak points in the bank, which can lead to bank failure. Based on anecdotal evidence, erosion at side inlets can be a major problem and is often cited as such in ditch assessments and repair reports.

Water Quality and Other Benefits

Side inlet controls are designed to accomplish three main objectives:

- Erosion control and prevention;
- Short-term stormwater volume control; and
- Water quality control associated with short-term ponding.

Erosion and bank failures at side inlets on public drainage systems can have profound negative effects on receiving waters. These failures occur at low points along the length of drainage ditches where concentrated flow causes bank failure. Negative effects include increased downstream sediment transport, reduced ditch conveyance capacity (see Figure 1), increased downstream nutrient loading, and potential loss of production land as failures move up-gradient.

Side inlet controls operate similarly to alternative tile intakes; they receive surface runoff from some contributing area and achieve water quality improvements by reducing the rate at which water enters either ditches or tile while also inducing sedimentation or filtering, in the case of rock inlets. As Strock et al. (2010) indicate, current designs do not consider water quality. Research is in the beginning stages of quantifying the benefits of side inlet controls and developing design guidance. The Heron Lake Watershed District reported that each alternative tile intake results in a phosphorus (P) reduction of 0.5 pounds/year and a sediment reduction of 400 pounds/year.

Side inlet control performance, in terms of peak flow reduction and sediment trapping efficiency, is primarily determined by the ratio of the side inlet storage area to the contributing watershed area, and the outlet configuration (Krider et al., 2014). Five outlet configurations were tested and estimated peak flow reductions were compared (Table 1).

The results represent over 400 years of modeling simulations. Larger storage to watershed areas results in much greater peak flow reduction. Practice selection is based on cost, ease of installation, ease of maintenance, and effectiveness. Given these considerations, a Hickenbottom style outlet is likely the most reasonable choice. Of the riser type inlets, Rendall and Cooke (2013) concluded that none of the commercially available risers in their tests (Hickenbottom, AgriDrain, Ag-Solutions) provided superior sediment inhibition to the tile lines.

Table 1. Average percent peak flow reduction from different side inlet configurations (adapted from Krider et al., 2014).

	10% A_s/A_w	1% A_s/A_w
Hickenbottom	85.83	0.92
Rock Inlet	87.45	0.38
Rock Weir	94.79	0.26
Flush Pipe	80.21	0.98
Straight Pipe	38.82	1.34

A_s = area of storage, A_w = area of watershed

Few field studies have been conducted on the effectiveness of side inlet controls; however, drainage of closed depressions is very similar in concept to side inlet controls. Smith and Livingston (2013) compared a tile riser to a rock inlet on both field and catchment scales in northwest Indiana. They found about a 60% reduction in total flow comparing the rock inlet to the tile riser (Hickenbottom-style) and commensurate reduction in sediment, total P, and nitrate. Key differences between the results of the Smith and Livingston study and the Krider et al. (2014) study are: 1) the Smith and Livingston results comprised 11 rainfall events, the largest of which was 2.6 inches, so the potential damage due to inundation couldn't be evaluated; 2) no stage/area information is provide, nor is the areal extent of inundation presented; 3) a side inlet location must be provided with an emergency overflow, which is not required in a closed depression so peak flow reductions in a side inlet will always be less compared to a closed depression.

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On a catchment scale, Smith and Livingston found that blind inlets were effective as well, but the short-duration study made firm conclusions regarding efficiency difficult. Krider et al. (2014) evaluated side inlet controls on a watershed basis and found that peak flows could be reduced by between six and 30%, depending on the magnitude of the rainfall. Return periods of less than two years resulted in considerably better reductions than for larger events.

Average sediment trapping efficiencies from different side inlet configurations are presented in Table 2 (Krider et al. 2014). The results are average trap efficiencies from modeling simulation of 400 years. Based on these results, the Hickenbottom style riser offers a reasonable combination of efficiency, economy, and ease of installation and maintenance.

Table 2. Average percent sediment trapping efficiency from different side inlet configurations (adapted from Krider et al., 2014).

	10% A_s/A_w	1% A_s/A_w
Hickenbottom	80.25	53.00
Rock Inlet	81.00	53.50
Rock Weir	82.25	53.75
Flush Pipe	80.25	52.50
Straight Pipe	71.75	46.50

A_s = area of storage, A_w = area of watershed

Key Design/Implementation Considerations

Location

Identifying suitable locations for side inlet controls can be done in the field or using a terrain-based approach. A terrain-based approach uses geographic information systems (GIS) and topographic information, such as Light Detection and Ranging (LiDAR) to identify probable locations. Galzki et al. (2011) and Krider et al. (2014) discuss methods for identifying side inlet locations using terrain analysis in Minnesota.

Design

Side inlet controls have many design variants. They can be designed with a sloped single pipe, vertical standpipe connected to a horizontal conduit, rock inlet, blind inlet, tile coil inlet, weir type drop structure or armored chute, vegetative buffer zones (Figures 2 and 3). These design variants are similar to the designs for alternative tile intakes.

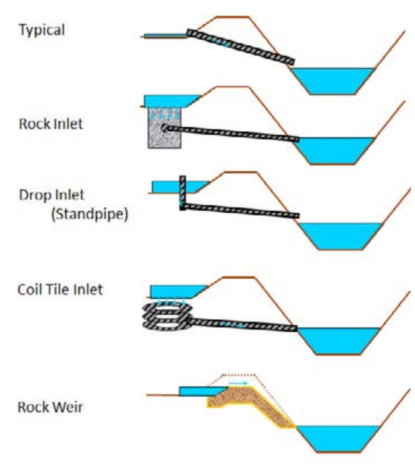

Figure 2. Side inlet control design variants.

Standpipes can be constructed with different opening configurations (e.g., perforated riser, slotted, etc.) to temporarily store the water and to control the release of water to the ditch (Figure 4). The side inlets manage peak runoff rates and improve water quality through deposition of sediment before it reaches receiving bodies of water.

Volume control for less than 48 hours can be accomplished by appropriately sizing a weir through the spoil berm or pipe under the berm. If a pipe is installed, a standpipe may be used to manage water release rate.

Erosion control is accomplished by providing rock riprap protection at a weir to the ditch or by providing energy dissipation at pipe outlets. Often, energy dissipation is not provided at pipe outlets.

Side inlet control design is site specific. Topography, soils, local hydrology, and property considerations will dictate the volume and release rate of temporary storage. NRCS Practice Standard 410 provides the hydraulic design criteria shown in Table 3 (USDA NRCS, 2016).

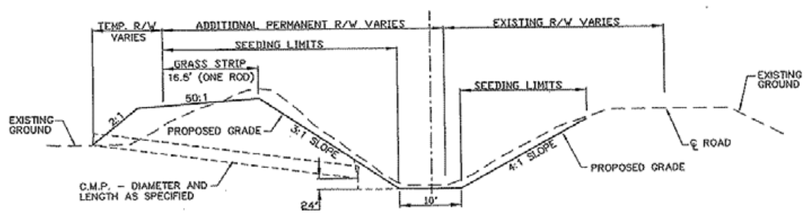

Figure 3. A cross section of a ditch with a side linet and seeding areas (BWSR, 2006).

Peterson and Wilson (2014) recommend a vertical riser with slots or perforations for most applications.

Rendall and Cooke (2013) evaluated the performance of different commercially available inlet designs by comparing inflow rates at different ponding depths with and without debris present. The authors state that both a 6" and 8" Ag-Solutions drains have the best drainage capacity in the absence of debris while the Hickenbottom had the least reduction in capacity due to debris.

Table 3. NRCS Practice Standard 410 minimum capacity design criteria for side-inlets, open weirs, or pipe-drop drainage structures*.

Maximum drainage area for indicated rainfall in a 5-year frequency, 24-hour duration storm (acres)			Frequency of minimum design, 24-hour duration storm	
0 – 3 in.	3 – 5 in.	Vertical Drop (ft)	Receiving channel depth (ft)	Total capacity (yrs)
1,200	450	0 – 5	0 - 10	5
1,200	450	5 - 10	10 – 20	10
2,200	900	0 - 10	0 - 20	25

*A principal spillway is required for all structures and may be designed based on drainage curves for watersheds with an average slope less than 2%. Use one drainage curve above the ditch design curve.

Land near side inlets is usually farmed, so crop inundation is a concern. Peterson and Wilson (2014) recommend crop inundation periods less than 48 hours. Other design considerations listed by Peterson and Wilson are:

- Take into consideration tail water elevation at the discharge side of the pipe. In many instances, tail water could be an issue.
- Take into account embankment pipe size. The size of pipe connecting the Hickenbottom and vertical riser must not limit the design flow rate.
- Consider and use anti-seep collars, trash guards, outlet erosion control, pest control (e.g., muskrats), if appropriate.
- Ensure adequate freeboard is present.
- Account for accumulated sediment in the design of detention ponding areas, or plan on periodic removal of sediment.
- Address permitting or other legal requirements.

Cost Information

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for installation of stabilization practices at side inlets may be eligible when used to prevent or control erosion, reduce sediment, or prevent downstream adverse impacts. Eligible cost include expenses such as land acquisition, easements, design, site preparation, excavation, construction, landscaping, stabilization structures and devices, water level control structures, inlets and outlets, initial seeding, and vegetation plantings. To be eligible, the practice must have a water quality benefit.

Typical operation and maintenance expenses such as periodic clean-out or repairs, and practices with no water quality improvements are ineligible.

Table 4. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/Unit
Side Inlet Structure	$3,400.00
Drop Inlet to Culvert	$4,400.00
Plunge Pool	$4,900.00
Embankment Dam	$5,900.00 - $41,800.00
Embankment Dam Rehab	$7,600.00 - $22,800.00

Operation and Maintenance Considerations

Operations and maintenance considerations for side inlet controls are similar to alternative tile intakes and grade stabilization structures, depending on the design variant.

Designs involving either a sloped pipe or drop inlet require that inlets be checked periodically to ensure that pipes are not blocked. Excessive erosion or scour at inlet and outlet locations is another concern. A study by Kröger et al. (2013) on slotted inlet pipes showed that once sediment had accumulated to a certain depth, about 65% of the depth in that study, sediment accumulation rate decreased, indicating decreased performance. The average time to reach 65% accumulation was 235 days, so annual cleanout of accumulated sediment appears to be a reasonable maintenance schedule to maintain performance.

As discussed in alternative tile intakes, rock inlets may become plugged over time. Therefore, excessive or persistent ponding in excess of design is probably indicative of a plugged inlet. In this case the media in the rock inlet would have to be replaced.

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Trapping: Grade Stabilization at Side Inlets

Local/Regional Design Examples

North Fork Crow River case study (Figure 4)

Because little research existed on types, sizing, and effectiveness of side inlet controls, there had been little guidance on sizing and effectiveness. For these reasons, Kandiyohi County's approach included a research element to their side inlet projects. Over 30 rock inlet installations were approved in the North Fork Crow River watershed in 2012 and completed in 2013. At three different project sites, with three different soil types, rock inlets were placed side-by-side with a standpipe inlet.

	Area (acre)	Soil Type
Site 1	3.5	SiCIL
Site 2	6.1	SiCIL
Site 3	3.7	L

Figure 4. Standpipe side inlet in Kandiyohi County, Minnesota.

Lessons Learned

Pea gravel generally works best for rock inlets. Larger rock tends to allow too much sediment into the void spaces. Rock inlets experience decreased infiltration over time. The maintenance or cleanout frequency depends on the amount of sediment delivered but experience in Kandiyohi County shows that an approximate 10-year frequency might be expected. Most of the sediment becomes trapped in the top 12 inches, so replacement of the top 18 inches of pea gravel will suffice.

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Clean Water Fund Research

Field experiments have been performed in recent years at the University of Minnesota's Southwest Research and Outreach Center in Lamberton, Minnesota, on side inlets (Krider et al., 2014; Peterson & Wilson, 2014). In combination with these experiments, numerous demonstration field days were conducted by the research group and hosted by Mower SWCD, Red Lake SWCD, Nicollet SWCD, and Hawk Creek Watershed Project (BWSR, 2014).

Legal/Permit Requirements

Work in the bed of a public water requires a Minnesota DNR Public Waters work permit; however, there are limited exceptions in the case of using rock riprap to prevent erosion (Minnesota DNR, 2012).

Research Gaps

Thorough research has been conducted in recent years on this practice but more needs to be conducted on the impact of large rain events on the effectiveness of various designs. There is still a limited understanding of the impact of inundation on an inlet during large rain events.

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Trapping: **Grade Stabilization at Side Inlets**

Water and Sediment Control Basin (638)

Water and sediment control basin in Nicollet County, Minnesota.

Definition and Introduction

Water and sediment control basins (WASCOBs) consist of an embankment across the slope of a field or minor waterway to temporarily detain and release water through a piped outlet or through infiltration. They are constructed perpendicular to the flow direction and parallel to each other. WASCOBs are usually installed in areas where the land is relatively steep and undulating (USDA NRCS, 2003).

WASCOBs are used to improve the ability to farm sloped land and to reduce erosion on farmland and waterways. WASCOBs are used to manage hydrology by controlling downstream flow rates, thereby reducing erosion. A buffer of permanent vegetation surrounding risers can help to filter sediment and pollutants.

While WASCOBs are similar to terraces, NRCS design criteria states that if the ridge and channel extend beyond the detention basin or level embankment, terraces should be used. The scientific literature uses the two terms somewhat interchangeably.

Water Quality and Benefits

The key benefits of WASCOBs are detaining water from contributing areas, allowing sedimentation and controlling the release of water, thereby reducing the erosive power of the water downstream.

Additional benefits are settling of sediment-bound pollutants, specifically phosphorus (P), and increased infiltration.

Mielke (1985) reported sediment trapping efficiencies ranging from 97 to 99% in northeastern Nebraska. In a modeling study simulated in northeast Iowa, Gassman et al. (2006) found a 92% reduction in sediment and 80% reduction in sediment-bound P using the Agricultural Policy/Environmental eXtender model (APEX) model and 64 and 74% reductions using the Soil and Water Assessment Tool (SWAT) for sediment and organic P, respectively.

Zhou et al. (2009) evaluated the use of different management structures and tillage systems on water quality using the WEPP model in the eight different major land use resource areas in Iowa. They found that terrace systems were very effective in areas that were prone to erosion.

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Key Design/Implementation Considerations

Design criteria for water and sediment control basins are described in NRCS Practice Standard 638.

WASCOBs are typically constructed where the combination of topography and soils would lead to watercourse or gully erosion. Common locations are in minor drainage paths, that when heavily inundated become small streams with erosive power. Contributing drainage area should not exceed 40 acres. The embankments tend to be placed in a parallel series along the drainage path. Maximum spacing should not exceed 700 feet, based on the slope and should accommodate farm machinery widths. The fill height of the embankment is dependent on the spacing between WASCOBs. NRCS Practice Standard 638 prescribes the design criteria. WASCOBs should be designed such that the extent and duration of ponding does not damage crops – typically no longer than 48 hours.

Cost Information

EQIP (USDA NRCS 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for construction of water and sediment control basins may be eligible when used to prevent erosion, reduce sediment or nutrients in runoff, or prevent downstream adverse impacts. Eligible cost include expenses such as land acquisition and easements, design, site preparation, excavation, construction, landscaping, stabilization structures and devices, water level control structures, inlets and outlets, waterways, exclusionary fencing, initial seeding, and vegetation plantings. To be eligible, the practice must have a water quality benefit, not just habitat improvements.

Typical operation and maintenance expenses such as repairs, periodic over-seeding, fuel for management activities, weed control herbicides, periodic clean-out, and practices with no water quality improvements are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost/Foot	Typical Units Installed	Estimated Total Installation Cost (rounded)
Berm less than 4 feet tall, grassed	$5.77	450	$2,600
Berm less than 4 feet tall, farmed	$11.97	450	$5,400
Berm between 4 feet and 6 feet tall, grassed	$8.92	600	$5,400
Berm between 4 feet and 6 feet tall, farmed	$15.38	600	$9,200
Berm between 6 feet and 8 feet tall, grassed	$15.32	600	$9,200
Berm between 8 feet and 10 feet tall, grassed	$23.15	600	$13,900
Berm between 10 feet and 12 feet tall, grassed	$35.35	500	$17,700
Berm between 12 feet and 15 feet tall, grassed	$51.18	250	$12,800

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Operation and Maintenance Considerations

Vegetation must be maintained on embankment slopes to prevent rill and sheet erosion. Any erosion on the embankment should be repaired as soon as possible so that further erosion or embankment failure does not occur.

Inlets must be inspected periodically, especially after large storm events, to ensure that pipes are not plugged.

Legal/Permit Requirements

Contact the local SWCD or watershed districts to determine if permit requirements or local rules apply.

Local/Regional Design Example

WASCOBs as a best management practice have been growing in popularity and are being installed throughout the state. For example, the Buffalo-Red River Watershed District and Becker County SWCD installed 30 water and sediment control basins in 2012. They estimate a reduction of 812 pounds of P and 706 tons of sediment per year to the Hay Creek watershed.

Research Gaps

While the use of WASCOBs are fairly widespread and they are considered effective at trapping sediment and associated nutrients, there is little research documenting on-the-ground effectiveness in Minnesota at the practice, field, or watershed scale.

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NRCS. 2017. NRCS Practice Standard 638. Water and Sediment Control Basin. efotg.sc.egov.usda.gov/references/public/MN/638mnCPS2017.pdf

Trapping: Water and Sediment Control Basin

Featured Projects

www.bwsr.state.mn.us/projects/Hay_Creek_Watershed.pdf

www.co.becker.mn.us/dept/soil_water/PDFs/Hay%20Creek%20Success%20Story.pdf

www.dakotacountyswcd.org/watersheds/ncrwmo/pdfs/Maureen%20Fasbender%20Control%20Basin.pdf

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Constructed (Treatment) Wetlands (656 & 658)

Figure 1. Constructed wetland near Granada, Minnesota. (Photo by David Hansen).

Definition and Introduction

Constructed wetlands, sometimes called treatment wetlands, are man-made systems engineered to simulate the water-cleansing process of natural wetlands. In agriculture, constructed wetlands are used to filter runoff and sub-surface drainage from cropland, feedlots, aquaculture operations, and agricultural processing facilities.

Although constructed wetlands are commonly sited within formerly drained wetland areas, they are distinguished from restored wetlands in that they are not designed, nor intended to re-create, the pre-disturbance vegetation or hydrologic conditions. Constructed wetlands can provide habitat for waterfowl and other birds, amphibians, and invertebrates; however, plant diversity is usually lower than found in restored wetlands and subsequently supports fewer invertebrate species, including insects. Created wetlands (658) are placed on a site location historically not wetland area.

Compared to restored wetlands, constructed wetlands typically are less effective at supporting wildlife and ecological functions (NRC, 2001). However, if properly designed they effectively remove excess nutrients, sediment and other pollutants from surface runoff (Kadlec & Wallace, 2008). Treatment wetlands have been most widely used in developed (urban/suburban) areas for wastewater treatment; however, more recent research quantifying their effectiveness at treating nitrate in agricultural drainage water is contributing to practice adoption across the Midwestern agricultural landscape (Hyberg et al., 2015; Iovanna et al., 2008).

Water Quality and Other Benefits

Wetlands are effective at settling sediment and thus have a high total suspended solids (TSS) removal efficiency, particularly if the basin has a large storage volume relative to the watershed inputs. For example, Schueler (1992) found that urban treatment wetlands had an average of 75% TSS removal in a study of 60 wetlands. Nitrogen (N) and phosphorus (P) removal is highly variable in treatment wetlands. They are often efficient at removing N but less effective at removing P. Nitrate-nitrogen can be permanently removed from the system through denitrification as nitrate is converted to mostly N_2 gas and released. In contrast, most P is in particulate form and is removed when sediment-bound P settles to the wetland bottom and eventually removed via uptake by plants. P taken up by plants can be released back into the water in autumn when plants die after the growing season. Therefore vegetative removal or harvest may be necessary to achieve lasting P reductions.

Since treatment wetlands are typically much smaller than natural wetlands, the flood reduction benefits are minimal in comparison. From a total load standpoint, the lack of hydrologic storage in an edge of field design reduces the potential for load reduction at higher flows. Although they are highly effective at removing sediment and pollutants from small areas, they can be overwhelmed by large agricultural watershed loads. At high flows much of the water may need to be diverted into an emergency overflow to maintain the nutrient removal effectiveness since the residence time is decreased. It is important to have realistic goals and expectations for nutrient removal rates with small treatment wetlands. Research in Iowa recommends a minimum wetland to watershed area ratio of 1% and up to 2% to maximize the cost-effectiveness for nitrate removal (Crumpton, 2001). Lubner-Ziegler (2016) in a study from Wisconsin for The Nature Conservancy cited ranges from 0.3% to 6% depending on hydraulic loading rates, regional differences and other factors that affect treatment effectiveness.

In Minnesota and the upper Midwest, treatment wetland effectiveness is limited by physical factors such as cold temperatures and a relatively short growing season compared to the rest of the United States (Axler et al., 2001). Plant uptake is important for P removal while denitrifying bacteria are critical for nitrate removal. There are also several logistical issues involving fitting wetlands into drainage systems. Sufficient topographic breaks are needed to allow routing of drain water into pipes to the wetland to prevent flooding of adjacent lands.

In Midwestern agricultural watersheds one of the major issues is treating tile water for high nitrate concentrations (MPCA, 2014). Since subsurface drainage pipes are normally routed directly to streams, it is necessary to capture the water in storage areas prior to discharge for treatment. Thus tile-interception wetlands may need to be placed into stream valleys and other marginally productive farmland that may not be optimally located for treatment of tile discharge.

Axler et al. (2001) studied sewage treatment wetlands near Duluth, Minnesota. Annual summer effluent TSS values averaged 8 mg/l +/- 2 and 85% removal. P removal rates were lower at 20-51%. A natural peatland in Houghton Lake, Michigan, also treating sewage effluent, was studied for nearly 20 years (Kadlec & Knight, 1996). It had N and P removal rates exceeding 90% for most of the study period. It should be noted that discharge to peatlands is not an option in most agricultural watersheds of Minnesota, but may be an option in northern Minnesota, if such discharges were be allowed under the Minnesota Wetland Conservation Act.

At Indian Lake, Ohio, a three-acre agricultural runoff treatment wetland had 40-43% removal efficiency for nitrate and 59% for total P, with 49-56% soluble reactive phosphorus (SRP) removal from 1999-2000 (Mitsch & Fink, 2001). This wetland had a 6.5% wetland to watershed area ratio, sufficient to effectively remove substantial quantities of nutrients.

At a three-cell, one half-acre treatment wetland located in Martin County, Minnesota, P and nitrate removal rates were monitored for three years. The wetland receives flow from sub-surface drainage, with occasional backflow from Elm Creek during large floods. This wetland was designed with a 1% wetland-to-watershed area ratio to minimize farmland area taken out of production.

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Vegetation harvest has been completed in late fall to determine the potential for increased P removal. Water monitoring data estimated the wetland had a 50-100% P load reduction and 60-93% nitrate load reduction from the tile inflow, with increasing effectiveness of nitrate removal in years two and three likely due to the establishment of mature vegetation. Subsurface treatment plays a more significant role than surface treatment at nitrate reduction due to the high infiltration rates. During large rain events when inflow was greatest, insufficient residence time limited nutrient removal effectiveness (Lenhart et al., 2016).

The time-scale to see water quality improvements with a treatment wetland can be immediate at the outlet of the wetland. Within the larger watershed, water quality improvements could take years or decades if the volume of water treated is small relative to the receiving stream (Cruse et al., 2012).

Key Design/Implementation Considerations

Treatment wetlands may be designed as surface flow or subsurface flow wetlands. Wetlands receiving surface flow maximize the removal of sediment and particulate P through physical settling and filtration by the wetland vegetation and soil surface (Mitsch and Jørgensen 2004). Wetlands receiving subsurface drainage water effectively reduce nitrate loading to surface waters through denitrification (Kovacic et al., 2000; Iovanna et al., 2008).

Sizing and placement of the wetland are critical to maximizing sediment and nutrient removal. Some of the key variables include the duration and depth of flooding in the wetland to insure optimal water levels and survival of wetland species. The hydraulic loading rate is defined as:

$$q = (Q/A)/100$$

where q is the inflowing hydraulic loading rate, which is equivalent to the depth of flooding over the treatment area (A) per unit time (inches/day) (Mitsch & Jørgensen, 2004). The hydraulic loading rate needs to be optimized to provide sufficient water and nutrient supply to the wetland vegetation, while not overloading it, since that would result in a greatly reduced removal efficiency. The percent mass nitrate removal is inversely related to the hydraulic loading rate. However to achieve sufficient nitrate removal to make the project cost-effective, researchers in Iowa determined that there should be hydraulic loading rate of at least 50 m/year (Crumpton et al., 2008).

Furthermore, consistent soil saturation should occur to maintain denitrifying bacteria levels (Bruland & Richardson, 2006). The mean depth of water needs to be maintained at less than one meter from soil surface to promote the development of emergent vegetation and wet prairie species. The vegetation subsequently helps maintain or build organic matter levels necessary for denitrification.

Treatment wetlands in flood prone areas should generally be placed to avoid frequent river flooding or protected by berms to prevent river inflow from occurring (assuming the goal is treatment of subsurface drainage and not surface water overflow from rivers). If treatment wetlands receive large amounts of sediment from floods, their performance will decline and maintenance costs will increase, although floodplain placement provides additional treatment for the larger watershed.

Limitations

To maximize nitrate removal efficiency, certain biogeochemical conditions need to exist in the wetlands. In particular there needs to be an adequate supply of organic carbon to maximize denitrification (Isenhart, 1992). Buildup of sufficient carbon could take years in wetlands with carbon-depleted (low organic-matter) soils. Anaerobic conditions need to exist as well, which can be a problem if the wetland is constantly fed with oxygen-rich water. For this reason denitrification will tend to be lower during the spring runoff season in addition to lower temperatures and reduced residence time. In some wetland environments, ammonium may be more abundant than nitrate. In these cases, some wetland

Trapping: **Constructed (Treatment) Wetlands**

systems are unable to convert sufficient ammonium to nitrate without sufficient oxygen, therefore preventing denitrification and reduction of the N load.

P removal by treatment wetlands can be limited by a variety of factors. If the soils are saturated with P, as commonly occurs in Midwestern agricultural watersheds, P may be released from decaying vegetation and from the soils during summer anaerobic time periods (Beutel et al., 2014).

Cost information

Costs to construct treatment wetlands vary considerably based on the size of the wetland, grading, and control structures needed. Christianson et al. (2013) calculated that establishment costs for constructed wetlands can range from $5,886.46 to 8,191.45/acre of wetland treatment area and buffer for establishment and $5,944.13 to 8,326.77/acre of wetland treatment area and buffer when establishment, maintenance, and replacement costs are included (Table 1).

EQIP (USDA NRCS 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for creation or installation of constructed or treatment wetlands when used to reduce sediment or nutrients in runoff and subsurface drainage or prevent downstream adverse impacts. Eligible cost include expenses such as land acquisition and easements, design, site preparation, excavation, construction, landscaping, stabilization structures and devices, water level control structures, inlets and outlets, waterways, exclusionary fencing, initial seeding, and vegetation plantings. To be eligible, the practice must have a water quality benefit, not just habitat improvements.

Typical operation and maintenance expenses such as repairs, periodic over-seeding, fuel for management activities, weed control herbicides, periodic clean-out, water level adjustments, and practices with no water quality improvements are ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
Small less than 0.1 acres, Vertical cells	$10.95/Square Foot	768	$8,400
Medium, 0.1 to 0.5 acres	$42,800.00/Acre	0.25	$10,700
Large, More than 0.5 acres	$38,463.95/Acre	1	$38,500

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Operation and Maintenance Considerations

Installation of treatment wetlands is fairly straightforward, following existing techniques used in wetland restoration and stormwater basin construction. Maintenance is another issue not often accounted for in cost-benefit analyses. The life-span of treatment wetlands is not well known since most have been built in the past 10-20 years. Wetlands that do not receive overland runoff may be less prone to sedimentation and erosion from destructive high-velocity flows. A study conducted in Illinois observed consistent nitrate removal potential 20 years after construction, which was attributed to low hydraulic loading rate (Groh et al., 2015). Periodic removal of accumulated sediment may be necessary, particularly if the design includes a sediment forebay which may fill in within a few years, as suggested by Mitsch and Jorgenson (2004).

If vegetation harvest is utilized for P removal, it is desirable to have a water control structure and/or subsurface pipe to drain the wetland in late fall. This would enable machinery into the area to remove the vegetation. While vegetation harvest may be feasible on a small scale, it is unlikely to be adopted on a large scale unless there is some market for the harvested vegetation, such as biofuel or livestock feed.

Barriers to BMP adoption

In agricultural regions of Minnesota with high land values, it is difficult to find landowners willing to take active row crop land out of production to restore or create wetlands due to the high value of row crops. Another barrier to widespread adoption is the cost of designing and building treatment wetlands. Restoring wetlands tends to be much more cost-effective per unit area. Other issues include the negative perception of wetlands many farmers have due to an association with regulation of activities impacting wetlands, government mandates involving private lands, and holding back water on the edge of a field.

Legal/Permit Requirements

The work shall not affect other properties or water users unless agreement is reached and written in a signed letter, easement, or permit. Constructed wetlands are typically not subject to wetlands laws because they are created in areas that are not existing wetlands. Project planners should consult appropriate local government units, state and federal agencies concerning wetlands and water regulations.

Local/Regional Design Example

Some Midwestern design examples are listed in Table 2. Due to the small number of examples designs located in Minnesota additional projects from outside Minnesota are presented. The Houghton Lake, Michigan study was a well-studied sewage treatment wetland in a northern climate similar to Minnesota so it was included. The Indian Lake, Oho example was one of the few treatment wetlands designed specifically for agricultural runoff and drainage in the Midwest. The last two examples were designed only for subsurface drainage and so the focus for treatment was nitrate and dissolved P since subsurface tile outflow is low in particulate pollutants. The Granada, Minnesota wetland is shown in Figure 1 and 2.

Trapping: **Constructed (Treatment) Wetlands**

Table 2: Treatment wetland removal efficiency studies in the Midwestern United States

Location and wetland type	Water source	TSS	Nitrate	Phosphorus
Duluth, Minnesota; sewage treatment system, subsurface flow (Axler et al. 2001)	Subsurface tile flow	85%	No data	20-51%
Houghton Lake, Michigan, sewage treatment, surface flow (Kadlec and Wallace 2008)	Surface	n/a	>90	No data
Indian Lake, Ohio; agricultural surface runoff, surface and subsurface flow (Mitsch and Fink 2001)	Surface runoff	No data	40-43	49-56 (SRP) 59 (TP)
Embarrass River Watershed, east-central Illinois, subsurface tile drainage (Kovacic et al. 2000; Groh et al. 2015)	Subsurface tile flow		54-62%	22% (SRP) and 2% (TP) in a 3-year period
Granada, Minnesota, agricultural subsurface flow (Current et al. 2016; (Lenhart et al. 2016)	Subsurface tile flow	No data	60-93%	50-100%

Figure 1. Constructed treatment wetland at the edge of farmland near Granada in Martin County, Minnesota treats tile drainage flow prior to discharge into Elm Creek. The three cells were designed to allow for different vegetation treatments and to prolong the flow path of water through a sinuous route (photo by David Hansen).

Research Gaps

Lubner-Ziegler (2016) describes overall research needs for constructed wetlands including more long-term studies, > 15 years) on nutrient reduction since few such studies exist. The tradeoffs between nutrient reduction and other wetland ecosystem services need to be better understood since wetlands are often assumed to provide multiple benefits.

Nutrient removal efficiency depends on a variety of design factors; however research has indicated that constructed wetlands are a cost effective practice for nitrate removal in both urban and agricultural regions (Lenhart et al., 2016; Groh et al., 2015; Iovanna et al., 2008; Kovacic et al., 2000). Research is needed to address the practical aspects of implementation, management and maintenance, including design methods for optimizing P removal efficiencies. Vegetation harvest is a method for enhancing P removal (Lenhart et al., 2016); however, there is insufficient data published on this topic to thoroughly establish its effectiveness. More research is needed on the ideal harvest timing to maximize nutrient extraction and which life forms (shrubs, grasses, or forbs) or plant species are best at removing nutrients, with the exception of a few well-studied species such as cattails (Lishawa et al., 2015). Similarly, use of species or mixes of species that lengthen the active plant transpiration season should be further studied.

Figure 2. Vegetation harvest in treatment wetlands can enhance phosphorus removal. In the wetland shown above, seasonal drying aids in the growth of wet prairie vegetation and plant harvesting in the fall prevents release of phosphorus in future years (photo by David Hansen).

The effect of landscape or watershed position on treatment performance is also poorly understood. For example, treatment wetlands placed in riparian corridors or depressions are more likely to receive groundwater discharge that may contain additional N affecting their performance. It needs to be determined what types of landscape positions, soil types, drainage-basin-to-wetland area ratios, and vegetation covers are best suited for treatment wetlands. Treatment wetland effectiveness is likely to vary by region in the upper Midwest, as there are likely to be differences between northern and southern areas in this regard. Even between northern Minnesota and much of the research done in southern Minnesota or Iowa, there are likely large differences due to the shorter growing season.

Lastly, additional research is needed to further quantify the long-term effectiveness and maintenance costs for continued nutrient reduction.

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Links

NRCS Conservation Practice Standard, Constructed Wetlands, Code 656
efotg.sc.egov.usda.gov/references/public/MN/656mn.pdf

NRCS Conservation Practice Standard, Wetland Creation, Code 658
efotg.sc.egov.usda.gov/references/public/MN/658.pdf

MDA Conservation Practice, Constructed Wetlands
www.mda.state.mn.us/protecting/conservation/practices/wetlandconst.aspx

The Nature Conservancy (TNC), Exploration of the use of treatment wetlands as a nutrient management strategy in Wisconsin.
www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/wisconsin/Documents/LubnerZiegler-treatment-wetlands-nutrient-manage.pdf

Wetland Restoration (657)

A restored wetland on the Kittleson property in Martin County, Minnesota. (Photo by C. Lenhart)

Definition and Introduction

Wetland Restoration re-establishes or repairs the hydrology, plant communities and soils of a former or degraded wetland that has been drained, farmed or otherwise modified since European settlement. The goal is to closely approximate the original wetland's natural hydrology and vegetation, resulting in multiple environmental benefits. Restoring wetland hydrology typically involves breaking drainage tile lines, building a dike or embankment to retain water and/or installing adjustable outlets to regulate water levels. Restored wetland plants usually include a mix of native water-loving grasses, sedges, rushes and forbs (broad-leaved flowering plants) in the basin or ponded area and a mix of native grasses and forbs in upland buffers around the basin. In Minnesota, the most commonly restored wetland types are depressional wetlands in the prairie pothole region of the state and floodplain wetlands along rivers and streams.

Wetlands are often restored for multiple purposes creating the need to balance sometimes conflicting goals and objectives. Restored prairie pothole wetlands provide breeding grounds for ducks, geese and other migratory waterfowl whose habitat has been greatly reduced. Waterfowl hunting groups supported much of the early wetland restoration work in the 1950s to provide habitat in place of prairie potholes being filled for agriculture (Galatowitsch & Van der Valk, 1998). Ducks Unlimited and others such as the US Fish and Wildlife Service and Minnesota DNR continue to promote wetland restoration for waterfowl and wildlife. Restoration projects that reduce habitat fragmentation by reconnection to larger complexes of wetlands are particularly valuable.

With the growth of TMDL studies in the late 2000s, interest in restoring wetlands for water quality increased greatly. Restored wetlands provide many of the same benefits as treatment wetlands, with the addition of typically being much larger and thus storing more water. Unfortunately there are trade-offs between managing for water quality treatment vs. wildlife and plant diversity. In short, discharge of large quantities of water, sediment and nutrients often leads to degradation of wetland habitat, eutrophication, loss of plant diversity and decreased value for some waterfowl species.

Water Quality and Other Benefits

Water quality is enhanced in wetlands by the collection and filtration of sediment, nutrients, pesticides and bacteria in runoff or subsurface drainage. Downstream flooding may be reduced through storage of water, particularly frequent floods (less than 10-year frequency) (Miller, 1999). Some wetlands may recharge groundwater supplies particularly in the fall and winter. Wetlands also help reduce soil erosion that would have occurred in bare farm fields by slowing overland flow and storing runoff water. Wetland plants utilize trapped nutrients while ponding restores soil organic matter levels and promotes carbon sequestration.

The type of restored wetland makes a large difference in its function and effectiveness (Mitch, 1992). For example, most wetlands restored in Minnesota are emergent marshes (Type 3-5 wetlands in the Minnesota Wetlands Conservation Act system). These are effective at storing water, removing sediment and reducing nutrient concentrations. Seasonal wetlands with less storage area may be less effective for reducing nutrient and water outflow.

There have been few detailed studies of water quality treatment by natural restored wetlands in Minnesota. The most detailed studies have been done at smaller constructed or treatment wetlands.

In Minnesota, the Kittleson and S.H.E.E.K. (an acronym for a group of local hunters who purchased the property) wetlands located southwest of Trimont, Minnesota, were two of the most studied restored wetland groups in the state (Lenhart, 2008; Fransen, 2012). Between 2005 and 2010, these wetlands were highly successful at reducing downstream flooding and removing nitrate-nitrogen (Table 1). However phosphorus (P) removal in the Kittleson and S.H.E.E.K. wetlands had mixed results and some organic matter was generated adding to TSS levels exiting the wetland (Fransen, 2012). P concentrations tend to be higher during the peak of runoff from storm events. P is oftentimes associated with sediment, so erosion during rain events tends to remove P along with the eroded sediment. During the summer when water levels are low and wetland sediments become anaerobic, P can be released from the wetland bed in soluble form.

Aside from the waterfowl and wildlife benefits discussed previously, wetlands can provide farmers with a land-use alternative to crops or livestock in wet marginal areas through programs like the Reinvest in Minnesota (RIM) and Wetland Reserve Program (WRP) or by growing hay or other water-tolerant crops. Wetlands may provide habitat for important pollinator species, such as bees, that many crops rely on. Aesthetics are often important for landowner acceptance and adoption.

Table 1: Restored wetland effectiveness

	TSS	Nitrate	Phosphorus
S.H.E.E.K. and Kittleson wetlands, Trimont, Minnesota (Lenhart 2008, Lenhart et al. 2010, Fransen 2012	>75%	>85%	0-50%
Wetlands in Iowa, Illinois and Maryland (Woltemade 2000)		68%	43%
Iowa CREP Wetlands (Crumpton and Stenback 2014)		26%	*
Willmar Discovery Farms, (Ranaivoson et al. 2013)		98%	*

*These wetlands were not designed to remove phosphorus; only nitrate removal was monitored

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Trapping: **Wetland Restoration**

Key Design/Implementation Considerations

In order for wetlands to be restored successfully there must be hydric soils, re-establishment of an appropriate hydrologic regime and hydrophytic vegetation. Since hydric soils already exist at restoration sites, reestablishment of hydrology is the key design goal in most wetland restoration projects. Establishing a hydrologic regime that mimics the pre-alteration site may require reestablishing flooding and variable water levels, not just a static pond (Middleton, 1999). Installation of a water control structure, such as an AgriDrain, allows for control of water level and drawdown.

Establishment of native species can be challenging in wetlands. Wetland vegetation will often re-colonize around the shallow wetland fringe, but not in deeper water initially. Drawdown of the wetland or seeding before flooding the basin may be necessary to achieve native vegetation establishment. Management of invasive species is a related major implementation and maintenance concern. Aggressive species like reed canary grass (*Phalaris arundinacaea*) and purple loosestrife (*Lythrum salicaria*) should be eliminated prior to flooding the site to improve species diversity. Hybrid cattail (*Typha x glauca*) can form monocultures that reduce plant diversity and habitat value.

Limitations

Nitrogen (N) removal efficiency can be limited in open water wetlands by lack of organic carbon needed for denitrification (Hernandez & Mitsch, 2007). Although done in constructed wetlands at Ohio State, the same principal should hold for restored wetlands. P removal can be reduced by a variety of factors. Often wetlands restored in former agricultural fields have high levels of P in the soil (Fransen, 2012). Sediment and P can be stirred up in open water wetlands by strong winds, common in the open prairie-pothole region of southern and western Minnesota. P can also be released from sediment at the wetland bottom during anaerobic conditions, which often occurs in shallow wetlands in late summer as water temperatures rise and oxygen is consumed. Fortunately this usually occurs during low water levels when less water is discharging from the wetlands.

Certain hydrologic patterns may be less than favorable for removing sediment and nutrients. If wetlands receive continually high levels of discharge, high oxygen levels may prevent or limit denitrification. Furthermore, the hydraulic loading rate is one of the primary determinants of nitrate removal due to high flows decreasing retention time and reducing the opportunity for denitrification (Stenback et al., 2014; Crumpton & Stenback, 2015). High levels of groundwater discharge may provide additional N, hindering effectiveness. Generally water levels are highest in the spring in Minnesota, so that wetlands leak the most nutrients in April-May and again in the fall when plants stop transpiring. It may be possible to draw down some wetlands in the fall to reduce water levels in the spring, enhancing their water quality treatment effectiveness.

Cost Information

The major costs with restored wetlands are buying the land or providing easement money. Secondly, construction and design costs may run into the $10,000s with the need for a water control structure to manage water levels. Maintenance costs tend to be less than for constructed wetlands because they are typically smaller, however there may be need to manage water levels by removing boards from the water control structure in both cases.

The Iowa Conservation Reserve Enhancement Program (CREP) is at the forefront in restoring wetlands across Iowa to treat nitrate. The average size of an Iowa CREP wetland is approximately nine acres; the total project cost for these wetlands averages at about $466,000. These costs include easements, design, construction, and CRP payments. While this total cost is higher than most BMPs, its cost per pound of nitrate treated is less than many other BMPs (Christianson et al., 2013; Crumpton & Stenback, 2015; Hyberg et al., 2015)

EQIP (USDA NRCS 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for incurred to restore a previously existing wetland may be eligible, such as land acquisition and easements, design, site preparation, excavation, construction, landscaping, stabilization structures and devices, water level control structures, inlets and outlets, waterways, exclusionary fencing, initial seeding, and vegetation plantings. To be eligible, the practice must attempt to restore pre-existing aquatic ecosystem and conditions.

Typical operation and maintenance expenses such as repairs, periodic over-seeding, fuel for management activities, weed control herbicides, periodic clean-out, water level adjustments, and practices with no water quality improvements are ineligible.

Table 2. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Component	Estimated Average Cost	Typical Units Installed	Estimated Total Installation Cost (rounded)
Depression Sediment Removal and Ditch Plug	$1,441.40/Acre	15	$21,600
Ditch Plug	$606.91/Plug	1	$610
Embankment	$7.40/Cubic Yard	250	$1,900
Riverine Levee Removal and Floodplain Features	$510.63/Acre	100	$51,100
Scrape, average depth 12'	$6,501.63/Acre	1	$6,500
Scrape, average depth 24'	$12,516.75/Acre	1	$12,500
Tile Break	$589.75 Each	1	$590

Barriers to BMP adoption

In agricultural lands of Minnesota, the high value of land and corn prices may limit adoption by farmers in the prevailing economy. Natural wetlands often require a larger land area than treatment wetlands currently making them less favorable. During periods of low crop prices it is much easier to get farmers to enroll in "land retirement" programs like the WRP and CRP. Efforts to develop markets for perennial crops that can be grown on marginally productive farmland have been slow to establish. In the future, if there were market-driven demand for wetland ecological services, BMP adoption may be increased. The permanent nature of wetlands makes them less popular than grass buffers or grasslands that are easily converted back to cropland when the farmer desires.

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Operation and Maintenance Considerations

Maintenance of restored wetlands is often less than constructed wetlands. However, management of water levels may be required at times. Managing invasive species may also be necessary.

Legal/Permit Requirements

Any work done on restoring a wetland shall not impact another's property or users of that water unless an agreement is reached by written letter, easement, or permit. Local laws must be followed when controlling noxious weeds and using seed from the correct distributors. Contact the local farm service agency, NRCS office, or conservation district for assistance with planning, regulations, and meeting EQIP requirements.

Local/Regional Requirements Design Example

In Minnesota wetland restoration has re-established thousands of acres in the past decade. Kloiber (2013) estimated that 2,030 acres of wetlands were restored in the state between 2006 and 2011 with an additional 1,360 acres gained by indirect expansion of existing wetlands through water level increases for a total gain of 3,390 acres. Most of these were natural, restored wetlands not intended directly for treating agricultural drainage or runoff. At the same time there was loss of 1,310 acres due to development encroachment, filling or indirect shrinking of existing wetlands due to hydrologic or climatic shifts. Johnston (2013) found a greater loss of wetlands due to conversion to row crop agriculture in the prairie pothole region of south central to western Minnesota, although she did not account for increases due to wetland and pond construction.

The State of Iowa developed the CREP program to restore wetlands for the purpose of removing N from farmland drainage and runoff to help reduce the Gulf of Mexico Hypoxia problem. Targeting low-lying areas in-line with the public ditch systems, impoundments were built to restore wetlands that cover at least 1% of the contributing drainage area. This ratio of wetland to watershed area was selected as the optimal balance to maximize the amount of N removed given cost and logistical considerations. As of the fall of 2015, there have been 83 wetlands restored through the Iowa CREP funding with 12 more under development heading into 2016. Iowa CREP has partner with many other programs to develop these wetlands. Some of the partnerships are with the Water Quality Initiative Program, Boone River Water Quality Project, Ducks Unlimited, The Nature Conservancy, Iowa Department of Agriculture and Land Stewardship, Lake Panorama Association, and other local, state, and federal programs (Crumpton & Stenback, 2015).

Research gaps

There is a need for additional research quantifying the effectiveness of wetland restoration for improving water quality. More specifically, the results would guide the prioritization of wetland restoration projects to maximize hydrologic storage and water quality benefits. Additionally, a Cost-Benefit analysis is necessary to determine what factors drive up costs, what factors make wetland restoration more feasible, and what landscape positions/geographic locations are best suited for restoration.

There could be further research into wetland design and management strategies that would make water quality treatment and wildlife habitat restoration more compatible. This may include design features such as multi-cells or sediment forebays to remove sediment before entering the wetland and water level management to maximize storage and promote emergent plant growth.

Certain types of wetlands are rarely restored, particularly shallower types such as wet prairies and sedge meadows. There is not a good understanding of what hydrologic functions these wetlands previously performed that we may now be missing from our set of agricultural BMPs. For example, wetlands higher in the landscape typically provide

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groundwater recharge. Additional research is needed on siting wetlands within watersheds to optimize water storage capacity and the removal of nitrate, sediment or P.

The Minnesota BWSR (2012) listed numerous research needs involving vegetation establishment, management and monitoring in restored wetlands. In summary they suggest that more research is needed on the rate of cover crop application in wetland seed mixes, the effectiveness of different planting techniques and the timing of planting. More research is needed on invasive species control, particularly for reed canary grass and Canada thistle, the role of burning in wetland management, and the role of biodiversity in reducing invasions and subsequent maintenance needs.

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Links

Minnesota BWSR, Wetland Restoration Guide www.bwsr.state.mn.us/restoration.

NRCS Conservation Practice Standard, Wetland Restoration, Code 657
efotg.sc.egov.usda.gov/references/public/MN/657_MN_Wetland_Restoration_2017.pdf

Status and Trends of Wetlands in Minnesota: Wetland Quantity Trends from 2006 to 2011
files.dnr.state.mn.us/eco/wetlands/wstmp_trend_report_2006-2011.pdf

Trapping: **Wetland Restoration**

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Denitrifying (Woodchip) Bioreactor (605)

Bioreactor installation in Nicollet County, Minnesota. (Photo by C. Lenhart).

Definition and Introduction

Bioreactors are practices that utilize a carbon source, commonly woodchips, to support the removal of nitrate-nitrogen from subsurface agricultural tile drainage.

Woodchip bioreactors have been identified as one means of removing nitrate from subsurface drainage water. They remove nitrate by the process of denitrification. Under anaerobic conditions, bacteria use carbon from the woodchips in their conversion of nitrate to nitrogen (N) gas. Advantages of denitrification beds are relatively high rates of nitrate removal, small footprints, minimal maintenance during the design life, and low installation costs.

The large majority of woodchip bioreactors used in agricultural subsurface drainage applications are the denitrification bed type. Typically a trench of 5- to 25-foot width and dozens of feet long is plumbed with an inlet and outlet manifold and filled with woodchips. Another bioreactor design is known as a denitrification wall. These walls are trenches filled with woodchips buried 1-2 meters (3.3 to 6.6 ft) into groundwater flow with the intent of removing nitrate from groundwater as it moves toward a tile or ditch rather than from tile drainage. Walls have been evaluated and have shown promise, but installation is challenging and removal rates are lower than those of beds. However, trenches filled with sawdust performed well in Iowa (Jaynes et al., 2008; Moorman et al., 2010; Schmidt & Clark, 2012; Addy et al., 2016)

Water Quality Effects

Woodchip bioreactors have been shown to reduce average annual nitrate loadings in the range of 30 to 45% in field studies in Illinois (Woli et al., 2010) and Iowa (Christianson, 2011; Christianson, Bhandari, et al., 2012). Christianson et al. (2013) list bioreactor nitrate removal as 37.5% on average in the Midwest. Nitrate removal rates are primarily governed by temperature, influent nitrate concentration, and hydraulic residence time. The percent load removal varies widely and can be 90+%. There is limited documentation in peer-reviewed literature of phosphorus removal in woodchip bioreactors, although substantial reduction has been measured in one instance (Ranaivoson et al., 2012). One recent study also recorded 71% reduction of total phosphorus by coupling a woodchip filter with a sediment settling tank in order to remove the particulate phosphorus associated with sediment (Choudhury et al., 2016). Increased dissolved carbon concentrations exiting bioreactors have been measured upon start up, but concentrations drop after the first year of operation (Robertson, 2010; David et al., 2016). Gaseous nitrous oxide (N_2O) emissions from bioreactor beds appear to be minimal (David et al., 2016); however, field measurements of nitrous oxide dissolved in the effluent are lacking.

Key Design/Implementation Considerations

The Natural Resources Conservation Service (NRCS) recently established a national design standard for denitrifying bioreactors, Code 605. It provides design guidelines and considerations, as well as operation and maintenance activities (USDA NRCS 2015).

The bioreactor capacity is designed to treat a portion of the estimated peak or annual flow of the drainage system and to maintain a minimum hydraulic residence time of three hours based on the NRCS Code. The bioreactor inlet and outlet manifolds need to extend from edge-to-edge of the bed walls to prevent dead spots. Inlet and outlet structures permit control of the water table in the bed such that anaerobic conditions are maintained. Water should have a maximum retention time of 48 hours when the tile drain is no longer flowing in order to prevent the water within the bioreactor from being left stagnant.

Bioreactor longevity is heavily dependent on maintaining anaerobic conditions. Periodic drying cycles could shorten the life of a bioreactor to less than 10 years while those maintaining anaerobic conditions should remain effective for approximately 20 years or more, depending on environmental conditions.

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Selection of a carbon source is important. Most research has focused on using wood products as a carbon source in bioreactors. Cooke et al. (2001) experimented with corn oil and methanol, as well as ground up corn cobs, but found wood chips to be superior. Greenan et al. (2006) found that soybean oil added to wood chips increased denitrification over wood chips alone. Feyereisen et al. (2016) reported that the nitrate removal rate for corn cobs was higher than for woodchips, including at temperatures near freezing.

When using woodchips, it is important to use chips with little to no dirt, debris, twigs, and leaves in the mix. Municipal yard waste is to be avoided (Christianson, Hoover et al., 2012). Tree species with high tannin content, such as oak or cedar, or wood that has been treated should be avoided. Wood chips should contain a relatively small portion of fines otherwise they will slow the rate of flow.

Cost Information

The cost of denitrification beds depends on size. Christianson et al. (2013) lists these items for consideration:

- Control Structures. If a high degree of control over applied hydraulic head is desired, a gated control structure can be installed at a cost of approximately $500-2,000 per structure.
- Contractor fees. Due to the precision required in digging some of these structures, some skill and time is necessary. Rates range from $35/hr to $125/hr.
- Amount of woodchips, cubic yards (CY). Good quality, clean woodchips may cost as much as $35/CY plus transport costs. Some money can be saved here if good woods chips are available on site.
- Pipe, seed, and accessories. These items should be a relatively small cost, but important part of the project.

Christianson et al. (2013) estimate the total costs for installation will be approximately $82.23-183.87

per acre in the watershed being treated. The total cost of establishment, maintenance, and replacement over a 40-year projection is estimated to be between $124 and $258 per acre being treated.

EQIP (USDA NRCS, 2017) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or installation of treatment systems that reduce nitrate in surface and subsurface drainage may be eligible. Eligible cost include expenses such as land acquisition or easements, design, site preparation, excavation, installation, initial materials for the reactor substrate, control structures, inlets and outlets, waterways, exclusionary fencing, initial seeding, and vegetation plantings.

Typical operation and maintenance expenses of the treatment system such as site maintenance, water testing, water level control changes, and partial or periodic replacement of media is ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2017 estimates.

Design Configuration	Estimated Average Cost/Cubic Yard of woodchips	Typical Units Installed	Estimated Total Installation Cost (rounded)
Bioreactor With Soil Cover	$63.97	200	$12,800
Bioreactor Without Soil Cover	$43.99	340	$15,000

Operation and Maintenance Considerations

The life of bioreactors is not known with certainty at this time but research indicates it is approximately 20 years until the woodchips need replacement if the bioreactors are maintained properly (Moorman et al. 2010; Christianson et al. 2013). Periodic water sampling from the inlet and outlets of a bioreactor is typically necessary to determine if a bioreactor is still functioning. The two main factors affecting longevity of this practice are a sufficient supply of carbon substrate and adequate hydraulic conductivity through the media. Board levels within the water control structures need to be adjusted to maintain saturation to the top of the woodchips at the inlet and to obtain the desired hydraulic residence time.

Legal/Permit Requirements

Since woodchip bioreactors have a relatively small footprint, it is unlikely that a storm water discharge permit would be required.

If the bioreactor is part of a Minnesota public drainage system, the drainage authority may have some requirements.

If placed next to a stream or ditch, the Minnesota Buffer Law should be consulted. The Minnesota Buffer Law was adopted in 2015 and requires buffer strips or alternative riparian water quality practice(s) along state public waters and publicly administered drainage ditches. The applicable watercourses and water bodies are identified on the Minnesota DNR Buffer Protection Map and implementation guidance is available on the BWSR Buffers webpage. These requirements should be considered when designing riparian management practices in the applicable areas.

Trapping: **Denitrifying (Woodchip) Bioreactor**

Local/Regional Design Examples

Two bioreactors were installed near Granada in Martin County in 2012. These bioreactors treat 18-acre and 13-acre watersheds. They are 176 and 143 cubic yards, respectively.

A woodchip bioreactor was constructed in 2009 on a failing county ditch in Kandiyohi County. The drainage area to the bioreactor is 5.7 acres. The bioreactor is 9.5 feet wide, 30 feet long and 2.5 feet deep (26 cubic yards). A hydraulic residence time of 7.5 hours was estimated. Limited sampling indicates a N reduction ranging from 10 to 94%. Construction cost was $2,934.

Stevens County – The West Central Research and Outreach Center near Morris, Minnesota, constructed a 60 x 20 x 5 foot woodchip bioreactor at the tile outlet of a 14-acre field. The bioreactor was constructed in 2012 and showed substantial reductions of nitrate in the first few years when the flow rate was less than 10,000 gallons per day. Results have not been published, but reductions were as much as 85% during some flow events (Nelson 2014).

Faribault County – A unique three-cell bioreactor was constructed in early 2016. The drainage area is 680 acres. As drainage flow exceeds capacity of the first cell, overflow enters the second cell, etc. The installation is a test for re-thinking bioreactor placement: many small edge-of-field units versus fewer, larger "community" units.

Research Gaps

Research at multiple sites and labs in Minnesota is now focusing on the potential for bioreactors to reduce dissolved phosphorus as well as nitrate. These bioreactors would utilize other forms of media from gravel to live plants growing above the reactors. Recent lab research showed that addition of a liquid carbon source greatly enhanced nitrate removal at low temperatures. The concept is now being field tested. Furthermore, research is underway on the use of biochar and other forms of carbon including agricultural residue to improve the rate of denitrification in bioreactors (Zhang and Magner 2014; Bock et al. 2016; Feyereisen et al. 2016). A sample of the latest research on denitrifying bioreactors was published in a special collection in the Journal of Environmental Quality in 2016, Volume 45, No. 3.

There is potential for microbial contaminant reductions through the use of bioreactors (Rambags et al. 2016). These authors mention that additional research of the expanded use of bioreactors for wastewater treatment is warranted.

As Schipper et al. (2012) point out, there is very little long-term data collected regarding hydraulic conductivity of bioreactors. Research has been focusing on this variable in recent years and will continue in order to improve the effectiveness of bioreactors. The efficiency of aging denitrifying beds is also a key research need (Addy et al. 2016). Furthermore, little is yet known about how bioreactors constructed for removal of other contaminants age or change in removal efficiency of each contaminant.

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Links

NRCS Conservation Practice Standard, Denitrifying Bioreactor, Code 605
efotg.sc.egov.usda.gov/references/public/MN/605_Denitrifying_Bioreactor_Sept2016final.pdf

University of Minnesota, Department of Soil, Climate and Water: Nature's Filter
www.swac.umn.edu/bioreactor

University of Illinois-Extension, web.extension.illinois.edu/bioreactors/nitrate-removal.cfm

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Saturated buffers (604)

Saturated buffer alongside a corn field. (Photo by Nathan Utt).

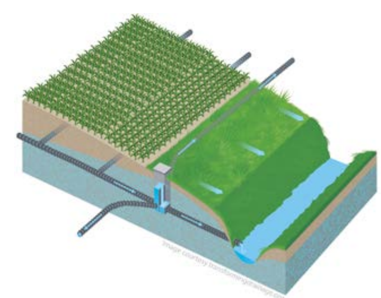
Definition and Introduction

A saturated buffer is a practice where subsurface (tile) drainage water is diverted and spread into the subsoil beneath a vegetated riparian area via a diversion structure and perforated subsurface pipe. The water moves laterally through the subsoil toward a stream or ditch. The primary purpose is to reduce nitrate loading to surface water from subsurface drain outlets and slow the movement of water towards the stream.

Saturated buffers are a relatively new BMP for treating agricultural subsurface drainage. Research is still guiding the design criteria; therefore, most of the information summarized below is based on the NRCS Practice Standard 604 with additional input from the developing researchers.

Unlike filter strips (NRCS Standard #393), field borders (#386) or riparian vegetation cover (#390) which are designed to intercept surface runoff, saturated buffers treat subsurface drainage water by routing it through the subsoil of the riparian buffer.

Figure 1. Saturated buffers store water within the soil of field buffers, by diverting tile water into shallow laterals that raise the water table within the buffer and slow outflow.



This creates saturated conditions and stores or slows the flow of the drainage water in the ground where nutrients can be removed within the buffer by plant uptake, microbial immobilization, or denitrification (Jaynes & Isenhart, 2014).

Water Quality and Other Benefits

The system should be designed to maximize the amount of subsurface drainage water distributed to the buffer subsoil. When the buffer reaches hydraulic capacity, the remaining flow must be diverted past the buffer to avoid impeding field drainage. Research by Jaynes and Isenhart (2014) found that over two years about 55% of the total flow coming from a tile outlet draining a 25-acre field was directed into the buffer for treatment. However, the percent of water diverted may vary widely based on field size and buffer capacity.

Research quantifying the effectiveness of this practice is ongoing and data documenting the nutrient reduction potential has been inconsistent due to variations in installation and design. Results are indicating that when the saturated buffers are properly sited and design criteria are met, they have great potential for serving as an effective method for reducing nitrate transport from subsurface drainage systems (Jaynes & Isenhart, 2014; Utt et al., 2015). For example, Christanson et al. (2016) found a 60% reduction in total nitrogen (N) load from a saturated buffer along Bear Creek near Story City, Iowa.

Since the water delivered to a saturated buffer is from sub-surface drainage water, which tends to be lower in suspended sediment and total phosphorus compared to surface runoff, they are designed primarily as a nitrate removal practice. Field measurements have been inconclusive regarding the potential as a practice for phosphorus removal (Utt et al., 2015).

Key Design/Implementation Considerations

Design considerations include the slope of the buffer and the bank, bank stability, and elevation difference between the distribution line and the stream. The system should be located and setup to maximize the amount of subsurface drainage water distributed to the saturated buffer. Without any adverse impacts to adjacent properties. Due to saturation of the bank the distribution pipe should not be placed along any channels deeper than eight feet, unless a slope stability analysis shows an acceptable level of safety against saturated streambank failure.

For saturated buffers to effectively reduce nitrate loads, the subsoil must have a sufficient soil carbon content (more than 0.75%) to encourage growth of denitrifying bacteria and the water table must periodically submerge the high carbon soil layer to create anaerobic conditions to encourage denitrification (Jaynes & Isenhart, 2004; Utt et al., 2015). Presence of a gravel layer or evidence of unsaturated condition may indicate that the site is unsuited for the necessary anaerobic environment.

The NRCS standard (code 604) for this practice provides more detailed guidance on buffer width, design of the diversion control structure, distribution and overflow pipes, as well as bank stabilization and other considerations. Since it is a relatively new practice the design guidelines are still evolving. Consult NRCS practice code 604 for the most up-to-date guidance.

Cost Information

Estimates from Iowa indicate that construction costs are commensurate with tile installation and control structure installation. Design work would be an additional cost. For cost-effectiveness, consider a location where the subsurface system receives drainage from at least 15 acres.

Installation costs may vary depending on system outline, installation depth, installation method, equipment relocation fees etc. Installing the saturated buffer as part of installing the rest of the drainage system often reduces the cost. Costs are listed as $3,000 to $5,000 for the water control structure and $10-12 per linear foot of tile pipe installed to spread water (Lewandowski et al., 2015) on the high side, and as little as $1,000 for the control structure and $0.33 per linear foot of drain tile (Jaynes & Isenhart, 2014). Utt et al. (2015) found lower costs, with totals ranging from $3,000 to $5,000 for 15 Midwestern projects.

Financial assistance is available through EQIP but the pipe and control structure may not be installed within a CRP buffer (USDA NRCS, 2015). If EQIP funding is not utilized, then these components may be placed in a CRP buffer. Saturated buffers may be installed in the new Minnesota state-mandated 50-foot buffers along public waterways.

EQIP (USDA NRCS 2016) provides payments ranging from 50-90% of the average cost to complete the work. The EQIP percentages vary from year to year, by applicant, and by region. For more information regarding funding and payment schedules, contact a local NRCS Field Office.

Capital expense for installation of these practices are eligible under the AgBMP Loan Program and may be coordinated with financing from state and federal cost share grants and incentives.

Under this BMP category, capital expenses for purchases or installation of saturated buffers and other practices that reduce nitrate or slows the rate of discharge from surface and subsurface drainage may be eligible. Eligible cost include expenses such as land acquisition or easements, design, site preparation, excavation, installation, pipe, control structures, inlets and outlets, waterways, exclusionary fencing, initial seeding, and vegetation plantings. Saturated buffers may be a component of a riparian buffer practice.

Typical operation and maintenance expenses of the treatment system such as site maintenance, and clearing of obstructions is ineligible.

Table 1. Estimated average statewide conservation practice costs. Average costs change each year. Updated estimates can be found at efotg.sc.egov.usda.gov. This table provides the 2016 estimates.

Component	Estimated Average Cost/ Foot	Typical Units Installed	Estimated Total Installation Cost (rounded)
Saturated Buffer	$6.70	400	$2,680

Operation and Maintenance Considerations

An operation and maintenance (O&M) plan should be developed following the Drainage Water Management (554) conservation practice standard. An O&M plan should consider water level management and timing, inspection and maintenance of both the control structure and drain tile, and vegetation management to minimize line plugging. As long as the system is designed and installed properly, maintenance should be minimal compared to practices such as bioreactors or controlled drainage that require water level management throughout the growing season.

Legal/Permit Requirements

A permit for soil disturbance may be required through the NPDES program if one or more acres are expected to be disturbed. The local drainage authority may also be involved if significant changes to hydrology are anticipated. It is recommended that the Soil and Water Conservation District be involved in design, permitting, and implementation of this conservation practice.

Local laws must be followed when controlling noxious weeds and using seed from the correct distributors. Burn permits are also required if the area is to be managed by burns. Contact the local farm service agency, NRCS office, or conservation district for

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Trapping: **Saturated buffers**

assistance with planning, regulations, and meeting EQIP requirements.

In addition, the Minnesota Buffer Law was adopted in 2015 and requires buffer strips or alternative riparian water quality practice(s) along state public waters and publicly administered drainage ditches. The applicable watercourses and water bodies are identified on the Minnesota DNR Buffer Protection Map and implementation guidance is available on the BWSR Buffers webpage. These requirements should be considered when designing BMPs in riparian areas.

Local/Regional Requirements Design Example

A saturated buffer was constructed on a farm in Wilkin County located in the Red River basin in west central Minnesota as an MDA Clean Water Fund technical assistance project. The Red River Valley Drainage Water Management project has served as a demonstration for innovative subsurface drainage practices in Minnesota.

The Utt et al. (2015) report lists additional saturated buffer sites in Minnesota and nearby Midwestern states. Three sites are located in Dodge County, Minnesota, northeast of Austin, and have been used for field trips.

Research Gaps

The saturated buffer is a newer practice and the first research study was published in 2014; therefore, additional research is needed to quantify the water quality benefits of the practice and to better understand design criteria. Establishing their nitrate removal efficiency in Minnesota is yet to be determined. Since data has been inconclusive regarding the potential for saturated buffers to remove phosphorus, more research should be explored including the implications of buffer management.

Currently there is limited design and planning guidance for the proper implementation of saturated buffers; research to inform water managers on siting and design parameters to prevent failure and increase effectiveness is necessary. This will lead to a better understanding of water management through the system to promote denitrification and nutrient uptake and inform the question regarding their cost-effectiveness.

A saturated buffer is a BMP that holds great promise to effectively reduce nitrate exports through subsurface drainage systems; however, because of the many considerations that enter into design such as soil conditions and infiltration rates, hydrology and drain flow rates, and land slope and proximity to receiving waters, development of engineering design guidelines is needed.

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Fields to Streams, University of Minnesota-Extension

Transforming Drainage.org, Saturated Buffers website: transformingdrainage.org/practices/saturated-buffers

Red River Valley Drainage Water Management project; http://www.mda.state.mn.us/protecting/cleanwaterfund/onfarmprojects/rrvdwmproject.aspx

Trapping: **Saturated buffers**

Appendix A: Minnesota and Upper Midwest BMP Matrix

Minnesota and Upper Midwest BMP Matrix

This resource matrix was compiled from empirical studies of BMP effectiveness in Minnesota and the Upper Midwest.

Table 1. Upper Midwest and Minnesota BMP Research

AVOIDING								
BMP	**Turbidity/Sediment**	**Phosphorus**	**Soluble Phosphorus**	**Nitrogen/Nitrates**	**Ammonia**	**Pesticides**	**Bacteria**	**Dissolved Oxygen**
Conservation Cover (327)	Christenson et al., 2009, Asbjornsen et al. 2013	Christensen and Kieta 2014; Williamson et al. 2014	Daigh et al. 2015)	Christenson et al., 2009; Randall et al., 1997; Huggins et al., 2001				
Conservation Crop Rotation (328)		Tomer and Liebman 2014, Smith et al., 2015	Smith et al., 2015	Huggins et al.,2001; Randal et al., 1997; Randal et al., 1993; Oquist et al., 2007, Tomer and Liebman 2014, Gaudin et al. 2015				
Contour Buffer Strips (332)	Arora et al., 1996			Pérez-Suárez et al. 2014, Mitchell et al. 2015, Ssegane et al. 2015		Arora et al., 1996		
Contour Farming (330)								
Cover Crops (340)		Nater et al. 2012, Maltais-Landry et al. 2015	Tank and Willows 2016	Logsdon et al., 2002,Feyereisen et al., 2006; Strock et al., 2004 Kaspar, 2008; Kaspar et. al, 2007; Jaynes et al., 2004; Kladivko et al. 2014, Tank et al. 2017				
Grade Stabilization (410)	Wilson et al. 2008, Thomas 2009							
Access Control/Fencing (382 and 472)	Tufekcioglu et al. 2013, Line 2015	Line 2015			Line 2015			
Nutrient Management (590)	Gilley and Risse, 2000Baker and Laflen, 1982; Baker and Laflen, 1983; Komiskey et al., 2011 Bundy et al., 2001	Ginting et al., 1998Baker and Laflen, 1982; Baker and Laflen, 1983; Bundy et al., 2001; Grande et al., 2005; Komiskey et al., 2011; Mallarino and Bundy, 2008; Tabbara 2003, King et al., 2015, Fawecett, n.d.	Gessel et al., 2004; Ginting et al., 1998Baker and Laflen, 1982; Baker and Laflen, 1983; Bundy et al., 2001; Grande et al., 2005; Komiskey et al., 2011; Mallarino and Bundy, 2008, King et al., 2015	Randall and Sawyer, 2008; Randall et al., 2003; Randall et al., 2002 Randall and Vetsch, 2005; Randall et al., 1993Baker and Laflen, 1982; Baker and Laflen, 1983; Baker and Johnson, 1981; Dolan et al., 1993; Randall et al. 1993, Jaynes and Colvin, 2006; Randall and Mulla 2001, Randall and Sawyer, 2008, Komiskey et al., 2011; Thoma et al. 2005, Thorp et al., 2007, Nangia et al. 2008, Christianson and Harmel 2015, Rubin et al. 2016, Struffert et al. 2016, MDA 2015	Baker and Laflen, 1982; Baker and Laflen, 1983; Komiskey et al., 2011			
Pest Management (595)						Buhler, 1993; Hansen et al., 2001, Bale et al. 2008, Radcliffe et al. 2009		
Tile System Design				Randall and Mulla 2001, Sands et al. 2003				

CONTROLLING								
BMP	**Turbidity/Sediment**	**Phosphorus**	**Soluble Phosphorus**	**Nitrogen/Nitrates**	**Ammonia**	**Pesticides**	**Pesticides**	**Dissolved Oxygen**
Alternative Tile Intakes	Gieseke, 2000; Oolman and Wilson, 2003; Ranaivoson, 1999; Wilson et al., 1999, Feyereisen et al. 2015	Ranaivoson, 1999; Wilson et al., 1999, , Smith and Livingston 2013, Feyereisen et al. 2015	Ranaivoson, 1999;	Smith and Livingston 2013				
Contour Stripcropping (585)	Hays and Bell 1949							
Controlled Drainage (554)		Feset et al., 2010	Feset et al., 2010	Feset et al., 2010; Luo et al., 2010; Singh et al., 2007ADMC, 2011, Skaggs et al. 2012, Ross et al. 2016				
Culvert Sizing / Road Retention / Culvert Downsizing	-	-	-	-				
Grassed Waterways	Arora et al., 2003; Dermsis et al., 2010, Helmers et al. 2008	Helmers et al. 2008	Ippolito et al. 2014			Arora et al., 2003		
Irrigation Management (442 and 449)				Sexton 1996, Derby et al. 2009				
Waste Storage Facility (313)								
Conservation Tillage (329, 345 and 346)	Ginting et al., 1998; Moncrief et al., 1996; Bundy et al., 2011; MWPS, 2000	Ginting et al., 1998; Moncrief et al., 1996; Andraski et al., 2003; Andraski et al. 1985; Bundy et al., 2011; Fawcett and Smith, 1999; Grande et al. 2005; Kanwar and Baker, 1993	Andraski et al., 1985, Andraski et al., 2003	Kanwar and Baker, 1993; Li et al. 2015				
Riparian and Channel Vegetation (322/390)				Yamada et al. 2007				
Prescribed Grazing (528)	Tufekcioglu et al. 2012; Tufekcioglu et al. 2013	Tufekcioglu et al. 2012; Tufekcioglu et al. 2013					Wagner et al. 2012	
Terrace (600)	Hays, and Bell, 1949							
Two Stage Ditch	Powell et al. 2007a; Krider et al. 2016a			Roley et al. 2012				
Feedlot/Wastewater Filter Strip (635) and Clean Runoff Water Diversion (362)	Young et al., 2006	Young et al., 2006	Young et al., 2006	Young et al., 2006			Young et al., 2006	

TRAPPING								
BMP	**Turbidity/Sediment**	**Phosphorus**	**Soluble Phosphorus**	**Nitrogen/Nitrates**	**Ammonia**	**Pesticides**	**Bacteria**	**Dissolved Oxygen**
Filter Strips (393) and Field Borders (386)	Arora et al., 2003; Arora et al., 1996; Blanco-Canqui et al., 2004; Schmitt et al., 1999 Udawatta et al., 2002	Blanco-Canqui et al., 2004; Eghball et al., 2000; Rickerl et al., 2000; Udawatta et al., 2002; Webber et al., 2009	Blanco-Canqui et al., 2004; Rickerl et al., 2000; Schmitt et al., 1999	Arora et al., 1996; Blanco-Canqui et al., 2004; Eghball et al., 2000; Rickerl et al., 2000; Schmitt et al., 1999; Udawatta et al., 2002	Blanco-Canqui et al., 2004; Udawatta et al., 2002	Arora et al., 1996	Arora et al., 2003	
Sediment Basin (350)								
Grade Stabilization at Side Inlets (410)	Krider et al. 2014							
Water and Sediment Control Basin (638)	Mielke (1985)							
Constructed (Treatment) Wetlands	Axler et al. 2001; Kadlec and Wallace 2008, Lenhart et al. 2016	Kadlec and Knight 1996,Mitsch and Fink 2001, Axler et al. 2001, Kadlec and Wallace 2008; Lenhart et al. 2016	Mitsch and Fink 2001, Kadlec and Wallace 2008, Lenhart et al. 2016	Kadlec and Knight 1996, Kovacic et al., 2000, Mitsch and Fink 2001, Crumpton et al. 2008, Kadlec and Wallace 2008, Lenhart et al. 2016	Kadlec and Wallace 2008			Axler et al. 2001
Wetland Restoration (651)	Lenhart 2008; Fransen 2012	Woltemade 2000, Lenhart 2008; Fransen 2012	Woltemade2000, Lenhart et al. 2008, Fransen 2012	Woltemade 2000, Lenhart 2008; Fransen 2012, Ranaivoson et al. 2013, Crumpton et al. 2014, Crumpton et al. 2105				
Denitrifying Bioreactor		Ranaivoson et al., 2012	Ranaivoson et al., 2012	Jaynes et al., 2004; Jaynes et al., 2007, Woli et al., 2010; Christianson et al., 2011; Christianson et al., 2012a; Christianson et al., 2013; Ranaivoson et al., 2012; Feyereisen et al., 2016		Ranaivoson et al., 2012	Ranaivoson et al., 2012	
Saturated Buffer		Utt et al., 2015		Jaynes and Isenhart, 2014; Utt et al., 2015; Christianson et al., 2016				

Appendix B: Other BMP Research From National Sources and Modeling

Many national sources of information regarding effectiveness of agricultural BMPs exist. The following chapter presents research conducted on BMPs outside of Minnesota and the Upper Midwest, selected modeling studies and compilations of BMP effectiveness from national sources. This information may or may not be applicable to Minnesota and Upper Midwest due to climatic, crop and soil differences. This chapter aims to capture much of the important national research and modeling information that didn't fit the criteria for inclusion in the BMP chapters. This chapter follows the same order as the BMP chapters and is separated into avoiding, controlling and trapping.

Avoiding

Conservation Cover

No additional commentary.

Conservation Crop Rotation

The impacts of conservation crop rotation on erosion and phosphorus (P) loss are likely due primarily to the benefit of having the land in perennials for the year. National sources (Merriman, 2009) list the pollutant reduction of sediment and TP as 72% and 60%, respectively, although the relevance of this figure to Minnesota has not been shown.

Study in northern Indiana used in Buffer Alternative practices

Table 1. Pollutant reduction estimates in percent for contour buffer strips.

Pollutant	Mean	Minimum	Maximum	Number of Entries	Number of Entries	Source
Total Sediment	78%	30%	94%	20	12	1, 2, 3
Total Phosphorus	62%	49%	80%	11	10	2, 3
Dissolved Phosphorus*	34%	20%	50%	11	9	2, 3
Total Nitrogen	36%	27%	50%	8	8	3
Dissolved Nitrogen	31%	18%	49%	31	8	3
Fecal Coliform	59%	43%	74%	22	2	1

1 – Coyne et al., 1995
2 – Daniels and Gilliam, 1996
3 – Schmitt et al., 1999
* an outlier in Daniels and Gilliam, 1996 was excluded from the dataset; it reported a 240% increase in dissolved phosphorus in one case

Contour Buffer Strips

Contaminant reductions are provided in Table 1, which are results of several studies having drainage area to buffer strip area ratios within or near the strip width specifications of NRCS 2007 standards for contour buffer strips (Code 332). Reported results are from two simulated rainfall studies (Coyne et al., 1995; Schmitt et al., 1999) and a North Carolina field trial (Daniels and Gilliam, 1996).

Iowa Strips

Contour Farming

Water quality models that compare sediment basins, terraces, filter strips, stripcropping, no till conservation practices, and contour farming have demonstrated that contour farming has the poorest performance in terms of sediment, total P, and total nitrogen (N) reduction (Hamlett and Epp, 1994). Contour farming has mean reductions in sediment delivery of approximately 10% to 40% at three sites compared to the baseline. Reductions in total P were higher and more comparable to stripcropping, having mean reductions in total P of approximately 30 to 80% compared to the baseline. Across each of the three field sites, total N reductions were relatively consistent at around 10% compared to the baseline, and again performing poorest among the pool of BMPs analyzed. Since these reported values are a comparison to reductions under baseline conditions, actual percent reductions in sediment delivery are higher. The additional implementation of waterways with contour farming improves sediment, total P and total N reductions compared to the baseline as much as 40%, 25%, and 25%, respectively.

The mean total sediment reduction for contour farming is 43% based on a database developed for estimating BMP effectiveness in Arkansas (Merriman et al., 2009). Contaminant reductions from a SWAT modeling study are provided in Table 2 (Tuppad et al., 2010).

Table 2. Pollutant reduction estimates in percent for contour farming (Tuppad et al., 2010).

Pollutant	Mean	Minimum	Maximum
Total Sediment	59	28	67
Total Phosphorus	42	10	62
Total Nitrogen	50	25	68

Cover Crops

See Table 3.

Grade Stabilization Structure

No additional commentary.

Livestock Exclusion

No additional commentary.

Nutrient Management

No additional commentary.

Pest Management

No additional commentary.

Tile System Design

No additional commentary.

Table 3. Summary of percent reduction in Nitrate leaching due to use of cover crop. (adapted from Kaspar, 2008)

Reference	Location	Cover Crop	Reduction in N Leaching
Morgan et al., 1942	Connecticut, U.S.	Rye	66%
Karracker et al., 1950	Kentucky, U.S.	Rye	74%
Nielsen and Jensen, 1985	Denmark	Ryegrass	62%
Martinez and Guirard, 1990	France	Ryegrass	63%
Staver and Brinsfield, 1990	Maryland, U.S.	Rye	77%
McCracken et al., 1994	Kentucky, U.S.	Rye	94%
Wyland, et al., 1996	California, U.S.	Rye	65% to 70%
Brandi-Dohrn et al., 1997	Oregon, U.S.	Rye	32% to 472%
Ritter et al., 1998	Delaware, U.S.	Rye	30%
Kasper et al., 2007	Iowa, U.S.	Rye	61%
Strock et al., 2004	Minnesota, U.S.	Rye	13%

Reference	Location	Cover Crop	Reduction in N Leaching
Kladivko et al., 2004	Indiana, U,.S.	Winter wheat + less fertilizer	61%

Table 4. Summary of percent reduction in total phosphorus due to use of cover crop. (adapted from Kaspar, 2008)

Reference	Location	Cover Crop	Reduction in Total P Losses in Runoff
Angle et al., 1984	Maryland, U.S.	Barley	92%
Langdale et al., 1985	Georgia, U.S.	Rye	66%
Pesant et al., 1987	Quebec, Canada	Alfalfa/timothy	94%
Yoo et al., 1988	Alabama, U.S.	Wheat	54%

Table 5. Pollutant reduction estimates in percent for contour stripcropping (Merriman et al. 2009; Gitau et al. 2005).

Pollutant	Mean	Minimum	Maximum	Standard Deviation	Number of Entries in Database	Source
Total Sediment	77%	43%	95%	20	5	1
Total Phosphorus	44%	8%	93%	25	22	1, 4, 5, 6
Dissolved Phosphorus	45%	20%	93%	28	5	7, 8
Particulate Phosphorus	60%	43%	76%	11	11	7, 8, 9
Total Nitrogen	37%	20%	55%	25	2	1,2,3

1 – Cestti et al., 2003
2 – Chesapeake Bay Program, 1987
3 – Dillaha, 1990
4 – Hamlett and Epp, 1994
5 – Novotny and Olem, 1994
6 – NYSDEC, 1991

Controlling

Alternative Tile Intakes

No additional commentary.

Channel Bank Vegetation

No additional commentary.

Contour Stripcropping

Pollutant reductions are provided in Table 5, which are results of databases developed for estimating BMP effectiveness from various national sources (Merriman et al., 2009; Gitau et al., 2005).

Controlled Subsurface Drainage

No additional commentary.

Culvert Sizing

No additional commentary.

Grassed Waterway

A seven-year field study in Germany showed a 77%-97% reduction in sediment for a large (2,100 ft long) grassed waterway on a 57 acre silty-loam site (Fiener and Auerswald, 2003). Although the scale of this grassed waterway may not be common in Minnesota, the climatic conditions of this site are similar and the results may transfer.

Modeling by Dermiss

Irrigation Water Management

No additional commentary.

Agricultural Waste Storage

No additional commentary.

Conservation Tillage

A simple change to fall chisel plowing that leaves 30% residue cover can reduce the amount of field erosion from 50-60% compared to a 0% residue system. This is an estimate of the reduction of field erosion and not the amount of sediment entering a waterway. The amount of sediment entering a waterway can be calculated from a sediment delivery ratio (SDR), which NRCS literature (USDA, 1999) estimates between 10% and 20%. This means that a 2-ton reduction in field erosion translates into 400-800lb/year reduction in sediment loading to water bodies. Table 6 presents the erosion reduction as reported in Core4 practices literature.

Table 6. Effect of percent residue cover on any day in reducing sheet and rill erosion compared to conventional, clean tillage without residue (Adapted from USDA, 1999)

Residue cover (%)	Erosion reduction % on any day % while residue present
10	30
20	50
30	65
40	75
50	83
60	88
70	91
80	94

No-till has been shown to increase water infiltration substantially over conventional tillage. A no till farm on a 9% slope exhibited a 99% reduction in runoff over a four-year period (Fawecett and Smith, 2009). Additional national studies comparing the runoff based on hydrologic soil group (HSG) have found that runoff averaged 56% less volume from no –till than that of conventional tillage on B soils and 67% reduction for C soils. Runoff reduction was not found on sites with D soils and no studies of A soils were reviewed.

Studies throughout Kansas, Kentucky also show similar reductions for P, presumably due to the decreased erosion and increased infiltration seen in conservation tillage systems (Andraski et al., 1985, Kimmel et al., 2001).

Riparian Vegetation

No additional commentary.

Rotational Grazing

No additional commentary.

Seasonal till

No additional commentary.

Streambank Protection

No additional commentary.

Stripcropping

No additional commentary.

Terrace

The mean total sediment, total P, and total N reductions for terraces are 86%, 78%, and 38%, respectively, based on Table 7, results of a database developed for estimating BMP effectiveness in Arkansas (Merriman et al., 2009). Not much new done in the is area.

Two-Stage Ditch

No additional commentary. Ohio State and Indiana.

Feedlot Runoff Controls - Clean Water runoff Diversion, Vegetated Treatment Area, Wastewater treatment Strip

Contaminant reductions from national sources are provided in Table 8, which are results of several studies measuring the efficiency of terraces and diversion (Merriman, 2009).

Fecal coliform count is usually reduced linearly along the slope of filter strips; however, mixed results show the extent of treatment. Roodsari et al. (2004) conducted a study using a two-sided lysimeter and found that filter strip (orchard and fescue grass) can significantly reduce surface transport of fecal coliform from bovine manure even for slopes as high as 20%, especially for soils with high filtration. Filter strips reduced fecal coliform in runoff to 1% in clay loam plots and to non-detectable level in sandy loam plots.

For some studies, the concentration of the fecal coliform remained high. The fecal coliform concentration remained 1000 times higher than the local standard for primary contact water (200 fecal coliforms per 100 mL) in runoff treated by filter strips (tall fescue and Kentucky bluegrass) established on 9% slope around a field amended with poultry manure (16.5 Mg ha-1) in Kentucky. The vegetation was maintained at 40 mm in height and the author suggests that higher grass filter strips or pre-treatment of poultry manure is probably necessary to prevent fecal contamination (Coyne et al., 1998). In the case of a study which used a two-ton pile of fresh bovine manure per a plot of filter strip (tall fescue) on a 4% slope to simulate a livestock confinement area, coliform counts on average remained high for all plots including the control plots without manure application (Fajardo et al., 2001). This may be due to excessive amount of water applied to manure as the amount of water applied to manure exceeded the energy of a 100-year, 24 hour rain. NO3-N was successfully reduced at 98% of an average.

Contaminant reductions are provided in Table 9, which are results of several studies measuring the efficiency of barn yard runoff management (Merriman, 2009).

Table 7. Pollutant reduction estimates in percent for terraces (Merriman et al. 2009).

Pollutant	Mean	Minimum	Maximum	Standard Deviation	Number of Entries in Database	Source
Total Sediment	86	80	95	7	4	1
Total Phosphorus	78	70	85	2	11	1
Total Nitrogen	38	20	55	25	2	1,2,3

1 – Cestti et al. (2003)
2 – Chesapeake Bay Program (1987)
3 – Dillaha (1990)

Table 8. Pollutant reduction estimates in percent for terraces and diversions (Merriman, 2009).

Pollutant	Mean	Minimum	Maximum	Standard Deviation	Number of Entries in Database	Source
Total Nitrogen	38	20	55	25	2	1
Total Phosphorus	78	70	85	11	2	1
Total Sediment	86	80	95	7	4	1,2,3

1 – Cestti et al., 2003
2 – Chesapeake Bay Program, 1987
3 – Dillaha, 1990

Table 9. Pollutant reduction estimates in percent for barn yard runoff management (Merriman, 2009).

Pollutant	Mean	Minimum	Maximum	Standard Deviation	Number of Entries in Database	Source
Total Nitrogen	27	10	45	25	2	1
Total Phosphorus	50	30	70	28	2	1
Total Sediment	56	35	77	30	2	1,2

1 – Cestti et al. 2003
2 – Dillaha 1990

Trapping

Filter Strips and Field Borders

Many studies show that width is a major factor to improve the performance of filter strips. Except for high slope area (> 11%) (Dillaha et al., 1989), sediment load, slope, vegetation type and density are found to have secondary influence and these influences tend to diminish as filter strips become wider (Abu-Zreig et al., 2003; Blanco-Canqui et al., 2004; Coyne et al., 1998; Dillaha et al., 1989; Helmers et al., 2008; Hook, 2003; Schmitt et al., 1999). Chaubey et al. (1994) tested six different strip widths to test runoff from swine manure applied field and found 3m and 9m to be sufficient for sediment and nutrient removal, respectively.

Contaminant reductions are provided in Table 41, which are results of several studies measuring the efficiency of filter strips from national sources (Merriman, 2009).

Sediment basin

No additional commentary.

Side Inlet Controls

No additional commentary.

Water/sediment control basin

No additional commentary.

Wetland, Constructed

No additional commentary.

Wetland, Restoration

No additional commentary.

Wood Chip Bioreactor

No additional commentary.

Table 10. Pollutant reduction estimates in percent for filter strips (Merriman, 2009).

Pollutant	Mean	Minimum	Maximum	Standard Deviation	Number of Entries in Database	Source
NH4-N	47	-35	98	35	28	4, 7, 13, 15, 16, 34, 52, 56
Dissolved Phosphorus	23	-108	89	55	21	4, 7, 13, 15, 16
NO3-N	22	-158	85	58	22	3, 4, 13, 15, 16, 34, 56
Particulate Phosphorus	79	68	90	15	2	4

Appendix B

Pollutant	Mean	Minimum	Maximum	Standard Deviation	Number of Entries in Database	Source
Total Nitrogen	54	1	93	25	31	3, 4, 6, 7, 13, 15, 16, 34, 46, 52, 56
Total Phosphorus	57	2	93	25	31	3, 4, 6, 7, 13, 15, 16, 46, 48, 52, 56
Total Sediment	56	0	99	32	40	4, 6, 10, 13, 15-18, 33-35, 47, 56, 61

References: 1 - Abtew et al., 2004; 2 - Berg et al., 1988; 3 - Bingham et al., 1980; 4 - Blanco-Canqui et al., 2004; 5 - Burchell II et al., 2005; 6 - Cestti et al., 2003; 7 - Chaubey et al., 1995; 8 - Chesapeake Bay Program, 1987; 9 - Cooper and Knight, 1990; 10 - Coyne et al., 1995; 11 - Dabney et al., 1993; 12 - abney et al., 2001; 13 - Daniels and Gilliam., 1996; 14 - Deal et al., 1986; 15 - Dillaha et al., 1988; 16 - Dillaha et al., 1989; 17 - Dillaha, 1990; 18 - Feagley et al., 1992; 19 - Gilliam et al., 1979; 20 - Gilliam, 1995; 21 - Hackwell et al., 1991; 22 - Hairston et al., 1984; 23 - Harmel et al., 2006; 24 - Hubbard et al., 2004; 25 - Jacobs and Gilliam, 1985; 26 - Langdale et al., 1979; 27 - Line et al., 2000; 28 - Lory, 2006; 29 - Lowrance and Sheridan, 2005; 30 - McDowell and McGregor, 1980; 31 - McGregor and Greer, 1982; 32 - McGregor et al., 1975; 33 - McGregor et al., 1999; 34 - Mendez et al., 1999; 35 - Meyer et al., 1995; 36 - Meyer et al., 1999; 37 - Mostaghimi et al., 1988a; 38 - Mostaghimi et al., 1988b; 39 - Mostaghimi et al., 1991; 40 - Mostaghimi et al., 1992; 41 - Mostaghimi et al., 1997; 42 - Mutchler and Greer, 1984; 43 - Mutchler and McDowell, 1990, 44 - Mutchler et al., 1985; 45 - Palone and Todd, 1997; 46 - Parsons et al., 2001; 47 - Renschler and Lee, 2005; 48 - Sanderson et al., 2001; 49 - Schreiber and Cullum, 1998; 50 - Sheffield et al., 1997; 51 - Sheridan et al., 1999; 52 - Srivastava et al., 1996; 53 - Storm et al., 1985; 54 - Trimble, 1994; 55 - Truman et al., 2003; 56 - Udawatta et al., 2002; 57 - VanDevender et al., undated; 58 - Vellidis et al., 2003; 59 - Yoo et al., 1986; 60 - Yoo et al., 1988; 61 - Yuan et al., 2002; 62 - Zhu et al., 1989.

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Table 11. Chesapeake Bay BMP effectiveness estimates. (Reproduced from Simpson and Weammert, 2009)

UPDATED BMP EFFECTIVENESS ESTIMATES			
BMPs	**BMP Effectiveness Estimate (%)**		
	TN	**TP**	**TSS**
Conservation Plans			
Conventional tillage	8	15	25
Conservation tillage	3	5	8
Hayland	3	5	8
Pastureland	5	10	14
Conservation Tillage	8	2	30
Forest Buffer			
Inner Coastal Plain	65	42	56
Outer Coastal Plain Well Drained	31	45	60
Outer Coastal Plain Poorly Drained	56	39	52
Tidal Influenced	19	45	60
Piedmont Scnist/Gneiss	46	36	48
Piedmont Sandstone	56	42	56
Valley and Ridge - marble/limestone	34	30	40
Valley and Ridge - Sandstone/Shale	46	39	52
Appalachian Plateau	54	42	56
Grass Buffer			
Inner Coastal Plain	46	42	56
Outer Coastal Plain Well Drained	21	45	60
Outer Coastal Plain Poorly Drained	39	39	52
Tidal Influenced	13	45	60
Piedmont Scnist/Gneiss	32	36	48
Piedmont Sandstone	39	42	56
Valley and Ridge - marble/limestone	24	30	40
Valley and Ridge - Sandstone/Shale	32	39	52
Appalachian Plateau	38	42	56

Appendix B

UPDATED BMP EFFECTIVENESS ESTIMATES			
BMPs	BMP Effectiveness Estimate (%)		
	TN	TP	TSS
Wetland Restoration and Creation			
Appalachian (1% of Watershed in wetlands)	7	12	15
Piedmont and Valley (2% of watershed in wetlands)	14	526	15
Coastal Plain (4% of watershed in wetlands)	25	50	15
Cover Crops			
Coastal Plain/Piedmont/Crystalline/Karst Settings:			
Drilled Rye early	45	15	20
Drilled Rye normal	41	7	10
Drilled Rye late	19	0	0
Other Rye earl	38	15	20
Other Rye normal	35	7	10
Other Rye late	16	0	0
Aeiral/soy Rye early	31	15	20
Aerial/soy Rye normal	N/A	N/A	N/A
Aerial/soy Rye late	N/A	N/A	N/A

UPDATED BMP EFFECTIVENESS ESTIMATES			
BMPs	BMP Effectiveness Estimate (%)		
	TN	TP	TSS
Aerial/corn Rye early	18	15	20
Aerial/corn Rye normal	N/A	N/A	N/A
Aeiral/soy Rye late	N/A	N/A	N/A
Drilled Wheat early	31	15	20
Drilled Wheat normal	29	7	10
Drilled Wheat late	13	0	0
Other Wheat early	27	15	20
Other Wheat normal	24	7	10
Other Wheat late	11	0	0
Aerial/soy Wheat early	22	15	20
Aerial/soy Wheat normal	N/A	N/A	N/A
Aerial/soy Wheat late	N/A	N/A	N/A
Aerial/corn Wheat early	13	15	20
Aerial/corn Wheat normal	N/A	N/A	N/A
Aerial/corn Wheat late	N/A	N/A	N/A
Drilled Barley early	38	15	20
Drilled Barley normal	29	7	10
Drilled Barley late	N/A	N/A	N/A
Other Barley early	32	15	20
Other Barley normal	24	N/A	10
Other Barley late	N/A	N/A	N/A
Aerial/soy Barley early	27	15	20
Aerial/soy Barley normal	N/A	N/A	N/A
Aerial/soy Barley late	N/A	N/A	N/A
Aerial/corn Barley early	15	15	20
Aerial/corn Barley normal	N/A	N/A	N/A
Aerial/corn Barley late	N/A	N/A	N/A

UPDATED BMP EFFECTIVENESS ESTIMATES			
BMPs	BMP Effectiveness Estimate (%)		
	TN	TP	TSS
Mesozoic Lowlands/Valley and Ridge Siliciclastic:			
Drilled Rye early	34	15	20
Drilled Rye normal	31	7	10
Drilled Rye late	15	0	0
Other Rye early	29	15	20
Other Rye normal	27	7	10
Other Rye late	12	0	0
Aeiral/soy Rye early	24	15	20
Aerial/soy Rye normal	N/A	N/A	N/A
Aerial/soy Rye late	N/A	N/A	N.A
Aerial/corn Rye early	14	15	20
Aerial/corn Rye normal	N/A	N/A	N/A
Aeiral/soy Rye late	N/A	N/A	N/A
Drilled Wheat early	24	15	20
Drilled Wheat normal	22	7	10
Drilled Wheat late	10	0	0
Other Wheat early	20	15	20
Other Wheat normal	18	7	10
Other Wheat late	9	0	0

UPDATED BMP EFFECTIVENESS ESTIMATES			
BMPs	BMP Effectiveness Estimate (%)		
	TN	TP	TSS
Aerial/soy Wheat early	17	15	20
Aerial/soy Wheat normal	N/A	N/A	N/A
Aerial/soy Wheat late	N/A	N/A	N/A
Aerial/corn Wheat early	10	15	20
Aerial/corn Wheat normal	N/A	N/A	N/A
Aerial/corn Wheat late	N/A	N/A	N/A
Drilled Barley early	29	15	20
Drilled Barley normal	22	7	10
Drilled Barley late	N/A	N/A	N/A
Other Barley early	25	15	20
Other Barley normal	19	7	10
Other Barley late	N/A	N/A	N/A
Aerial/soy Barley early	20	15	20
Aerial/soy Barley normal	N/A	N/A	N/A
Aerial/soy Barley late	N/A	N/A	N/A
Aerial/corn Barley early	12	15	20
Aerial/corn Barley normal	N/A	N/A	N/A
Aerial/corn Barley late	N/A	N/A	N/A
Off-Stream Watering With Fencing	25	30	40
Off-Stream Watering Without Fencing	15	22	30
Forest Harvesting	50	60	60
Urban Wetlands and Wet Ponds	20	45	60
Urban Erosion and Sediment Control	25	40	40
Dry Extended Detention Basins	20	20	20
Dry Detention Ponds/Basins and HydrodynamicStructures	5	10	10

UPDATED BMP EFFECTIVENESS ESTIMATES			
BMPs	BMP Effectiveness Estimate (%)		
	TN	TP	TSS
Ammonia Emission Reduction			
Poultry Litter Treatment	50	N/A	N/A
Poultry House Biofilter	60	N/A	N/A
Cover	15	N/A	N/A
Dairy Feed Management *default numbers for when direct measurement not an option	24	25	N/A
Mortality Composting	40	10	0
Infiltration and Filtration:			
Bioretention			
C/D soils, underdrain	25	45	55
A/B soils, underdrain	70	75	80
A/B soils, no underdrain	80	85	980
	±15	±20	±15
Filters			
All (sand, organic, peat)	40	60	80
	±15	±10	±10
Vegetated Open Channels			
C/D soils, no underdrain	10	10	50
A/B soil, no underdrain	45	45	70
	±20	±20	±30
Bioswale	70	75	80
	±15	±20	±15

Appendix B

UPDATED BMP EFFECTIVENESS ESTIMATES			
BMPs	BMP Effectiveness Estimate (%)		
	TN	TP	TSS
Permeable Pavement (no sand/veg)			
C/D soils, underdrain	10	20	55
A/B soils, underdrain	45	50	70
A/B soils, no underdrain	75	80	85
	±15	±20	±15
Permeable Pavement (with sand, veg)			
C/D soils, underdrain	20	20	55
A/B soils, underdrain	50	50	70
A/B soils, no underdrain	80	80	85
	±15	±15	±15
Infiltration Practices (no sand/veg)			
A/B soils, no underdrain	80	85	95
	±15	±15	±10
Infiltration Practices (with sand/veg)			
A/B soils, no underdrain	85	85	95
	±15	±10	±10

Table 12. This example of BMP effectiveness from New York State was compiled with an emphasis on farms that use manure as a nutrient source. (reproduced from Gitau et al., 2006)

BMP Class	Variable	Average %	Std. Dev. %	Min. %	Max. %	Number	Reference number
Animal waste systems, AWS	DP§	-13*	71	-117	40	4	3, 21
	TP#	42	24	21	90	7	3, 5, 16, 20, 21 3
	PP†	59	21	35	72	3	3
Barnyard runoff management, BYRM	DP	30	35	5	81	4	4, 28
	TP	53	23	23	82	7	4, 22, 28
	PP	33	–	33	33	1	21
Conservation tillage, CONST	DP	-167	262	-889	73	18	1, 2, 11, 13, 15, 17, 27, 29, 32
	TP	62	29	-22	95	21	2, 5, 11, 14, 15, 17, 20, 21, 22, 32
	PP	63	20	15	92	17	1, 11, 13, 15, 29, 32

BMP Class	Variable	Average %	Std. Dev. %	Min. %	Max. %	Number	Reference number
Contour strip crop, CSC	DP	45	28	20	93	5	11, 13
	TP	44	25	8	93	22	14, 21, 22
	PP	60	11	43	76	6	6, 11, 13
Crop rotation, CR	DP	50	17	30	75	6	5, 6, 13, 22
	TP	30	—	30	30	1	21
	PP	65	4	60	70	4	13, 22
Filter strips, FS	DP	26	25	-56	59	18	8, 9, 10, 21, 30
	TP	56	18	22	93	23	6, 8, 10, 11, 14, 19, 22, 24, 30
	PP	41	4	38	43	2	10
Nutrient management plan, NMP	DP	26	41	-66	94	14	23, 31, 33
	TP	47	24	14	91	9	4, 22, 23, 31
	PP	46	4	42	50	3	31
Riparian forest buffers, RFB	DP	62	26	28	99	8	7, 9, 12, 18, 26
	TP	43	36	2	93	9	12, 18, 21, 25
	PP	84	—	84	84	1	26
* Negative values signify increases in P losses § Dissolved phosphorus	# Total phosphorus † Particulate phosphorus						

 # Reference (short form)
1 Baker and Laflen, 1983
2 Berg et al., 1988
3 Brannan et al., 2000
4 Brown et al., 1989
5 Chesapeake Bay Program, 1987
6 Clark et al., 1985
7 Corley et al., 1999
8 Daniels and Gilliam, 1996
9 Doyle et al., 1977
10 Eghball et al., 2000
 # Reference (short form)
11 EPA, 1993
12 Franco et al., 1996
13 Haith, 1979 3
14 Hamlett and Epp, 1994
15 Hansen et al., 2000
16 Hession et al., 1989
17 Laflen and Tabatabai, 1984
18 Lee et al., 2000
19 Magette et al., 1989
20 Mostaghimi et al., 1989
21 Novotny and Olem, 1994
 # Reference (short form)
22 NYSDEC, 1991
23 Osei et al., 2000
24 Parsons et al., 2001
25 Perry et al., 1999
26 Peterjohn and Correll, 1984
27 Phillips et al., 1993
28 Robillard et al., 1983
29 Romkens et al., 1973
30 Schmitt et al., 1999
31 Schuman et al., 1973
32 Sharpley et al., 1991
 # Reference (short form)
33 Walter et al., 2001

Table 13. Selected average BMP effectiveness values contained in the Arkansas BMP tool. (reproduced from Table 2, Merriman, 2009)

	Pollutant Reduction (%)[b]						
BMP Name	**PP**	**DP**	**TP**	**NO3-N**	**NH4-N**	**TN**	**T Sed**
Agricultural waste treatments amendments			70				
Conservation crop rotation			53			68	
Conservation tillage general			55			53	66
Constructed wetland			71				
Contour farming							43
Cover crop (general)							70
Diversion			50			27	35
Drainage water management				56			
Feed management		9	25				
Field border							34
Grassed waterway							17
Manure application by subsurface injection				68	93	58	
Mulching							77
No-till	60	24	69	37	15	59	78
No-till to critical areas			9			9	23
No-till with subsurface injection	38	92	91	84	97	95	92
Pasture and hay planting			67			66	59
Pond		80	72	82			77
Reduced tillage			44			55	55
Riparian forest buffer	63		53	59	48	47	76
Subsurface drain			4	-372[c]		-17	
Surface drainage, field ditch			-6	-518		-32	
Terraces			77			37	85
Use exclusion/stream protection			76	32		-78	83
Waste storage facility			58			52	
Waste treatment lagoon			62			43	
Watering facility			-10	41		-27	38
Wetland restoration			74	83	63	64	
Winter cover crop		37		75	37		76

[a] Blank cells indicate no data for the specified BMP and pollutant.

[b] PP - Particulate Phosphorus; DP - Dissolved Phosphorus; TP - Total Phosphorus; NO3-N - Nitrate Nitrogen; NH4-N - Ammonium Nitrogen; TN - Total Nitrogen; Tsed - Total Sediment.

[c] Negative values indicate increases in the pollutant.

Appendix B

Table 14. The Georgia manual presents the following pollutant removals but offers little in the way of references.

BMP	BMP Target	Effectiveness / Reduction (%)
Access Roads	Sediment	70
Forage Harvest Management	Nutrients	75
Pasture and Hayland Planting	Sediment	85
Ponds	Sediment	80
Roof Runoff Structures	Sediment and Manure	Reduction not quantified
Alternative Water Sources	Sediment and Manure	Reduction not quantified
Anaerobic Digesters	E. coli	90
Anaerobic Digesters	Fecal coliform	99.9
Anaerobic Digesters	M. avium paratuberculosis	99
Animal Moritality Facilities	Water contamination	Reduction not quantified
Animal Trails and Walkways	Sediment	Reduction not quantified
Closure of Wastewater Impoundments	Nutrients	Reduction not quantified
Composting Facilities	Erosion	86
Composting Facilities	Runoff	70
Composting Facilities (compared to silt fences)	Sediment	99
Composting Facilities (compared to hydroseeding)	Sediment	38
Critical Area Planting	Sediment	75
Fences and Use Exclusion	Nitrogen	60
Fences and Use Exclusion	Sediment	75
Fences and Use Exclusion	Sediment	50-90
Fences and Use Exclusion	Fecal coliform colony forming units	99
Heavy Use Area Protection	Sediment	80
Land Leveling and Land Smoothing	Sediment	Reduction not quantified
Manure Storage Facilities	Fecal coliform (over two weeks)	96
Manure Transfer	Nutrients	Reduction not quantified
Nutrient Management	Phosphorus	35
Nutrient Management	Nitrogen	15
Prescribed Grazing	Sediment	75
Stream Crossings	Sediment and Nutrients	Reduction not quantified
Water Facility Covers		Reduction not quantified
Waste Treatment Lagoons	Nitrogen	80
Wastewater Treatment Strips	Solids	80-90
Wastewater Treatment Strips	Phosphorus	60
Wastewater Treatment Strips	Nitrogen	70
Irrigation Water Management	Sediment, nutrients, pesticide	Reduction not quantified
Drip Irrigation	Water	90-95
Drip Irrigation (for field and container nurseries)	Water savings potential	10
Drip Irrigation (compared to conventional irrigation for vegetable production)	Water savings potential	74
Irrigation Pits	Sediment and Nutrients	Reduction not quantified
Pipelines	Sediment	Reduction not quantified
Sprinklers	Sediment	50-95
Subsurface Drains	Total runoff reduction	29-65
Subsurface Drains	Peak runoff reduction	15-30
Subsurface Drains	Sediment	16-65
Subsurface Drains	Phosphorus	45
Subsurface Drains	Nutrient	30-50
Surface and Subsurface Irrigation Systems	Water reduction	25
Tailwater Recovery Systems (Greenhouse / Container Nursery)	Water reduction	50
Conservation Cover	Sediment	90
Conservation Tillage (No-till) in dry weather	Herbicide	70
Conservation Tillage (30% cover)	Sediment	50-60
Contour Farming	Sediment	25-50
Contour Stripcropping	Sediment	50-60
Contour Buffer Strips	Sediment	20-75
Cover Crops	Sediment	40-60
Cover Crops	Herbicide	40
Crop Rotation	Sediment	40-50

Appendix B

BMP	BMP Target	Effectiveness / Reduction (%)
Diversions	Sediment	30-60
Field Borders	Nutrients	50-80
Field Borders	Sediment	50-80
Field Borders	Pesticide	50
Field Borders	Pathogens	60
Field Borders	Nitrogen	60-80
Field Borders	Phosphorus	60-80
Field Stripcropping	Sediment	75
Filter Strips	Nutrients	50-80
Filter Strips	Sediment	50-80
Filter Strips	Pesticide	50
Filter Strips	Pathogens	60
Filter Strips	Nitrogen	60-80
Filter Strips	Phosphorus	60-80
Grade Stabilization Structure	Sediment	75-90
Grassed Waterways	Sediment	60-80
Grassed Waterways	Herbicide	78
Pest Management (Integrated Pest Management [IPM])	Pesticide use reduction (over 5 years)	40-50
Pest Management (Integrated Pest Management [IPM])	Pesticide use reduction (over 10 years)	70-80
Scouting	Insecticide	Reduction not quantified
Sediment Basins	Sediment	75-95
Sediment Basins	Insecticide and Herbicide loss	10
Terraces	Sediment	85-95
Terraces	Nitrogen	20
Terraces	Phosphorus	70
Water and Sediment Control Basins	Sediment	40-60
Underground Outlets	Sediment and Nutrients	Reduction not quantified
Riparian Herbaceous Cover	Nitrogen	17-58
Riparian Herbaceous Cover	Phosphorus	50-75
Riparian Herbaceous Cover	Sediment	50-75
Riparian Forest Buffer	Nitrogen	25-85

Appendix B

BMP	BMP Target	Effectiveness / Reduction (%)
Riparian Forest Buffer	Phosphorus	50-75
Riparian Forest Buffer	Sediment	50-75
Riparian Forest Buffer - Restored Zone 3 Buffers	Nitrogen	60
Riparian Forest Buffer - Restored Zone 3 Buffers	Phosphorus	65
Streambank and Shoreline Protection	Sediment	Reduction not quantified
Stream Channel Stabilization	Sediment	Reduction not quantified
Tree/Shrub Establishment	Sediment	Reduction not quantified
Tree/Shrub Establishment	Dust particles from poultry houses	50
Wetland Creation, Enhancement and Rehabilitation	Nitrogen	59
Wetland Creation, Enhancement and Rehabilitation	Phosphorus	66

Table 15. Statistical parameters of BMP effectiveness values contained in the Arkansas BMP tool. (reproduced from Table 4, Merriman, 2009) [a]

BMP Class [b]	Pollutant [c]	Mean	Min	Max	Std	Count	Reference [d]
Alternative water supply	NH4-N	77				1	50
	DP	75				1	50
	NO3-N	32	12	41	16	3	27, 50
	PP	92				1	50
	TN	0.5	-27	56	48	3	27, 50
	TP	26	-10	97	62	3	27, 50
	Tsed	57	38	96	34	3	27, 50
Animal waste systems	DP	9				1	57
	TN	57	29	80	25	4	6, 8, 24, 41
	TP	61	25	90	31	7	6, 8, 20, 24, 28, 41, 57
	Tsed	60				1	6
Barn yard runoff management	TN	27	10	45	25	2	6
	TP	50	30	70	28	2	6
	Tsed	56	35	77	30	2	6, 17

BMP Class [b]	Pollutant [c]	Mean	Min	Max	Std	Count	Reference [d]
Conservation tillage	NH4-N	30	-43	93	50	6	39, 40, 49, 59, 60
	DP	-63	-329	91	186	4	38, 40, 59
	NO3-N	37	10	68	23	6	39, 40, 49, 59, 60
	PP	69	27	93	31	4	38, 40, 49, 59
	TN	57	-3	91	35	14	2, 6, 8, 23, 30, 39-41, 49, 59, 60
	TP	61	5	97	33	13	2, 6, 8, 23, 28, 30, 38, 40, 41, 49, 60
	Tsed	69	6	99	28	48	2, 6, 8, 11, 17, 21-23, 26, 30-32, 36, 38-42, 44, 53, 59-61
Contour strip crop	TN	37	20	55	25	2	6
	TP	77	70	85	11	2	6
	Tsed	77	43	95	20	5	6, 8, 17
Cover crops	NH4-N	37	35	41	3	3	61, 62
	DP	37	7	63	28	3	61, 62
	NO3-N	75	4	39	18	3	61, 62
	TN	66				1	41
	TP	67				1	41
	Tsed	70	32	92	20	10	17, 33, 35, 41, 43, 46, 61, 62
Crop rotation	NH4-N	37	35	41	3	3	62
	DP	37	7	63	28	3	62
	NO3-N	75	74	77	1	3	62
	TN	67	66	68	2	2	8, 41
	TP	60	53	67	10	2	8, 41
	Tsed	72	32	92	22	7	17, 41, 43, 61, 62
Drainage systems	DP	80				1	9
	NO3-N	-265	-1528	82	540	14	5, 8, 9, 14, 19, 25
	TN	-24	-47	0	15	8	14
	TP	1	-73	73	65	9	9, 14
	Tsed	77				1	9

BMP Class [b]	Pollutant [c]	Mean	Min	Max	Std	Count	Reference [d]
Filter strips	NH4-N	47	-35	98	35	28	4, 7, 13, 15, 16, 34, 52, 56
	DP	23	-108	89	55	21	4, 7, 13, 15, 16
	NO3-N	22	-158	85	58	22	3, 4, 13, 15, 16, 34, 56
	PP	79	68	90	15	2	4
	TN	54	1	93	25	31	3, 4, 6, 7, 13, 15, 16, 34, 46, 52, 56
	TP	57	2	93	25	31	3, 4, 6, 7, 13, 15, 16, 46, 48, 52, 56
	Tsed	56	0	99	32	40	4, 6, 10, 13, 15-18, 33-35, 47, 56, 61
Nutrient management plan	NH4-N	-1133	-4979	97	2173	3	39, 40
	DP	-35	-171	92	127	3	13, 40
	NO3-N	46	0	84	39	3	39, 40
	PP	38	-57	85	57	3	13, 40
	TN	10	-102	95	74	3	39, 40
	TP	48	8	91	30	6	13, 28, 40
	Tsed	84	72	92	9	3	13, 40
Riparian forest buffers	NH4-N	48				1	29
	NO3-N	59				1	29
	PP	63				1	29
	TN	47	37	57	14	2	29, 45
	TO	53	50	56	4	2	17, 29
	Tsed	76	55	95	16	5	17, 45, 51
Sediment basins	DP	80				1	9
	NO3-N	82				1	9
	TP	72				1	9
	Tsed	77				1	9
Stream fencing	NO3-N	32				2	27
	TN	-78				2	27
	TP	75				2	27
	Tsed	83	82	84	0.9	3	27, 54
Terraces and diversions	TN	38	20	55	25	2	6
	TP	78	70	85	11	2	6
	Tsed	86	80	95	7	4	6, 8, 17

BMP Class [b]	Pollutant [c]	Mean	Min	Max	Std	Count	Reference [d]
Wetland	NH4-N	63				1	58
	NO3-N	83				1	58
	TN	64				1	58
	TP	72	71	74	2	2	1, 58

[a] There are no data for Irrigation Water Management or Rotational Grazing.

[b] BMP - Best Management Practice;

[c] PP - Particulate Phosphorus; DP - Dissolved Phosphorus; TP - Total Phosphorus; NO3-N - Nitrate Nitrogen; NH4-N - Ammonium Nitrogen; TN - Total Nitrogen; Tsed - Total Sediment.

[d] References: 1 - Abtew et al., 2004; 2 - Berg et al., 1988; 3 - Bingham et al., 1980; 4 - Blanco-Canqui et al., 2004; 5 - Burchell II et al., 2005; 6 - Cestti et al., 2003; 7 - Chaubey et al., 1995; 8 - Chesapeake Bay Program, 1987; 9 - Cooper and Knight, 1990; 10 - Coyne et al., 1995; 11 - Dabney et al., 1993; 12 - Dabney et al., 2001; 13 - Daniels and Gilliam., 1996; 14 - Deal et al., 1986; 15 - Dillaha et al., 1988; 16 - Dillaha et al., 1989; 17 - Dillaha, 1990; 18 - Feagley et al., 1992; 19 - Gilliam et al., 1979; 20 - Gilliam, 1995; 21 - Hackwell et al., 1991; 22 - Hairston et al., 1984; 23 - Harmel et al., 2006; 24 - Hubbard et al., 2004; 25 - Jacobs and Gilliam, 1985; 26 - Langdale et al., 1979; 27 - Line et al., 2000; 28 - Lory, 2006; 29 - Lowrance and Sheridan, 2005; 30 - McDowell and McGregor, 1980; 31 - McGregor and Greer, 1982; 32 - McGregor et al., 1975; 33 - McGregor et al., 1999; 34 - Mendez et al., 1999; 35 - Meyer et al., 1995; 36 - Meyer et al., 1999; 37 - Mostaghimi et al., 1988a; 38 - Mostaghimi et al., 1988b; 39 - Mostaghimi et al., 1991; 40 - Mostaghimi et al., 1992; 41 - Mostaghimi et al., 1997; 42 - Mutchler and Greer, 1984; 43 - Mutchler and McDowell, 1990, 44 - Mutchler et al., 1985; 45 - Palone and Todd, 1997; 46 - Parsons et al., 2001; 47 - Renschler and Lee, 2005; 48 - Sanderson et al., 2001; 49 - Schreiber and Cullum, 1998; 50 - Sheffield et al., 1997; 51 - Sheridan et al., 1999; 52 - Srivastava et al., 1996; 53 - Storm et al., 1985; 54 - Trimble, 1994; 55 - Truman et al., 2003; 56 - Udawatta et al., 2002; 57 - VanDevender et al., undated; 58 - Vellidis et al., 2003; 59 - Yoo et al., 1986; 60 - Yoo et al., 1988; 61 - Yuan et al., 2002; 62 - Zhu et al., 1989.