MINNESOTA DEPARTMENT
OF AGRICULTURE

The Agricultural BMP Handbook for Minnesota

September 2012

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WATER
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AMENDMENT

MINNESOTA DEPARTMENT OF AGRICULTURE

To the reader,

The Minnesota Department of Agriculture (MDA) is pleased to present The Agricultural BMP Handbook for Minnesota. It is a literature review of empirical research on the effectiveness of 30 conservation practices. This handbook was authored by Emmons & Olivier Resources, Inc. in response to a 2010 request for proposals: *to conduct a comprehensive inventory of agricultural conservation practices that address current Minnesota water quality impairments*. The inventory includes the following information:

- Definition for each conservation practice;
- Effectiveness estimates based on existing scientific literature;
- Costs and other economic considerations for each practice.

Having realistic expectations about pollutant reductions associated with the implementation of conservation practices is a primary step in enhancing agriculture's role in addressing water quality concerns in Minnesota. The literature cited herein represents the most current published effectiveness data available for the upper Midwest. This document is intended to be a reference for consultants, agronomists, conservation and watershed district professionals, and producers for prioritizing practices that would have the greatest impact in reducing the loading of pollutants of concern in their specific region of the state. The document is meant to complement other sources of information used to quantify conservation practice effectiveness. Local conditions should be considered when reviewing the literature cited.

The AG BMP Handbook references conservation practices that are defined by the Natural Resource Conservation Service (NRCS) and state Best Management Practices for nitrogen fertilizer and pesticides. However, this document is NOT intended to be a standards manual or a replacement for the NRCS Field Office Technical Guide (FOTG). This handbook will also help the MDA identify practices that require additional research and set priorities for future request for proposals.

The AG BMP Handbook for Minnesota is intended to be a living document that will be updated to reference ongoing and future research pertaining to the effectiveness of conservation practices in reducing sediment, pesticide, and nutrient losses. We hope that this inventory and review of conservation practice effectiveness serves as a guide to implementers of conservation practices in addressing water quality concerns in their watershed.

Cordially,

Joshua Stamper, *Minnesota Department of Agriculture*

Cover photo: Corn and alfalfa on the contour. Winona County, MN

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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) received an appropriation for years 2010 and 2011 for research related to ways agricultural practices contribute to restoring impaired waters and assist with the development of TMDL plans. The MDA put out an Request for Proposal (RFP) to conduct this research and this project was selected as a recipient of the appropriation.

Citation

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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
HUP	Historically Underserved Producers
IBI	Index of Biotic Integrity
IPM	Integrated Pest Management
MAWRC	Minnesota Agriculture and Water Resources Coalition

Acronyms

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
P.R.	Payment Rate
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
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
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: *http://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.

Drain tiles
Pipe made of high density polyethylene (HDPE), concrete, or clay buried in fields that are used to remove excess water.

Ecoregions
Fourteen regions of the United States delineated by the USEPA. Parts of Minnesota are in regions VI, VII, and VIII.

Evapotranspiration
Evaporation of water from earth's surface and transpiration by 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 (NH_3) becomes nitrite (NO_2-) which then becomes nitrate (NO_3). 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 2 year return period event is a precipitation amount (e.g. 2.4 inches of rain or 3 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 in microrelief 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, organic material, or dissolved constituents.

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 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 nitrogen loss effectiveness research that went into the development of state N BMP's is cited in the contextual chapters and in the matrices of this document.

Inconsistencies exist in how agricultural 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 very proactive approach to assessing the condition of water bodies throughout the state. The Impaired Waters Program is the primary tool used in Minnesota to assess the water quality of water bodies 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 predominance of agricultural land in the watersheds of some impaired water bodies has been a significant component of many of these studies, which call for agricultural BMPs as the primary method of improving water quality in lakes and streams. Farmers, agencies and researchers must now work together to bridge knowledge gaps and clean up all of Minnesota's waters. Though the discussions in St. Paul are just beginning, the Agriculture Water Quality Certification Program (called, "Certainty") is one possible avenue that may serve to ensure improved implementation of BMPs while assuring producers that they are meeting water quality standards.

Conservation in Minnesota

Many conservation organizations and programs are doing great work to protect the water quality of Minnesota's lakes and streams. The MDA maintains a comprehensive table of funding opportunities that can be found at http://www.mda.state.mn.us/conservationfundingguide.

Pollutants of Primary Concern in Agricultural Stormwater Runoff

The primary pollutants that are relevant to both TMDLs and agriculture are sediment, nutrients (phosphorus and nitrogen), 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 357 rivers or streams as impaired by sediment and algae. This represents 18.4% of the 1,941 impaired rivers and streams (MPCA, 2012b) or 5.4% of the 6,564 natural rivers and streams in the state (MN DNR, website).

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 et al.,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 3 centuries the sediment could completely fill in the lake (MPCA, 2007). The Minnesota River contributes 74% of Lake Pepin's sediment load (MPCA, 2012a). 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. 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 (MPCA, 2011).

The South Metro Mississippi River – which has high turbidity – includes parts of several basins: the Upper Mississippi, the Minnesota, Cannon, and St. Croix Rivers, as well as smaller tributaries (MPCA, 2012a). 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 & Nitrogen)

There are 16 rivers and streams in Minnesota impaired by nitrates (less than 1% of impaired rivers). 527 lakes (or 31% of all impaired lakes) show Nutrient/Eutrophication Biological Indicators, which is impairment due to phosphorus pollution, according to the Minnesota Pollution Control Agency (MPCA, 2012b).

Nitrate nitrogen ($NO3^-$) is applied to agricultural fields in the form of manure and fertilizer. It is also present due to decaying vegetation. Excess nitrates 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% (2,057,000 pounds per year) of total phosphorus contributions to Minnesota surface waters (MPCA, 2003). Feedlot runoff is also a contributor; statewide, manure accounts for between 70,000 to 242,000 pounds of phosphorus per year, depending on the magnitude of runoff.

Phosphorus 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 phosphorus in the water system. The Minnesota, Upper Mississippi and St. Croix Rivers as well as the Twin Cities urban area all contribute phosphorus pollution to Lake Pepin.

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 phosphorus is directly related, and similar, to the lag time for sediment. Phosphorus 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 in Minnesota (see Table 1) and they will continue to see widespread use and expansion as more effective and safer products are introduced. 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 correspond to a particular product, knowing the adsorption, solubility and persistence allows the behavior in the environment of similar products to be established.

There are 16 Minnesota surface water bodies on the 2012 MPCA impaired waters list due to pesticides. Toxaphene, Acetochlor, Chlorpyrifos, DDT and Dieldrin have all been listed as pollutants causing impairments. It is also likely that some of the fish and macro invertebrate impairments will also be attributed to pesticides when TMDL studies are conducted on those waters. Additionally, the Minnesota Department of Agriculture's well testing program consistently shows the presence of pesticide compounds – atrazine and Acetochlor ESA and Acetochlor OSA, for example – in well water samples.

Time lags for pesticides were not studied by Cruse and colleagues (2012); however, effects will vary based on the persistence and mobility (retardation factor) of a particular chemical, with effects being seen almost immediately in highly degradable products (such as organophosphates) and years or more in persistent products (like DDT and other organochlorines formerly in use in agriculture).

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 416 rivers and streams with elevated E. coli or fecal coliform counts, which represents 21% 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 (EOR, 2009). In agricultural regions, these stressors can be sediment, phosphorus or pesticides.

Table 1. Top 10 crop chemicals sold in Minnesota in 2009 (the most current year with data available).

Pesticide	Pounds of Pesticide Sold in MN
Glyphosate	20,335,480
Metam Sodium	5,267,163
Acetochlor	2,614,786
S-Metolachlor	1,281,983
Propionic Acid	1,199,959
Chlorpyrifos	1,182,990
Atrazine	690,649
2,4-D	579,333
Mancozeb	446,194
Chlorothalonil	434,910

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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 conducted in Minnesota and the Upper Midwest. Research from elsewhere in the country as well as modeling studies were included as a supplement 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. Often, estimates of effectiveness from these sources are optimistic when compared to monitored bmp studies. The information in the BMP chapters of this report should be used whenever possible to define BMP effectiveness.

There is a difference between results from modeling studies and data obtained from field research. Modeling studies are theoretical and less certain yet provide a look at a broader set of scenarios. Removal efficiencies discussed in BMP chapters is primarily monitored research data, although a handful of particularly robust and useful modeling studies have been included as well.

Another important consideration is whether the pollutant effectiveness data is based on concentration or on load. In general throughout this document, load reduction has been reported, where pollutant removal effectiveness is based solely on concentration data, it will be stated explicitly.

One final caveat of the pollutant removal data in this handbook is that many of the practices studied in the research projects were newly constructed or recently implemented BMPs. In general, the removal efficiency of structural BMPs will decline over time due to lack of maintenance while the removal efficiency of non-structural BMPs may remain constant.

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:

1. Creating a preliminary BMP list
2. Creating a preliminary resource list
3. Researching all BMPs
4. Identifying research gaps
5. Receiving additional sources of data
6. Compiling all data into BMP chapters

Direction and collaboration with the MDA Technical Advisory Committee (TAC) was received throughout the process and TAC reviews were completed at critical development junctures.

The project team developed a list of BMPs for inclusion in the handbook using the MN NRCS eFOTG, our own expertise and through consultation with MDA. This BMP list contained the name, position on the landscape, primary use and a 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 project team assembled a preliminary list of resources and met with the TAC 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)
5. Other data sources (e.g., SWCD and Watershed District reports)

U of M Agricultural Research Stations

Ten agricultural research stations around the state have provided science-based agricultural information for over 150 years. The U of M research stations study all aspects of agriculture and horticulture including yield, economics, water quality, genetics and the list goes on and on. These world-class research facilities make up the basis for much of what we know and practice regarding agriculture in the state of Minnesota.

Discovery Farms - Minnesota

Discovery Farms has been conducting water quality research on working farms in Wisconsin since 2001. A joint partnership between the University of Wisconsin, 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-

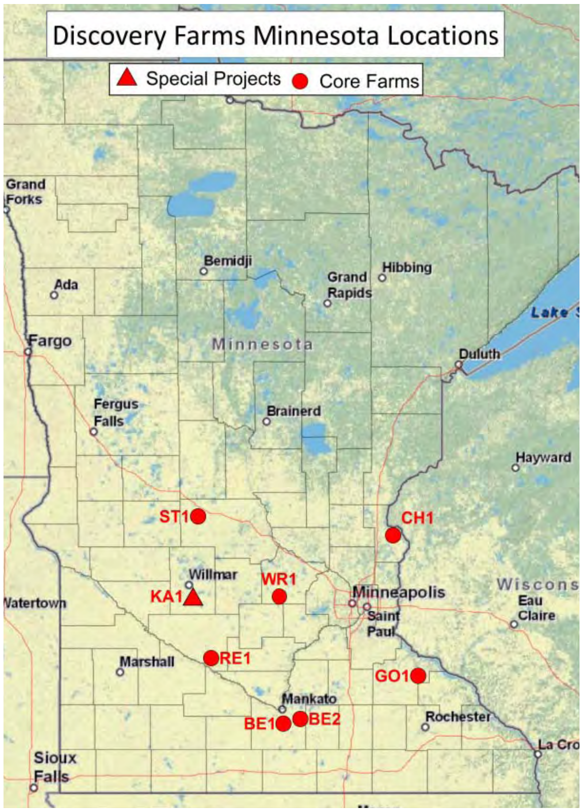

Figure 1. Discovery Farms Minnesota Locations (reproduced from Discovery Farms Minnesota, 2011)

Table 2. Description of Discovery Farms Minnesota Projects (reproduced from Discovery Farms Minnesota, 2011)

Farm ID	Farm Enterprise	Start of Project	Water Quality Monitoring
KA1	Turkey and corn-soybean	August 2007	Surface runoff and tile drainage
GO1	Wine farrow to wean and beef cow-calf	September 2010	Surface runoff
ST1	Conventional Dairy	March 2011	Surface runoff and tile drainage
CH1	Corn-soybean (modified no-till)	March 2011	Surface runoff
BE1	Wine finishing and corn-soybean	June 2011	Surface runoff and tile drainage
BE2	Corn-soybean (conventional tillage)	July 2011	Surface runoff and tile drainage
WR1	Conventional Dairy	December 2011	Surface runoff and tile drainage
RE1	Corn-soybean (conventional tillage)	December 2011	Surface runoff and tile drainage

specific information to enable better farm management. The program is designed to collect accurate measurements of sediment, nitrogen and phosphorous 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 Wisconsin has 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 North Dakota and Minnesota as well with 8 core discovery farms (Table 2, Figure 1). Although now in their infancy, these working farms will provide Minnesota agricultural research over the next 10 years and beyond.

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 1-4). These tables present the references from Minnesota sources, Upper Midwest (including Minnesota) sources, national sources and all sources, with the all sources table being a compilation of the other 3 tables. 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 this section (Table 2).

BMP Chapters

Individual chapters were developed for each BMP. They have been grouped according to the concept of Avoid/Control/Trap meaning that the first aspect of pollution prevention is avoiding the introduction of pollutants into the environment. If the pollutant can not be avoided than methods should be used to control the risk of pollution. As a last step, trapping the pollutant near its source reduces the extent of pollution throughout a watershed.

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, etc.

Suites of BMPs and Conservation Farming Systems throughout the State

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 accrue additional 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 where they are most effective.

Applying CORE 4 conservation (conservation tillage, nutrient management, pesticide management and buffers) is an example of a suite of conservation systems that can be implemented on most farms throughout the state. In this example, the practices are fairly unrelated although they have practical and water quality impacts on one another. For instance, conservation tillage reduces loading to buffer strips, increasing the effectiveness of those buffers but a change in tillage also may require different nutrient and pesticide management.

Other BMPs are often even more linked on the landscape. For instance, terracing often requires grassed waterways or tile system design to function properly. Contour farming is often paired with contour buffer strips and a conservation crop rotation as a whole farming system.

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.

Agricultural BMP pollutant removal research conducted in Minnesota and the upper Midwest has been summarized by pollutant and BMP type. This matrix (Table 3) can be used to find the status of research and direct future BMP project funding.

References

Discovery Farms Minnesota. 2011. Core Farm Year in Review – 2011.

Minnesota Department of Agriculture website. Available at: http://www.mda.state.mn.us/

Table 3. Status of Upper Midwest and Minnesota BMP Research

Type	BMP	Turbidity/ Sediment	Phosphorus	Soluble Phosphorus	Nitrogen/ Nitrates	Ammonia	Pesticides	Bacteria	Dissolved Oxygen
AVOIDING	Conservation Cover (327)	◖	◖	○	●	○	○	○	○
	Conservation Crop Rotation (328)	○	○	○	●	○	○	○	○
	Contour Buffer Strips (332)	●	○	○	○	○	●	○	○
	Contour Farming (330)	○	○	○	○	○	○	○	○
	Cover Crops (340)	○	○	○	●	○	○	○	○
	Grade Stabilization (410)	○	○	○	○	○	○	○	○
	Livestock Exclusion/Fencing (382 and 472)	○	○	○	○	○	○	○	○
	Nutrient Management (590)	●	●	●	●	●	○	○	○
	Pest Management (595)	○	○	○	○	○	◖	○	○
	Tile System Design	○	○	○	◖	○	○	○	○
CONTROLLING	Alternative Tile Intakes	◖	◖	◖	○	○	○	○	○
	Contour Stripcropping (585)	○	○	○	○	○	○	○	○
	Controlled Drainage (554)	○	◖	◖	◖	○	○	○	○
	Culvert Sizing / Road Retention / Culvert Downsizing	○	○	○	○	○	○	○	○
	Grassed Waterways	●	○	○	○	○	●	○	○
	Irrigation Management (442 and 449)	○	○	○	○	○	○	○	○
	Waste Storage Facility (313)	○	○	○	◖	○	○	○	○
	Conservation Tillage (329, 345 and 346)	●	●	●	●	○	○	○	○
	Riparian and Channel Vegetation (322/390)	○	○	○	○	○	○	○	○
	Rotational Grazing	○	○	○	○	○	○	○	○
	Terrace (600)	○	○	○	○	○	○	○	○
	Two Stage Ditch	◖	○	○	◖	○	○	○	○
	Feedlot/Wastewater Filter Strip (635) and Clean Runoff Water Diversion (362)	◖	◖	◖	◖	○	○	◖	○
TRAPPING	Filter Strips (393) and Field Borders (386)	●	●	●	●	●	●	●	○
	Sediment Basin (350)	○	○	○	○	○	○	○	○
	Grade Stabilization at Side Inlets (410)	○	○	○	○	○	○	○	○
	Water and Sediment Control Basin (638)	○	○	○	○	○	○	○	○
	Constructed (Treatment) Wetlands	◖	◖	○	○	○	○	○	◖
	Wetland Restoration (651)	◖	◖	○	◖	○	○	○	○
	Woodchip Bioreactor (Denitrification Beds)	○	◖	◖	◖	○	◖	◖	○

○ Not Studied ◖ Some Study ● Well Documented

AVOIDING

Conservation cover on highly erodible land (HEL)

Conservation Cover (327)

Definition & Introduction

Conservation Cover is establishing and maintaining permanent vegetative cover with the intention of reducing soil erosion. Conservation Cover is often the result of the Conservation Reserve Program (CRP), Reinvest in Minnesota (RIM) and/or 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 the establishment of grasses on lands previously used for row crops.

Water Quality & Other Benefits

Conservation cover reduces erosion and nutrient loss by changing landcover from row crop to grasses. A recent landmark study (Christensen et al., 2009) conducted in the Minnesota River Basin examined the water quality characteristics and responses to land retirement (conservation cover) in three streams. The three basins were primarily row crop agriculture with percentage of land in retirement of 1.71%, 2.72% and 4.32%. They found that total nitrogen, suspended sediment, and chlorophyll-a concentrations all improved with increasing land retirement. In-stream nitrogen concentrations measured were 15 mg/L, 10.6 mg/l and 7.9 mg/l and correlated to increasing land retirement. These results indicate that even small percentage changes in conservation cover may lead to large changes in nitrogen concentrations in streams.

In addition to improved water quality, the fish and index of biotic integrity (IBI) scores also increased as local land-retirement percentages increased. Although this was most apparent when the land retirement was located within 50 and 100 meters of the stream.

Phosphorus 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 phosphorus concentrations are realized. A new Minnesota study (Mohring and Christensen, ongoing) funded by the Environment and Natural Resources Trust Fund will examine the long-term benefits of conservation cover by assessing phosphorus reduction achieved through perpetual easements.

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

Following conversion of perennials back to row crops, the resulting reduced nitrate export was negated within 1 to 2 years when the cropping system reverted to corn (Huggins et al., 2001). This indicates that although there is some benefit to nitrate export immediately following conversion of perennials to row crops, the benefit may be short-lived if perennial vegetation is not maintained.

Key Design/Implementation Considerations

Conservation cover (NRCS Code 327) can be applied to any land needing permanent vegetative cover. Seeding species, planting dates, planting methods and establishment should be directed by a local 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.

Conservation cover provides important habitat for game species such as pheasants

Cost Information

The EQIP payment for installing conservation cover is generally $122.00/ac (see Table 4). A report (Cowan, 2010) on the status of the CRP put the average rental payment for all CRP programs at $53/ac.

Operation and Maintenance Considerations

The NRCS code 327 provides the operation and maintenance of conservation cover.

If wildlife habitat enhancement is an important component of the conservation cover, it is important that maintenance activities do not disturb cover during the reproductive period for the desired species except when necessary to maintain the health of the plant community.

Maintenance measures must be adequate to control noxious weeds and other invasive species. 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.

Table 4. 2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Practice	Component	Unit	P.R./ unit
Conservation Cover	Lime	ton	22
Conservation Cover	Lime - HUP	ton	26
Conservation Cover	Introduced Grasses and Legumes	acre	50
Conservation Cover	Introduced Grasses and Legumes - HUP	acre	60
Conservation Cover	Pollinator Native Grass/Forbs Conventional Planting into Crop	acre	204
Conservation Cover	Pollinator Native Grass/Forbs Conventional Planting into Crop - HUP		245
Conservation Cover	Native Grass/Forbs Conventional Planting into Crop		122
Conservation Cover	Native Grass/Forbs Conventional Planting into Crop - HUP		147
Conservation Cover	Pollinator Native Grass/Forbs Conventional Planting into Grass		224
Conservation Cover	Pollinator Native Grass/Forbs Conventional Planting into Grass - HUP	acre	269
Conservation Cover	Native Grass/Forbs Conventional Planting into Grass	acre	142
Conservation Cover	Native Grass/Forbs Conventional Planting into Grass - HUP	acre	170
Conservation Cover	Pollinator Native Grass/Forbs No-till Planting into Soybeans	acre	180
Conservation Cover	Pollinator Native Grass/Forbs No-till Planting into Soybeans - HUP	acre	216
Conservation Cover	Native Grass/Forbs No-till Planting into Soybeans	acre	98
Conservation Cover	Native Grass/Forbs No-till Planting into Soybeans - HUP	acre	118

References

Christensen, V.G., Lee, K.E., Sanocki, C.A., Mohring, E.H., and Kiesling, R.L., 2009, Water-quality and biological characteristics and responses to agricultural land retirement in three streams of the Minnesota River Basin, water years 2006–08: U.S. Geological Survey Scientific Investigations Report 2009–5215, 52 p., 3 app.

Cowan, Tadlock, 2010, Conservation Reserve Program Status and Current Issues. Congressional Research Service. 7-5700 RS21613. Prepared for Members and Committees of Congress.

Huggins, D.R., G.W. Randall, and M.P. Russelle. 2001. "Subsurface Drain Losses of Water and Nitrate Following Conversion of Perennials to Row Crops." *Agronomy Journal* 93 (3): 477–485.

Minnesota Natural Resource Conservation Service (MN NRCS). 2011. "2011 Minnesota Eqip Conservation Practice Payment Schedule."

Mohring, Eric and Victoria Christensen. Ongoing. Potential Benefits of Perpetual Easements on Phosphorus Reduction. Project number: 035-B. *Environment and Natural Resources Trust Fund Research Addendum for Peer Review*.

Randall, G.W., D.R. Huggins, M. P. Russelle, D. J. Fuchs, W. W. Nelson, and J. L. Anderson. 1997. "Nitrate Losses Through Subsurface Tile Drainage in Conservation Reserve Program, Alfalfa, and Row Crop Systems." *Journal of Environmental Quality* 26: 1240–1247.

Research Gaps

Recent and ongoing studies in Minnesota have help fill the phosphorus research gaps relating to conservation cover.

Links

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

MDA Conservation Funding Guide, Grass Planting
http://www.mda.state.mn.us/protecting/conservation/practices/grass.aspx

Grasslands in Pope County, MN

AVOIDING


Alfalfa. Houston County, MN.

Conservation Crop Rotation (328)

Definition & 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-hay 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.

Water Quality & Other Benefits

The water quality effects of a conservation crop rotation occur in two ways. The first is that growing legumes and other crops can provide N credits in subsequent years, reducing fertilizer inputs and the risk of nitrate leaching. The second effect is that a year in the soil conserving crop serves to directly improve the water quality of runoff from the land by reducing erosion.

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.

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 1 to 2 years following corn.

A six-year (1987-1993) Lamberton, MN 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.

Key Design/Implementation Considerations

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

Cost Information

Conservation crop rotations are generally beneficial both financially and environmentally. The current EQIP payment is $40/ac for annual crops to 2 years of cover.

2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/Unit	HUP/unit	Payment Cap
Annual crops to 2 yrs with cover	ac	40	71	
Low residue crops to high residue crop rotation - one time payment	ac	33	59	

References

Huggins, D.R., G.W. Randall, and M.P. Russelle. 2001. "Subsurface Drain Losses of Water and Nitrate Following Conversion of Perennials to Row Crops." *Agronomy Journal* 93 (3): 477–485.

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Randall, G.W., D.R. Huggins, M. P. Russelle, D. J. Fuchs, W. W. Nelson, and J. L. Anderson. 1997. "Nitrate Losses Through Subsurface Tile Drainage in Conservation Reserve Program, Alfalfa, and Row Crop Systems." *Journal of Environmental Quality* 26: 1240–1247.

Randall, G. W., D. J. Fuchs, W. W. Nelson, D. D. Buhler, M. P. Russelle, W. C. Koskinen, and J. L. Anderson. 1993. "Nitrate and Pesticide Losses to Tile Drainage, Residual Soil N, and N Uptake as Affected by Cropping Systems.", 468–470. Minneapolis, Minnesota USA: Soil and Water Conservation Society.

Links

Natural Resources Conservation Service (NRCS). July 2010. *Electronic Field Office Technical Guide (eFOTG), Section IV Practice Standards and Specifications: Contour Buffer Strips, Code 328*. Saint Paul, MN. http://efotg.sc.egov.usda.gov/references/public/MN/328mn.pdf

MDA Conservation Funding Guide, Crop Rotation
http://www.mda.state.mn.us/en/protecting/conservation/practices/croprotation.aspx

AVOIDING

Contour buffer strip.

Contour Buffer Strips (332)

Definition & 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 stripcropping, are narrower than adjacent crop strips and are planted in permanent vegetation. Established buffer vegetation is herbaceous and dense.

Water Quality & Other Benefits

Contour buffer strips slow the flow of water, thereby facilitating infiltration and diffuse flow, reducing sheet and rill erosion, and reducing the transport of sediment and associated contaminants to downstream water bodies. Contour buffer strips can also provide pollutant removal to shallow groundwater flow that interacts with the buffer root zone.

Contaminant reductions are provided in Table 5, which are results of a natural rainfall study in Iowa (Arora et al., 1996) 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).

Key Design/Implementation Considerations

As a result of farming on the contour, buffer 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 . Cropped strip widths should be a multiple of the width of farming equipment.

Table 5. Pollutant reduction estimates in percent for contour buffer strips. (Arora et al., 1996)

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

Buffers with higher drainage-area to buffer-area ratios are expected to result in lower contaminant retention rates (Dosskey et al., 2002). Consideration should be given to variable-width buffers as a response to variable upland contributing areas. This will enhance infiltration and thereby improve removal efficiencies of soluble pollutants such as pesticides or dissolved nutrients (Helmers et al., 2008; NRCS, 2000).

Implementation of grass barriers at the upstream end of the buffer strip, covering approximately the first 10% of the buffer increases removal rates in applications 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 facilitates diffuse 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 (NRCS, 1999).

The root zone of contour buffer strips interact with shallow groundwater flow, providing treatment of contaminants. Fields having draintiles that intercept shallow groundwater flow would cause short-circuiting of groundwater interaction with the root zone of contour buffer strips and are not ideal applications for contour buffer strips.

The NRCS standard (Code 332) recommends for this practice (NRCS, 2007):

- Buffer Widths:
    - 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 not to exceed the lesser of:
    - 50% of the slope length used for erosion calculation
    - Table 6 widths based on land slope.

Table 6. Maximum cropped strip widths for contour buffer strip farming practice (NRCS, 2007)[1]

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.

Cost Information

The cost of contour buffer strips is dependent upon value of the land taken out of production, buffer installation, plant establishment, and maintenance. In Missouri, assuming a 10-year time horizon, the annualized cost of installation and taking the land out of production is $62.40 per acre (Qiu, 2003). In this scenario, installation cost is estimated to be $51.85 per acre and land opportunity cost is estimated to be $55.68 per acre.

Table 7. 2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/ unit	HUP/ unit	Payment Cap
<10 acres of native grass mix	ac	242	271	
10 acres or more of native grass mix	ac	234	262	
Introduced grasses and legumes mix	ac	204	226	
Introduced grass mix	ac	195	215	
Lime	ton	22	26	

A limitation to adoption of contour buffer strips is the land that is taken out of production and the cost for implementation. That said, Qui's 2003 study indicated a net annualized benefit to the landowner of $10.90 per acre over a 10-year time horizon.

Operation and Maintenance Considerations

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

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).

Establishment and maintenance of 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 and mowing should be delayed until after the nesting period of song birds and other wildlife.

Grass barriers at the upstream end of the buffer strip can be an effective mechanism for trapping sediment, reducing deposition throughout the 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 if it has not been able to spread throughout buffer strip. Grasses appropriate for barriers would have stiff stems that remain erect throughout periods of runoff.

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 nitrogen and phosphorus content of each size fraction (Helmers et al., 2008).

Subsurface flow that interacts with the root zone of the buffer provides contaminant removal. However, the extent of interaction and contaminant removal characteristics are not as well understood for subsurface processes as compared to surface processes.

References

Arora, K., Mickelson, S.K., Baker, J.L., Tierney, D.P., Peters, C.J. 1996. Herbicide retention by vegetative buffer strips from runoff under natural rainfall. *Transactions of the American Society of Agricultural Engineers.* 39(6):2155-2162.

Dabney, S.M., Moore, M.T., Locke, M.A. 2006. Integrated management of in-field, edge-of-field, and after-field buffers. Journal of the American Water Resources Association. 42(1):15-24.

Dosskey, M.G., Helmers, M.J., Eisenhauer, D.E., Franti, T.G., Hoagland, K.D. 2002. Assessment of concentrated flow through riparian buffers. *Journal of Soil and Water Conservation*. 57(6): 336-343.

Helmers, Matthew J., Thomas M. Isenhart, Michael G. Dosskey, Seth M. Dabney, and Jeffrey S. Strock. 2008. "Chapter 4: Buffers and Vegetative Filter Strips." UMRSHNC (Upper Mississippi River Sub-basin Hypoxia Nutrient Committee). Final report: Gulf hypoxia and local water quality concerns workshop. American Society of Agricultural and Biological Engineers. St. Joseph, Michigan. P. 43-58.

Hoffman D.W. Gerik T.J., Richardson, C.W. 1995. Use of contour strip cropping as a best management practice to reduce atrazine contamination of surface water. In *Proc. 2nd International Association on Water Quality (IAWQ) Specialized Conference on Diffuse Pollution*, 595-596. London, U.K.: International Water Association Publishing.

Minnesota Natural Resource Conservation Service (MN NRCS). 2011. "2011 Minnesota Eqip Conservation Practice Payment Schedule."

NRCS (Natural Resources Conservation Service). March 2000. Conservation buffers to reduce pesticide losses. Washington, D.C. Available at: http://www.in.nrcs.usda.gov/technical/agronomy/newconbuf.pdf

NRCS (Natural Resources Conservation Service). September 2007. *Electronic Field Office Technical Guide (eFOTG), Section IV Practice Standards and Specifications: Contour Buffer Strips, Code 332*. Saint Paul, MN.

Qiu, Z. 2003. A VSA-based strategy for placing conservation buffers in agricultural watersheds. *Environmental Management*. 32(3): 299-311.

Links

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

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

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

AVOIDING

Corn and alfalfa on the contour. Winona County, MN

Contour Farming (330)

Definition & Introduction

Contour farming entails farming along the contour such that ridges, furrows and planting are perpendicular to the slope of the land. Contour farming is an erosion control system that has the effect of changing the direction of runoff from directly downslope to across the slope. 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 United States Soil Conservation Service (subsequently renamed the Natural Resources Conservation Service) when it was formed in the 1930s.

Water Quality & Other Benefits

Contour farming 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 farming improves the performance of downstream buffer-type practices such as contour buffer strips, terraces, contour stripcropping, cover crop, filter strips, and grassed waterways because it helps to prevent concentrated flow. Contour farming has a long history of implementation but a disproportionately sparse record of contaminant concentration reduction as a stand-alone conservation practice.

Key Design/Implementation Considerations

The NRCS standard (Code 330) provides design guidance for this practice.

The water quality and soil conservation benefits of contour farming are largely dependent upon integration with other conservation practices that are performed on the contour. In particular, contour buffer strips, terraces, and contour stripcropping. In addition, contour farming can be an effective tool to maintain 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 entail taking land out of production, though it may require consolidation of fields so that they may be farmed efficiently. Since contour farming is based on a change in operations, costs are low and are primarily associated with initial field design.

Table 8. 2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/ unit	HUP/ unit	Payment Cap
Contour Farming	ac	10	13	

Operation & 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.

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 of the United States, possibly suggesting that in the U.S. contour farming is not often being used as a stand-alone practice.

References

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NRCS (Natural Resources Conservation Service). September 2007. *Electronic Field Office Technical Guide (eFOTG), Section IV Practice Standards and Specifications: Contour Farming, Code 330*. Saint Paul, MN.

Links

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

MDA Conservation Funding Guide, Contour Farming
http://www.mda.state.mn.us/protecting/conservation/practices/contourfarm.aspx

AVOIDING

Cover crop. Washington County, MN

Cover Crops (340)

Definition & Introduction

Cover Crops as a BMP refers to the use of grasses, legumes or forbs planted to provide seasonal soil cover on cropland when the soil would otherwise be bare. In Minnesota, the cover crop is commonly rye, although oats, barley, alfalfa, buckwheat and hairy vetch are also used. The short growing season in Minnesota limits the use of cover crops although use is expanding as farmers are seeing the environmental and financial benefits of the practice.

The MDA categorizes cover crops into 5 main categories with winter cover crops and catch crops being the most commonly used (MDA, website):

- A **winter cover crop** is planted in late summer or fall to provide soil cover over winter. In Minnesota, winter cover crops are commonly planted after potato harvest primarily to reduce wind erosion.
- A **catch crop** is a cover crop planted after harvesting the main crop, primarily to reduce nutrient leaching. Many southeastern Minnesota growers use cover crops in this way and are cooperating with the Minnesota Department of Agriculture on related research and demonstration projects.
- A **smother crop** is a cover crop planted primarily to outcompete weeds. In Minnesota, buckwheat and rye cover crops commonly serve this purpose.
- A **green manure** is a cover crop incorporated into the soil while still green, to improve soil fertility. Currently in Minnesota, green manures are used primarily by organic growers.

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

Water Quality & Other Benefits

Water quality benefits of cover crops come from three processes. The first is the literal cover that the crop provides to the soil, reducing erosion from raindrop impact. 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. A 3 year study at Lamberton, MN (Strock et al., 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 and cold climate (Kaspar, 2008).

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). The other regional example of research is from central Iowa where researchers found a nitrate load reduction of 61% for rye cover crop (Kaspar et al., 2007). 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.

Key Design/Implementation Considerations

Cover crops can be used to reduce erosion, hold nutrients and/or provide forage. An excellent factsheet published by the MDA provides a good summary of conditions where farmers are deploying cover crops and can be used as a starting point for designing a cover cropping system (Figure 2). 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. http://www.mccc.msu.edu/

Cover Crops are often used on beet fields and have become part of the southern MN Beet Growers cooperative P trading program. A precedent-setting program where a co-op provided financial incentives for farmers to use cover crops. http://www.smbsc.com/.

Cost Information

The EQIP payment for cover crops is $40.00/ac.

Table 9. 2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
Legumes or mixed covers on cropland	ac	40	48	$7,000
Small grain seeding	ac	16	19	$6,000

CROP	GROWING SEASON											
	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
FIELD CORN	Plant Crop											
						Aerial Seed Winter Rye						
CORN SILAGE	Plant Crop											
							Plant Winter Rye					
SOY-BEANS		Plant Crop										
						Aerial Seed Winter Rye						
PEAS	Plant Crop											
			Plant Oats/Barley									
							Harvest: Green Chop or Round Bale					
						Plant Winter Rye						
SWEET CORN					Plant Oats/Barley				Winter Kill / Pre-season Cover Crop			
	Pre-season Cover Crop No-till Sweet Corn											
					Plant Alfalfa							
					Plant Winter Rye							
SOY-BEANS			Plant Crop									
						Aerial Seed Winter Rye						

Figure 2. Cover crop uses and timeline by crop type. (adapted from MDA 2005)

Operation and Maintenance Considerations

None.

Research Gaps

Although erosion and phosphorus 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.

References

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Feyereisen, G.W., B. N. Wilson, G.R. Sands, J.S. Strock, and P. M. Porter. 2006. "Potential for a Rye Cover Crop to Reduce Nitrate Loss in Southwestern Minnesota." *American Society of Agronomy* 98: 1416–1426.

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Links

EQIP information
http://www.mn.nrcs.usda.gov/programs/eqip/2012/eqip.html

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

Midwest Cover Crop Council: Decision Tool
http://www.mccc.msu.edu/

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

AVOIDING

Gully erosion in forested pasture land. Houstoun County, MN.

Grade Stabilization (410)

Definition & Introduction

A grade control structure is used to control the grade and head cutting in natural or artificial channels. NRCS Practice Standard 410 also applies to Grade Stabilization at Side Inlets (410), which is contained in a separate chapter in this document. Grade control structures are used to prevent the formation of gullies or stop the advancement of gullies.

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. Ravines connect relatively flat, cropped upland areas to incised channels and ditches below. Ravines therefore transport sediment generated from field that are up-gradient, as well as sediment generated from within the gully due to both geotechnical and fluvial processes.

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..

Key Design/Implementation Considerations

Grade stabilization can be addressed through upland hydrologic management of the contributing area and/or direct vegetative or structural means.

Design criteria for grade stabilization structures are referenced in NRCS Practice Standard 410. Structures with a height of less than 15 feet and storing less than 10 acre-feet for the 10-year, 24-hour storm should be designed to the 10-year frequency the event (NRCS, 1999). Other specific design guidance is contained in the NRCS National Engineering Handbook, Part 650, Chapters 6 and 10 (NRCS, 1984).

A MN DNR permit is required if the grade stabilization structure can be classified as a dam. Criteria for dam classification are provided by the MN DNR (2012).

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 2012 EQIP payments depend on the type of structure and the drainage area. Payments are provided for fabric reinforced vegetated chutes ($571/foot of drop), flexible armor chutes ($2,100/foot of drop), or pipe drop structures, which depend on the drainage area. Payments for pipe drop structures range from $3,750 for drainage areas between 0 and 10 acres to $60,000 for drainage areas greater 500 acres.

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 as a sediment source has been the subject of intense scrutiny recently in relation to the turbidity of the Minnesota River (Wilcock, 2009; Gran et al., 2011). 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 an 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.

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 vegetative stabilization within the ravine (see Table 1 below). 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.

Table 10. 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

TECHNIQUES			GROUP CONSENSUS				NOTES
Category		Practice	Favored	Favored In Certain Settings	Further Exploration warranted	Not Preferred	
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
	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

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).

References

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AVOIDING

Fencing at stream crossing. Goodhue County, MN.

Livestock Exclusion/Fencing (382 and 472)

Definition & Introduction

MDA Definition: Livestock Exclusion/ Access Control
The temporary or permanent exclusion of livestock 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 and rotational grazing (see chapter). While appropriately timed grazing of the riparian zone can provide some benefits to the stream, complete exclusion of livestock is usually preferred.

Most research so far suggests that complete exclusion 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. Also see chapters on riparian buffers and rotational grazing for additional information.

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 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. Soil can become compacted from livestock leading to an increase in runoff. Of secondary benefit is the health and vitality of the plant community within the riparian zone that results from not being grazed. A healthy plant community immediately adjacent to the stream typically translates to greater bank stability and lower water temperatures. A well vegetated riparian zone serves to filter runoff flowing across land into the stream. 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.

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.

Fencing materials should have 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.

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, fire, etc.)
- Stream crossings
- Durability of materials.

Cost Information

Table 11. Construction costs by fence type (Iowa State University Extension, 2005)

Fence Type	Construction Cost/Foot
Woven wire fence	$1.51
Barbed wire fence	$1.23
High-tensile non-electric wire fence	$1.12
High-tensile electrified wire fence	$0.70

Table 12. Annual average ownership cost by fence type

Fence Type	Total Cost/ Foot/Year
Woven wire fence	$0.26
Barbed wire fence	$0.21
High-tensile nonelectric (8-strand)	$0.15
High-tensile electric (5-strand)	$0.09

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 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.

References

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Brown, Larry, Kris Boone, Sue Nokes, and Andy Ward. 2010. "Ohio State University FactSheet: Agricultural Best Management Practices" (October 18).

NRCS Conservation Practice Standard for Fence, Code 382

Links

NRCS Conservation Practice Standard, Fencing, Code 382
http://efotg.sc.egov.usda.gov/references/public/MN/382mn.pdf

NRCS Conservation Practice Standard, Access Control, Code 472
http://efotg.sc.egov.usda.gov/references/public/MN/472mn.pdf

MDA Conservation Funding Guide, Fencing
http://www.mda.state.mn.us/protecting/conservation/practices/fencing.aspx

MDA Conservation Funding Guide, Exclusion
http://www.mda.state.mn.us/protecting/conservation/practices/exclusion.aspx

Electric fence.

Fence line. Polk County, Mn.

AVOIDING

Anhydrons application. Hubbard County, MN.

Nutrient Management (590)

Definition & Introduction

Nutrient management is the management of the Amount, Method, and Timing of applications 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 because of the extent of nutrient related water quality issues. Nutrient Management is one of the most common BMPs used on farms state-wide and is recognized as a Core 4 practice that can be implemented on almost every farm.

In the new (2012) 590 standard the NRCS adopted the 4Rs of nutrient management being, the Right source, Right rate, Right time and Right place for plant nutrient application.

Excesses of both N and P 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 to the Gulf of Mexico where they cause seasonal hypoxia.

In Minnesota, cold weather makes nutrient management challenging due to a non-growing season with a low 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 best management practices 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. *http://www.extension.umn.edu/nutrient-management/*

Water Quality and Other Benefits

Nutrient management can be divided into three management areas: Amount, Method and Timing. 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 related to all three management areas so the discussion overlaps between sections.

Amount

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, expected return, and University of Minnesota Extension Service guidelines are all factors used in selecting an application rate.

Phosphorus reacts slowly and is slowly released from fertilizer into the soil. Therefore knowing the P fertilizer application history and management practice are essential to understanding the accumulated available P. In soils of the north central region of the U.S. total soil P typically range between 300 and 1000 ppm (Mallarino and Bundy, 2008). 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

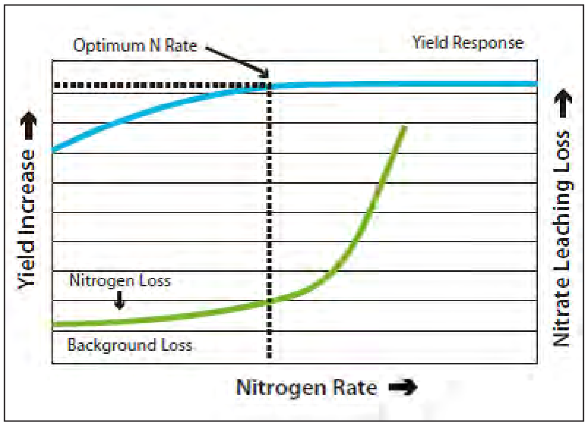

Figure 3. Importance of using optimum N rate for greatest profit and minimal nitrate-N loss (U of M Extension, Website)

Olsen test (U of M Extension, 1997).

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 phosphorus is 80-100 pounds of P_2O_5 per ton for some poultry manures and 5-10 pounds of P_2O_5 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%; the remaining P is a more stable organic form, which is not immediately available for crops during the first year of application (Mallarino and 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 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 and 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 and Risse, 2000; Mallarino and Bundy, 2008). Application of manure is further discussed in this chapter under the sections of timing and method.

For nitrogen, rotating in crops such as soybean adds nitrogen to the soil and can reduce the amount of N fertilizer needed (see Crop Rotation section). Other factors that influence the nutrient application rate are type of fertilizer, the use of other soil amendments such as manure and nitrification inhibitor, soil type, tillage method, fertilizer application methods, and timing (Baker et al., 1975; Fawecett and Smith, 2009).

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 a 18% reduction in N loss could be seen if the optimum N rate was applied. Using the optimum N rate makes N leaching loss minimal under normal conditions (see Figure 3). 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 tool 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 nitrogen application resulted in a 45% reduction in nitrate loss from the field.

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 (Fawecett and Smith, 2009; Redulla et al., 1996). Besides all the scientific challenges to determine the optimal amount of nutrients, it is also important to understand that farmers have less interest

Liquid dairy manure application. Winona County, MN.

in controlling nutrient loss in runoff, which they cannot readily observe (USDA and NRCS, website), and that farmers are in general not comfortable reducing the fertilizer rate based on nitrogen credits (Legg et al., 1993).

Timing

The timing of nutrient application is a critical component of nutrient management. 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 way to reduce N loss is to apply it during the maximum N demand period of a crop's growth (Fawecett and Smith, 2009; Randall and Sawyer, 2008). Although not as mobile as N, P should not be applied prior to rainfall or on frozen ground conditions.

- ***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, in general, anhydrous ammonia in fall is acceptable if the soil temperature is below 50°F and trending downward. However, 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 is rapidly drained or poorly drained soils where nitrogen is easily washed away with runoff.

  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. Extended rainy season and risk of soil compaction can also restrict spring N fertilizer application. Randall et al. (2002) demonstrated a 36% reduction of N loss from tile drainage when N was applied in spring compared to the fall application.

- ***Split Application***
  Split application for nitrogen is highly recommended for irrigated corn fields (Brach, n.d.) and if ridge-till or no-till planting systems are used on irrigated sandy soils (U of M Extension, website). Split application involves a preplant N fertilizer application and sidedress

Fall manure application on corn.
Winona County, MN.

application, which is typically made four to six weeks after planting crops. Sidedress 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 sidedress application due to weather or labor and equipment shortage (Fawecett and Smith, 2009). 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 preplant anhydrous ammonia from a water quality or economic perspective on medium and fine-textured Corn Belt soils (Jaynes and Colvin, 2006; Randall and 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 (Randall and Mulla, 2001).

In Waseca and similar areas, 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 preplant N vs. sidedress 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 and Sawyer, 2008).

- ***Time of Application vs. N 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 nitrogen 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.

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 and Sawyer, 2008).

The timing of P application is not critical for 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 run-off event 10-15 days after application of manure had 50% less dissolved P compared to run-off 24 hours after application (Mallarino and 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 despite relatively lower application rates (Komiskey et al., 2011).

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. Infrequent N-based applications of manure may be a good strategy as it reduces the use of fertilizer and help to meet the full N need for crops such as corn grown in rotation (Mallarino and Bundy, 2008).

Method

The method by which nutrients are applied to a field can greatly affect the mobility of those nutrients. In general, carefully placing fertilizer and incorporating the fertilizer into the soil profile is the best management practice.

- ***Placement***
  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 and Smith, 2009). This method is also effective for no-till planting systems (U of M Extension, website). 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 and 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 from cornfields harvested for silage (Baker and Laflen, 1982).

- ***Incorporation***
  Urea N fertilizer can be lost into air by volatilization (evaporation) at higher temperatures. Incorporating urea-based 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 and 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 and Laflen, 1982; Baker and 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 is the only way to effectively apply ammonia. Banding slows nitrification of anhydrous 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 immobilized by micro-organisms (U of M Extension, website).

For liquid manure with high inorganic, soluble P content, incorporation or injection are highly recommended methods that reduce P losses. P losses from corporation 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).

- ***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. 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. 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 reduce the period of nitrification inhibition (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 losses 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 and 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 drainage nor any increase in yield or profitability (Randall and Sawyer, 2008). Using nitrification inhibitor with fall N fertilizer application resembles 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 and Sawyer, 2008).

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
http://efotg.sc.egov.usda.gov/references/public/MN/590mn.pdf

MDA Conservation Funding Guide, Nutrient Management
http://www.mda.state.mn.us/protecting/conservation/practices/nutrientmgmt.aspx

BMPs for Nitrogen Fertilizer Use in Minnesota-MN Department of Agriculture
http://www.mda.state.mn.us/protecting/bmps/nitrogenbmps.aspx

The Minnesota Phosphorus Index-University of MN Extension: overview of P management and how to use P Index in Minnesota
http://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 MN could save more than $10/acre and 86% could save more than $6/acre, after assessing about 700 nutrient management plans prepared by farmers. Nutrient management is covered under the EQIP according to the following table.

Table 13. 2011 EQIP payment schedule (reproduced from MN NRCS, 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
Basic Nutrient Management	ac	7	9	3,000
Basic Nutrient Management - With Manure	ac	10	12	4,000
Enhanced Nutrient Management Option A	ac	9	11	3,500
Enhanced Nutrient Management Option A - With Manure	ac	13	16	5,000
Enhanced Nutrient Management Option B	ac	16	19	6,000

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.

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 rates 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 and 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 preplant application while maintaining crop yield (Randall and 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 and Bundy, 2008).
- Cost effectiveness of Alum use for liquid manure application
- Research to validate and calibrate P Index in each state

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Lime stockpiles. Washington County, MN.

Links

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

MDA Conservation Funding Guide, Nutrient Management
http://www.mda.state.mn.us/protecting/conservation/practices/nutrientmgmt.aspx

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

The MN Phosphorus Index: Assessing Risk of Phosphorus Loss from Cropland by University of Minnesota Extension
http://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
http://www.extension.umn.edu/distribution/cropsystems/DC6074.html

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

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

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

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

4Rs Right for Nutrient Stewardship
http://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
http://www.soil.ncsu.edu/publications/NIFACEAP/Factsheet_2.pdf

AVOIDING

Canada thristle (*Cirsium arvense*).

Pest Management (595)

Definition & Introduction

Pest management is 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. Pest management 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.

Use of pesticides to control crop pests is the first piece of pest management, although integrated pest management (IPM) is growing more popular. 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. Integrated pest management is more advanced than using pesticide alone for insect control, especially for fruit and vegetable production.

A cornerstone of IPM is regular scouting (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 eradication and may result in lower pesticide application rates and toxicity of the compounds used.

Selecting integrated strategies to prevent or treat pests requires knowledge of pest and crop ecology. In addition to pesticides IPM strategies include cultural, mechanical and biological controls.

Examples of cultural controls include crop rotation, pest-resistant crop varieties and timing of field operations to avoid or better manage pest outbreaks. Also, field borders and other types of conservation 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.

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. Studies of Atrazine and Alachlor losses in draintile near Waseca, MN showed that over a 5 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 4+ 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, 1993).

A 2001 field study in Scott County, MN on Alachlor and Cyanazine compares broadcast application to banding over 2 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).

Key Design/Implementation Considerations

The NRCS criteria are more strict when one applies pest management 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.

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.

Cost Information

The EQIP payment for pest management is \$5.68/ac with a maximum of \$3,000.

Table 14. 2011 EQIP payment schedule (reproduced from MN NRCS, 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
Pest Management on cropland	ac	5.68	10	3,000
Apple orchards - Level 1 IPM	ac	230	277	3,000
Apple orchards - Level 2 IPM	ac	359	430	4,500

Operation and Maintenance Considerations

None.

Research Gaps

The effects of pest management and integrated pest management are not well studied in Minnesota or nationally. Studies of pesticide mobility in non-draintile water is completely lacking.

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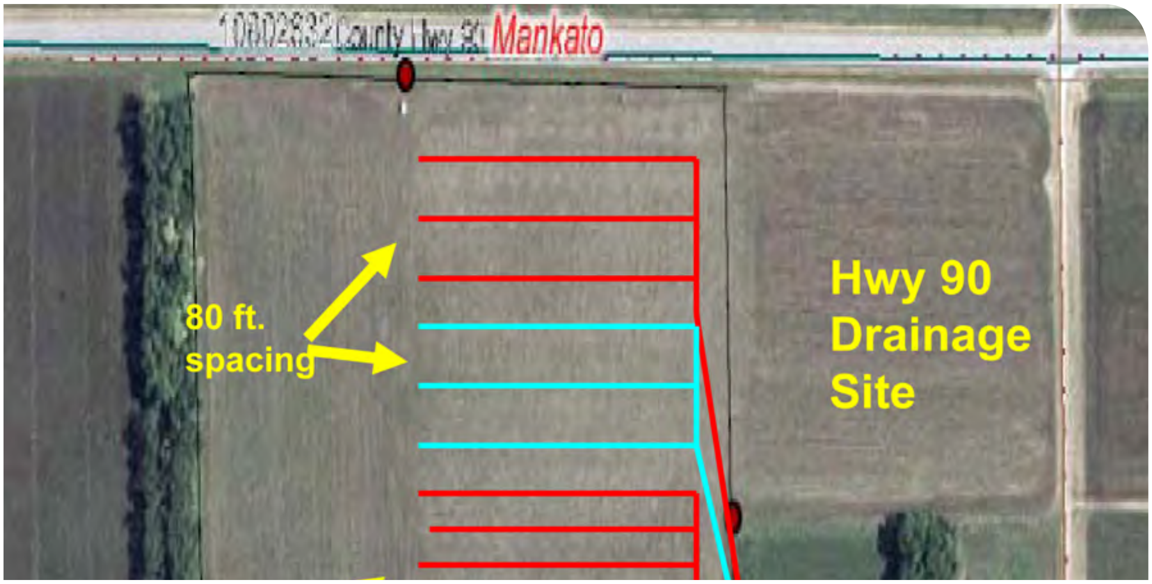
Minnesota Natural Resource Conservation Service (MN NRCS). 2011. "2011 Minnesota Eqip Conservation Practice Payment Schedule."

Links

NRCS Conservation Practice Standard, Pest Management, Code 595
http://efotg.sc.egov.usda.gov/references/public/MN/595mn.pdf

MDA Conservation Funding Guide, Pest Management
http://www.mda.state.mn.us/en/protecting/conservation/practices/pestmgmt.aspx

AVOIDING



Tile drainage design at the HWY 90 demonstration site (Bistodeau 2008).

Tile System Design

Definition & Introduction

Tile system design refers to selecting tile system parameters that acknowledge the tradeoffs between agronomic benefit and environmental impacts. 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.

The volume of drainage water removed is closely correlated with nitrate load, so changes in drainage volume generally correspond to a proportional change in nitrate load.

Water Quality and Other Benefits

Numerous researchers have found that nitrate concentrations 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, it is conservative to assume that load is reduced solely through flow reduction.

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, though that value ranged from 8.3% to 18.8%, with the bulk of that occurring April through June. A simple estimate 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 and Mulla, 2001). Sands et al (2003) also showed for a 2 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-feet.

Key Design/Implementation Considerations

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, k_s, the height of the water table above the drains, m_0, the depth, d, below the drains to an impermeable layer, and the drainage coefficient, q. Note, 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.

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

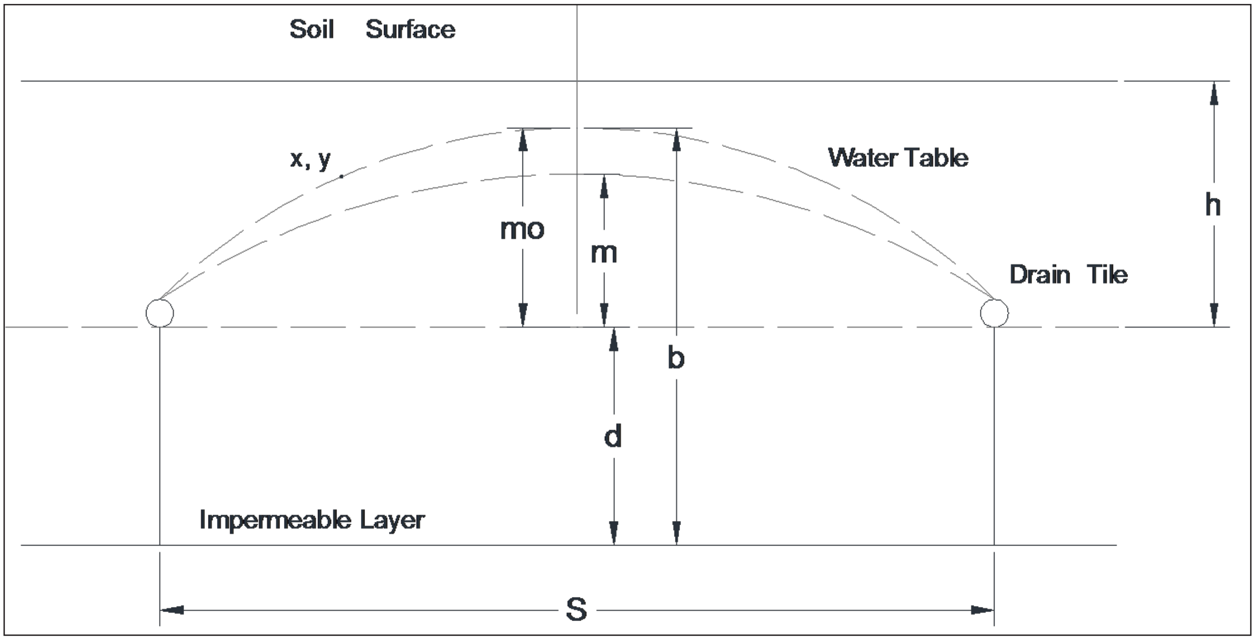


Figure 4. Cross section depiction of tile drainage system.

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 0.375 to 0.75 inches/day, depending on the crop (ASABE, 2008). Typical tile installation depth is about 4 feet.

Another approach assumes the same drainage coefficient with a shallower tile depth and solves for spacing. This approach should provide a reduction in annual drainage volume, on the order of 20%, as indicated by Sands et al. (2008).

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

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.

Operation and Maintenance Considerations

There are no additional operation and maintenance considerations for alternative drainage design above and beyond that of conventional drainage

Local/Regional Design Examples

The Bois de Sioux and Two Rivers Watershed Districts in Minnesota have required that permitted tile installations design to a 0.5 inch/day drainage coefficient (Kean, 2012). The cumulative effects of this requirement have not been studied to date.

Research Gaps

While there is fairly good understanding of the impact of selecting a smaller drainage coefficient 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 the potential basis for creating an incentive payment for operators to adopt this practice.

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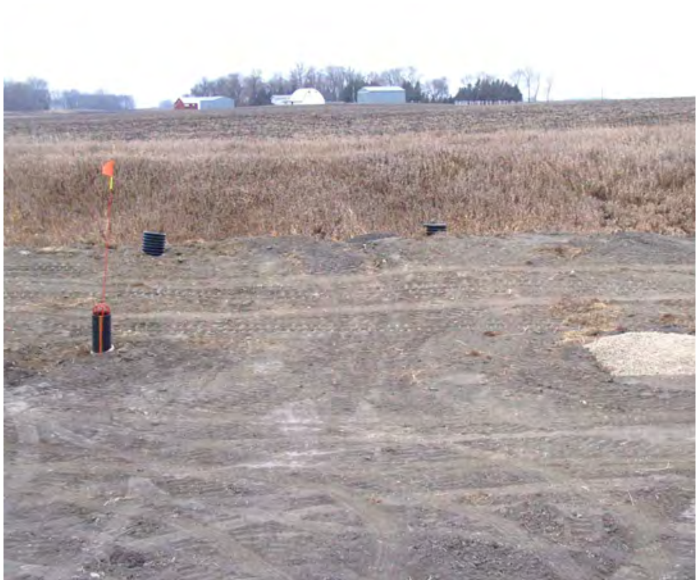
Skaggs, R.W. and G.M. Chescheir III. 2003. Effects of subsurface drain depth on nitrogen losses from drained lands. Transactions of the ASABE. 46(2): 237-244.

Links

NRCS. 2012. EQIP Payment Schedule. http://www.mn.nrcs.usda.gov/programs/eqip/2012/payment.html.

U of M extension Guide to Agricultural Drainage
http://www.extension.umn.edu/distribution/cropsystems/DC7685.html

CONTROLLING



(L) Demonstration site: Slotted riser and gravel inlet. Kandiyohi County, MN. (R)Slotted-raised inlet.

Alternative Tile Intakes

Definition & Introduction

Isolated surface depressions in agricultural fields are commonly drained with subsurface tile having surface intakes. 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. Although a body of research on alternative tile intakes has been amassed in Minnesota (Table 15), the vast majority has been conducted in laboratories or simulations.

There is a wide range of reported performance:

- Perforated riser sediment trapping efficiency approximately 90 – 95%

- Gravel inlet trapping efficiency of 70 – 95% occurs during temporary ponding (Wilson et al., 1999).
- Dense pattern tile sediment trapping efficiency approximately 100% in most soil types
- Phosphorus trapping efficiency is associated with sediment trapping. However, soluble P concentration may increase, depending on the amount of residue present.
- Potentially reduces peak flows into the tile system

Key Design/Implementation Considerations

Perforated Risers
Perforated risers must be farmed around.

Gravel Inlets
Inlet dimensions presented by Gieseke (2000) were 12-ft long, 3-ft wide, and 3-ft deep, using pea gravel with dimension 0.25 (1/4") to 0.87 (7/8") inches. Most design guidance specifies that the pea gravel be mounded 1 foot above the surrounding land. Pipe material is 5" muck pipe with 5/8" holes.


Drop inlet

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.

Cost Information

Hawk Creek Watershed Project lists the following average project costs:

- Pattern Tile with Open Intake Removed: $500
- Rock or Blind Intakes: $200 to $450
- Hickenbottom Intakes: $200

There are no cost estimates in the "2011 Minnesota EQIP Conservation Practice Payment Schedule" for alternative tile intakes.


Rock inlet

Table 15. Water quality impacts of different alternative intake studies.

Source	Type	Site Description	Drainage Area (Ac)	Soil Type	Type of Study	Number of Years	Number Events	Percent Reduction Reported (%)		
								Sediment	Total P	Sediment Bound P
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			5.1	66.6	
Wilson et al. (1999)	Slotted Pipe	Lab	12		Lab Prototype	N/A	15	91.5	65.9	
Wilson et al. (1999)	Flush Pipe	Lab	12		Lab Prototype	N/A	15	83.1	66.6	
Wilson et al. (1999)	Gravel #7 (d50 = 10.9mm)	Lab	12		Lab Prototype	N/A	3	95.2	81.6	
Wilson et al. (1999	Gravel #67 (d50 = 11.5mm)	Lab	12		Lab Prototype	N/A	5	93.4	88.1	
Wilson et al. (1999)	Gravel #6 (d50 = 15.4mm)	Lab	12		Lab Prototype	N/A	12	90.2	82.4	
Ranaivoson (1999)	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	N?A	Clay loam	Simulated Storm	N/A	1	98		

Operation and Maintenance Considerations

Gravel inlets can become clogged, reducing drainage capacity. Lifespan depends on site and management. According to Ranaivoson (1999) the expected life of a gravel inlet is around 10 years.

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.

Heron Lake Watershed District
http://www.hlwdonline.org/hlwd/index.php?option=com_content&view=article&id=87&Itemid=187

Jackson County SWCD
http://www.co.jackson.mn.us/index.asp?Type=B_BASIC&SEC={0F82400D-AD6C-496B-8079-F540EC768D20}

Research Gaps

1. 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.
2. The longevity of gravel inlets is still poorly understood. Ranaivoson 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.
3. 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.
4. Many of the informational brochures available from SWCDs and WDs highlight the results from Gieseke (2000) for rock inlets. However, results from that study need to be verified to determine if long-term effectiveness is similar to short-term results. Also, it is not known what affect the perforated tile line in the rock inlet basin had on the results in that study. Ideally, the experiment would be repeated, switching basins.

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CONTROLLING

Stripcropping. Houston County, MN.

Contour Stripcropping (585)

Definition & Introduction

Contour stripcropping means planting erosion-susceptible crops perpendicular to the slope and alternating 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, which have the ability to trap sediment, include close-growing crops such as forages, small grains, or dense grasses. Erosion-susceptible strips include row crops.

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 due to wind and protects growing crops from wind-associated damage.

Key Design/Implementation Considerations

In contour stripcropping, the erosion-resistant and erosion-susceptible strips should have the same 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).

Key recommendations from the NRCS standard (Code 585) are:

- *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 are primarily associated with initial field design. Out-of-pocket expenses are minimal.

Field road near stripcropped filed.

Table 16. EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
Contour Stripcropping	ac	39	46	
Wind Stripcropping	ac	8.71	10	

Operation and Maintenance Considerations

Implementation of 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 the sediment builds-up, it can be more easily re-distributed 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 periods of runoff.

Research Gaps

Although national studies are available (see appendices), research in Minnesota and the Upper Midwest is lacking. Cost-benefit analyses would address changes in productivity and herbicide application or other operations associated with contour stripcropping.

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Links

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

MDA Conservation Funding Guide, Stripcropping
http://www.mda.state.mn.us/protecting/conservation/practices/contourstrip.aspx

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Erodible strip flanked by hay.

CONTROLLING

Demonstration site: Nicollet County, MN.

Controlled Drainage (554)

Definition & Introduction

Controlled drainage, sometimes referred to as drainage water management, is a practice used to control or manipulate the ground water elevation in a tile drained field. Controlled drainage is similar to traditional tile drainage except that tile outflow is intercepted by a water control structure that effectively controls the elevation of the water table in a field by adding or removing stoplogs within the structure to raise or lower the water table. Controlled drainage may be implemented as part of a new system or as part of a system retrofit.

Water Quality Effects

Water quality benefits attributed to controlled drainage result primarily from reductions in water yield volume. In other words, most studies 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. Additionally, because controlled drainage is a relatively new BMP to the Midwest, the water quality benefits have been documented primarily through modeling.

Feset et al. (2010) conducted a field study in Minnesota comparing freely drained fields to those with controlled drainage. This study showed reductions in nitrate-nitrogen, total phosphorus, and ortho-phosphorus loads 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 water table 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. Results from the 5-state Conservation Innovation Grant (CIG) project indicate that nitrate reductions from 20 to 60% can be achieved, depending on precipitation and climate (ADMC, 2011).

Automatic water control valve (inside).

Automatic water control valve (in place).

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 stoplogs are raised, the date at which they are lowered, and the degree to which they are raised. The date the stoplogs are installed should occur sometime after spring planting. Ale et al. (2008) 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. Stop logs may again be installed after harvest until about 4-6 weeks before planting.

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 indicates 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.

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. Decision-makers may want to consider adjusting subsidy rates such that farmers reach a break even point.

Table 17. 2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
Drainage Water Management	ea	57	68	1,000

Operation and Maintenance Considerations

As stated above, the key operation consideration is when and by how much stoplogs are added or removed. The following operation schedule is the recommended strategy for the Hayfield, MN site of the CIG project (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 are part of the CIG project. The Minnesota sites are the Dundas, Hayfield, Wilmont, and Windom sites. All sites exhibited a decrease in drainage volume over the study period.

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 a 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. Other locations, such as North Carolina, have investigated the use of subirrigation, which may be worthy of investigation in Minnesota. 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.

Water control structure

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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CONTROLLING

Road retention. Traverse County, MN.

Culvert Sizing / Road Retention / Culvert Downsizing

Definition & 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 channels and culverts having larger capacities. The associated increase in runoff can result in higher peak flows downstream and unequal levels of protection along the length of drainage systems. Culvert sizing is the design of conduits through road embankments to help manage runoff timing and peak flows within a drainage network.

The purpose of culvert sizing is to reduce or prevent flood damages by better utilizing 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. Reduced field and channel erosion, along with short-term ponding of runoff may also provide a water quality benefit.

The principle of road retention is the same as culvert sizing, though a distinction may be made on the basis of the magnitude of the practice and the length of time water is stored by the structure. 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. McEnroe and Gonzalez (2006) stated that storage effects are less likely to be significant for large culverts than for small culverts.

Water Quality Effects

The water quality effects of culvert sizing have not been documented; however, it seems reasonable to assume that some water quality benefit may be expected if peak flows are reduced.

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 1 square mile drainage area, 33% at 8 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.

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 those benefits at this time (Solstad, et al., 2007).

Key Design/Implementation Considerations

Culvert sizing provides short-term temporary storage within channels and on adjacent lands upstream from road crossings. It is most applicable for small drainage areas up to approximately 20 square miles.

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.

Culvert sizing may be adopted in using one of two approaches: incrementally or on a system basis (Solstad, et al., 2007). The incremental approach assumes replacement of culverts one at a time, as individual culverts fail or need replacement. The system approach is to replace all culverts in a subwatershed at one time. Solstad, et al. (2007) discuss both approaches in more detail.

Guiding Principles

- risk 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, to the extent practical;
- 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, to the extent practical;

Challenges

- Modifying the predominant current paradigms for design of culverts, roadways, and drainage ditches, among the many federal, state and local road authorities involved, as well as many drainage system administrators and designers. Fears about negative impacts to road safety, road maintenance, and crop production should be expected.
- Implementation will require ongoing leadership to provide information and education, to pilot adoption of this measure and to refine implementation based on experience.
- In many instances, incremental implementation will be necessary over a long period of time before the goal of full implementation of culvert sizing within subwatersheds is achieved.

Cost Information

According to the Area II Minnesota River Basin Projects, Inc. (Area II, 2011), 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 noncropped areas and $400/acre for cropland with encouragement to site projects where cropland can be avoided. The objective of culvert sizing is to avoid easement costs.

There is no information about costs for culvert sizing in the 2011 EQIP payment schedule.

Operation and Maintenance Considerations

The maintenance and operations concerns pertaining to any culvert apply to this practice.

Legal/Permit Requirements

Permits from local road authorities may be required.

Local/Regional Design Examples

The Upper Cedar River Surface Water Management Plan was (UCRW, 2007) 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, MN 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 RCP). The conceptual approach taken in the report appears to have guided subsequent efforts by the Cedar River Watershed District.

The Cedar River Watershed District (CRWD, 2011) has implemented a cost share program to assist townships in the district to analyze culvert capacity when culverts need to be replaced. As stated on their website, the goal of the program is not necessarily downsizing but 'right' sizing.

The Area II Joint Powers Area in southwest Minnesota has been using road retentions as a flood control tool since 1989 (Area II, 2011). No information was available regarding effectiveness.

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CONTROLLING

Grassed waterway. Washington County, MN.

Grassed Waterways

Definition & 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 steeper slopes. Grassed waterways are commonly used to convey runoff from terraces and diversions but are an important BMP wherever concentrated flows occur.

Water Quality 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. The literature does show, however, that grassed waterways have a positive effect on water quality by reducing peak discharge and sediment yield.

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

A modeling study in southeastern Iowa using WEPP included monitoring of 8 storms for volume and sediment which were used to calibrate the model (Dermsis et al., 2010). Because this is a particularly good calibration on a well defined drainage area, the reductions reported in this study are likely a good starting point for estimating grassed waterway performance in Minnesota.

Figure 5. Runoff reduction by grassed waterways of various lengths in calibrated WEPP model in Iowa (reproduced from Dermsis et al., 2010).

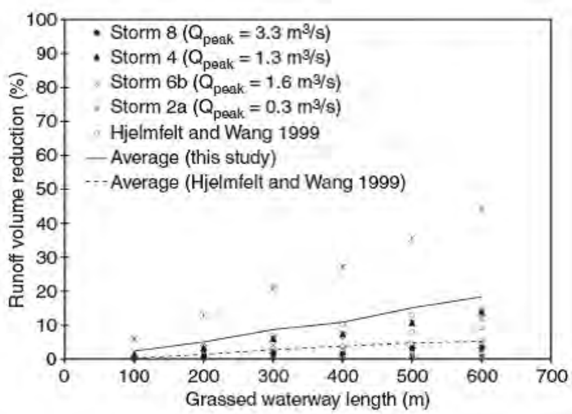
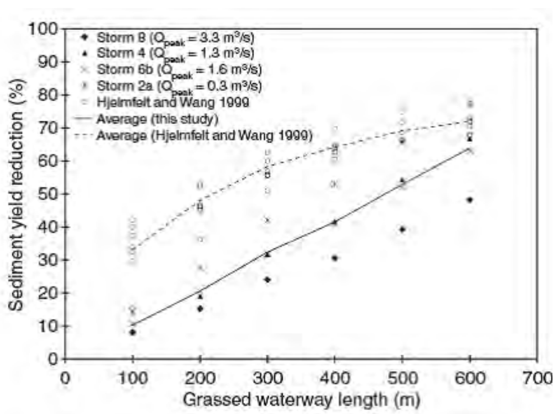


Figure 6. Sediment reduction by grassed waterways of various lengths in calibrated WEPP model in Iowa (reproduced from Dermsis et al., 2010).



Key Design/Implementation Considerations

The NRCS lists important design considerations regarding design 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. When designed for pollutant removal, grassed waterways should be as large as possible to reduce velocity, which induces settling. Such waterways have reduced effectiveness when compacted or if the grass is too short.

Cost Information

Grassed waterways are covered under the EQIP according to the following table.

Table 18. 2011 EQIP payment schedule (reproduced from MN NRCS, 2011)

Component	Unit	PR/unit	HUP/ unit	Payment Cap
Fabric Barrier	lin ft of fabric	1.19	1.43	
Grassed Waterway -Less than 12 Ft Bottom Width	lin ft	1.06	1.27	
Grassed Waterway - 12 to 16 Ft Bottom Width	lin ft	1.25	1.49	
Grassed Waterway - 16.1 to 20 Ft Bottom Width	lin ft	1.95	2.34	
Grassed Waterway - 20.1 to 35 Ft Bottom Width	lin ft	2.14	2.57	
Grassed Waterway - Greater than 35 Ft Bottom	lin ft	3.65	4.38	

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. Mowing or periodically grazing vegetation can help maintain capacity and vegetation vigor.

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.

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Links

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

MDA Conservation Funding Guide, Grassed Waterways
http://www.mda.state.mn.us/protecting/conservation/practices/waterway.aspx2

Grassed waterway opportunity.

CONTROLLING

Center pivot irrigation. Sherburne County, MN.

Irrigation Management (442 and 449)

Definition & Introduction

According to Kenney et al. (2009) irrigation accounted for about 6% (89.1 billion gallons) of Minnesota's total 2005 use. Of that total, 89% came from groundwater sources. Irrigation accounted for 25% of the total groundwater withdrawal in 2005 (Kenney et al., 2009). About 467,000 acres were irrigated in 2005.

Irrigation management means controlling the rate, volume and timing of irrigation such that water is applied efficiently and without negative 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 phosphorus.

If not managed properly, excessive leaching in sandy soils can lead to groundwater pollution via soluble nutrients, like nitrogen, and pesticides. Derby et al. (2009) showed that over-application of irrigation water can lead to greater nitrate leaching. In a long-term study in southeastern North Dakota, Derby et al. (2009) found that soil nitrogen concentration in the fall was the most important variable in terms of explaining nitrogen concentration in leachate.

Newville and Stuewe (2011) reported that at an irrigation forum MPCA presented data linking irrigation pumping withdrawals to harmful effects on Little Rock Creek. In the MPCA study (discussed in Newville and Stuewe) low flow conditions were exacerbated in mid to late summer by irrigation pumping.

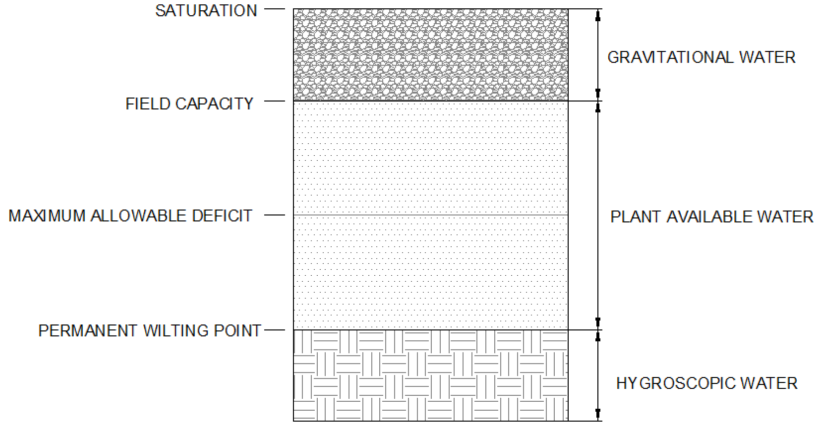
Key Design/Implementation Considerations

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:

1. NRCS National Engineering Handbook. Part 623, Section 15
2. NRCS National Engineering Handbook. Part 652. Irrigation Guide.
3. NRCS National Engineering Handbook. Part 650, Chapter 15, Irrigation.
4. NRCS Practice Standard 449, Irrigation Water Management
5. NRCS Practice Standard 442, Irrigation System, Sprinkler
6. University of Minnesota Extension Publication FO-03875, Irrigation Water Management Considerations for Sandy Soils in Minnesota
7. FAO Paper No. 56 Crop evapotranspiration.

The traditional approach to irrigation management is to schedule irrigation using a moisture accounting method, or checkbook



method. The soil water content is allowed to be depleted to its maximum allowable depletion (MAD) level and that triggers an irrigation back to near field capacity, slightly less is often recommended to account for the possibility of rainfall (Wright, 2008). Additional inputs (rainfall) and withdrawals (e.g., ET)are monitored to track the water balance.

There are sophisticated means of estimating daily evapotranspiration (e.g., Allen et al., 1998); however, the University of Wisconsin Extension publishes daily estimates, based on the Priestly-Taylor method at: http://www.soils.wisc.edu/uwex_agwx/sun_water/et_wimn.

One management strategy to reduce water or energy inputs is deficit irrigation. Where water supply may be limiting or the cost of energy is high, deficit irrigation may be employed. According to English (1990): "Deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water." Under deficit irrigation, some degree of production loss is expected, but water productivity is maximized.

Cost Information

EQIP payments are available for converting a conventional sprinkler package to a low pressure system ($4.51/ft) and for developing following an irrigation water management plan $4.06/ac, capped at $1,500.

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

Operation and Maintenance Considerations

None.

Legal/Permit Requirements

A new irrigation system may require a water withdrawal permit from the Minnesota Department of Natural Resources.

Local/Regional Design Examples

The links between nitrogen, irrigation and water quality were examined in project by the East Otter Tail Soil and Water Conservation District and the Minnesota Department of Agriculture to increase educational outreach and technical assistance to producers in central Minnesota, an area of sandy textured soils and shallow groundwater aquifers (Newville and Stuewe, 2011).

Research Gaps

There is currently no extension position at the University of Minnesota devoted to irrigation. As a result, research aimed at improving irrigation efficiency and understanding environmental impacts in Minnesota are lacking. This gap was noted several times by Newville and Stuewe (2011). Other gaps noted at the forum included better and easier-to-use irrigation scheduling methods, more evapotranspiration and weather data available, and in general, more irrigation research conducted and disseminated.

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CONTROLLING

Horse manure stockpile. Washington County, MN.

Waste Storage Facility (313)

Definition & 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 and phosphorus 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). 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 of the full-scale storage facilities they examined had leakage rates that would have exceeded Minnesota's standard of 1/56 (0.0179) inches/day.

Deleterious 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 NRCS National Engineering Handbook (NEH) Part 651 addresses agricultural waste management, including design of lagoons (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.

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

Operation and Maintenance Considerations

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

Research Gaps

Previous research conducted in Minnesota indicates that earthen storage lagoons do have the potential to contribute elevated nitrate and phosphorus levels (MPCA, 2001). There is not a good understanding of the effect leaking manure storage facilities have on water quality in the state, particularly on seepage rates from lagoons that have been in existence for over 5 years.

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Links

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NRCS. 2012. EQIP Payment Schedule. http://www.mn.nrcs.usda.gov/programs/eqip/2012/payment.html.

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CONTROLLING

Conservation tillage corn stubble next to hay field. Pipestone County, MN.

Conservation Tillage (329, 345 and 346)

Definition & Introduction

Conservation tillage is any tillage practice that leaves additional residue on the soil surface for purposes of erosion control on agricultural fields. 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, the specific variation selected 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).

No-till and strip till involve planting directly into crop residue that either hasn't 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, 2000).

In a Wisconsin field study, Andraski et al. (2003) found that no-till reduced dissolved P loads by 57% and 91% for total phosphorus when compared to conventional tillage. A simulated rainfall study in Wisconsin by Bundy et al. (2011) 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, MN 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. Phosphorus loss reduction ranged from 2.9 lbs/ac to 1.9 lbs/ac, an average 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. Longterm studies on continuous corn in Iowa have studied nitrate leaching in draintile and have shown that although the leaching is similar the first two years, in subsequent years leaching is reduced in no-till systems (Kanwar and 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 a 80-91% reduction in total P loss for soybeans following corn and a 66-77% reduction in P loss for corn following soybeans.

Andraski et al. (1985) studied tillage effects on phosphorus 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.

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 was examined in a single-event simulated rainfall study in the Minnesota River Basin by Zhao et al., (2001). This study indicated that ridge till performed 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 nitrogen of all tillage types examined.

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 deciding 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 and Senjem, 1996). 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.

Olson and Senjem (1996) 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 3 years and conversion to ridge-till from chisel plow may take as long as 7 years.

Switching costs may include the cost of switching twisted shanks to straight shanks 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 shanks. 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.


0% residue cover.

Table 19. 2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
Residue Management - Mulch Till	ac	7	8.50	$3,000

Table 20. 2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
Residue Management - No Till, Strip Till	ac	23	27	$9,000

Table 21. 2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
Residue Management - Ridge Till	ac	23	27	$9,000

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. Recent work by Bundy et al. (2011) should be expanded upon to further explore the relationship between common management practices that also achieve the greatest pollutant protection.

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Links

NRCS Conservation Practice Standard, Mulch Till, Code 345
http://efotg.sc.egov.usda.gov/references/public/MN/345mn.pdf

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

NRCS Conservation Practice Standard, Ridge Till, Code 346
http://efotg.sc.egov.usda.gov/references/public/MN/346mn.pdf

MDA Conservation Funding Guide conservation tillage
http://www.mda.state.mn.us/en/protecting/conservation/practices/constillage.aspx

Conservation tillage. Chisago County, MN.

CONTROLLING

Dense streambank vegetation. Dakota County, MN.

Riparian and Channel Vegetation (322/390)

Definition & Introduction

Riparian 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. 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 be play an important role in providing habitat, helping to regulate water body temperature through shade and can help to dissipate stream energy.

Water Quality Effects

If receiving runoff from upland sources, riparian vegetation has similar water quality benefits to vegetative filters. Riparian vegetation can improve water quality by promoting sedimentation of sediment and associated pollutants, as well as nitrates. There are multiple pathways for nitrogen species transformation, including plant uptake, microbial immobilization, soil storage, groundwater mixing, and denitrification (Mayer et al., 2007). Denitrification is the microbially aided conversion of nitrate to N_2.

Mayer et al. (2007) found in a meta-analysis of 45 different studies that mean nitrogen 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 removed 57.9% of nitrogen, those between 26 and 50 m wide removed 71.4%, and buffer widths greater than 50 m removed 85.2% of nitrogen. Yamada et al. (2007) found that significant reductions in nitrate were realized within about 2 years of riparian buffer establishment.

Hoffman et al. (2009) performed a review of the efficiency of riparian buffers in retaining phosphorus in the US, Canada, and Europe. Phosphorus retention was dependent on both chemical and physical characteristics. Chemical characteristics included: iron: phosphorus 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 phosphorus is essentially negligible.

Liu et al. (2008) present a comprehensive review of the effectiveness of vegetated buffers on sediment trapping. Sediment trapping efficiency was found to be primarily a function of buffer width and slope. Liu differentiated in their summary of the literature between vegetated filter strips and riparian buffers. For the riparian buffers, sediment trapping efficiency ranged from 53 to 98%.

The use of shrubs in addition to grasses and forbs has also been investigated in the use of 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, species of plant, and position on the streambank or landscape. The NRCS (2011) practice standard 390 provides basic design criteria and guidance. Additional criteria are provided for specific goals, like streambank stabilization or water quality improvement, for example.

The NRCS Stream Restoration Design guide (NRCS, 2007) provides extensive technical guidance regarding bioengineering.

A critical aspect of riparian vegetation design is identification of locations that provide the most benefit. The Minnesota Department of Agriculture's Precision Conservation Initiative (http://www.mda.state.mn.us/protecting/cleanwaterfund/toolstechnology/precisionconsinit.aspx) is aimed at identifying priority placement sites. Galzki et al. (2009) used terrain analysis to identify gully locations, side inlets, and riparian areas.

Tomer et al. (2008) also provide 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.

A key concern is enforcement and maintenance of buffers. The Shoreland Buffer Initiative in Blue Earth County found that Minnesota statutes requiring buffers on rivers was not being widely enforced although voluntary compliance was high.

Cost Information

No payment information is contained in the 2012 EQIP payment schedule for practices 322 and 390. Bank shaping for vegetative treatment eligible for a $0.66 sq/yd under practice 580, streambank and shoreline protection. Practice 393, Filter Strip, is eligible for $222/acre for mixed native grasses with or without forbs and $282/acre for mixed native grasses with or without forbs, with shaping.

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 and vegetative buffers may be subject to a Minnesota Department of Natural Resources public waters permit (http://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.

Local/Regional Design Examples

Numerous examples of riparian and channel vegetation exist in the state.

Research Gaps

There are few examples of monitoring studies documenting the benefits of riparian and channel vegetation in Minnesota.

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CONTROLLING

Cows grazing in paddock. Chippewa County, MN.

Rotational Grazing

Definition & Introduction

Rotational Grazing, also called prescribed or managed grazing, 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. See the Livestock Exclusion chapter for additional information on restricting access to sensitive areas.

Animal rotations can vary from a simple rotational grazing system in which animals move or rotate to a fresh paddock every 3 to 6 days, to an intensive rotational grazing system in which animals are moved to a fresh paddock as frequently as every 12 hours. Grazing is started when forage is about 8 inches tall and stopped once it is grazed down to about 4 inches tall (depending on vegetation type). The means less need to feed hay, silage or grain.

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.

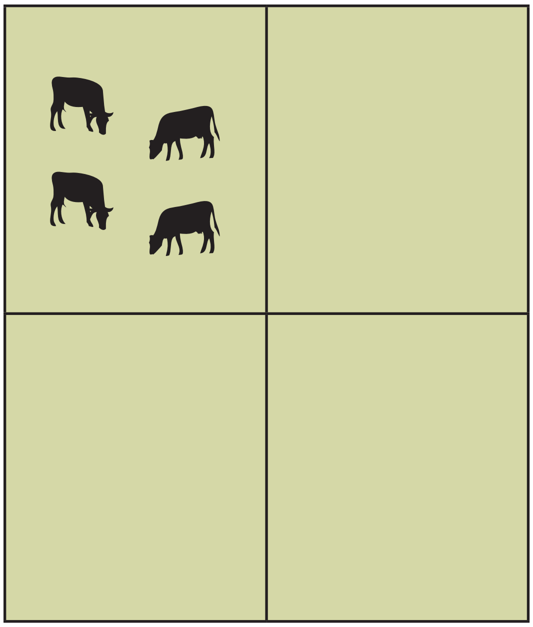

Figure 7. Simple Rotational Grazing System (Blanchet, 2003)

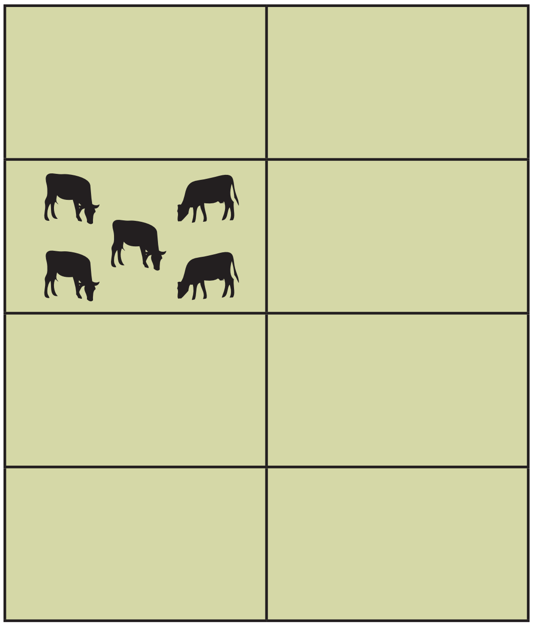

Figure 8. Intensive Rotational Grazing System (Blanchet, 2003)

Typically in Minnesota, cattle are grazed in marginal farmland - wet areas and stream valleys. Uplands are reserved for corn and soybeans (Lenhart, 2011).

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, 2000), fecal coliform and turbidity were found to be consistently lower at the rotationally grazed sites than at the continuously grazed sites.

The research portion of the economic, environmental & social analysis by the Land Stewardship Project entitled (LSP, 2001), documented significant water quality benefits when a managed year-round cover scenario (including rotational grazing) is used on working farms to replace intensive row cropping. In that scenario (Scenario D) the Chippewa Study Area of the Minnesota River Basin identified expected water quality improvements of an 49% reduction in sediment, 62% reduction in nitrogen and a 75% reduction in phosphorus.

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 nutrient.

The MDA maintains 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 .

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:

A Grazing Resource Inventory that identifies:

- 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?
- Forages - What are the existing forage species and how healthy and in what condition is 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?

A Grazing Plan that determines the following components and associated costs:

- Paddock Design and Layout - How many paddocks, how large 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.

A Pasture Management strategy that takes into account:

- Pasture Forage and Livestock Management - Proper grazing management for desired forage species. When to start in spring, when to move from paddock to paddock.

- 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

- 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 June 2010 publication "Improving and Sustaining Forage Production in Pastures" by Howard Moechnig. 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 water systems can be higher than with continuous grazing and tend to increase with increased intensity of the grazing system.

The University of Minnesota Extension article "Knee Deep in Grass – A survey of twenty-nine grazing operations in Minnesota", which had converted to rotational grazing, identified per farm fencing equipment costs associated with implementation of Managed Intensive Grazing (MIG) ranging from $0 - $11,000 per farm. The average spent on fencing was $2,220 with costs being 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 were reported to have significantly decreased on 15 of the 29 farms with 26 of the 29 farms reporting a decrease or no change in whole farm labor costs following conversion to MIG.

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 making progress towards the established goals for the grazing system.

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).

Research Gaps

There is limited research directly comparing rotation grazing to continuous grazing. In general, the research available is for sites in Minnesota River watershed and looks at rotational grazing as a part of a more holistic system to replace intensive row crop operations while still being profitable. The majority of work on these studies was completed between 1995 and 2001; follow-up on the same study sites is recommended. Additional research on rotational grazing is needed in the northern half of Minnesota.

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Links

MDA Conservation Funding Guide Rotational Grazing. http://www.mda.state.mn.us/protecting/conservation/practices/grazing.aspx

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

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

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

CONTROLLING

Eroded streambank. Blue Earth County, MN.

Streambank and Shoreline Protection (580)

Definition & 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 at key areas, maintaining adequate flow conveyance, or improvements for habitat, recreation or aesthetics.

Water Quality Effects

Gran et al. (2011) estimate that 8% of TSS in the LeSueur River watershed is 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. This varies greatly by stream type and setting.

The primary benefit of streambank stabilization is reduced erosion. 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 is 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.

A water quality benefit in terms of reduced sediment concentration (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.

Key Design/Implementation Considerations

NRCS' Stream Restoration Design Manual (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 (MN 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 $4.32/sf according to NRCS (2012).
- Cable Concrete: $7.50/sf
- Vegetation: EQIP reimbursement is $0.66/sy for bank shaping and Practice 393, Filter Strip, is eligible for $222/acre for mixed native grasses with or without forbs and $282/acre for mixed native grasses with or without forbs, with shaping.
- Stream barb: $48/cy

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 and vegetative buffers may be subject to a Minnesota Department of Natural Resources public waters permit (http://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.

Local/Regional Design Examples

There are numerous examples of streambank protection throughout the state. Two local examples that used differing techniques are located at Raspberry Island in St. Paul, Minnesota and Rice Creek in Blaine, MN.

The Raspberry Island project used large (Class 5) limestone riprap to stabilize an eroding island on the Mississippi River in downtown

St. Paul. This hard-armor approach was necessary to address the erosion and aesthetic demands of a highly visible part project.

Raspberry Island Riprap Protection Project

The Rice Creek Remeander project took a bioengineering approach to improve habitat and increase channel stability using root wads, channel shaping and erosion resistant plantings.

Rice Creek Remeander Project

Research Gaps

As indicated in Gran et al. (2011), the primary driver of changes in streambank erosion and failure is hydrologic change. More research is needed to understand how changes in hydrology affect erosion and sediment transport, particularly streambank erosion and system stability.

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CONTROLLING

Terrace.

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. 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 5 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

Table 22. 2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/unit	HUP/unit	Payment cap
Terrace - Narrow Base – 6% slopes or less	lin ft	2.44	2.93	
Terrace - Narrow Base – greater than 6% slopes	lin ft	3.19	3.83	
Terrace - Narrow Base – graded w/ grass outlet	lin ft	0.98	1.17	
Terrace - Broad Base – graded w/ grass outlet	lin ft	1.35	1.62	
Terrace - Farmable Front w/ grassed back slope - 24 feet or greater front	lin ft	3.19	3.83	
Terrace - Farmable front w/ grassed back slope - 24 feet or greater front	lin ft	3.64	4.37	
Terrace - Broad Base - Less than 24 feet front slope	lin ft	2.63	3.15	
Terrace - Broad Base - 24 feet to 32 ft front slope	lin ft	4.13	4.95	
Terrace - Broad Base - Greater than 32 ft front slope	lin ft	5.25	6.30	

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:

1. Provide periodic inspections, especially immediately following storms with a 10-year or greater return frequency.
2. Promptly repair or replace damaged components as necessary.
3. Maintain terrace capacity, ridge height, and outlet elevations.
4. Remove sediment that has built up in the terrace to maintain a positive channel grade.
5. 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.
6. Vegetation shall be maintained and trees and brush controlled by chemical or mechanical means.
7. Keep machinery away from steep back sloped terraces. Keep equipment operators informed of all potential hazards.

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CONTROLLING

Two stage ditch.

Two Stage Ditch

Definition & Introduction

The extensive artificial drainage network in MN 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 tile and ditch have been constructed to provide soil conditions more suitable for production of row crops. According to the MN Department of Natural Resources (DNR), there are approximately 21,000 miles of channelized streams and ditches in the state (DNR, 1980). Of these 21,000 miles, about 17,000 miles are public drainage ditches, which are administered according to MN Statute 103E (MN BWSR, 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. The two-stage ditch contains an inset channel at the bottom that passes the channel forming flow and floodplain benches on either side that convey less frequent, high-discharge events. The objective of the two stage ditch is to mimic the 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. This results in deposition, which necessitates costly ditch maintenance and clean-out.

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 year return period), while the floodplain bench conveys the flood discharge (~ 10 – 50 year return period).

Water Quality and Other Benefits

Although relatively untested, a two stage ditch can be used to:

- Mimic sediment transport characteristics of natural streams
- Remove nitrogen
- Improve habitat

Key benefits are:

- Reduced maintenance to clean out accumulated sediment
- Self sustaining by mimicking natural system's fluvial processes.
- Increased contact time with vegetation provides denitrification
  - Work by Dr. Jennifer Tank at Notre Dame on nitrate removal of two-stage ditches indicates, in limited data, a 500% removal, but may only represent 5 to 15% of the total load since enhanced removal occurs when the floodplain bench is accessed. However, this monitoring was only performed for a short time so long-term removal rates are not known..
- Enhanced habitat. Overflow benches provide area for diverse, preferably native vegetation.
- Additional toe stability, reducing related failures and erosion.

Key Design/Implementation Considerations

Design Considerations:

- Design inset channel based on channel forming discharge. Channel forming discharge may range from approximately the 0.5-year to the 2-year return period event.
- 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.

The following must be taken into account during the planning and design phases:

- A two stage ditch may require additional land on either side of the ditch to accommodate the width of the floodplain benches
- A hydrologic analysis should be conducted to determine downstream hydrologic impacts
- Construction should be planned for low-flow periods.

Cost Information

The cost to construct a two stage ditch primarily involves the following key factors:

- Earthwork. The cost will be substantially reduced if excavated material can be wasted onsite rather than transported.
- Additional land. If the channel is widened, additional land area may be required.

- 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. Required erosion control measures

Table 23. Construction cost information for two-stage ditches. Data for Ohio ditches from Powell et al. (2007b).

Project	Year	Location	Length (ft)	Cost/ ft ($)
Crommer Ditch	2007	OH	2100	10
Bull Creek	2007	OH	1100	37
Needles Creek	2007	OH	1312	25
Klase Ditch	2007	OH	1969	68
Mullenbach	209	MN	6100	30

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.

During establishment, the ditch must be monitored to address any erosion issues or to maintain vegetation.

Legal/Permit Requirements

- 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.
- Minnesota Pollution Control Agency Construction Stormwater Permit. Certain provisions of the stormwater permit regarding discharges to impaired water may be of special interest when constructing a two-stage ditch.
- Minnesota DNR – Public Waters Permit. A Public Water Permit may be required if the ditch is a public water.
- U.S. Army Corps of Engineers Section 404 Permit.

Local/Regional Design Examples

Mower County

The project site is located in Mower County, MN (Figure 1), 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 the Fall of 2009 at a cost of $181,000. 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. The original ditch was constructed in the historic drainage way. The dominant soil type in the ditch is a Clyde silty clay loam (Fine-loamy, mixed, mesic Typic Haplaquolls). The Clyde series developed in shallow depressions and drainageways and is poorly drained with moderate permeability (NRCS, 1989). As indicated in the soil survey and evidenced in the field, this soil is typified

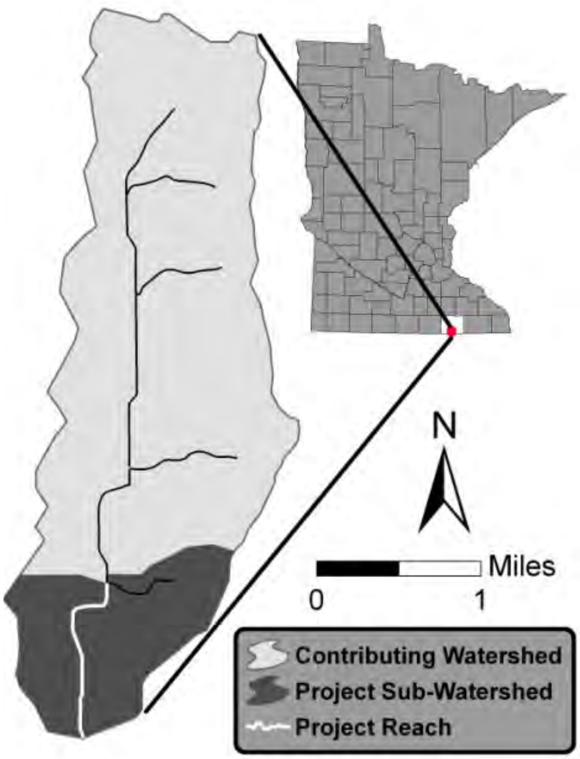

Figure 9. Mower County

by bands of pebbles and other course material. These bands of coarse material act as conduits, conveying water to the ditch. More information regarding this example can be found from Peterson et al. (2010) and Kramer (2011).

Lake of the Woods County
A two-stage ditch was completed on JD-28 in Lake of the Woods County in 2009.

Buffalo Red Watershed District
Laterals to Whiskey Creek. In the Buffalo Red Watershed district two lateral ditches in the Whisky Creek ditch system near Barnesville MN were reconstructed using a two stage ditch approach. The two lateral ditches were rebuilt with a wider bottom, flatter side slopes, and a sinuous pilot channel.

Buffalo Red Watershed District
The Buffalo Red Watershed District has also implemented a project that created a two-stage channel when a set-back levee system was installed along a sinuous watercourse called Deerhorn Creek. In this case, a few reaches of the creek were also rehabilitated from a channelized reach.

Two Rivers Watershed District
In the Two Rivers watershed district a ditch in Spring Brook township was reconstructed using a two stage approach. In this case, the ditch was a high maintenance system with associated road damage. The ditch was reconfigured with a wider bottom and a designed "E" channel was excavated in the improved ditch bottom. Since construction, maintenance has been required to establish vegetation and repair some areas due to washouts..

Wild Rice Watershed District
Several miles of a ditch system were filled in and a new meandering channel was designed and replaced the old system with at least 300 feet of permanent vegetative covers on each side of the meander belt. This is known as the Dalen Coulee project.

Bois de Sioux Watershed District
In the Bois de Sioux watershed a two-stage type approach has been designed and proposed for a portion of the channelized reach of the Mustinka River. With funding, this project will be implemented in the next year or two.

Numerous Indiana, Ohio

Research Gaps

Based on a review of the literature the following research gaps have been identified:

1. The engineering design aspects of the two stage ditch have been studied somewhat extensively. A key question regarding two-stage ditches is its impact on downstream flows. In most cases a two-stage ditch will have a greater channel cross-sectional area than a traditionally designed ditch, thus increasing the conveyance potential. The implications of this increase are poorly defined at this time.

2. Another key issue is vegetation. Vegetation in drainage ditches is a key component, helping to stabilize the soil from erosion and aiding in the denitrification process. There is not presently an adequate understanding of the proper seed mix - or whether some shrubs should be allowed to grow - in order to balance stability, water quality, and habitat goals.

3. Cost and benefits of two-stage ditches are not fully understood. One of the advantages of two-stages ditches is a reduction in maintenance costs. Obviously the savings are site specific, but there is no published research presenting a methodology for determining the point at which the two-stage ditch makes economic sense.

4. It is recognized that the two-stage ditch likely results in less maintenance (removal of sediment) than traditional ditch design. However, the implication of traditional ditch design, which requires periodic cleanout, means that less sediment would be transported downstream as compared to a 'natural' channel, i.e., the traditional ditch design acts as an in-channel sediment trap. Is it more beneficial to utilize existing, over-sized ditches as sediment traps that require periodic clean out or to pass the sediment downstream?

5. 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 on the inset benches and in other years net degradation. It is not clear over what time frame a net zero is expected - but it is likely on the order of decades.

6. A topic for consideration for the Drainage Work Group, or other policy group, is the expansion of the definition of the 1 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.

7. One of the key benefits of the two-stage ditch often cited is increased habitat for aquatic invertebrates, fish and riparian vegetation. While this claim makes sense, there is no supporting data to suggest that once created, the habitat is utilized.

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CONTROLLING

Feedlot. Washington County, MN.

Feedlot Runoff Control

Feedlot/Wastewater Filter Strip (635) and Clean Runoff Water Diversion (362)

Definition & 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 areas of vegetation that receive and reduce sediment, nutrients, and pathogens in discharge from a settling basin or the feedlot itself. In Minnesota, there are five levels of runoff control, with Level 1 being the strictest and for the largest operations (>1,000 animal units). Levels 2 to 5 involve runoff treatment systems where runoff is treated by a strip of permanent herbaceous vegetation.

Water Quality and Other Benefits

Sediment is reduced in runoff to a 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 a filter strip width of 118 feet 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., 2006).

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 NRCS standard (code 362) recommends a minimum capacity not less than a 25-year return period, 24-hour duration storm. All slopes should be 5:1 or flatter and vegetated.

Feedlot/Wastewater Filter Strip

For runoff control levels 2 through 5, manure solids should be 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 pollutant removal and decreasing the amount of 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 NRCS standard (code 635) recommends the use of multiple wastewater filter strips s to allow for resting, harvesting vegetation, maintenance, and to minimize the possibility of overloading. It is also important to plant a diversity of species to ensure the maximum growth and nutrient removal throughout the year.

Use of inlet control structures can prevent undesirable debris from entering filter strips and control inflow rates.

Cost Information

Feedlot/Wastewater Filter Strip

Table 24. 2011 EQIP payment schedule (reproduced from MN NRCS 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
Single species introduced or native grass	ac	191	210	
Single species introduced or native grass with shaping	ac	258	191	
Introduced grasses and legumes	ac	170	185	
Introduced grasses and legumes with shaping	ac	230	257	
Mixed native grasses with or without forbs	ac	222	247	
Mixed native grasses with or without forbs with shaping	ac	282	319	

Operation and Maintenance Considerations

Clean Runoff Water Diversion

Diversions should be periodically inspected, especially after significant storms. Accumulated sediments should be removed and vegetation reastablished when neccesary.

Feedlot/Wastewater Filter Strip

Maintaining proper vegetation density and continuity is important so that water quality benefits are maximized (Helmers et al., 2008).

Filter strips should be inspected and repaired after storm events to fill in gullies, remove sediment accumulation, and re-seed disturbed areas.

Some additional maintenance recommendations by USDA (1999) are to routinely mow your filter strips 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.

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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NRCS Conservation Practice Standard, Vegetated Treatment Area, Code 635 http://efotg.sc.egov.usda.gov/references/public/MN/635mn.pdf

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TRAPPING

Narrow filter strip. Clay County, MN.

Filter Strips (393) and Field Borders (386)

Definition & 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 most 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 linked together in this chapter because of there likely similarity in pollutant removal capacity and because they are both established with permanent herbaceous vegetation consisting of a single species or mixture of grasses, legumes and/or forbs.

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 that 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 bound to sediments, such as phosphorus. There is little data showing the percent erosion reduction or contaminant removal specifically by field borders.

Filter Strips

Filter strips reduce runoff, sediments, and contaminants by settling of sediment, infiltration, and filtration (Schmitt et al., 1999). Most sediments settle upgradient of where the filter strip vegetation meets the contributing area (Jin and Romkens, 2000).

Filter strips 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 (See Figure 10). However, total phosphorus tends to adsorb to fine particles such as silt and clay, which take longer time to settle than larger sediments, and their reduction is usually less than the total sediment reduction. Dissolved contaminants such as total nitrogen, 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 (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 very valuable 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%. TSS showed least removal improvement (from 77 to 83%) with increased width (Figure 10). Volume of outflow was also reduced significantly with increased width, contributing to the reduction of contaminant masses.

Table 25. Pollutant load 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., 2000

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., (2000) and Webber et al. (2009) have both studied the phosphorus removal of filter strips in Iowa under natural rainfall conditions (Table 25). Buffers in general can remove nutrients from shallow groundwater (Helmers et al., 2008), and are particularly valuable on shallow soil (Dabney et al., 2006). Tile drainage beneath a filter strip bypasses the potential treatment of the strip. Kasper et al. (2007) observed no significant nitrate-N removal by gamagrass 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, a subsurface drainage system was installed at a depth of 1.2 m below the 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 a 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 by applying 100mg of different pesticides per kg of soil. Filter strips retained 49.7% of Atrazine, 51.2 % of Metolachlor, and 80.0% of Chlorpyrifos for the buffers tested. Buffer area ratios in the study were between15:1 and 30:1.

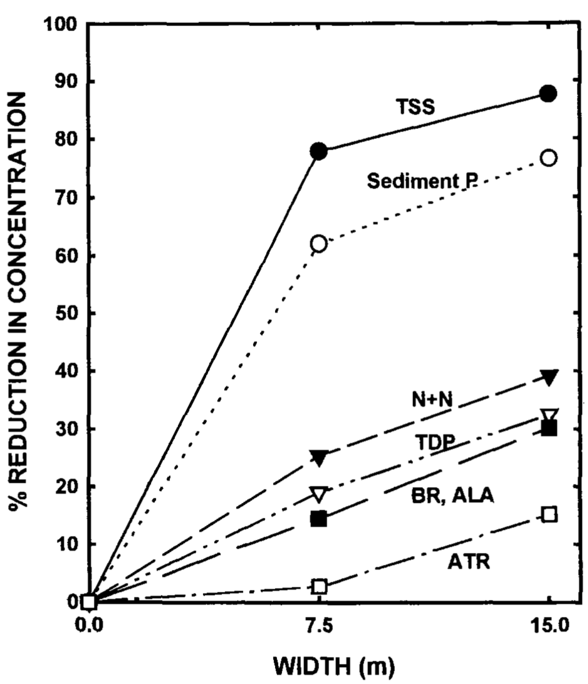

Figure 10. Percentage of reduction in concentration of contaminants in relation to width of filter strip. Plotted values represent measured averages for 2-yr-old grass and 2-yr-old-grass-shrub-tree plots at N+N, nitrate plus nitrite; TN, total nitrogen; ATR, atrazine; ALA, alachlor; TDP, total dissolved phosphorus; TSS, total suspended solids; BR, bromide (Schmitt et al., 1999)

In a study for the MN department of transportation, Nieber et al. (2011) summarized two other literature reviews showing that TSS, TP and TN removal could be shown as a function of buffer width according to the following equations:

TSS: $y = 8.5 \, LN(x) + 51.3$
TP: $y = 15.84 Ln(x) + 5.9$
TN: $y = 20.24 Ln(x) - 13.18$.

where y = removal efficiency (%) and x = buffer width (ft).

A recent study in Wisconsin shows that 50% of mean annual runoff occurred in February and March when the 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 an alternative BMP to filter strips in winter may have to accompany filter strips to protect water quality all year around (Stuntebeck et al., 2011).

Key Design/Implementation Considerations

Field Borders

The NRCS standard (NRCS, 2007, code 386) and the MN Department of Agriculture recommend for this practice:

✓ Border Widths:
   - At least 16.5 feet (1 rod) or a half of the height of adjoining trees, whichever is greater

- Enough to accommodate equipment turning, parking, loading/unloading equipment, and grain harvest operations

✓ Plant Species:

- Permanent grass, legumes, and/or shrubs that have the physical characteristics necessary to control wind and water erosion on the field border area
- At least 1 foot height during the critical wind erosion period
- For shrub cover, plant a minimum of two rows
- No plants listed on the noxious weed list of the state

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).

The age of vegetation influences the infiltration capacity in filter strips. 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 a 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 not be used as a travel lane for equipment or livestock, the strip serves as a turning and parking area, facilitating season-long access to fields (NRCS, 2010; MNDA).

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. Future design of filter strips should incorporate variable-width design depending on the upland contributing area to minimize nutrient runoff to water bodies (Helmers et al., 2008).

The NRCS standard (NRCS, 2010, code 393) and the MN Department of Agriculture recommend for this practice:

✓ Slope of the Area Contributing Runoff to the Filter Strip:

- Between 1% and 12% with some exceptions

✓ Strip Widths:

- A least 16.5 feet (1 rod) for strips along public drain ditches
- A least 50 feet for agricultural lands in shoreland areas adjacent to designated public waters
- Depends on the ratio of area contributing runoff to filter strip area (< 60:1) vs. % 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)

✓ Plant Species:

- Stiff, upright stemmed vegetation is required and it depends on purpose of filter strips, soil types, existence of flood and draught, and latitude of the location.
- For removal of nitrate N, at least 50% of the cool season species shall be deep-rooted and legumes have to be all be deep rooted (≥ 3 feet)

✓ 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

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. In Missouri, assuming a 10-year time horizon, the annualized cost of installation and taking the land out of production is $62.40 per acre (Qiu, 2003). In this scenario, installation cost is estimated to be $51.85 per acre and land opportunity cost is estimated to be $55.68 per acre. NRCS estimates filter strip establishment cost at $154 per acre. If a 33-foot filter strip is developed along 1312 feet, the distributed establishment cost, which is the cost of establishment divided by the 30 acre subwatershed area, results in the distributed cost of $5 per acre. The additional annual distributed land rent cost was estimated to be $6.50 per acre. Amortized fixed cost and total annual cost at 10% interest rate were $0.53 per acre per year and $7.00 per acre per year, respectively (Yuan et al., 2002).

Table 26. 2011 EQIP payment schedule for field borders (reproduced from MN NRCS 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
< 2 acres introduced grasses and legumes	ac	174	190	
2 to 5 acres introduced grasses and legumes	ac	164	178	
> 5 acres introduced grasses and legumes	ac	160	173	
< 2 acres native grasses and forbs	ac	230	257	
2 to 4 acres native grasses and forbs	ac	205	227	
> 2 acres native grasses and forbs	ac	191	210	

Table 27. 2011 EQIP payment schedule filter strips (reproduced from MN NRCS 2011)

Component	Unit	PR/unit	HUP/unit	Payment Cap
Single species introduced or native grass	ac	191	210	
Single species introduced or native grass with shaping	ac	258	291	
Intorduced grasses and legumes	ac	170	185	
Intorduced grasses and legumes with shaping	ac	230	257	
Mixed native grasses with or without forbs	ac	222	247	
Mixed native grasses with or without forbs with shaping	ac	282	319	

Operation and Maintenance Considerations

The maintenance of filter strips and field borders 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 in order to maximize water quality effects: maintaining flow direction, proper density, and continuity of the buffer (Dabney et al., 2006; Helmers et al., 2008). USDA (1999) recommends a list of maintenance work for filter strips and field borders:

- Any development of channel and rills within the must be repaired. Shallow furrows or small berms can be placed across any concentrated flow to re-establish sheet flow.
- If a concentrated flow area is not redirected, it must be treated separately. A grassed waterway, shallow impoundment, terraces, dikes, berms, trenches, or vegetative barriers can be used to stabilize the waterway and reduce water velocity.
- Sediments accumulate along the upper gradient of the strips. This sediment has to be removed before it reaches 6 inches high and diverts runoff flow around the strip. 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 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. However, over-mowing and excessive vehicle traffic can lead to poor root growth, soil compaction and reduced effectiveness.
- Weeding is important to maintain the designed width and density of filter strips.

Research Gaps

No research measuring 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 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 borders may be necessary.

Increasingly, saturated buffers are being promoted as a way to increase N uptake although additional study on these specialty buffers is lacking. These types of buffers are commonly being used as part of a conservation drainage system.

For filter strips, there is little data on nutrient reduction efficiency studied under unconfined flow-path conditions and more research is necessary on plots similar to actual agricultural settings. Also, 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).

Tile drainage is widely used practice in Minnesota; however, there are few filter strip research projects conducted to find the nutrient removal on drained fields. Research is needed to understand the mechanism of filter strips when combined with a drainage system to maximize performance.

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Links

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NRCS Conservation Practice Standard, Filter Strips, Code 393 http://efotg.sc.egov.usda.gov/references/public/MN/393mn.pdf

MNDA Conservation Practices Minnesota Conservation Funding Guide, Field Border

http://www.mda.state.mn.us/protecting/conservation/practices/fieldborder.aspx

Minnesota Conservation Funding Guide, Grass Filter Strip, http://www.mda.state.mn.us/protecting/conservation/practices/buffergrass.aspx

TRAPPING

Wet pond. Houston County, MN.

Sediment Basin (350)

Definition & Introduction

A sediment basin is a basin constructed with an engineered outlet, formed by excavation or use of an embankment, or a combination of the two. A sediment basin may also be utilized for the purpose of nutrient removal.

A sediment basin functions by detaining sediment or nutrient-laden water for sufficient time to attain a desired level of treatment. Sediment basins may be used in agricultural or urban locales and are used to treat water from disturbed areas or construction sites, either on a temporary or a permanent basis.

Water Quality and Other Benefits

Water quality effects from sedimentation ponds are well documented. The MPCA (2005) reports average TSS removal rates of 84%, total phosphorus rates of 50% and total nitrogen removal of 30%.

Table 28. Removal efficiency of stormwater ponds. (From MPCA, 2005).

Practice	TSS High-Med-Low[2]	TP High-Med-Low[2]	TN	Metals (average of Zn and Cu)	Bacteria	Hydro-carbons
Stormwater Ponds[1]	60-84-90	34-50-73	30	60	70	80

[1] Standard pond designed according to state requirements
[2] See appendix N discussion

Removal efficiencies for agricultural sediment basins is likely to be different than averages reported for more urban locations.

Edwards et al. (1999) and Rauhofer et al. (2001) found trapping efficiencies of sediment greater than 90% when evaluating sediment basin performance for runoff typical of construction sites.

Key Design/Implementation Considerations

Detailed and extensive design guidance is provided in both MPCA (2005) and NRCS (2010).

If used to treat construction or other disturbed site runoff, an MPCA General Construction permit may be required (see http://www.pca.state.mn.us/water/stormwater/stormwater-c.html). If a permit is required, the reader is encouraged to review the MPCA Stormwater Manual, Chapter 12-9, which discusses wet sedimentation ponds.

Cost Information

Current EQIP payments (NRCS, 2012) provide payment for a concrete bottom ($3.14/feet^2), slotted wall on a feedlot basin ($42/foot), silt fence ($1.73/foot), and flotation silt curtain ($500 each).

Operation and Maintenance Considerations

The key considerations in operations and maintenance are:

1. Periodic inspection of inlet and outlet for plugging or debris accumulation, as well as emergency or auxiliary spillways.
2. Inspection of embankments for excessive erosion or seeping.
3. Maintenance of vegetation on embankments, including mowing and removal of trees, brush and invasive species.
4. Periodic sediment removal.

Local/Regional Design Examples

The University of Minnesota, MN Department of Agriculture and Nature Conservancy are investigating the use of sedimentation ponds, termed 'surge ponds,' in combination with woodchip bioreactors in Mower County, MN (http://www.mowerswcd.org/SurgePonds.html).

The University of Minnesota's Southwest Outreach and Research Center (SWROC) at Lamberton, MN, is investigating the use of surface flow wetlands, which are similar to sediment basins (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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TRAPPING

Side inlet control (Nicollet SWCD 2007)

Grade Stabilization at Side Inlets (410)

Definition & 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 (MN 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 2).

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:

1. Erosion control and prevention;
2. Short-term stormwater volume control; and
3. 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 11), increased downstream nutrient loading, and potential loss of production land as failures move up-gradient.

Figure 11. Reduced conveyance due to side inlet failure

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 reduction of 0.5 pounds/year and a sediment reduction of 400 pounds/year.

Key Design/Implementation Considerations

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 (Figure 12). These design variants are similar to the designs for alternative tile intakes.

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).

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.

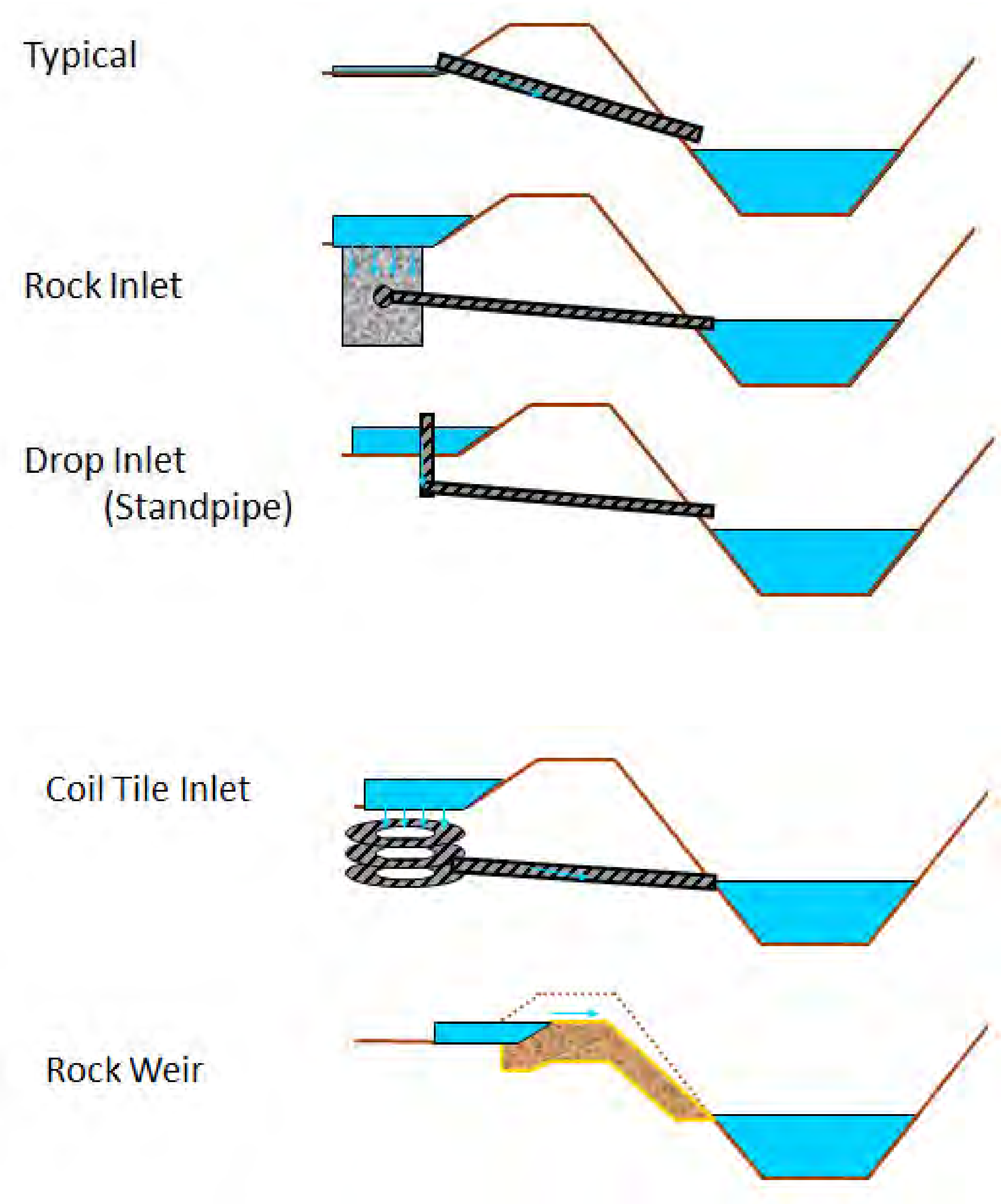

Figure 12. Side inlet control design variants.

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 29 (NRCS, 1999).

Table 29. NRCS Practice Standard 410 Hydraulic Design Criteria.

Drainage Area (acres)	Vertical Drop (ft)	Design Return Period based on 24-hr duration storm (yrs)
0 – 250	0 - 10	10
250 - 900	0 - 10	25
All others		50

Work in the bed of a public water requires a MN DNR Public Waters work permit; however, there are limited exceptions in the case of using rock riprap to prevent erosion (MN DNR, 2012).

Cost Information

2012 EQIP payments for side inlet control depend on contributing drainage area. Payment rates for 2012 are as follows: for drainage area greater than 250 acres, $6,471, for drainage areas between 80.1 and 250 acres, $4,283, and for drainage areas less than 80 acres, $2,863 (NRCS, 2012).

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.

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.

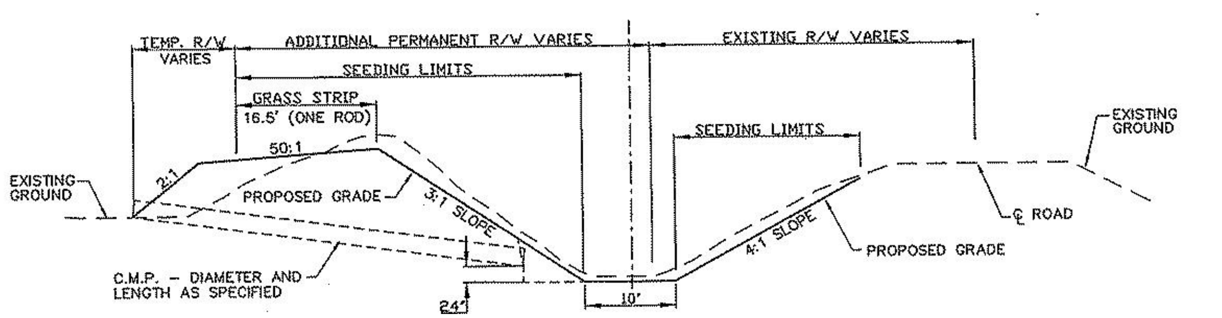

Figure 13. Schematic of a drainage ditch with side inlet (BWSR, 2006).

Local/Regional Design Examples

Kandiyohi County

Because little research exists on types, sizing, and effectiveness of side inlet controls, there is little guidance on sizing and effectiveness. For these reasons, Kandiyohi County's approach has been to include a research element to their side inlet projects. At three different project sites, with three different soil types, rock inlets were placed side-by-side with a standpipe inlet.

Site	Area (acre)	Soil Type
1	3.5	SiClL
2	6.1	SiClL
3	3.7	L

The research goal is to determine the differences in water quality entering drainage ditches from the two inlet types. Water sampling is being conducted but no conclusions have been reached yet.

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.

Research Gaps

Design guidance is lacking. While NRCS standard 410 provides guidance on the design storm, the standard does not provide design

Figure 14. Standpipe side inlet in Kandiyohi County, MN.

guidance to improve water quality. Design guidance needs to be developed based on research being conducted by the BWSR and University of Minnesota

Lack of research makes it difficult to quantify effectiveness. There have not been any research projects on side inlet controls to determine the effectiveness of different designs.

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TRAPPING

Water and sediment control basin. (NRCS)

Water and Sediment Control Basin (638)

Definition & 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.

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, inducing sedimentation and controlling the release of water, thereby reducing the erosive power of the water downstream.

Additional benefits are settling of sediment-bound pollutants and some 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 phosphorus using the APEX model and 64 and 74% reductions using 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.

Key Design/Implementation Considerations

Design criteria for water and sediment control basins are set forth in NRCS Practice Standard 638.

Generally, WASCOBs are constructed where the combination of topography and soils would lead to watercourse or gully erosion or otherwise damage the land.

WASCOBs should be designed such that the extent and duration of ponding does not damage crops.

Two of the key considerations in WASCOB design are the fill height of the embankment and the drainage area. The fill height of the embankment is dependent on the spacing between WASCOBs. NRCS Practice Standard 638 prescribes maximum spacing based on slope.

Cost Information

EQIP (NRCS, 2012) payments vary based on both embankment fill height and drainage area and range from $750 (fill height less than 3 feet) to $9,000 (fill height greater than 10 feet and drainage area between 20 and 40 acres).

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.

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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Treatment wetland.

Constructed (Treatment) Wetlands

Definition & Introduction

Constructed wetlands, sometimes called treatment wetlands, are man-made systems engineered to approximate the water-cleansing process of natural wetlands. In agriculture, constructed wetlands are used to filter runoff from cropland, feedlots, aquaculture operations and agricultural processing facilities. Constructed wetlands can also provide habitat for some waterfowl, other birds, amphibians and invertebrates.

Constructed wetlands are known to be less effective at supporting wildlife and ecological functions than wetlands restored where they existed historically (NRC, 2001). However, if properly designed, they effectively remove excess nutrients, sediment and other pollutants from surface runoff (Kadlec and Knight, 1996). Treatment wetlands have been most widely used in developed (urban/suburban) areas for wastewater treatment because they require intensive design calculations and are fairly expensive per area of wetland installed. There has not been widespread use of treatment wetlands in agricultural regions of the upper Midwest because of the cost and design requirements. Therefore, while it is known that treatment wetlands are generally effective it is unclear how well they work in rural upper Midwestern settings.

Efforts currently underway by Minnesota agencies on the CRP "CP39" constructed wetlands initiative should result in more implementation of constructed wetlands in Minnesota.

Water Quality and Other Benefits

Wetlands are effective at settling sediment and so 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 and phosphorus removal is varied. Treatment wetlands are often efficient at removing nitrogen but less effective at removing phosphorus. Nitrate-nitrogen can be permanently removed from the system through denitrification as nitrate is converted to N_2 gas and released. In contrast, most phosphorus is in particulate form and is removed when sediment-bound phosphorus settles to the wetland bottom and via uptake by plants. Phosphorus taken up by plants can be leached back into the water in fall when plants die after the growing season. Therefore vegetative removal or harvest may be necessary to achieve lasting phosphorus reductions. Since treatment wetlands are typically much smaller than natural wetlands, the flood reduction benefits are minimal.

In Minnesota and the upper Midwest treatment wetland effectiveness is limited by physical factors such as a relatively short growing season compared to the rest of the United States (Axler et al., 2001). There are also several logistical issues involving fitting wetlands into drainage systems.

In Midwestern agricultural watersheds one of the major issues is treating tile water for high nitrate levels. Since subsurface tile pipe is routed directly to streams it is necessary to capture the water in storage areas prior to discharge. Thus tile-interception wetlands may need to be squeezed into stream valleys and other marginally productive farmland that may not be optimally located for treatment of tile flow.

Axler et al. (2001) studied sewage treatment wetlands near Duluth, Minnesota. Annual summer effluent values averaged 8 mg +/- 2 and 85%- removal. BOD had a 92% removal rate over several years. Phosphorus removal was fairly low at 20-51%.

At Indian Lake, Ohio a 3 acre agricultural runoff treatment wetland had 40-43% removal efficiency for nitrate and 59% for total phosphorus, with 49-56% soluble reactive phosphorus (SRP) removal (Mitsch and Fink, 2001). This wetland had a 14:1 watershed to wetland area ratio, apparently sufficient to effectively remove substantial quantities of nutrients.

A natural peatland in Houghton Lake, Michigan was treated with sewage effluent and studied for nearly 20 years. It had very high removal rates, with nitrogen and

Table 30. Treatment wetland removal efficiency studies in the Midwestern United States

Location and wetland type	TSS	Nitrate	Phosphorus	BOD
Duluth, Minnesota; subsurface treatment system for sewage (Axler et al. 2001)	85%	No data	20-51%	79-92%
Indian Lake, Ohio; agricultural surface runoff system (Mitsch and Fink 2001)	No data	40-43	49-56 (SRP) 59 (TP)	No data
Houghton Lake, Michigan (Kadlec and Knight 1996)	n/a	>90	>90	No data

phosphorus removal exceeding 90% for most of the study period from 1981-1998. Discharge to peatlands is not an option in most agricultural watersheds of Minnesota, but may be an option in northern Minnesota, if such discharges would be allowed under the Minnesota Wetland Conservation Act.

From a TMDL standpoint, treatment wetlands are limited by lack of hydrologic storage for reduction of water volume and nitrate load. Although they are highly effective at removing sediment and pollutants from small focused areas, such as treatment of sewage from residential houses, they can be overwhelmed by large agricultural watershed loads that need to be treated for TMDLs. Therefore it is important to have realistic goals and expectations in building treatment wetlands.

The time-scale to see water quality improvements with treatment wetlands 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 (Cruz et al., 2012).

Key Design/Implementation Considerations

Treatment wetlands may be designed as surface flow or subsurface flow wetlands. Subsurface flow wetlands maximize the removal of sediment and particulate phosphorus which are largely removed by filtration through the ground (Mitsch and Jorgensen, 2004). Surface flow wetlands are more widely applicable and would be preferable for achieving nitrogen removal as ponded, anaerobic water is needed for denitrification, the primary removal pathway for nitrogen.

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 inundation 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 and Jorgensen, 2004). The hydraulic loading rate needs to be optimized to provide sufficient water and nutrient supply to the wetland vegetation, while not overloading it so that the removal efficiency is greatly reduced.

Treatment wetlands in flood prone areas should 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 be decreased and increased maintenance costs incurred.

Limitations

To maximize nitrate removal efficiency, certain biogeochemical conditions need to exist in the wetlands. There needs to be an adequate supply of organic carbon to maximize denitrification (Isenhart, 1992). 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 when wetlands are overloaded with water and much of it is running out of the wetlands. In some wetland environments, ammonium may be more abundant than nitrate. In these cases, some wetlands systems are unable to convert sufficient ammonium to nitrate without sufficient oxygen, therefore preventing denitrification and reduction of the nitrogen load.

Phosphorus removal by treatment wetlands can be limited by a variety of factors. If the soils are saturated with phosphorus, as commonly occurs in Midwestern agricultural watersheds, phosphorus may be released from the soils during summer anaerobic time periods.

Cost information

Costs to construct treatment wetlands varies considerably based on the size of the wetland, grading and control structures needed.

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. Periodically cleaning out accumulated sediment may be necessary, particularly if the design includes a sediment forebay, as suggested by Mitsch and Jorgenson (2004).

If vegetation harvest is utilized for phosphorus 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 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 a biomass plant.

In agricultural regions of Minnesota 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 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 and government mandates involving private lands.

Research Gaps

We know from a multitude of urban sewage treatment wetlands that sediment (usually measured as TSS) can be removed by treatment wetlands very effectively. Nutrient removal depends on a variety of factors that may limit removal efficiency. Nitrate removal has been studied in detail but reasons for lower phosphorus removal need to be studied in more detail as well as design options for improving removal. Vegetation harvest has been done very little in the United States and should be studied in more detail. There are also many unknowns concerning the use of vegetation to optimize nutrient removal. We don't know a lot about which life forms (shrubs, grasses, forbs) or individual species are best at removing nutrients with the exception of a few well-studied species. Similarly, use of species or mix of species that lengthen the active plant transpiration season should be better studied.

Another major factor that is poorly understood is how treatment wetland performance varies by landscape or watershed position. For example, treatment wetlands placed in riparian corridors or depressions are more likely to receive groundwater discharge that may contain additional nitrogen, affecting their performance.

Finally, cost-benefit analyses need to be performed for specific regions and environmental conditions. 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 counties in this regard.

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TRAPPING

Restoration site. Ramsey County, MN.

Wetland Restoration (651)

Definition & 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 hydrologic regime 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 and van der Valk, 1994). Ducks Unlimited and others such as the US Fish and Wildlife Service, MN DNR, and MN BWSR 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. On the other hand, peatlands may be less effective at restoring water since they are saturated at the surface, but very effective at removing sediment and nutrients, as in the Houghton Lake, Michigan example (Mitsch and Jorgensen, 2004).

There have been few detailed studies of water quality treatment by natural restored wetlands. The most detailed studies have been done at smaller constructed or treatment wetlands. In Minnesota, the Kittleson and S.H.E.E.K. wetlands located southwest of Trimont, Minnesota were one of the most studied restored wetland groups in the state (Lenhart et al., 2010; Lenhart, 2008; Fransen, 2011). Between 2005-2010, these wetlands were highly successful at reducing downstream flooding and removing nitrate-nitrogen. However phosphorus removal had mixed results and some organic matter was generated adding to turbidity levels exiting the wetland.

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 that many crops rely on, such as bees. Aesthetics are often important for landowner acceptance and adoption.

Restored wetland effectiveness	TSS	Nitrate	Phosphorus
S.H.E.E.K. & Kittleson wetlands, Trimont, Minnesota	>75%	>85%	0-50%
Wetlands in Iowa, Illinois and Maryland (Woltemode 2000)		68%	43%

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 removal efficiency can be limited in open water wetlands by lack of organic carbon needed for denitrification (Hernandez and Mitsch, 2007). Although done in created wetlands at Ohio State, the same principal should hold for restored wetlands. Phosphorus removal can be reduced by a variety of factors. Often wetlands restored in former agricultural fields have high levels of phosphorus in the soil (Fransen, 2011). Sediment and phosphorus can be stirred up in open water wetlands by strong winds, common in the open prairie-pothole region of southern and western Minnesota. Phosphorus 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 less oxygen is available because of increased biologic activity and decreased dissolved oxygen capacity of the wetland. 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 denitrification. High levels of groundwater discharge may provide additional nitrogen, 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 drawdown some wetlands in the fall to reduce water levels in the spring, enhancing their water quality treatment effectiveness.

Costs

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 set to manage water levels. Maintenance costs tend to be less than treatment wetlands, however there may be need to manage water levels by adding or lowering stoplogs from the water control structure. The permanent nature of wetlands make them less popular than grass buffers or grasslands that are easily converted back to cropland when the farmer desires.

Research gaps

There is a need for research on prioritization of wetland restoration to maximize hydrologic storage and water quality benefits. Related to this, there is a need for cost-benefit type research to determine what factors drive up costs and what factors make wetland restoration more feasible and in what landscape positions/geographic locations. 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 restored very rarely, particularly shallower types such as wet prairies and sedge meadows. There is not a good understanding of what hydrologic functions these wetlands performed that we may be missing from our set of BMPs in agricultural watershed. Typically wetlands higher in the landscape provided groundwater recharge.

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Links

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NRCS. 2010. NRCS Practice Standard 657. Restored Wetlands http://efotg.sc.egov.usda.gov/references/public/MN/wetland_rest.pdf

Woodchip bioreactor installation.

Woodchip Bioreactor (Denitrification Beds)

Definition & Introduction

Nitrates in subsurface drainage water are a concern for receiving bodies of water. Excessive nitrate concentrations in drinking water have been linked with health problems in humans and nitrates have been linked with hypoxia in the Gulf of Mexico.
Methods of nitrate removal from drainage water include improved fertilizer management, tillage management, and wetland restoration.

The use of woodchip bioreactors has been identified as one means of removing nitrate from subsurface drainage water. Nitrates are removed from the system as the carbon from the wood chips is used by bacteria that break down the nitrate through the process of denitrification. Advantages of denitrification beds are that they have a relatively high rate of nitrate removal, small footprint, minimal to zero maintenance during the design life, and low installation cost.

There are several different design variants of the woodchip bioreactor. The most prevalent are the denitrification bed or bioreactor and the denitrification wall, though the denitrification bed is the most promising for treatment of N-laden tile drainage water. Schipper et al. (2010) provide an extensive review of different variants, performance, design parameters, and directions for future research. Denitrification walls have been evaluated, where a trench filled with woodchips intercepts laterally moving groundwater, but denitrification beds, where tile drainage water is introduced to the bed, have been found to be more effective (Schipper et al., 2010).

Water Quality & Other Benefits

Removal rates of NO_3- are primarily governed by influent NO_3- concentration and temperature. Nitrate removal is generally in the 30% to 40% (van Driel et al., 2006; Chun et al., 2009a)range for wood-based bioreactors, though greater and lower removal rates are possible during certain time periods, mainly dictated by flow conditions (i.e., hydraulic residence time).

Key Design/Implementation Considerations

The key design parameter for woodchip bioreactor construction is to make sure that the bioreactor is anaerobic and to ensure proper hydraulic residence time.

Bioreactor longevity is heavily dependent on maintaining anaerobic conditions. Moorman et al. (2010) reported a half-life of 4.6 years for woodchips at a depth of 35 to 40 inches, while the half-life of wood chips at 61 to 70 inches was 36.6 years. 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.

Selection of a carbon source is also 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.

Based on the literature, it does not appear that wood species is important. For example, Cameron and Schipper (2010) found no significant different between hardwood and softwood media.

The effect of wood chip size was not important (Cameron and Schipper, 2010).

Cost Information

The cost of denitrification beds obviously depends on size. Items to consider are:

- Quantity of excavation (CY). Because many bioreactors are of relatively small size and require some skilled excavation around existing infrastructure (tile), the cost per unit is likely to be in the $10 – $15/CY range.
- Amount of woodchips (CY) – Good quality, clean woodchips may cost as much as $35/CY. However, as research by Cameron and Schipper (2010) show, neither wood species nor particle size seem to be overly important.
- 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 $1,000 per structure. However, fixed head control is less expensive.
- Pipe and appurtenance. These accessory items should be a relatively small part, but important part of the project.

Year	Location	Size (CY)	Cost ($)	Cost/ CY
2009	Kandiyohi Co	120	2,934	$24.45
2007?	Jackson Co, ?	150	6,000	$42.67

There is no cost information for wood bioreactors in the "2011 Minnesota EQIP Conservation Practice Payment Schedule."

Operation and Maintenance Considerations

The life of bioreactors is not known with certainty at this time but research indicates it is decadal (Robertson, 2010). The two main factors affecting longevity of this practice are a sufficient supply of carbon substrate and adequate hydraulic conductivity through the media. According to Robertson et al. (2008) there are no known examples of reactors failing due to carbon depletion.

Legal/Permit Requirements

Since woodchip bioreactors have a relatively small footprint, it is unlikely that a stormwater discharge permit would be required.

If the bioreactor is part of a Minnesota public drainage system, the drainage authority may have some requirements.

Local/Regional Design Examples

The Dundas and Claremont sites in Rice and Dodge Counties were both constructed in 2007.

Kandiyohi County

This woodchip bioreactor was constructed in 2009 on a failing county ditch. The drainage area to the bioreactor is 5.7 acres. The bioreactor is 9.5 feet wide, 30 feet long and 2.5 thick (woodchip thickness), for a woodchip volume of 720 cubic feet. A saturated conductivity of 0.003 feet/second was assumed with a head difference of 1 foot for an estimated HRT of 7.5 hours. Limited sampling indicates a nitrogen reduction ranging from 10 to 94%. Construction cost was $2,934.

Research Gaps

As Schipper et al. (2010) point out, there are very little long-term data regarding hydraulic conductivity of bioreactors. Good design guidance should include these data.

Wood chips are a relatively inexpensive source of carbon substrate for bioreactors. Investigation into carbon sources that have little or no value could improve the cost:benefit ratio of bioreactors. For example, chipped or shredded buckthorn may be an effective source of carbon substrate that encourages harvest of that invasive species.

The use of denitrification beds in the upper Midwest has been limited to edge of field practices. Robertson and Merkley (2009) installed an instream bioreactor to reduce nitrate levels, and showed promising results, reducing instream nitrate concentrations by about 50%. This practice may hold promise for instream use in Minnesota's 21,000 miles of channelized streams and ditches, particularly in impaired or sensitive areas.

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Minnesota and Upper Midwest BMP Matrix

This resource matrix was compiled from empirical studies of BMP effectiveness in Minnesota and the Upper Midwest.

Table 31. 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	Mohring and Christensen, ongoing		Christenson et al., 2009; Randall et al., 1997; Huggins et al., 2001				
Conservation Crop Rotation (328)				Huggins et al.,2001; Randal et al., 1997; Randal et al., 1993; Oquist et al., 2007				
Contour Buffer Strips (332)	Arora et al., 1996					Arora et al., 1996		
Contour Farming (330)								
Cover Crops (340)				Feyereisen et al., 2006; Strock et al., 2004 Kaspar, 2008; Kaspar et. al, 2007; Jaynes et al., 2004; Logsdon et al., 2002				
Grade Stabilization (410)								
Livestock Exclusion/ Fencing (382 and 472)								

AVOIDING								
BMP	**Turbidity/ Sediment**	**Phosphorus**	**Soluble Phosphorus**	**Nitrogen/ Nitrates**	**Ammonia**	**Pesticides**	**Bacteria**	**Dissolved Oxygen**
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	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	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; Jaynes and Colvin, 2006; Komiskey et al., 2011; Thorp et al., 2007	Baker and Laflen, 1982; Baker and Laflen, 1983; Komiskey et al., 2011			
Pest Management (595)						Buhler, 1993; Hansen et al., 2001		
Tile System Design								

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	Ranaivoson, 1999; Wilson et al., 1999	Ranaivoson, 1999;					
Contour Stripcropping (585)								

CONTROLLING								
BMP	Turbidity/ Sediment	Phosphorus	Soluble Phosphorus	Nitrogen/ Nitrates	Ammonia	Pesticides	Pesticides	Dissolved Oxygen
Controlled Drainage (554)		Feset et al., 2010;	Feset et al., 2010;	Feset et al., 2010; Luo et al., 2010; Singh et al., 2007ADMC, 2011				
Culvert Sizing / Road Retention / Culvert Downsizing								
Grassed Waterways	Arora et al., 2003; Dermsis et al., 2010					Arora et al., 2003;		
Irrigation Management (442 and 449)								
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., 2003 Andraski et al., 1985	Kanwar and Baker, 1993				
Riparian and Channel Vegetation (322/390)								
Rotational Grazing								
Terrace (600)								
Two Stage Ditch								

CONTROLLING								
BMP	Turbidity/ Sediment	Phosphorus	Soluble Phosphorus	Nitrogen/ Nitrates	Ammonia	Pesticides	Pesticides	Dissolved Oxygen
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)								
Water and Sediment Control Basin (638)								
Constructed (Treatment) Wetlands	Axler et al. 2001	Axler et al. 2001						Axler et al. 2001
Wetland Restoration (651)	Lenhart 2008; Lenhart et al.,; Fransen 2011	Lenhart 2008; Fransen 2011		Lenhart 2008; Fransen 2011				
Woodchip Bioreactor		Ranaivoson et al., n.d.	Ranaivoson et al., n.d.	Ranaivoson et al., n.d.Jaynes et al., 2004; Jaynes et al., 2007		Ranaivoson et al., n.d.	Ranaivoson et al., n.d.	

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 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.

Table 32. 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 32, 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).

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 phosphorus, and total nitrogen 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 phosphorus were higher and more comparable to stripcropping, having mean reductions in total phosphorus of approximately 30 to 80% compared to the baseline. Across each of the three field sites, total nitrogen 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 phosphorus and total nitrogen 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 33 (Tuppad et al., 2010).

Table 33. 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 34.

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 34. 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%
Kladivko et al., 2004	Indiana, U,.S.	Winter wheat + less fertilizer	61%

Table 35. 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 36. 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 36, 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 7 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.

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 37 presents the erosion reduction as reported in Core4 practices literature.

Table 37. 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 4 year period (Fawecett and Smith, 1999). 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 phosphorus, 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 phosphorus, and total nitrogen reductions for terraces are 86%, 78%, and 38%, respectively, based on Table 38, results of a database developed for estimating BMP effectiveness in Arkansas (Merriman et al., 2009).

Two-Stage Ditch
No additional commentary.

Feedlot Runoff Controls - Clean Water runoff Diversion, Vegetated Treatment Area, Wastewater treatment Strip
Contaminant reductions from national sources are provided in Table 39, 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. NO_3-N was successfully reduced at 98% of an average.

Contaminant reductions are provided in Table 40, which are results of several studies measuring the efficiency of barn yard runoff management (Merriman, 2009).

Table 38. 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 39. 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 – Cetti et al., 2003

2 – Chesapeake Bay Program, 1987

3 – Dillaha, 1990

Table 40. 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 – Cetti 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., 2002; 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. (1993) 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 41. Pollutant reduction estimates in percent for filter strips (Merriman, 2009).

Pollutant	Mean	Minimum	Maximum	Standard Deviation	Number of Entries in Database	Source
NH_4-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
NO_3-N	22	-158	85	58	22	3, 4, 13, 15, 16, 34, 56
Particulate Phosphorus	79	68	90	15	2	4
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 - anDevender 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 42. 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
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
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 Hydrodynamic Structures	5	10	10
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

UPDATED BMP EFFECTIVENESS ESTIMATES			
BMPs	BMP Effectiveness Estimate (%)		
	TN	TP	TSS
Vegetated Open Channels *C/D soils, no underdrain* *A/B soil, no underdrain*	 10 45 ±20	 10 45 ±20	 50 70 ±30
Bioswale	70 ±15	75 ±20	80 ±15
Permeable Pavement (no sand/veg) *C/D soils, underdrain* *A/B soils, underdrain* *A/B soils, no underdrain*	 10 45 75 ±15	 20 50 80 ±20	 55 70 85 ±15
Permeable Pavement (with sand, veg) *C/D soils, underdrain* *A/B soils, underdrain* *A/B soils, no underdrain*	 20 50 80 ±15	 20 50 80 ±15	 55 70 85 ±15
Infiltration Practices (no sand/veg) *A/B soils, no underdrain*	 80 ±15	 85 ±15	 95 ±10
Infiltration Practices (with sand/veg) *A/B soils, no underdrain*	 85 ±15	 85 ±10	 95 ±10

Table 43. 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
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 44. Selected average BMP effectiveness values contained in the Arkansas BMP tool. (reproduced from Table 2, Merriman, 2009)

BMP Name	Pollutant Reduction (%)[b]						
	PP	DP	TP	NO_3-N	NH_4-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; NO_3-N - Nitrate Nitrogen; NH_4-N - Ammonium Nitrogen; TN - Total Nitrogen; Tsed - Total Sediment.

[c] Negative values indicate increases in the pollutant.

Table 45. 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 2 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

BMP	BMP Target	Effectiveness / Reduction (%)
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
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

BMP	BMP Target	Effectiveness / Reduction (%)
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
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 46. 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	NH_4-N	77				1	50
	DP	75				1	50
	NO_3-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
Conservation tillage	NH_4-N	30	-43	93	50	6	39, 40, 49, 59, 60
	DP	-63	-329	91	186	4	38, 40, 59
	NO_3-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	NH_4-N	37	35	41	3	3	61, 62
	DP	37	7	63	28	3	61, 62
	NO_3-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

BMP Class [b]	Pollutant [c]	Mean	Min	Max	Std	Count	Reference [d]
Crop rotation	NH_4-N	37	35	41	3	3	62
	DP	37	7	63	28	3	62
	NO_3-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
	NO_3-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
Filter strips	NH_4-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
	NO_3-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	NH_4-N	-1133	-4979	97	2173	3	39, 40
	DP	-35	-171	92	127	3	13, 40
	NO_3-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	NH_4-N	48				1	29
	NO_3-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
	NO_3-N	82				1	9
	TP	72				1	9
	Tsed	77				1	9

BMP Class [b]	Pollutant [c]	Mean	Min	Max	Std	Count	Reference [d]
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
Wetland	NH_4-N	63				1	58
	NO_3-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.

Annotated Bibliography

This bibliography is a comprehensive list of resources reviewed during development of this handbook. It includes local and national sources of empirical and modeling data, background information and industry standards. Some of the resources listed in this bibliography were not reported in the body of the handbook but have been included in the bibliography as additional information for the reader.

Surface Water Quality Phosphorus Removal in Vegetated Filter Strips

Type	Journal Article
Author	Majed Abu-Zreig
Author	Ramesh P. Rudra
Author	Hugh R. Whiteley
Author	Manon N. Lalonde
Author	Narinder K. Kaushik
Publication	Journal of Environment Quality
Volume	32
Pages	613-619
Date	2003

Notes:

A study on phosphorus removal by vegetated field strips (VFS) using artificial runoff in Ontario, Canada. The length, slope, type of vegetation, and density of vegetation cover were varied to see the effect. P removal mechanisms were also identified.

Drainage water management for Midwestern row crop agriculture.

Type	Report
Author	ADMC
Report Number	63-3A75-6-116
Report Type	Final
Date	2011

Notes:

This report describes the results from an NRCS Conservation Innovation Grant across the five states of Indiana, Iowa, Ohio, Illinois, and Minnesota. One of the goals of the project was to demonstrate and better understand the impact of managing water table depths to reduce nutrient transport and reduce water deficit stress during the growing seasons at selected sites in the five participating states.

Agricultural Water Management

Type	Journal Article
Author	S Ale
Volume	96
Pages	653-665
Date	2009

Notes:

This study examined the effects of controlled drainage at a plot scale using the DRAINMOD model over a 15-year period. The model was first calibrated using monitored data. Key operational parameters were the dates of raising and lowering the stop logsand the control height of the outlet. Simulated drain flows were reduced 60% over the 15-yr period by raising the outlet 50 cm from the 10th day to the 85th day after planting. The result was an increase of 68% on vertical seepage, a 27% increase in soil moisture storage, and 5% increase in evapotranspiration. These results indicate that controlled drainage has the potential to better mimic a natural system than conventional drainage.

Simulated effect of drainage water management operational strategy on hydrology and crop yield for Drummer soil in the Midwestern United States

Type	Report
Author	S. Ale
Author	L.C. Bowling
Author	S.M. Brouder
Author	J.R. Frankenberger
Author	M.A. Youssef
Date	2008 December 08

Simulated effect of drainage water management operational strategy on hydrology and crop yield for Drummer soil in the Midwestern United States

Type	Report

Author	S. Ale
Author	L.C. Bowling
Author	J.R. Frankenberger
Author	M.A. Youssef
Date	2009
Pages	653-665

Climate Variability and Drain Spacing Influence on Drainage Water Management System Operation

Type	Journal Article
Author	Srinivasulu Ale
Author	Laura C. Bowling
Author	Jane R. Frankenberger
Author	Sylvie M. Brouder
Author	Eileen J. Kladivko
Publication	Vadose Zone Journal
Volume	9
Issue	1
Pages	43-52
Date	2010 February
DOI	doi:10.2136/vzj2008.0170

Phosphorus Transport through Subsurface Drainage and Surface Runoff from a Flat Watershed in East Central Illinois, USA

Type	Journal Article
Author	A. S. Algoazany
Author	P. K. Kalita
Author	G. F. Czapar
Author	J. K. Mitchell
Publication	Journal of Environment Quality
Volume	36
Issue	3
Pages	681
Date	2007
DOI	10.2134/jeq2006.0161
ISSN	1537-2537
URL	https://www.agronomy.org/publications/jeq/abstracts/36/3/681
Accessed	Tuesday, April 26, 2011 3:43:15 PM
Library Catalog	CrossRef

Tags:

buffer Illinois pesticide phosphorus soluble phosphorus tile water quality

Notes:

Application of the Flow Reduction Strategy in the Bois de Sioux Watershed

Type	Report
Author	Charles L. Anderson
Author	Michael A. Bakken
Date	2010 June 4

Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List

Type	Document
Author	Pam Anderson
Author	W. Bouchard
Author	D. Christopherson
Author	M. Feist
Author	J. Genet
Author	D. Hansen
Author	L. Hotka
Author	S. Lotthammer
Author	H. Markus
Author	B. Monson
Author	A. Preimesberger
Author	C. Sinden
Publisher	MPCA
Date	2012

A COST EFFECTIVE APPROACH TO STORMWATER MANAGEMENT SOURCE CONTROL AND DISTRIBUTED

STORAGE

Type	Journal Article
Author	R.Y.G. Andoh
Author	C. Declerck
Volume	36
Issue	8-9
Pages	307-311
Date	1997

Phosphorus losses in runoff as affected by tillage.

Type	Journal Article
Author	B.J. Andraski
Author	D.H. Mueller
Author	T.C. Daniel
Publication	Soil Science Society of America Journal
Volume	49
Pages	1523-1527
Date	1985
Extra	Wisconsin

Tags:

agricultural best management practice BMP Lab manure management No till / minimum till / strip till nutrient management

Notes:

Conservation tillage is tested to determine the benefit of nutrient retention of 3 tillage methods. The results show that conservation tillage systems can effectively reduce phosphorus losses in runoff relative to conventional, especially at times when high sediment concentrations and losses occur from conventionally tilled land.

Manure History and Long-Term Tillage Effects on Soil Properties and Phosphorus Losses in Runoff

Type	Journal Article
Author	T. W. Andraski
Author	L. G. Bundy
Author	K. C. Kilian
Publication	Journal of Environment Quality
Volume	32
Pages	1782-1789
Date	2003

Notes:

A six-year study in Wisconsin measuring the long-term effect of tillage system on soil P levels in the top 10-cm soil profile and phosphorus level in runoff. Chisel plow and no-till were compared and dissolved P, bioavailable P, total P, and sediment loads in runoff were measured. The graphs showing phosphorus load in runoff vs. soil test P nicely highlight the soil property differences resulted from the two tillage systems.

Effectiveness of vegetated buffer strips in reducing pesticide transport in simulated runoff

Type	Journal Article
Author	K. Arora
Author	S. K. Mickelson
Author	J. L. Baker
Publication	Transactions of the American Society of Agricultural Engineers
Volume	46
Issue	3
Pages	635-644
Date	2003
Extra	Iowa, Ames

Tags:

agricultural best management practice buffer contour stripcropping filter strip grassed waterways nutrient management riparian forest buffer

Notes:

This paper describes a good research project using a controlled runoff experiment to estimate pesticide reduction across a buffer strip. It also provides a good summary of previous work on buffer strip pollutant removals. It shows pesticide removals of 46.8%-83.1%.

Herbicide retention by vegetative buffer strips from runoff under natural rainfall

Type	Journal Article
Author	K. Arora
Author	S. K. Mickelson
Author	J. L. Baker
Author	D. P. Tierney
Author	C. J. Peters
Publication	Transactions of the American Society of Agricultural Engineers
Volume	39
Issue	6
Pages	2155-2162
Date	1996
Extra	Iowa, Ames

Tags:

agricultural best management practice BMP buffer filter strip manure management nutrient management

Notes:

A natural rainfall study of the impact of buffer strips on herbicide retention in Iowa showed that infiltration was the key process for herbicide retention by the buffer strips. The buffer strips showed a high sediment retention ranging from 40-100%.

Manure Production and Characteristics

Type	Journal Article
Author	ASAE
Publication	American Society of Agricultural Engineers
Issue	ASAE Standards 2005
Date	March 2005

Tags:

agricultural best management practice fecal manure management nutrient management

Notes:

A guidebook for the physical and chemical characteristics of different manures.

Controlled drainage for improved water management in arid regions irrigated agriculture

Type	Journal Article
Author	J.E. Ayars
Author	E.W. Christen
Author	J.W. Hornbuckle
Publication	Agricultural Water Management
Volume	86
Pages	128-139
Date	2006

WATER QUALITY AS DESIGN CRITERION IN DRAINAGE WATER MANAGEMENT SYSTEMS

Type	Journal Article
Author	James E. Ayars
Author	Mark E. Grismer
Author	John C. Guitjens
Publication	Journal of Irrigation and Drainage Engineering
Pages	154-158
Date	1997 May/June

Nitrate-Nitrogen in tile drainage as affected by fertilization

Type	Journal Article
Author	J. L. Baker
Author	H.P. Johnson
Publication	Journal of Environmental Quality
Volume	10
Pages	519-522
Date	1981
Extra	Iowa, Ames

Tags:

agricultural best management practice tile system design

Notes:

An early study of nitrogen in drain tile conducted in iowa.

Water quality consequences of conservation tillage

Type	Journal Article
Author	J. L. Baker
Author	J. M. Laflen
Publication	Journal of Soil and Water Conservation
Volume	38
Issue	3
Pages	186-193
Date	1983
Extra	Iowa, Ames

Tags:

agricultural BMP No till / minimum till / strip till nutrient management

Notes:

A look at the environmental implications of conservation tillage on water quality. Provides some good field data comparing Plow, chisel and no-till techniques. Shows that the greatest benefit is realized at highly erodible soils.

Runoff losses of nutrients and soil from ground fall-fertilized after soybean harvest

Type	Journal Article
Author	J. L. Baker
Author	J. M. Laflen
Publication	American Society of Agricultural Engineers
Volume	26
Issue	4
Pages	1122-1127
Date	1983

Notes:

A study in Iowa on fertilizer application methods in relation to water quality. Fertilizer was either surface applied or incorporated by injection, chisel plowing, or disking. Different residue amount and its effect on water quality was also analyzed.

Effects of crop residue management on soluble nutrient runoff losses

Type	Journal Article
Author	J.L. Baker
Author	J. M. Laflen
Publication	American Society of Agricultural Engineers
Volume	25
Issue	2
Pages	344-348
Date	1982

Notes:

A study in Iowa on fertilizer management using different fertilizer rates and placements and corn residue amounts on the soil surface. Nutrient concentrations in runoff were plotted as a function of time after simulated rainfall began for NH_4-N, NO_3-N, PO_4-P, and Bromide (tracer).

Nitrate, Phosphorus, and Sulfate in Subsurface Drainage Water

Type	Journal Article
Author	J.L. Baker
Author	K.L. Campbell
Author	H.P. Johnson
Author	J.J. Hanway
Publication	Journal of Environment Quality
Volume	4
Issue	3
Pages	406-412
Date	1975

Notes:

A three-year nutrient study in Iowa analyzing runoff from tile drainage. Flow weighted-nitrate data in tile drainage are compared with data from adjacent piezometers and with nitrate data from the receiving river.

Understanding Nutrient Fate and Transport

Type	Report
Author	James L. Baker
Author	Mark B. David
Author	Dean W. Lemke
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Institution	ASABE
Date	2008
Pages	17

Tags:

MN

Notes:

An introduction chapter of the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. A basic information is provided on nutrient transport mechanisms, hydrology, agricultural trends associated with water quality and watershed loss as well as some data on runoff volume, sediment loss, nutrients loss in response to rainfall.

Are you covered? Stop soil erosion on canning crop acres

Type	Document
Author	BALMM Cover Crop Strategy Team
Publisher	MN Department of Agriculture
Date	2005 March

Notes:

Effect of tillage systems on runoff losses of nutrients, A Rainfall simulation study

Type	Journal Article
Author	S.G. Barisas
Author	J. L. Baker
Author	H.P. Johnson
Author	J. M. Laflen
Publication	Transactions of the American Society of Agricultural Engineers
Pages	893-897
Date	1978
Extra	Iowa

Tags:

agricultural All pollutants No till / minimum till / strip till nutrient management

Notes:

A rainfall simulation study looking at conservation tillage practices in Iowa. This report shows that conservation tillage practices were ineffective in reducing the loss of water soluble nutrients; however, they did reduce total nutrient loss by controlling erosion.

Nutrient transport through a Vegetative Filter Strip with subsurface drainage

Type	Journal Article
Author	Rabin Bhattarai
Author	Prasanta Kumar Kalita
Author	Mita Kanu Patel
Publication	Journal of Environmental Management
Volume	90
Issue	5
Pages	1868-1876
Date	04/2009
Journal Abbr	Journal of Environmental Management
DOI	10.1016/j.jenvman.2008.12.010
ISSN	03014797
URL	http://linkinghub.elsevier.com/retrieve/pii/S0301479708003666
Accessed	Tuesday, July 05, 2011 11:58:45 AM
Library Catalog	CrossRef

Tags:

All pollutants buffer

Notes:

A study at the university of Illinois looking at the effectiveness of buffer strips on tiled fields. Results demonstrate that although a VFS can be very effective in reducing runoff and nutrients from surface flow, the presence of a subsurface drain underneath the VFS may not be environmentally beneficial. Such a combination may increase NO3-N transport from the VFS, thus invalidating the purpose of the BMP.

Grass Barriers for Reduced Concentrated Flow Induced Soil and Nutrient Loss

Type	Journal Article
Author	Humberto Blanco-Canqui
Author	C.J. Gantzer
Author	S.H. Anderson
Author	E.E. Alberts
Publication	Soil Science Society of America Journal
Date	2004

Tags:

buffer filter strips nitrogen phosphorus sediment

Notes:

A study of vegetative filter strips in concentrated flow. This document studies and suggests that use of switchgrass barriers in conjunction with fescue provides more treatment than fescue alone.

Potential Implications of Expanded Agricultural Subsurface Tile Drainage for Aquatic Ecosystems of the Red River Basin

Type	Document
Author	Kristen L. Blann
Author	James L. Anderson
Author	Gary L. Sands
Author	Bruce Vondracek
Date	2007

Tags:

MN tile system design

Notes:

A detailed assessment of the impact of tile drainage on the aquatic ecosystems of the red river basin.

Third Crop Opportunities in the Blue Earth River Basin

Type	Document
Author	Blue Earth River Basin Initiative
Author	Institute for Agriculture and Trade Policy
Date	2003 February

An Innovative, Basinwide Approach to Flood Mitigation: The Waffle Project

Type	Report
Author	Bethany Bolles
Author	Xixi Wang
Author	Lynette de Silva
Author	Heith Dokken
Author	Gerald Groenewold
Author	Wesley Peck
Author	Edward Steadman
Date	N.D.

Efficiency of controlled drainage and subirrigation in reducing nitrogen losses from agricultural fields

Type	Journal Article
Author	Gabriele Bonaiti
Author	Maurizio Borin
Publication	Agricultural Water Management
Volume	98
Pages	343-352
Date	2010

Agriculture and Water Quality: Best Management Practices for Minnesota

Type	Document

Contributor	James Anderson
Contributor	John Berg
Contributor	John Brach
Contributor	Greg Buzicky
Contributor	Greg Johnson
Contributor	Mark Nelson
Contributor	Dwaine Otte
Contributor	Mark Waggoner
Author	John Brach
Publisher	Minnesota Pollution Control Agency: Division of Water Quality
Date	n.d.

Tags:

All BMPs All pollutants MN

Notes:

A comprehensive handbook describing best management practices in Minnesota. This was the original attempt at a complete look at bmps in minnesota. General water quality issues in minnesota are discussed as well as chosing bmps to fit specific needs and technical standards for implementing bmps. Also includes fact sheets on specific bmps including information on bmp siting and water quality impacts.

HYDRAULIC CONDUCTIVITY OF A GEOSYNTHETIC CLAY LINER TO A SIMULATED ANIMAL WASTE SOLUTION

Type	Journal Article
Author	L. C. Brown
Author	C. D. Shackelford
Publication	American Society of Agricultrual and Biological Engineers
Volume	50
Issue	3
Pages	831-841
Date	2007

Ohio State University FactSheet: Agricultural Best Management Practices

Type	Journal Article
Author	Larry Brown
Author	Kris Boone
Author	Sue Nokes
Author	Andy Ward
Date	October 18 2010

Tags:

agricultural All BMPs All pollutants best management practice

Notes:

A factsheet describing a large array of BMPs. A table of BMP effectiveness against at controlling pollution is provided but is not quantitative.

Atrazine and alachlor losses from subsurface tile drainage of a clay loam soil

Type	Journal Article
Author	D.D. Buhler
Author	G.W. Randall
Author	W.C. Koskien
Author	D.L. Wyse
Publication	Journal of Environmental Quality
Volume	22
Pages	583-588
Date	1993
Extra	Minnesota, Waseca

Tags:

agricultural MN nutrient management pesticides tile system design

Notes:

Tillage systems had minimal impacts on atrazine concentration or loss in tile drainage water. This research indicates that low concentrations of atrazine may contaminate tile drainage water during and after long-term use and may persist for several years after use is stopped. Contamination of drainage from similar use of alachlor appears minimal.

Management Practice Effects on Phosphorus Losses in Runoff in Corn Production Systems

Type	Journal Article
Author	L. G. Bundy
Author	T. W. Andraski
Author	J. M. Powell
Publication	Journal of Environment Quality
Volume	30
Pages	1822-1828
Date	2001

Notes:

A study in Wisconsin on the effect of different P sources and tillage systems on phosphorus concentrations and loads in runoff. Inorganic fertilizer P, manure and biosolids were applied on the fields with no-till, chisel plow, or shallow till system. For manure applied fields, tillage reduced dissolved reactive phosphorus load, but the least total phosphorus load came from no-till field.

Field-Scale Tools for Reducing Nutrient Losses to Water Resources

Type	Report
Author	L. G. Bundy
Author	A. P. Mallarino
Author	L. W. Good
Author	P. Nowak
Author	J. Norman
Author	D. J. Mulla
Report Number	12
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Date	2008
Pages	12

Tags:

MN

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. An introduction of P Index and a good comparison of P Index components used in Iowa, Minnesota, and Wisconsin.

The Nature of Phosphorus in Soils

Type	Document
Author	Lowell Busman
Author	John Lamb
Author	Gyles Randall
Author	George Rehm
Author	Michael Schmitt
Publisher	University of Minnesota
Date	2002

Tags:

phosphorus

Notes:

A description of the phosphorus cycle and phosphorus in soils.

Public Drainage Ditch Buffer Study

Type	Report
Author	BWSR
Institution	BWSR in Partnership with Minnesota State University, Mankato, Water Resources Center and University of Minnesota Water Resources Center
Date	February 2006

Tags:

agricultural best management practice BMP buffer fecal filter strip MN nutrient management

Notes:

A comprehensive study of the extent of buffers on public ditches in Minnesota.

Minnesota's State-Funded RIM Reserve Conservation Easements 1986-2006

Type	Report

Author BWSR
Date April 24, 2007

Tags:

agricultural buffer MN

Notes:

A map showing state funded RIM locations

Public Drainage Ditch Buffer Strip Reporting

Type	Report
Author	BWSR
Institution	BWSR
Date	Calendar Year 2008

Tags:

buffer MN

Notes:

A description of public drainage buffer strips in minnesota

Nitrate removal and hydraulic performance of organic carbon for use in denitrification beds

Type	Journal Article
Author	Stewart G. Cameron
Author	Louis A. Schipper
Publication	Ecological Engineering
Volume	36
Pages	1588-1595
Date	2010

Improving Soil Productivity with Conservation Tillage and Double Cropping: a History of the P1 Watershed

Type	Document
Author	J. Phil Campbell
Date	N.D.

Economic impact of varying swine manure application rates on continuous corn

Type	Journal Article
Author	Chase, Craig
Author	Duffy, Michael
Author	Lotz, William
Publication	Soil and Water Conservation Society
Volume	46
Issue	6
Pages	460-464
Date	1991

Notes:

Effectiveness of vegetative filter strips in retaining surface-applied swine manure constituents

Type	Journal Article
Author	I. Chaubey
Author	D.R. Edwards
Author	T.C. Daniel
Author	P. A. Moore Jr.
Author	D. J. Nichols
Publication	American Society of Agricultural Engineers
Volume	37
Issue	3
Pages	845-850
Date	1994

Notes:

A study in Arkansas on vegetative filter strips treating runoff from a swine manure applied field. The reductions of sediments, nutrients, COD, and fecal count were measured at six different width points in a filter strips and optimum widths for each constituents were calculated based on first-order kinetics.

Effects of six tillage methods on ressidue incorporation and crop performance in a heavy clay soil

Type	Journal Article
Author	Y Chen
Author	F.V. Monero
Author	D. Lobb
Author	S. Tessier
Author	C. Cavers
Publication	Transactions of the American Society of Agricultural Engineers
Volume	47
Issue	4
Pages	1003-1010
Date	2004
Extra	Manitoba (Canada), Elm Creek (Red River Valley)

Tags:

agricultural best management practice manure management No till / minimum till / strip till tillage

Notes:

A look at different tilling practices in the red river valley of the canadian prairies. It concludes that no-till gave the best results.

Non-Point Source Best Management Practices and Efficiencies currently used in Scenario Builder Values in parentheses are in progress of official approval

Type	Document
Author	Ches
Date	February 9, 2011

Tags:

All BMPs All pollutants best management practice BMP buffer livestock access control manure management nutrient management

Notes:

This is the master table of how the chesapeake Bay credits bmps to meet water quality reductions. A large amount of research went into creating this table and some of the values may be representative of Minnesota.

Water-Quality and Biological Characteristics and Responses to Agricultural Land Retirement in Three Streams of the Minnesota River Basin, Water Years 2006–08

Type	Report
Author	Victoria G. Christensen
Author	Kathy E. Lee
Author	Christopher A. Sanocki
Author	Eric H. Mohring
Author	Richard L. Kiesling
Report Type	Scientific Investigations Report 2009-5215
Institution	U.S. Department of the Interior
Date	2009

Notes:

Suggested citation:
Christensen, V.G., Lee, K.E., Sanocki, C.A., Mohring, E.H., and Kiesling, R.L., 2009, Water-quality and biological
characteristics and responses to agricultural land retirement in three streams of the Minnesota River Basin, water
years 2006–08: U.S. Geological Survey Scientific Investigations Report 2009–5215, 52 p., 3 app.

Mississippi River Basin Healthy Watersheds Initiative

Type	Document
Contributor	Christensen, Thomas
Publisher	USDA
Date	N.D.

Tags:

MN

Notes:

A description of the MRBI program.

Estimation of flow and transport parameters for woodchip-based bioreactors: II. field-scale bioreactor

Type	Journal Article
Author	J.A. Chun
Author	R.A. Cooke
Author	J.W. Eheart
Author	J. Cho
Publication	Biosystems Engeineering
Volume	105
Pages	95-102
Date	2010

Estimation of flow and transport parameters for woodchipbased bioreactors: I. laboratory-scale bioreactor

Type	Journal Article
Author	J.A. Chun
Author	R.A. Cooke
Author	J.W. Eheart
Author	M.S. Kang
Publication	Biosystems Engeineering
Volume	104
Pages	384-395
Date	2009

International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Fecal Indicator Bacteria

Type	Report
Author	Clary, Jane
Author	Marc Leisenring
Author	Joe Jeray
Date	2010 December

Notes:

Summary of the International Stormwater BMP database on bacteria. Not focused on agriculture.

Design of Anaerobic Lagoons for Animal Waste Management

Type	Document
Author	ASAE Agricultural Sanitation and Waste Management Committee
Date	2011 February

Drainage Water Management: A Practice for Reducing Nitrate Loads from Subsurface Drainage Systems

Type	Report
Author	R. A. Cooke
Author	G. R. Sands
Author	L. C. Brown
Report Number	2
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Institution	ASABE
Date	2008
Pages	10

Tags:

MN

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. An introduction of a controlled drainage system (drainage water management) and its potential nitrate reduction in runoff by reducing drain outflow volume.

Conservation Reserve Program: Status and Current Issues

Type	Document
Author	Tadlock Cowan
Publisher	Congressional Research Service for Congress

Date	2010 September 15

Fecal bacteria trapping by grass filter strips during simulated rain

Type	Journal Article
Author	Coyne, M.S.
Author	R.A. Gilfillen
Author	A. Villalba
Author	Z. Zhang
Author	R. Rhodes
Author	L. Dunn
Author	R.L. Blevins
Publication	Journal of Soil and Water Conservation
Volume	53
Issue	2
Date	1998

Tags:

bacteria filter strips manure management sediment waste water treatment strip

Notes:

A study in Kentucky on poultry manure amended cropland. This study used simulated rainfall to generate runoff and measured reduction in sediment and bacteria after passing over filter strips of various widths. It concludes that grass filter strips are effective at reducing sediment loss and bacteria, although will not reduce fecal contamination to sufficiently meet water quality standards.

Using wetlands for water quality improvement in agricultural watersheds; the importance of a watershed scale approach

Type	Journal Article
Author	W.G. Crumpton
Publication	Water Science and Technology
Volume	44
Issue	11
Pages	559-564
Date	2001
Extra	Iowa, Walnut Creek Watershed

Tags:

agricultural best management practice nutrient management wetland, restoration

Notes:

A discussion of the importance of site selection on the water quality benefits of wetland restorations.

Potential of Restored and Constructed Wetlands to Reduce Nutrient Export from Agricultural Watersheds in the Corn Belt

Type	Report
Author	W. G. Crumpton
Author	D. A. Kovacic
Author	D. L. Hey
Author	J. A. Kostel
Report Number	3
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Date	2008
Pages	14

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. A discussion of wetland capacity to remove nitrate and sequester phosphorus and carbon. Data from Upper Mississippi and Ohio River Basin is provided.

Potential of Restored and Constructed Wetlands to Reduce Nutrient Export from Agricultural Watersheds in the Corn Belt

Type	Report
Author	William G. Crumpton
Author	David A. Kovacic
Author	Donald L. Hey
Author	Jill A. Kostel
Institution	Upper Mississippi River Sub-basin Hypoxia Nutrient Committee
Date	2008
Rights	American Society of Agricultural and Biological Engineers

Tags:

agricultural best management practice buffer filter strip nutrient management wetland, constructed wetland, restoration

Notes:

A chapter of the UMRSHNC final report discussing the role of wetland restorations on nutrients.

Potential benefits of wetland filters for tile drainage systems: Impact on nitrate loads to Mississippi River sub-basins.

Type	Journal Article
Author	Crumpton, W.G.
Author	Stenback, G.A.
Author	Miller, B.A.
Author	Helmers, M.J.

Assessing the Health of Streams in Agricultural Landscapes: The Impacts of Land Management Change on Water Quality

Type	Book
Author	Rick Cruse
Author	Don Huggins
Author	Christian Lenhart
Author	Joe Magner
Author	Todd Royer
Author	Keith Schilling
Publisher	The Council for Agricultural Science and Technology
Date	2012 March
ISBN	978-1-887383-34-9

Effects of Erosion Control Practices on Nutrient Loss

Type	Report
Author	G. F. Czapar
Author	J. M. Laflen
Author	G. F. McIsaac
Author	D. P. McKenna
Report Number	9
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Place	St. Joseph, Michigan
Institution	ASABE
Date	2008
Pages	117-127

Tags:

MN

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. A discussion and a cost-and-benefit analysis of the BMPs for prevention of soil erosion and nutrient loss. No-till, contouring, strip cropping, terrace with vegetative outlet, and water and sediment control basin are compared with moldboard plow and typical tillage.

Effects of geomorphology, habitat, and spatial location on fish assemblages in a watershed in Ohio, USA

Type	Journal Article
Author	Jessica L. D'Ambrosio
Author	Lance R. Williams
Author	Jonathan D. Witter
Author	Andy Ward
Publication	Environmental Monitoring Assessment
Volume	148
Pages	325-341
Date	2009

INTEGRATED MANAGEMENT OF IN-FIELD, EDGE-OF-FIELD, AND AFTER-FIELD BUFFERS

Type	Journal Article
Author	Seth M. Dabney
Author	Matthew T. Moore
Author	Martin A. Locke
Publication	JAWRA
Pages	24
Date	February 2006

Tags:

buffer dissolved phosphorus nitrogen phosphorus riparian forest buffer riparian vegetation vegetated treatment area

Notes:

A north Carolina study of grass and riparian filter strips. Pollutant removals are reported. the results show that forested ephemeral channels had little vegetation and were effective sediment sinks during dry periods but were ineffective during large storms.

Sources of Nitrate Yields in the Mississippi River Basin

Type	Journal Article
Author	Mark B. David
Author	Gregory F. McIsaac
Author	Laurie E. Drinkwater
Publication	Journal of Environment Quality
Volume	39
Pages	1657-1667
Date	2010 September-October

Modeling Nitrate nitrogen leaching in response to nitrogen fertilizer rate and tile drain depth or spacing for southern Minnesota, USA

Type	Journal Article
Author	D.M. Davis
Author	P.H. Gowda
Author	D.J. Mulla
Author	G.W. Randall,
Publication	Journal of Environmental Quality
Volume	29
Pages	1568-1581
Date	2000
Extra	Minnesota, Waseca

Tags:

agricultural best management practice manure management MN nitrogen nutrient management tile system design

Notes:

the model ADAPT is used to predict relative losses of nitrogen to drain tile water. Simulations indicate that much greater reduction in nitrogen losses occure with reduced N application rates than with increases in drain spacing or decreases in drain depth.

On-Farm Comparison of Conservation Tillage Systems for Corn Following Soybeans

Type	Journal Article
Author	Jodi DeJong-Hughes
Author	Jeffrey Vetsch
Publication	University of Minnesota Extension
Date	2007

Tags:

agricultural best management practice MN No till / minimum till / strip till

Notes:

A producers guide to conservation tillage systems in MN.

Study highlights benefits of CRP and WRP programs

Type	Newspaper Article
Author	Delta Farm Press
Publication	The Farm Press
Date	2011 June 14

Notes:

A news introducing the benefits of participating the USDA conservation programs, CRP and WRP. An overall estimate of soil loss prevented through the programs and a link to some data provided by the Conservation Effects Assessment Project (CEAP) are listed.

Long-term observations of vadose zone and groundwater nitrate concentrations under irrigated agriculture.

Type	Journal Article
Author	N.E. Derby
Author	F.X.M Casey
Author	R.E. Knighton
Publication	Vadose Zone Journal
Volume	8
Pages	290-300
Date	N.D.

Notes:

The goal of this study in SE North Dakota was to evaluate multiple long-term nitrate concentrations in groundwater under irrigated row crop production. The data were collected over a twenty-year period under a center pivot irrigation system. Soils were loamy fine sand and sandy loam. Crops grown were corn, soybeans, and potatoes.

Nitrogen application rates were managed for enhanced nitrogen and irrigation efficiency. Prior to this study, N application rates had been greater than NDSU extension recommendation. Following adoption of low N rates, nitrate concentrations in groundwater decreased markedly.

Elevated nitrate concentrations in groundwater were found after infiltration of irrigation on sandy soil, even though N rates were conservative. Greater N application rates resulted in elevated groundwater nitrate levels. The most important factor influencing soil N concentration was residual soil nitrate in the fall.

One particularly interesting fact coming from the study was that nitrate concentration in tile was significantly lower than that in shallow wells, attributed to biological nitrate reduction by bacteria in the tile and gravel filter.

Long-Term Observations of Vadose Zone and Groundwater Nitrate Concentrations under Irrigated Agriculture

Type	Journal Article
Author	Nathan E. Derby
Author	Francis X. M Casey
Author	Raymond E. Knighton
Publication	Vadose Zone Journal
Volume	8
Issue	2
Pages	290-300
Date	2009 May

Evaluating grassed waterway efficiency in southeastern Iowa using WEPP

Type	Journal Article
Author	D. Dermsis
Author	O. Abaci
Author	A.N. Papanicolaou
Author	C.G. Wilson
Publication	Soil Use and Management
Volume	26
Pages	183-192
Date	2010
Extra	Iowa, Clear Creek Watershed

Tags:

agricultural best management practice BMP buffer grassed waterways nutrient management

Notes:

A model based study of grassed waterways in IA.

An economic analysis of the Waffle

Type	Journal Article
Author	E.A. DeVuyst
Author	D.A. Bangsund
Author	F.L. Leistritz
Publication	Journal of Soil and Water Conservation
Volume	64
Issue	1
Pages	7-16

Date 2009 January/February
DOI 10.2489/jswc.64.1.7

Two-Stage Ditches and Water Quality Solutions for Agricultural NPS

Type	Journal Article
Author	Scott Dierks
Publication	Pipeline
Volume	19
Issue	1
Pages	32-35
Date	2010

Vegetative filter strips for agricultural nonpoint source pollution control

Type	Journal Article
Author	T. A. Dillaha
Author	R. B. Reneau
Author	S. Mostaghimi
Author	D. Lee
Publication	American Society of Agricultural Engineers
Volume	32
Issue	2
Pages	513-519
Date	1989

Notes:

A study in Virginia estimating the nutrient removal efficiency of filter strips on agricultural fields simulating storm events. Addition to nutrient removal efficiency, this study provides a visual observation of sediment accumulation within filter strip. Filter strips installed in 18 farms were also qualitatively evaluated and the evaluation showed the importance of receiving uniform sheet flow and avoiding parallel flow for effective sediment removal.

Core Farm: Year in Review - 2011

Type	Document
Author	Discovery Farms Minnesota
Date	2012 April

Nitrogen Placement and Leaching in a Ridge-Tillage System

Type	Conference Paper
Author	P. W. Dolan
Author	B. Lowery
Author	K. J. Fermanich
Author	N. C. Wollenhaupt
Author	K. C. McSweeney
Date	1993 February
Conference Name	Agricultural Research To Protect Water Quality
Place	Minneapolis, Minnesota USA
Publisher	Soil and Water Conservation Society
Pages	176-183

Notes:

A study in Wisconsin measuring the effect of fertilizer placement on ridge vs. farrow on N loss in runoff. In this experiment, it was effective to drip N solution, immediately covering by the ridging operation.

Quantifying Water Pollution Abatement

Type	Journal Article
Author	M. G. Dosskey
Date	2001

Tags:

buffer nitrogen phosphorus sediment

Notes:

A literature review of buffers effectiveness and reducing water pollution. This study contains a summary of a great deal of research and provides many recorded values for pollutant removals due to buffers. This study found that no experimental study reported on the impact of buffers on pollutant levels in streams or lakes. It also concludes that there is abundant evidence that indicates that buffers can retain pollutants from surface runoff from fields.

Interactive Effects of Controlled Drainage and Riparian Buffers on Shallow Groundwater Quality

Type	Journal Article
Author	M. D. Dukes
Author	R. O. Evans
Author	J. W. Gilliam
Author	S. H. Kunickis
Publication	Journal of Irrigation and Drainage Engineering
Pages	82-92
Date	2003 March/April
DOI	10.1061/(ASCE)0733-9437

THE EFFECT OF TERRACES ON PHOSPHORUS MOVEMENT

Type	Report
Author	ECOLOGISTICS LIMITED
Date	1990 July

SEDIMENTATION BASIN RETENTION EFFICIENCIES FOR SEDIMENT, NITROGEN, AND PHOSPHORUS FROM SIMULATED AGRICULTURAL RUNOFF

Type	Journal Article
Author	C. L. Edwards
Author	R. D. Shannon
Author	A. R. Jarrett
Publication	American Society of Agricultural Engineers
Volume	42
Issue	2
Pages	403-409
Date	1999

Sedimentation basin retention efficiencies for sediment, nitrogen, and phosphorus from simulated agricultural runoff

Type	Journal Article
Author	C.L. Edwards
Author	R.D. Shannon
Author	A.R. Jarrett
Publication	American Society of Agricultural Engineers
Volume	42
Issue	2
Pages	403-409
Date	1999

Notes:

A study in Pennsylvania on the effect of sedimentation basin detention time and previous storm events on sediment and nutrients removal efficiency. The results from one- and three-day detention time were compared for five storm events

Effect of BMP implementation on storm flow quality of two northwestern Arkansas streams

Type	Journal Article
Author	D. R. Edwards
Author	T. C. Daniel
Author	H. D. Scott
Author	P. A. Moore Jr.
Author	J. F. Murdoch
Author	P. F. Vendrell
Publication	American Society of Agricultural Engineers
Volume	40
Issue	5
Pages	1311-1319
Date	1997

Notes:

A three-year study measuring the effect of BMP implementation in a watershed in Arkansas. The major land use in the watershed was pasture and the BMPs applied were nutrient management, pasture and hayland management, waste utilization, dead poultry composting, and waste storage structure construction. In this study, nutrient management was most effective in reducing NO_3-N, TKN, and COD.

Narrow Grass Hedge Effects on Phosphorus and Nitrogen in Runoff following Manure and Fetilizer Application

Type	Journal Article
Author	B. Eghball
Author	J.E. Gilley
Author	L.A. Kramer
Author	T.B. Moorman
Publication	Journal of Soil and Water Conservation
Volume	64
Issue	2
Pages	163-171
Date	March/April 2009

Tags:

filter strip manure management nitrogen phosphorus US

Notes:

This IA study was conducted to determine the effectiveness of grass hedges at removing phosphorus and nitrogen from manure applied fields. This study concludes that narrow grass hedges were effective in reducing P and N losses in runoff from both manure and fertilizer application with TP reduction fo 40% realized.

Nitrate removal and greenhouse gas production in a stream-bed denitrifying bioreactor

Type	Journal Article
Author	Z. Elgood
Author	W.D. Robertson
Author	S.L. Schiff
Author	R. Elgood
Publication	Ecological Engineering
Volume	36
Pages	1575-1580
Date	2010

Manure Production and Characteristics

Type	Document
Author	Engineering Practices Subcommittee of the ASAE Agricultural Sanitation and Waste Management Committee
Date	2010

Manure Storages

Type	Document
Author	Engineering Practices Subcommittee of the ASAE Agricultural Sanitation and Waste Management Committee
Date	2010

Design Guidelines for Water Table Management Systems on Coastal Plain Soils

Type	Journal Article
Author	R. O. Evans
Author	R. W. Skaggs
Publication	American Society of Agricultural Engineers
Volume	5
Issue	4
Pages	539-548
Date	1989

Design Guidelines for Water Table Management Systems on Coastal Plain Soils

Type	Journal Article
Author	R.O. Evans
Author	R.W. Skaggs
Publication	American Society of Agricultural Engineers
Volume	5
Date	December 1989

Controlled versus conventional drainage effects on water quality

Type	Journal Article
Author	R.O. Evans
Author	R.W. Skaggs
Author	J.W. Gilliam
Publication	Journal of Irrigation and Drainage Engineering
Volume	121
Issue	4
Pages	271-276
Date	1995

Notes:

This paper reviews previous work and summarizes impacts of traditional and controlled drainage on water, sediment, and nutrient, and fertilizer export. Most of the results presented are from research conducted in North Carolina.

The authors note that converting undeveloped land (primarily broad, flat land) to agricultural production with drainage results in about a 20% increase in water yield for subsurface systems and about 5% for surface drainage systems. Use of controlled drainage may reduce outflows by about 30% compared to conventional subsurface drainage. This may vary year to year, depending on local climate. During dry years, controlled drainage may eliminate outflow and during particularly wet years, there may be no affect on outflow. During wet periods, controlled drainage may increase peak outflow rates due to a high water table, which forces increased surface runoff.

Nitrogen and phosphorus concentrations are generally the same as for conventional drainage, although some reduced nitrate concentrations were shown (1- - 20%), associated with greater denitrification rates.

CONTROLLED VERSUS CONVENTIONAL DRAINAGE EFFECTS ON WATER QUALITY

Type	Journal Article
Author	Robert O. Evans
Author	R. Wayne Skaggs
Author	J. Wendell GiIliam
Publication	Journal of Irrigation and Drainage Engineering
Pages	271-276
Date	1995 July/August

Managing nitrate and bacteria in runoff from livestock confinement areas with vegetative filter strips

Type	Document
Author	Fajardo, J.J.
Author	J.W. Bauder
Author	S.D. Cash
Date	2001

Tags:

bacteria filter strips MN nitrogen vegetated treatment area

Notes:

This is a Montana field study of runoff over filter strips. The study concludes that the filter strips effectively reduced nitrogen levels but had no impact on fecal coliform counts.

A Review of BMPs for Managing Crop Nutrients and Conservation Tillage to Improve Water Quality

Type	Document
Author	Richard Fawecett
Author	Tim Smith
Publisher	Conservation Technology Information Center
Date	2009

Tags:

agricultural bacteria best management practice BMP buffer filter strip livestock access control livestock riparian pasture manure management MN nutrient management rotational grazing

Notes:

A great summary of literature from across the country on reducing losses of Nitrogen and phosphorus using many different BMPs. Provides removal efficiencies of different studies in narrative format.

ROLE OF URBAN STORM-FLOW VOLUME IN LOCAL DRAINAGE PROBLEMS

Type	Journal Article
Author	Bruce K. Ferguson
Author	Tamas Deak
Publication	JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT
Volume	120
Issue	4
Pages	523-530
Date	1994 July/August

ROLE OF URBAN STORM-FLOW VOLUME IN LOCAL DRAINAGE PROBLEMS

Type	Journal Article
Author	Bruce K. Ferguson
Author	Tamas Deak
Publication	ASCE
Pages	523-530
Date	1994 July/August

Controlled drainage to improve edge-of-field water quality in southwest Minnesota, USA

Type	Journal Article
Author	S. Feset
Author	J.S. Strock
Author	G.R. Sands
Author	A.S. Birr
Publication	Proceedings of International Drainage Sympoisum of ASABE
Date	2010
Extra	Minnesota, Lamberton

Tags:

agricultural controlled subsurface drainage fecal manure management MN nutrient management

Notes:

A field study comparing free-draining fields with those that have a controlled drainage system in Minnesota. This field study showed that conservation drainage has potential benefit of reducing nutrient losses in drainage water.

Potential for a Rye Cover Crop to Reduce Nitrate Loss in Southwestern Minnesota

Type	Journal Article
Author	G.W. Feyereisen
Author	B. N. Wilson
Author	G.R. Sands
Author	J.S. Strock
Author	P. M. Porter
Publication	American Society of Agronomy
Volume	98
Pages	1416-1426
Date	2006
Extra	Minnesota, St. Paul

Tags:

agricultural best management practice cover crop MN nitrogen nutrient management

Notes:

Cover crops are studied to determine the potential for reduction of nitrogen loss through drain tiles in southwest Minnesota. This study concludes that cover crops can reduce nitrogen loss by 7.4 kg/Ha if timed properly.

Effectiveness of Grassed Waterways in Reducing Runoff and Sediment Delivery from Agricultural Watersheds

Type	Journal Article
Author	P. Fiener
Author	K. Auerswald
Publication	Journal of Environmental Quality
Volume	32
Date	May-June 2003

Tags:

grassed waterways sediment

Notes:

A 7-year german study of grassed waterways using field monitoring to estimate reduction of sediment. They received exceptional pollutant reduction of 77-97% on the 23 ha (57 ac) site.

Suitability of Using "End of Pipe" Systems to Treat Farm Tile Drainage Water

Type	Document
Author	Fleming, Ron
Author	Roberta Ford
Date	October 2004

Tags:

BMPs

Notes:

This report is essentially a literature review of a variety of treatment systems designed for use downstream of the cultivated field (e.g. filter strips and water/sediment control basins). It provides significant narrative (as opposed to tables) of results from a seemingly eclectic group of approximately 10 studies. The most current study in this literature review is from 2002. A set of commercially available systems are compiled and described; each is also defined for which constituents (not how much) they treat.

Balancing wildlife needs and nitrate removal in constructed wetlands: The case of the Irvine Ranch Water District's San Joaquin Wildlife Sanctuary

Type	Journal Article
Author	Horne, AJ Fleming-Singe, MS
Publication	Ecological Engineering
Volume	26
Issue	2
Pages	147-166
Date	2006
DOI	http://dx.doi.org/10.1016/j.ecoleng.2005.09.010
URL	http://www.sciencedirect.com/science/article/pii/S0925857405001849

Best Management Practices for Georgia Agriculture: Conservation Practices to Protect Surface Water Quality

Type	Report
Author	Fowler, C. L. P.
Report Type	Manual
Place	Athens, GA
Institution	The Georgia Soil and Water Conservation Commission
Date	March, 2007
Pages	114
Language	English
URL	http://www.gaswcc.org/docs/ag_bmp_Manual.pdf
Accessed	Wednesday, April 06, 2011 7:00:00 PM

Tags:

agricultural bacteria best management practice BMP buffer fecal filter strip livestock access control livestock riparian pasture manure management nutrient management rotational grazing

Notes:

A Agricultural BMP manual for the state of Georgia. Climatic differences make this manual only marginally applicable to MN agriculture.

Drainage Water Management for the Midwest

Type	Document
Author	Jane Frankenberger
Author	Eileen Kladivko
Author	Gary Sands
Author	Dan Jaynes
Author	Norm Fausey
Author	Matt Helmers
Author	Richard Cooke
Author	Jeff Strock
Author	Kelly Nelson
Author	Larry Brown

Date	2006 August

Tags:

controlled subsurface drainage MN tile system design

Notes:

A brochure designed for the producer answering general questions about drainage water management, controlled drainage.

Reducing herbicide losses from tile-outlet terraces

Type	Journal Article
Author	T.G. Franti
Author	C.J. Peter
Author	D.P. Tierney
Author	R.S. Fawcett
Author	S.A. Myers
Publication	Journal of Soil and Water Conservation
Volume	53
Issue	1
Pages	25-31
Date	1998

Impacts of Agricultural Drainage on Watershed Peak Flows Briefing Paper #1

Type	Document
Contributor	Fritz, Charles
Publisher	Red River Retention Authority
Date	2011 April 2

Tags:

agricultural best management practice controlled subsurface drainage MN tilling

Notes:

A technical note discussing the state of knowledge of agricultural drainage impacts on flooding in the red river basin. This paper concludes many things including that "any statement implying the subsurface drainage decreases (or increases) flood peaks is strongly discouraged because it oversimplifies the complex processes involved.

Revised Regional Total Maximum Daily Load Evaluation of Fecal Coliform Bacteria Impairments In the Lower Mississippi River Basin in Minnesota

Type	Document
Author	Lee Ganske
Publisher	Minnesota Pollution Control Agency: Division of Water Quality
Date	2006 January

Alternative practices for sediment and nutrient loss control on livetock farms in northeast Iowa.

Type	Journal Article
Author	P.W. Gassman
Author	E. Osei
Author	A. Saleh
Author	J. Rodecap
Author	S. Norvell
Author	J. Williams
Publication	Agriculture, Ecosystems and Environment
Volume	117
Pages	135-144
Date	2006
Extra	Iowa, Upper Maquoketa River Watershed

Tags:

agricultural best management practice BMP buffer contour farming manure management no-till nutrient management terrace

Notes:

Results of this model simulation in NE IA show that although most of the practices reduce sediment and sediment-bound nutrient losses, they have little benefit on soluble nitrogen and phosphorus losses due to extensive draintiling. Includes economic modeling. Results are based primarily on APEX modeling.

Alternative practices for sediment and nutrient loss control on livestock farms in northeast Iowa

Type	Journal Article
Author	Philip W. Gassman
Author	Edward Osei
Author	Ali Saleh
Author	John Rodecap
Author	Stuart Norvell
Author	Jimmy Williams
Publication	Agriculture, Ecosystems & Environment
Volume	117
Pages	135-144
Date	2006

Phosphorus Transport Pathways to Streams in Tile-Drained Agricultural Watersheds

Type	Journal Article
Author	L. E. Gentry
Author	M. B. David
Author	T. V. Royer
Author	C. A. Mitchell
Author	K. M. Starks
Publication	Journal of Environment Quality
Volume	36
Pages	408-415
Date	2007

Persistence of zoonotic pathogens in surface soil treated with different rates of liquid pig manure

Type	Journal Article
Author	P Gessel
Publication	Applied Soil Ecology
Volume	25
Issue	3
Pages	237-243
Date	03/2004
Journal Abbr	Applied Soil Ecology
DOI	10.1016/j.apsoil.2003.09.008
ISSN	09291393
URL	http://linkinghub.elsevier.com/retrieve/pii/S0929139303001537
Accessed	Friday, July 01, 2011 11:08:36 AM
Library Catalog	CrossRef

Tags:

bacteria manure management nutrient management_amount

Notes:

A detailed look at pathogens found in land-applied livestock manure. In this study, manure application rate was positively correlated to the persistence of pathogens with long survival times. It concludes that controlling manure application rate may be a means to reduce the risk of some pathogens moveing with runoff.

Rate of Fall-Applied Liquid Swine Manure: Effects on Runoff Transport of Sediment and Phosphorus

Type	Journal Article
Author	P. D. Gessel
Author	N. C. Hansen
Author	J. F. Moncrief
Author	M. A. Schmitt
Publication	Journal of Environment Quality
Volume	33
Pages	1839-1844
Date	2004

Notes:

A study in Morris, Minnesota, measuring the effect of liquid swine manure incorporated in fall on sediment and nutrient loss in runoff and runoff volume. Unlike solid manure, liquid swine manure does not contain livestock bedding materials, which increase surface residue cover. Therefore, manure's effect on soil physical properties was successfully isolated in this study.

A Comparison of Sediment and Phosphorus Losses from Rock Inlets and Open Inlets in the Lower Minnesota River Basin

Type	Presentation
Presenter	Tim Gieseke
Date	N.D.

A comparison of sediment and phosphorus losses from rock inlets and open tile inlets in the lower Minnesota River Basin

Type	Thesis
Author	Timothy Gieseke
Type	Master of Science
University	Minnesota State University, Mankato
Date	2000

Notes:

This study was conducted in Carver County, evaluating the effectiveness of an open intake and a gravel filter. The drainage area of the basin with the open intake was 8.57 acres with an average slope of 7%, while the drainage area of the basin with the gravel filter was 6.84 acres with a drainage area of 5%. The difference in slope was not accounted for in the results. The adjacent basins both comprised Lester-Kilkenney (clay loam) (80%) and Glencoe clay loam (20%) soils.

Over a two-year period, runoff, total suspended solids, and ortho-phosphorus were compared at the discharge points for the rock and open intakes. Over the study period there were four rainfall events that produced runoff in both basins. Total runoff for the open inlet was 139 kL/ha and 80 kL/ha for the rock inlet. The TSS loading for the open inlet was 227 kg/ha and 35 kg/ha for the rock inlet, which is reported as a 85% reduction. Because the basin with the rock inlet produced less runoff, a considerable reduction in TSS would be expected. In fact, the excess shear equation for sediment detachment is dependant on both the amount of water (hydraulic radius) and slope. This was not accounted for in the study. Thus, the 85% reduction in TSS is misleading since some of the difference can be accounted for my taking into account the increase in runoff and slope.

In the study, the rock inlet was installed in a basin where there had previously been two open intakes. The open intakes were removed by the tile line remained intact. The open intakes were removed but the perforated tile line was left intact. This likely had an affect on the amount of runoff entering the rock inlet and the associated transported sediment. The parallel non-perforated tile line for the rock inlet was 365 m (1200 feet) long. If one assumed a 50 ft drainage influence zone (25 feet on either side of the pipe), the perforated pipe would affect 1.25 acres, or almost 20% of the basin. Thus, comparisons between the basins, notwithstanding the fact that slope differences were not accounted for, are difficult. Because of the lower average slope, partial drainage, and smaller drainage area, the rock inlet received consistently less runoff than the open intake. Even on a per area basis, the rock inlet received less runoff.

The other major component of the study was a simulated storm event where water was premixed with sediment and introduced into the rock inlet. The discharge rate to the rock filter was 38 L/min, which is 0.022 cfs. This flow rate is extremely small for a multi-acre site and is really not representative of a typical erosion causing storm. The other assumption made in this portion of the study was that a open inlet would directly convey 100% of the flow and sediment. This is an accurate statement for very small flow rates but at greater flow rates the capacity of the inlet pipe will limit the flow rate and induce settling.

According to Ranaivoson, the gravel inlet had an initial infiltration rate of more than 3.11 cm/s, but decreased 82% to 0.57 cm/s over a two-year period. Ranaivoson also reported that the gravel inlet reduced total solids and ortho-phosphate by 88 and 64%, respectively, compared to open surface inlets. Gieseke showed in a simulated runoff event that the gravel inlet reduced total solids load by 98% and TP by 69%.

Runoff and soil loss as affected by the application of manure

Type	Journal Article
Author	J. E. Gilley
Author	L. M. Risse
Publication	American Society of Agricultural Engineers

Volume	43
Issue	6
Pages	1583-1588
Date	2000

Notes:

A comprehensive study which assembled and summarized information from nationwide experiments on the effect of manure application on runoff and soil erosion due to natural rainfall events. Regression equations were developed relating runoff and soil loss to annual manure application rate. Experimented areas include Minnesota, Iowa, and Wisconsin.

Interaction between Manure and Tillage System on Phosphorus Uptake and Runoff Losses

Type	Journal Article
Author	D. Ginting
Author	J. F. Moncrief
Author	S. C. Gupta
Author	S. D. Evans
Publication	Journal of Environment Quality
Volume	27
Pages	1403-1410
Date	1998

Notes:

A study in Morris, Minnesota, on the effect of solid beef manure application incorporated either by moldboard plow or ridge tillage on phosphorus load in runoff. Particulate P, dissolved molybdate reactive P, and total P were measured in snow melt and rain runoff.

Runoff, solids, and contaminant losses into surface tile inlets draining lacustrine depressions

Type	Journal Article
Author	D. Ginting
Author	J. F. Moncrief
Author	S.C. Gupta
Publication	Journal of Environment Quality
Volume	29
Pages	551-560
Date	2000

Notes:

This study evaluated the quantity and quantity of runoff and pollutant loss via surface tile inlets in the Blue Earth River basin.

The authors found snowmelt runoff ranged from 3.2 to 9.^ of total snowfall over a three year period (1996 – 1998). However, snow drifting caused loss of some of the total snow depth, so runoff contribution as a percentage of actual snowpack was between 5.8 and 15%. As a percentage of annual rainfall, snowmelt runoff represents between 1.0 and 3.1% of the average annual volume. Snowmelt was the predominant source of runoff in both watersheds.

Total solids concentrations were markedly higher in rainfall runoff (0.23 to 13.9 g/L) as compared to snowmelt runoff (0.09 to 0.41 g/L). The difference is attributed to different erosion and transport mechanisms and because of greater residue on the soil surface during snowmelt. More sediment was deposited in the area surrounding the tile inlets than leaving the system via tile inlet. This suggests temporary ponding to promote settling is an important component of tile inlet design.

Both COD and TP concentrations in rainfall runoff were correlated with TS concentration. The fraction of dissolved P was greater in snowmelt runoff than from in rainfall runoff. With the exception of on year (1 of 3), TP losses were greater in snowmelt than in rainfall runoff. This suggests that snowmelt is likely equally important as rainfall runoff in delivering pollutants to surface inlets.

Dynamics of Pollutant Delivery into Surface Tile Inlets

Type	Document
Author	D. Ginting
Author	A. H. Ranaivoson
Author	J. F. Moncrief
Author	S. C. Gupta
Date	2001 January

A tool for estimating best management practice effectiveness for phosphorus pollution control

Type	Journal Article
Author	M.W. Gitau
Author	W.J. Gburek
Author	A.R. Jarrett
Publication	Soil and Water Conservation Society
Volume	60
Issue	1
Pages	1-10
Date	2005

Tags:

contour buffer strips contour farming filter strips manure and agricultural waste storage manure management nutrient management phosphorus riparian forest buffer

Notes:

A literature review of the effectiveness of manure management BMPs in reducing phosphorus loading to an impaired lake in New York. Provides removal estimates for many of these bmps. Also includes contour strip crop, conservation tillage, nutrient management plans and riparian forest buffers.

MEASUREMENT OF LEAKAGE FROM EARTHEN MANURE STRUCTURES IN IOWA

Type	Journal Article
Author	T. D. Glanville
Author	J. L. Baker
Author	S. W. Melvin
Author	M. M. Agua
Publication	American Society of Agricultural Engineers
Volume	44
Issue	6
Pages	1609-1616
Date	2001
ISSN	0001–2351

Assessing channel-forming characteristics of an impacted headwater stream in Ohio, USA

Type	Journal Article
Author	Rebecca M. Gorney
Author	Dawn R. Ferris
Author	Andy D. Ward
Author	Lance R. Williams
Publication	Ecological Engineering
Volume	37
Pages	418-430
Date	2011
DOI	10.1016/j.ecoleng.2010.11.013

Simulated long-term nitrogen losses for a midwestern agricultural watershed in the United States

Type	Journal Article
Author	P.H. Gowda
Author	D.J. Mulla
Author	D.B. Jaynes
Volume	95
Pages	616-624
Date	2008
Extra	Iowa, Central IA (Walnut Creek subwatershed)

Tags:

agricultural IA manure management MN nitrogen nutrient management nutrient management_timing

Notes:

A model was used to predict losses from agricultural areas in IA. THis study concludes that the loss of N can be reduced by 17% by switching from fall to spring application of fertilizer and reducting the apllciation rate by 20%. Further reduction in N losses may require changes in landuse.

Effects of Best-Management Practices in the Black Earth Creek Priority Watershed, Wisconsin, 1984–98

Type	Report
Author	D.J. Graczyk
Author	J. F. Walker
Author	J.A. Horwatich
Author	R.T. Bannerman
Report Type	Water-Resources Investigations Report 03-4163
Date	2003

Corn residue level and manure application timing effects on phosphorus losses in runoff

Type	Journal Article
Author	Joseph D. Grande
Author	K.G. Karthikeyan
Author	P.S. Miller
Author	J.M. Powell
Publication	Journal of Environmental Quality
Volume	34
Pages	1620-1631
Date	2005
Extra	Wisconsin, Arlington

Tags:

agricultural manure management No till / minimum till / strip till nutrient management WI

Notes:

The effects of residue level and manure application timing on phosphorus loss in runoff from no-till corn was examined. The combination of manure application and higher residue levels significantly reduced P losses for corn fields harvested for silage.

Denitrification in wood chip bioreactors at different water flows

Type	Journal Article
Author	C.M. Greenan
Author	T.B. Moorman
Author	T.C. Kaspar
Author	T.B. Parkin
Publication	Journal of Environmental Quality
Volume	38
Pages	1664-1671
Date	2009
Extra	Iowa, Boone

Tags:

agricultural IA nutrient management wood chip bioreactor

Notes:

A comparison of woodchip bioreactors at different flow rates.
Concludes that woodchip bioreactors may be useful for removing N at flow rates generally seen in subsurface drainage in central Iowa.

Comparing carbon substrates for denitrification of subsurface drainage water

Type	Journal Article
Author	Colin M. Greenan
Author	T.B. Moorman
Author	T.C. Kaspar
Author	T.B. Parkin
Author	D.B. Jaynes
Publication	Journal of Environmental Quality
Volume	35
Pages	824-829
Date	2006
Extra	Iowa, Boone

Tags:

agricultural nutrient management wood chip bioreactor

Notes:

Wood chips, cardboard fibers, cornstalks, and woodchips with soybean oil were tested for the ability to denitrify water from tile drained corn. the results show that cornstalks were the best denitrifyers and that the addition of soybean oil to wood chips significantly increased denitrification over wood chips alone.

Denitrifi cation in Wood Chip Bioreactors at Diff erent Water Flows

Type	Journal Article
Author	Colin M. Greenan
Author	Thomas B. Moorman
Author	Timothy B. Parkin
Author	Thomas C. Kaspar
Author	Dan B. Jaynes
Publication	Journal of Environment Quality
Volume	38
Pages	1664-1671
Date	2009

Minnesota River Basin Total Maximum Daily Load Project for Turbidity

Type	Document
Author	Larry Gunderson
Author	Jackie Brasuhn
Publisher	Minnesota Pollution Control Agency: Division of Water Quality
Date	2011 October

Identifying Sediment Sources in the Minnesota River Basin

Type	Document
Author	Larry Gunderson
Author	Forrest Peterson
Publisher	Minnesota Pollution Control Agency: Division of Water Quality
Date	2009 August

4th Drainage Water Management Field Day

Type	Document
Author	Dr. Satish Gupta
Author	Dr. Chris Hay
Author	Dr. Gary Sands
Author	Mr. Mike Talbot
Author	Dr. Andry Ranaivoson
Author	Dr. Joe Magner
Author	Jeff Strock
Date	2011 August 23

Effects of Pipe-Outlet Terracing on Ground-Water Quantity Near Churchtown, Pennsylvania

Type	Journal Article
Author	David W. Hall
Publication	Ground Water
Volume	31
Issue	1
Pages	41-49
Date	1993 January-February

Toward Site-Specific Design Standards for Animal-Waste Lagoons: Protecting Ground Water Quality

Type	Journal Article
Author	J. M. Ham
Author	T. M. DeSutter
Date	2000 November/December

Toward Site-Specific Design Standards for Animal-Waste Lagoons: Protecting Ground Water Quality

Type	Journal Article
Author	J.M. Ham
Author	T.M. DeSutter
Publication	Journal of Environment Quality
Volume	29
Issue	6
Pages	1721-1731
Date	2000 November-December

Water quality impacts of conservation and nutrient management

practices in Pennsylvania

Type	Document
Author	J.M Hamlett
Author	D.J. Epp
Date	1994

Tags:

All BMPs nitrogen phosphorus sediment

Notes:

Nutrient management practices as well as best management practices (sediment basins, parallel terraces, filter strips strip crops contours and no till conservation practices) were evaluated through computer modeling against a baseline scenario to determine relative surface runoff, sediment delivery, total phosphorus, and total nitrogen benefits. Three sites in Pennsylvania were modeled each having a different combination of soil types, crop rotations, manure applications, and field characteristics. Results provide a helpful comparison of the water quality benefits of best management practices and the effects of combining these with nutrient management practices. Actual percent reductions of sediment, total phosphorus, and total nitrogen are not provided.

DESIGNING CONSTRUCTED WETLANDS FOR NITROGEN REMOVAL

Type	Journal Article
Author	DA Hammer
Author	RL Knight
Publication	Water Science and Technology
Volume	29
Issue	4
Pages	15-27
Date	1994

Tags:

livestock exclusion - fencing riparian forest buffer riparian vegetation

Notes:

Contains a variety of references on streamside vegetation and the importance to macroinvertebrate communities and water quality.

Herbicide banding and tillage system interactions on runoff losses of alachlor and cyanazine

Type	Journal Article
Author	N. C. Hansen
Author	J. F. Moncrief
Author	S. C. Gupta
Author	P. D. Capel
Author	A. E. Oleness
Publication	Journal of Environmental Quality
Volume	30
Pages	2120-2126
Date	2001
Extra	Minnesota, Scott County

Tags:

agricultural best management practice MN No till / minimum till / strip till pesticide

Notes:

A field study of Alachlor and Cyanazine that compares broadcast application to banding. The results show 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 herbicides.

Compilation of Measured Nutrient Load Data for Agricultural Land Uses in the United States

Type	Journal Article
Author	Daren Harmel
Author	Steve Potter
Author	Pamela Casebolt
Author	Ken Reckhow
Author	Colleen Green
Author	Rick Haney
Publication	JAWRA
Issue	Paper No. 05084

Date	October 2006

Tags:

All BMPs nitrogen phosphorus

Notes:

A description of the MANAGE database. A database of agricultural runoff monitoring from a variety of sources across the country. This database contains monitored results organized by date, location conservation practice, watershed size and many other important characteristics.

Conservation Effects Assessment Project research in the Leon River and Riesel watersheds

Type	Journal Article
Author	R.D. Harmel
Author	C.G. Rossi
Author	T. Dybala
Author	J. Arnold
Author	K. Potter
Author	J. Wolfe
Author	D. Hoffman
Publication	Journal of Soil and Water Conservation
Volume	63
Issue	6
Pages	453-460
Date	11/2008
Journal Abbr	Journal of Soil and Water Conservation
DOI	10.2489/jswc.63.6.453
ISSN	1941-3300
URL	http://www.jswconline.org/cgi/doi/10.2489/jswc.63.6.453
Accessed	Tuesday, July 05, 2011 12:02:23 PM
Library Catalog	CrossRef

Tags:

deep tilling nutrient management tilling

Notes:

A brief description of research conducted in Texas at 28 monitoring sites. This data was used as calibration data for the SWAT model. The full report of the monitoring research may be more applicable when looking for pollutant reduction numbers to associate with specific bmps.

Removal of Pathogens in Stormwater

Type	Magazine Article
Author	Jon M. Hathaway
Publication	Urban Waterways
Date	2002

Notes:

A factsheet describing pathogen sources in stromwater, pathogen removal mechanisms for stormwater BMPs, and their effectiveness.

Buffers and Vegetative Filter Strips

Type	Report
Author	Matthew J. helmers
Author	Thomas M. Isenhart
Author	Michael G. Dosskey
Author	Seth M. Dabney
Author	Jeffrey S. Strock
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Place	St. Joseph, Michigan
Institution	ASABE
Date	2008
Pages	43-58

Nitrate Removal in Stream Riparian Zones

Type	Journal Article
Author	Alan R. Hill
Publication	Journal of Environment Quality
Volume	25
Pages	743-755
Date	1996

Notes:

A comprehensive review and evaluation of the current state of knowledge about the role of riparian zones in removing Nitrate-N in groundwater. It is focused on Nitrate-N in subsurface flow from agricultural areas.

Southern Minnesota Regional Research & Demonstration Summary

Type	Document
Author	LuAnn Hiniker
Publisher	University of Minnesota
Date	2010

An Improved Understanding of Phosphorus Origin, Fate and Transport within Groundwater and the Significance for Associated Receptors

Type	Report
Contributor	Ian Holman
Contributor	Nicholas Howden
Contributor	Mick Whelan
Contributor	Patricia Bellamy
Contributor	Monica Rivas-Casado
Contributor	Nigel Willby
Contributor	Peter McConvey
Contributor	Tim Besien
Contributor	Sean Burke
Contributor	Deborah Ballantine
Contributor	Garrett Killroy
Contributor	Rebecca Kelly
Report Number	Project WFD85
Institution	EPA, Environment Agency, SEPA, Environment & Heritage Service, SNIFFER
Date	July 2008

Tags:

dissolved phosphorus groundwater phosphorus

Notes:

A study conducted in england on the fate and transport of phosphorus. Includes conceptual models that may have relevance to Minnesota.

Wetlands and Aquatic Processes: Sediment Retention in Rangeland Riparian Buffers

Type	Journal Article
Author	Paul B. Hook
Publication	Journal of Environment Quality
Volume	32
Pages	1130-1137
Date	2003

Notes:

A study in Montana on sedimentation removal using clipped vegetation (2-15 cm stubble) as riparian buffers. It focuses more on issues associated with rangeland and grazing.

Livestock and Streams Best Management Practices to Control the Effects of Livestock Grazing Riparian Areas

Type	Journal Article
Author	James J. Hoorman
Author	Jeff McCutcheon
Publication	The Ohio State University Extension FactSheet
Date	2005

Tags:

best management practice BMP livestock access control livestock exclusion - fencing livestock riparian pasture riparian vegetation rotational grazing

Notes:

Contains a good discussion of riparian grazing strategies. Concludes that over grazing has adverse impacts on stream characteristics although very little research has been conducted and published for grazing practices in the Midwest.

Peak Discharge for Small Agricultural Watersheds

Type	Journal Article
Author	Rollin H. Hotchkiss
Author	Brian E. McCallum
Publication	Journal of Hydraulic Engineering
Volume	121
Issue	1
Pages	36-48
Date	1995 January

Peak Discharge for Small Agricultural Watersheds

Type	Journal Article
Author	Rollin H. Hotchkiss
Author	Brian E. McCallum
Publication	Journal of Hydraulic Engineering
Pages	36-48
Date	1995 January 1

Ecological restoration design of a stream on a college campus in central Ohio

Type	Journal Article
Author	Jung Chen Huang
Author	William J. Mitsch
Author	Li Zhang
Publication	Ecological Engineering
Volume	35
Pages	329-340
Date	2009

Ecological restoration design of a stream on a college campus in central Ohio

Type	Journal Article
Author	Jung Chen Huang
Author	William J. Mitsch
Author	Li Zhang
Volume	35
Pages	329-340
Date	2009
DOI	10.1016/j.ecoleng.2008.07.018

DESIGN OF EXPERIMENTAL STREAMS FOR SIMULATING HEADWATER STREAM RESTORATION

Type	Journal Article
Author	Jung-Chen Huang
Author	William J. Mitsch
Author	Andrew D. Ward
Publication	Journal of American Water Resources Association
Volume	46
Issue	5
Pages	957-971
Date	2010 October

DESIGN OF EXPERIMENTAL STREAMS FOR SIMULATING HEADWATER STREAM RESTORATION

Type	Journal Article
Author	Jung-Chen Huang
Author	William J. Mitsch
Author	Andrew D. Ward
Publication	JAWRA
Pages	957-971
Date	October 2010

Demonstration of a conceptual model for using LiDAR to improve the estimation of floodwater mitigation potential of Prairie Pothole Region wetlands

Type	Journal Article
Author	Shengli Huang
Author	Claudia Young
Author	Min Feng

Author Karl Heidemann
Author Matthew Cushing
Author David M. Mushet
Author Shuguang Liu
Publication Journal of Hydrology
Volume 405
Pages 417-426
Date 2011

Demonstration of a conceptual model for using LiDAR to improve the estimation of floodwater mitigation potential of Prairie Pothole Region wetlands

Type Journal Article
Author Shengli Huang
Author Claudia Young
Author Min Feng
Author Karl Heidemann
Author Matthew Cushing
Author David M. Mushet
Author Shuguang Liu
Date 2011 May 31

Subsurface drain losses of water and nitrate following conversion of perennials to row crops

Type Journal Article
Author D.R. Huggins
Author G.W. Randall
Author M.P. Russelle
Publication Agronomy Journal
Volume 93
Issue 3
Pages 477-485
Date 2001
Extra Minnesota, Lamberton

Tags:

agricultural best management practice BMP buffer conservation cover conservation crop rotation cover crop manure management MN nitrogen nutrient management tile system design

Notes:

A study of nitrogen losses at the SW experiment station in Lamberton. Provides a look at the effects of crop rotation on water quality in subsurface drains.

Bioretention Performance, Design, Construction, and Maintenance

Type Document
Author Hunt, William F.
Author Lord, William G.
Publisher North Carolina Cooperative Extension Service
Date N.D.

Tags:

bacteria metals nitrogen phosphorus sediment temperature vegetated treatment area water/sediment control basin

Notes:

This bioretention design guidance document comes out of the North Carolina State University Cooperative Extension. It summarizes treatment efficiencies of some North Carolina bioretention facilities and provides design guidelines for specific pollutants (sediment, pathogens, metals, temperature, nitrogen, and phosphorus). Bioretention vegetation, stabilization and maintenance guidance is also provided. The implied application appears to be more urban in nature, but this is not specified.

ROCK INLET DESIGN AND SPECIFICATIONS

Type Document
Author Jackson County SWCD
Author Heron Lake Watershed District
Date 2004 October

Corn yield and nitrate loss in subsurface drainage from midseason nitrogen fertilizer application

Type	Journal Article
Author	D.B. Jaynes
Author	T.S. Colvin
Publication	Agronomy Journal
Volume	98
Pages	1479-1487
Date	2006
Extra	Iowa, Central Iowa

Tags:

agricultural best management practice buffer filter strip nitrogen nutrient management

Notes:

A look at mid-season nitrogen application on water qualiity in Iowa. It concludes that midseason N application was beneficial for recovering some of the potential yield in corn when initial n applications are insufficient for optimum yield, but the practice did not benefit water quality compared to a single application.

Sustaining Soil Resources While Managing Nutrients

Type	Report
Author	D. B. Jaynes
Author	D. L. Karlen
Report Number	11
Report Type	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Date	2008
Pages	10

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. A discussion on nutrient management focusing on the influence on soil organic matter (SOM) content and long-term soil productivity.

Nitrate loss in subsurface drainage as affected by nitrogen fertilizer rate

Type	Journal Article
Author	D.B. Jaynes
Author	T.S. Colvin
Author	D.L. Karlen
Author	C.A. Cambardella
Author	D.W. Meek
Publication	Journal of Environmental Quality
Volume	30
Pages	1305-1314
Date	2001
Extra	Iowa, central IA

Tags:

agricultural MN nutrient management nutrient management_amount

Notes:

A Iowa field study of nitrogen loss on fields receiving different rates of nitrogen application. Not suprisingly, the field receiving the highest rate of nitrogen application also had the greatest loss of nitrogen.

Potential methods for reducing nitrate losses in artificailly drained fields.

Type	Journal Article
Author	D.B. Jaynes
Author	T.C. Kaspar
Author	T.B. Moorman
Author	T.B. Parkin
Publication	American Society of Agricultural Engineers Conference proceedings
Volume	ASAE publication number 701P0304
Pages	059-069
Date	2004
Extra	Iowa, Ames

Tags:

agricultural cover crop nutrient management tile wood chip bioreactor

Notes:

Discussion of woodchip bioreactors and cover crops for reducing nitrogen leaching through subsurface drainage.

In Situ Bioreactors and Deep Drain-Pipe Installation to Reduce Nitrate Losses in Artifi cially Drained Fields

Type	Journal Article
Author	D.B. Jaynes
Author	T.C. Kaspar
Author	T.B. Moorman
Author	T.B. Parkin
Publication	Journal of Environmental Quality
Volume	37
Pages	429-436
Date	2008
Extra	Iowa, Ames

Tags:

agricultural bacteria best management practice controlled subsurface drainage nitrogen nutrient management tile wood chip bioreactor

Notes:

A field test of a woodchip bioreactor showing and annual reduction of 55% in nitrate loss with no difference in crop yeild.

In Situ Bioreactors and Deep Drain-Pipe Installation to Reduce Nitrate Losses in Artificially Drained Fields

Type	Journal Article
Author	Dan B. Jaynes
Author	Tom C. Kaspar
Author	Tom B. Moorman
Author	Tim B. Parkin
Publication	Journal of Environment Quality
Volume	37
Pages	429-436
Date	2008
DOI	10.2134/jeq2007.0279

In Situ Bioreactors and Deep Drain-Pipe Installation to Reduce Nitrate Losses in Artifi cially Drained Fields

Type	Journal Article
Author	Dan B. Jaynes
Author	Tom C. Kaspar
Author	Tom B. Moorman
Author	Tim B. Parkin
Publication	Journal of Environment Quality
Issue	37
Pages	429–436
Date	2008

Effect of Controlled Drainage and Vegetative Buffers on Drainage Water Quality from Wastewater Irrigated Fields

Type	Journal Article
Author	Z. Jia
Author	R. O. Evans
Author	M.ASCE
Author	J. T. Smith
Publication	Journal of Irrigation and Drainage Engineering
Pages	159-170
Date	April 2006
DOI	10.1061/(ASCE)0733-9437(2006)132:2(159)

Effect of Controlled Drainage and Vegetative Buffers on Drainage Water Quality from Wastewater Irrigated Fields

Type	Journal Article
Author	Z. Jia
Author	R. O. Evans
Author	J. T. Smith
Publication	Journal of Irrigation and Drainage Engineering
Volume	132
Issue	2
Pages	159-170
Date	2006 April 1
DOI	10.1061/ ASCE 0733-9437

Experimental studies of factors in determining sediment trapping in vegetative filter strips

Type	Journal Article
Author	C.-X. Jin
Author	J. M. Romkens
Publication	Transactions of the American Society of Agricultural Engineers
Volume	44
Issue	2
Pages	277-288
Date	2001
Extra	Laboratory experiment

Tags:

agricultural buffer filter strip MN

Notes:

A laboratory flume was used to study the effect of sediment trapping in filter strips. Shows that the effectiveness of filter strip trapping is primarily a function of slope and vegetative density. Test did not take into account infiltration in the filter strip.

The long-term field-scale hydrology of subsurface drainage systems in a cold climate

Type	Journal Article
Author	C.-X. Jin
Author	G.R. Sands
Publication	Transactions of the American Society of Agricultural Engineers
Volume	46
Issue	4
Pages	1011-1021
Date	2003
Extra	Minnesota, St. Peter

Tags:

agricultural MN Model tile system design

Notes:

Research using DRAINMOD to evaluate long-term tile drainage. Drain spacing and depth was shown to greatly impact infiltration and drainage.

Tillage system effects on sediment and nutrients in runoff from small watersheds

Type	Journal Article
Author	H. P. Johnson
Author	J. L. Baker
Author	W. D. Shrader
Author	J. M. Laflen
Publication	American Society of Agricultural Engineers
Volume	22
Pages	1110-1114
Date	1979

Notes:

A three-year study in Iowa determining the effect of different tillage systems on runoff, employed at fields of continuous corn. The compared tillage systems were conventional, till-plant, and (no till) ridge-plant, and samples were collected in three adjacent subwatersheds.

Downstream Economic Benefits of Conservation Development

Type	Journal Article
Author	Douglas M. Johnston
Author	John B. Braden
Author	Thomas H. Price
Publication	JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT
Volume	132
Issue	1
Pages	35-43
Date	2006 January 1
DOI	10.1061/ ASCE 0733-9496

Downstream Economic Benefits of Conservation Development

Type	Journal Article
Author	Douglas M. Johnston
Author	John B. Braden
Author	Thomas H. Price
Publication	JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT
Pages	35-43
Date	Jan/Feb 2006

SUBSURFACE DRAINAGE AND WATER QUALITY : THE ILLINOIS EXPERIENCE

Type	Journal Article
Author	P. K. Kalita
Author	R. A. C. Cooke
Author	S. M. Anderson
Author	M. C. Hirschi
Author	J. K. Mitchell
Publication	American Society of Agricultrual and Biological Engineers
Volume	50
Issue	5
Pages	1651-1656
Date	2007
ISSN	0001-2351

A Decade Later: The Establishment, Channel Evolution, and Stability of Innovative Two-Stage Agricultural Ditches in the Midwest Region of the United States

Type	Document
Author	Rebecca Kallio
Author	Andy Ward
Author	Jessica D'Ambrosio
Author	J.D. Witter
Date	2010 June 13-17

Design of drainage culverts considering critical storm duration

Type	Journal Article
Author	M.S. Kang
Author	J.H. Koo
Author	J.A. Chun
Author	Y.G. Her
Author	S.W. Park
Author	K. Yoo
Publication	Biosystems Engeineering
Volume	104
Pages	425-434
Date	2009

Potential and Limitations of Cover Crops, Living Mulches and Perennials to Reduce Nutrient Losses to Water Sources from Agricultural Fields in the Upper Mississippi River Basin

Type	Report
Author	T. C. Kaspar
Author	E. J. Kladivko
Author	J. W. Singer
Author	S. Morse
Author	D. R. Mutch
Report Number	10
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Institution	ASABE
Date	2008
Pages	20

Tags:

MN

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. An introduction of cover crops, living mulches, and perennials as a BMP. Information includes efficiency data on cover crop N reduction in runoff by region and by cover type and cost estimates.

Rye cover crop and gamagrass strip effects on NO3 concentration and load in tile drainage

Type	Journal Article
Author	T.C. Kaspar
Author	D.B. Jaynes
Author	T.B. Parkin
Author	T.B. Moorman
Publication	Journal of Environmental Quality
Volume	36
Pages	1503-1511
Date	2007
Extra	Iowa, near Ames

Tags:

agricultural best management practice cover crop IA MN nutrient management

Notes:

A study of cover crops on tile drained fields for 3 years in IA. Tiles were measured using automated samplers with a particular focus on nitrogen. This study concludes that planting strips of gamma-grass over tiles does not reduce pollutant loading through tile drains but using a rye cover crop reduced nitrogen leaching by ~60%.

Study of Riparian Buffer Areas

Type	Report
Contributor	Kean, Al
Institution	BWSR
Date	February 2010

Tags:

agricultural bacteria best management practice BMP buffer filter strip MN nutrient management riparian vegetation

Notes:

Study of the quantity of riparian buffers on ditches and waterways in Minnesota. Focused on amount of buffers currently employed and incentives for adoption.

BacterraTM Advanced Bioretention Technology: A Best Management Practice for Stand Alone Stormwater Treatment for Bacteria Removal

Type	Presentation
Presenter	Kelly, Dr. Robert F.
Presenter	Mindy Ruby
Date	N.D.

COVER CROP/DAIRY MANURE MANAGEMENT SYSTEMS: WATER QUALITY AND SOIL SYSTEM IMPACTS

Type	Journal Article
Author	Kern, J.D.
Author	M.L. Wolfe
Publication	American Society of Agricultural Engineers
Volume	48
Issue	4
Date	2005

Tags:

bacteria cover crop field manure management phosphorus sediment

Notes:

A field trial of four management systems in Virginia: traditional, double-crop, roll-down, and undercut. Results may inform the use of cover crop.

The Efficiency Function of Detention Reservoirs in Urban Drainage Systems

Type	Journal Article
Author	A. KESSLER
Author	M. H. DISKIN
Publication	Water Resources Research
Volume	27
Issue	3
Pages	253-258
Date	1991 March

Nitrate Leaching to Subsurface Drains as Affected by Drain Spacing and Changes in Crop Production System

Type	Journal Article
Author	E. J. Kladivko
Author	J. R. Frankenberger
Author	D. B. Jaynes
Author	D. W. Meek
Author	B. J. Jenkinson
Author	N. R. Fausey
Publication	Journal of Environment Quality
Volume	33
Pages	1803-1813
Date	2004

Notes:

A 15-year drainage study in Southeaster Indiana, where soils contain relatively low organic matter compared to Minnesota (1.3%). The results also reflect the farming practice change from monoculture corn with high fertilizer N rate to a no-till corn-soybean rotation with lower fertilizer N rates and a winter cover crop.

A Producers Guide to Comprehensive Nutrient Management Plans in Wisconsin: Benefits and Challenges of a CNMP

Type	Document
Author	Kevan Klingberg
Publisher	Discovery Farms
Date	July, 2008
Language	English

Tags:

agricultural manure management nutrient management WI

Notes:

A guide for WI producers seeking to start comprehensive nutrient management planning.

CORN YIELD RESPONSE TO DEFICIT IRRIGATION

Type	Journal Article
Author	N. L. Klocke
Author	R. S. Currie
Author	D. J. Tomsicek
Author	J. Koehn
Publication	American Society of Agricultrual and Biological Engineers
Volume	54
Issue	3
Pages	931-940
Date	2011

SPATIAL DYNAMICS OF WATER AND NITROGEN MANAGEMENT IN IRRIGATED AGRICULTURE

Type	Journal Article
Author	KEITH C. KNAPP
Author	KURT A. SCHWABE
Publication	American Journal of Agricultural Economics
Volume	90
Issue	2
Pages	524-539
Date	2008 May
DOI	10.1111/j.1467-8276.2007.01124.x

Nutrients and sediment in frozen-ground runoff from no-till fields receiving liquid-dairy and solid-beef manures

Type	Journal Article
Author	M. J. Komiskey
Author	T. D. Stuntebeck
Author	D. R. Frame
Author	F. W. Madison
Publication	Soil and Water Conservation Society
Volume	66
Issue	5
Pages	303-312
Date	2011

Notes:

A four-year study in southern Wisconsin on the effect of different types and forms of manure and rates and timing of application on nutrient concentrations in frozen-ground runoff. Runoff data were collected between January and March and lower nutrient concentrations were observed from fall and early winter applied fields.

Quantification of Postsettlement Deposition in a Northwestern Illinois Sediment Basin

Type	Journal Article
Author	W. R. Kreznor
Author	K. R. Olson
Author	D. L. Johnson
Author	R. L. Jones
Publication	Soil Science Society of America Journal
Volume	54
Pages	1393-1401
Date	1990

Agricultural Waste Management Field Handbook

Type	Document
Author	James N. Krider
Author	Donald Settler
Author	Michael F. Walter
Date	June 1999

Tags:

agricultural bacteria best management practice BMP buffer escherichia fecal filter strip livestock access control livestock riparian pasture manure management MN nutrient management

Notes:

A waste management handbook covering all aspects of farm waste management. Not particular to pollutant removals from practices, but more of a practical, how-to guidebook.

A preliminary study of an alternative controlled drainage strategy in surface drainage ditches: Low-grade weirs

Type	Journal Article
Author	R. Kroger
Author	C.M. Cooper
Author	M.T. Moore
Publication	Agricultural Water Management
Volume	95
Pages	678-684
Date	2008

Impact of Microbial Partitioning on Wet Retention Pond Effectiveness

Type	Journal Article
Author	Leigh-Anne H. Krometis
Author	Patricia N. Drummey
Author	Gregory W. Characklis
Author	Mark D. Sobsey
Publication	Journal of Environmental Engineering
Volume	135
Issue	9
Pages	758
Date	2009
Journal Abbr	J. Envir. Engrg.
DOI	10.1061/(ASCE)EE.1943-7870.0000040
ISSN	07339372
URL	http://link.aip.org/link/JOEEDU/v135/i9/p758/s1&Agg=doi
Accessed	Wednesday, July 06, 2011 8:50:07 AM
Library Catalog	CrossRef

Tags:

bacteria water/sediment control basin

Notes:

A study of bacteria fate and transport in wet detention ponds in north carolina. This study concludes that treatment ponds are most effective when placed near the source of the bacteria and that bacteria removal by ponds is far less than 65%, the value assumed by the EPA.

Conservation practice effects on sediment load in the Goodwin Creek Experimental Watershed

Type	Journal Article
Author	R.A. Kuhnle
Author	R.L. Bingner
Author	C.V. Alonso
Author	C.G. Wilson
Author	A. Simon
Publication	Journal of Soil and Water Conservation
Volume	63
Issue	6
Pages	496-503
Date	2008 November/December
DOI	10.2489/jswc.63.6.496

MANAGEMENT OF AGRICULTURAL DRAINAGE SYSTEMS IN THE CZECH REPUBLIC

Type	Journal Article
Author	Z. KULHAVY
Author	F. DOLEZAL
Author	P. FUCIK
Author	F. KULHAVY
Author	T. KVITEK
Author	R. MUZIKAR
Author	M. SOUKUP
Author	V. SVIHLA
Publication	Irrigation and Drainage
Volume	56
Pages	S141-S149
Date	2007
DOI	10.1002/ird

Effect of crop residue on soil loss from continuous row cropping

Type	Journal Article
Author	J. M. Laflen
Author	T. S. Colvin
Publication	American Society of Agricultural Engineers
Volume	24
Pages	605-609
Date	1981

Notes:

A study in Iowa on the effects of tillage systems and crop rotation treatments on soil erosion. Mulch factor – crop residue relationships for different canopy levels were plotted under conservation tillage systems. Tillage systems employed were no-till, reduced, and conventional.

How Farms Can Improve Water Quality

Type	Document
Author	Land Stewardship Project
Publisher	Land Stewardship Project
Date	2008 April
Short Title	Fact Sheet #7

Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Upper Mississippi River Basin

Type	Document
Author	Douglas Lawrence
Publisher	USDA
Date	JUNE 2010

Tags:

agricultural All BMPs best management practice buffer filter strip livestock access control livestock riparian pasture manure management MN nutrient management pesticides US

Notes:

A large scale look at conservation in the upper mississippi river basin for the years 2003-2006. Identifies the most critical conservation concern as loss of nitrogen through leaching. Concludes that use of soil erosion control practices is widespread. and the 15% of cultivated cropland acres still have excessive sediment loss from fields and require additional practices.

Current Nitrogen Management Practices on Coarse Textured Soils in Central Minnesota

Type	Conference Paper
Author	T. D. Legg
Author	B. Montgomery
Date	1993 February
Conference Name	Agricultural Research To Protect Water Quality
Place	Minneapolis, Minnesota USA
Publisher	Soil and Water Conservation Society
Pages	157-160

Notes:

A report on nutrient managements practiced by large farms in central Minnesota. Data collected by interviews show that legume and manure N-credits were usually not considered and N fertilizer was over applied. This study shows the potential to further improve water quality as well a reflection of uncertainty about the N provided by legume and manure.

Attenuating Excessive Sediment and Loss of Biotic Habitat in an Intensively Managed Midwestern Agricultural Watershed

Type	Document
Author	C. Lenhart
Author	K. Brooks
Author	J. Magner
Author	B. Suppes
Date	2010

Artificially Drained Catchments— From Monitoring Studies towards Management Approaches

Type	Journal Article
Author	Bernd Lennartz
Author	Bärbel Tiemeyer
Author	Gerrit de Rooij
Author	Franktišek Doležal
Publication	Vadose Zone Journal
Volume	9
Issue	1
Pages	1-3
Date	2010 January 11

JURY VERDICT: FREQUENCY VERSUS RISK-BASED CULVERT DESIGN

Type	Journal Article
Author	Gary L. Lewis
Publication	JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT
Volume	118
Issue	2
Pages	166-184
Date	1992 March/April

Bioretentionfor StormwaterQuality Improvement in Texas

Type	Presentation
Presenter	Ming-Han Li

Nitrate Leaching as Influenced by Cover Crops in Large Soil Monoliths

Type	Journal Article
Author	S. D. Logsdon
Author	T. C. Kaspar
Author	D. W. Meek
Author	J. H. Prueger
Publication	Agron Journal
Volume	94
Pages	807-814
Date	2002

Notes:

A two-year study in Iowa measuring influences of cover crops on nitrate leaching rates. Rye or oat was inter-planted into soybean as a fall cover crop and results were compared with other studies.

Manure Characteristics

Type	Journal Article
Author	Jeff Lorimor
Author	Wendy Powers
Author	Al Sutton
Publication	MWPS-18 Section 1 Second Edition
Date	2004
Series	Manure Management Systems Series

Tags:

agricultural bacteria best management practice IA Lab manure and agricultural waste storage manure management nutrient management US

Notes:

Detailed description of manure as a resource. Focusing on the physical and chemical properties of manure.

Using Manure as a Fertilizer for Crop Production

Type	Report
Author	J. A. Lory
Author	R. Massey
Author	B. C. Joern
Report Number	8
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Date	2008
Pages	12

Tags:

MN

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. A discussion on manure application: the differences from chemical fertilizers, and limitations and concerns from storage, feasibility, and economic stand points. It provides estimated nutrient concentration for different animal types and manure storage and handling systems.

Modeling the impact of alternative dranage pratieces in the Northern Corn-belt with DRAINMOD-NII

Type	Journal Article
Author	W. Lou
Author	G.R. Sands
Author	M. Youssef
Author	J. Strock
Author	I. Song
Author	D. Canelon
Publication	Agricultural Water Management
Volume	97
Pages	389-398
Date	2010
Extra	Minnesota, Waseca

Tags:

controlled subsurface drainage MN nitrogen

Notes:

Controlled subsurface drainage is explored using DRAINMOD-NII using a MN site as the field data. Results show that drainage losses of nitrogen can be reduced by 30% without appreciably affecting yeilds.

This study utilized the DRAINMOD-NII model to assess the hydrologic impact of controlled drainage and shallow drainage as compared to conventional drainage. After calibrating the model using measured data collected at Waseca, MN, the model was validated and then applied to a Webster silty clay loam soil using a corn-soybean rotation over a 90-year simulation period. Conventional drainage was simulated with tile at a 1.2-m depth (4 ft). Shallow drainage was modeled at a depth of 0.9 m. Multiple spacings were modeled for each management scenario.

Annual subsurface drainage accounted for 16.5% of annual precipitation under the conventional drainage scenario. Across all treatments the relative yield was consistently near 70% for drain spacings less than about 18 m, but decreased for all treatments for spacings greater than 18 m.

The controlled drainage scenario at 15-m spacing resulted in a 28% reduction in annual subsurface drainage and a 40% reduction at 30-m spacing (100 ft). The authors note the hydrologic benefits of the controlled drainage scenario were accompanied by a 2% decrease in average crop yield.

Agronomic and Environmental Implications of Phosphorus Management Practices

Type	Report
Author	A. P. Mallarino
Author	Bundy
Report Number	7
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Institution	ASABE
Date	2008
Pages	18

Tags:

All BMPs MN phosphorus

Notes:

A discussion of phosphorus BMPs across the upper Mississippi river basin focused on P application rates.

Surface Water Quality Pollutant Removal Efficacy of Three Wet Detention Ponds

Type	Journal Article
Author	Mallin, Michael A.
Author	Scott H. Ensign
Author	Tracey L. Wheeler
Author	David B. Mayes
Publication	Journal of Environmental Quality
Volume	31
Pages	654-660
Date	2002

Tags:

sediment basin water quality water/sediment control basin

Notes:

The drainage area to these ponds is mostly urban and suburban as opposed to agricultural. Several pollutants are evaluated. Design elements that can increase removal efficiencies are summarized.

Field evaluation of vegetative filter effectiveness and runoff quality from unstocked feedlots

Type	Journal Article
Author	Mankin, K.R.
Author	P.L. Barnes
Author	J.P. Harner
Author	P.K. Kalita
Author	J.E. Boyer
Publication	J|A
Volume	61
Issue	4
Date	2006

Tags:

filter strips vegetated treatment area water quality

Notes:

Feedlot runoff is treated with filter strips. Several water quality constituents were evaluated at the field scale. Several variables are evaluated for their ability to predict water quality treatment. This study really targets filter strips as a stand-alone practice. In addition, it provides a summary table of percent reductions seen in several different studies.

Radiochemical assay of glutathione S-epoxide transferase and its enhancement by phenobarbital in rat liver in vivo

Type	Journal Article
Author	J Marniemi
Author	M G Parkki

Publication	Biochemical Pharmacology
Volume	24
Issue	17
Pages	1569-1572
Date	Sep 1, 1975
Journal Abbr	Biochem. Pharmacol
ISSN	0006-2952
URL	http://www.ncbi.nlm.nih.gov/pubmed/9
Accessed	Tuesday, July 05, 2011 12:07:26 PM
Library Catalog	NCBI PubMed
Extra	PMID: 9

Tags:

Animals Carrier Proteins Epoxy Compounds Glutathione Glutathione Transferase Hydrogen-Ion Concentration Liver Male Methylcholanthrene Phenobarbital Rats Stimulation, Chemical Styrenes

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Fecal Coliform TMDL Assessment for 21 Impaired Streams in the Blue Earth River Basin

Type	Document
Contributor	Matteson, Scott
Contributor	Lee Ganske
Contributor	Julie Conrad
Contributor	Wayne Cords
Contributor	Dan Girolomo
Contributor	Bruce Johnson
Contributor	Michelle Stindtman
Contributor	Tom Warmka
Contributor	Pat Baskfield
Contributor	Bill Vanryswyk
Contributor	Kim Musser
Contributor	Dr. Beth Proctor
Contributor	John Freiderich
Contributor	Zak Pagel
Contributor	Sushant Paudel
Contributor	Rachel Scheurer
Contributor	Joel Wurscher
Publisher	Minnesota State University, Mankato
Date	2007 June

Tags:

bacteria MN

Notes:

Not a lot (if any) mention of agricultural BMPs. The implementation plan is very general. A source assessment was done too.

Estimated costs for livestock fencing

Type	Document
Author	Ralph Mayer
Author	Tom Olsen
Publisher	Iowa State University Extension
Date	2005 July

Notes:

A 2005 extension document listing the cost of fencing in Iowa.

New hydroepidemiological models of indicator organisms and zoonotic pathogens in agricultural watersheds

Type	Journal Article
Author	Graham B. McBride
Author	Steven C. Chapra
Publication	Ecological Modelling
Volume	222
Issue	13
Pages	2093-2102
Date	7/2011
Journal Abbr	Ecological Modelling
DOI	10.1016/j.ecolmodel.2011.04.008
ISSN	03043800
URL	http://linkinghub.elsevier.com/retrieve/pii/S030438001100216X
Accessed	Tuesday, July 05, 2011 11:59:50 AM
Library Catalog	CrossRef

Tags:

bacteria

Notes:

This is an intensive modeling study, rather than a field study, on the fate and transport of bacteria. It tackles the difference between treating bacteria (an indicator) and the outcome for actual pathogens.

Nitrate Leaching as Influenced by Cover Cropping and Nitrogen Source

Type	Journal Article
Author	Daniel V. McCracken
Author	M. Scott Smith
Author	John H. Grove
Author	Charles T. MacKown
Author	Robert L. Blevins
Publication	Soil Science Society of America Journal
Volume	58
Pages	1476-1483
Date	1994

Notes:

A three-year study in Kentucky comparing the effect of rye and hairy vetch as a winter cover crop to reduce nitrate in runoff from corn fields. Fertilizer NH_4^+ or hairy vetch was used as NH_4^+ source.

STORAGE EFFECTS AT CULVERTS

Type	Report
Author	Bruce M. McEnroe
Author	Scott A. Gonzalez
Report Number	K-TRAN: KU-04-3R
Date	2006 May

DAIRY LAGOON DESIGN AND MANAGEMENT UNDER CHRONIC RAINFALL

Type	Journal Article
Author	A. M. S. McFarland
Author	M. J. McFarland
Author	J. M. Sweeten
Publication	Applied Engineering in Agriculture
Volume	16
Issue	3
Pages	285-292
Date	2000

Nitrogen and Phosphorus concentrations in Runoff from Corn and Soybean Tillage Systems

Type	Conference Paper
Author	G. McIsaac
Author	J. K. Mitchell
Author	M. C. Hirschi
Date	1993 February
Conference Name	Agricultural Research To Protect Water Quality
Place	Minneapolis, Minnesota USA
Publisher	Soil and Water Conservation Society
Pages	230-232

Notes:

A study in Illinois comparing several tillage systems and their effect on dissolved P concentrations in runoff using simulated rainfall. The tillage systems employed were no-till, ridge-till, strip till, and chisel and moldboard plow on two different soil types.

NRCS Terrace Design Tool

Type	Presentation
Presenter	Philip R. McLoud
Date	2011 August 7-10

Establishing Storm-Water BMP Evaluation Metrics Based upon Ambient Water Quality Associated with Benthic Macroinvertebrate Populations

Type	Journal Article
Author	Jacquelyn K. McNett

Author	William F. Hunt
Author	Jason A. Osborne
Publication	Journal of Environmental Engineering
Volume	136
Issue	5
Pages	535
Date	2010
Journal Abbr	J. Envir. Engrg.
DOI	10.1061/(ASCE)EE.1943-7870.0000185
ISSN	07339372
URL	http://link.aip.org/link/JOEEDU/v136/i5/p535/s1&Agg=doi
Accessed	Tuesday, July 05, 2011 12:01:24 PM
Library Catalog	CrossRef

Tags:

clean runoff water diversion sediment basin vegetated treatment area water/sediment control basin wetland, constructed wetland, creation wetland, enhancement wetland, restoration

Notes:

This study challenges the goals for loading reduction provided by BMPs versus an effluent concentration from BMPs. Two brief tables of percent reductions and, alternatively, effluent concentrations, available from literature for a few BMP types are provided. The applications are not primarily in agricultural areas.

Nitrogen management and Crop Rotation effects on Nitrate Leaching, Crop Yields, and Nitrogen Use Efficiency

Type	Conference Paper
Author	S. W. Melvin
Author	J. L. Baker
Author	P. A. Lawlor
Author	B. W. Heinen
Author	D. W. Lemke
Date	1993 February
Conference Name	Agricultural Research To Protect Water Quality
Place	Minneapolis, Minnesota USA
Publisher	Soil and Water Conservation Society
Pages	411-415

Notes:

A study in Iowa on the effects of crop rotation on nitrate leaching. Quarterly and annual average concentration of nitrate in the agricultural drainage wells were compared among continuous corn, corn-soybean, soybean-corn.

Surface wetlands for the treatment of pathogens in stormwater: three case studies at Lake Macquarie, NSW, Australia

Type	Journal Article
Author	H. Méndez
Author	P. M. Geary
Author	R. H. Dunstan
Publication	Water Science & Technology
Volume	60
Issue	5
Pages	1257
Date	2009 September
Journal Abbr	Water Science & Technology
DOI	10.2166/wst.2009.470
ISSN	0273-1223
Short Title	Surface wetlands for the treatment of pathogens in stormwater
URL	http://www.iwaponline.com/wst/06005/wst060051257.htm
Accessed	Tuesday, July 05, 2011 3:36:12 PM
Library Catalog	CrossRef

Tags:

bacteria clean runoff water diversion sediment basin water/sediment control basin wetland, constructed

Notes:

This paper focuses on treatment of bacteria from stormwater runoff (primarily non-agricultural) using trash racks, gross pollutant traps and surface constructed wetlands. Wet weather and dry weather results are analyzed separately.

A Tool for Estimating Best Management Practices Effects in Arkansas

Type	Document
Author	K. Merriman
Author	M. Gitau

Author I. Chaubey
Date N.D.

Tags:

All BMPs water quality

Notes:

A BMP database (treatment effectiveness including soil and slope characteristics)was developed for Arkansas which includes data from throughout the southeast United States. Where and how to assess the actual tool is unclear.

A Tool for Estimating Best Management Practice Effectiveness in Arkansas

Type Journal Article
Author K. R. Merriman
Author M. W. Gitau
Author I. Chaubey
Publication Applied Engineering in Agriculture
Volume 25
Issue 2
Pages 199-213
Date 2009

Tags:

agricultural All BMPs best management practice BMP buffer fecal filter strip livestock access control livestock riparian pasture manure management nutrient management rotational grazing water quality

Notes:

A BMP database (treatment effectiveness including soil and slope characteristics) was developed for Arkansas which includes data from throughout the southeast United States. Where and how to assess the actual tool is unclear. The database appears to be well-referenced and extraordinarily helpful for the region.

Effects of soil incorporation and setbacks on herbicide runoff from a tile-outlet terraced field

Type Journal Article
Author S.K. Mickelson
Author J.L. Baker
Author S.W. Melvin
Author R.S. Fawcett
Author D.P. Tierney
Author C.J. Peter
Publication Journal of Soil and Water Conservation
Volume 53
Issue 1
Pages 18-25
Date 1998

Performance of water and sediment control basins in northeastern Nebraska

Type Journal Article
Author L. N. Mielke
Publication Journal of Soil and Water Conservation
Volume 40
Issue 6
Pages 524-528
Date 1985

BWSR - Assisted Research Toward Improving Conservation Outcomes

Type Document
Author Minnesota Board of Water and Soil Resources
Publisher BWSR
Date 2010 June

Vegetation Buffer Strips in Agricultural Areas

Type Report
Author Minnesota DNR
Institution MN DNR Waters
Date November 2007

Tags:

agricultural best management practice buffer filter strips MN nutrient management

Notes:

Minnesota DNR informational fact sheet about MN buffer requirements and environmental benefits. DNR recommends a width of at least 100 feet. Maintenance needs are discussed as well.

Tillage Best Management Practices for the Minnesota River Basin Based on Soils, Landscape, Climate, Crops, and Economics

Type	Report
Author	Minnesota Extension Service
Institution	University of Minnesota Extension Service, College of Agricultural, Food and Environmental Sciences
Date	1996

Life support for the South Metro Mississippi

Type	Journal Article
Author	Minnesota Pollution Control Agency
Date	N.D.

Lake Pepin Watershed TMDL Eutrophication and Turbidity Impairments Project Overview

Type	Document
Author	Minnesota Pollution Control Agency
Publisher	Minnesota Pollution Control Agency: Division of Water Quality
Date	2007 April

Restoring the South Metro Mississippi River

Type	Document
Author	Minnesota Pollution Control Agency
Publisher	Minnesota Pollution Control Agency: Division of Water Quality
Date	2010 February

Understanding Biotic Impairments and Associated Pollutants

Type	Document
Author	Minnesota Pollution Control Agency
Date	2010 October

Detailed Assessment of Phosphorus Sources to Minnesota Watersheds — Streambank Erosion

Type	Document
Author	Minnesota Pollution Control Agency
Author	Barr Engineering
Date	2003 December

HAZARD MITIGATION GRANT PROGRAM APPLICATION PACKET

Type	Document
Author	Minnestoa Department of Public Safety
Date	2008 August

Tags:

MN

Notes:

A proposal of a flood control project in Winnebago Watershed in Minnesota including a summary of the project, effectiveness of proposed flood controls, and cost estimations for the recent flood damages and for the project implementation.

Bostic and Zippel Creeks Watershed Assessment Project

Type	Document
Author	MN Board of Water and Soil Resources

Date N.D.

Clay County Drainage Demonstration Site Innovative Research with Innovative Farmers

Type	Document
Author	MN Department of Agriculture
Publisher	MN Department of Agriculture
Date	2011 February

Tags:

MN

Notes:

Brief information about monitoring procedures for the Clay County drainage demonstration site.

Clay County Drainage Demonstration Site Innovative Research with Innovative Farmers

Type	Document
Author	MN Department of Agriculture
Publisher	MN Department of Agriculture
Date	February 2011

Tags:

agricultural best management practice BMP MN nutrient management

Notes:

Fact sheet from the MDA regarding their demonstration site in Clay County. This pamphlet discusses the goals, intent, and set-up of the project, but not the results.

Ground Water Quality Monitoring 2011 Annual Plan Work

Type	Document
Author	MN Department of Agriculture
Publisher	MN Department of Agriculture
Date	2011 April

Steps for establishing native grasses

Type	Document
Author	MN DNR
Publisher	MN DNR
Date	2011 June 14

Tags:

MN

Notes:

A factsheet describing how to establish and maintain native grass on roadside for wildlife.

Ground-water Quality Adjacent to Animal Feedlots

Type	Document
Author	MN Pollution Control Agency
Date	2005 May

FEEDLOT RULES OVERVIEW: Minnesota Rules chapter 7020

Type	Document
Author	MN Pollution Control Agency
Date	2007 August

Managing Grazing in Stream Corridors

Type	Document
Author	Howard Moechnig
Publisher	MN Department of Agriculture
Date	November 2007

Tags:

bacteria livestock access control livestock riparian pasture manure management MN nutrient management rotational grazing

Notes:

MDA guidance - practical and useful. Not quantitative in nature. Includes guidance for fencing and watering systems.

Grazing Systems Planning Guide

Type	Document
Author	Howard Moechnig
Author	Kevin Blanchet
Author	Jodi DeJong-Hughes
Date	2003

MANAGING GRAZING IN STREAM CORRIDORS

Type	Document
Author	Moechnig, Howard
Publisher	Minnesota Department of Agriculture
Date	2007 November

Tags:

bacteria livestock access control livestock riparian pasture manure management MN nutrient management rotational grazing

Notes:

repeat - this article saved elsewhere in Zotero.

Environment and Natural Resources Trust Fund Research Addendum for Peer Review

Type	Report
Author	Eric Mohring
Author	Victoria Christensen
Date	N.D.

Environment and Natural Resources Trust Fund - Research Addendum for Peer Review

Type	Document
Author	Eric Mohring
Author	Victoria Christensen
Date	N.D.
Extra	Potential Benefits of Perpetual Easements on Phosphorus Reduction

Prioritisation of farm scale remediation efforts for reducing losses of nutrients and faecal indicator organisms to waterways: A case study of New Zealand dairy farming

Type	Journal Article
Author	R Monaghan
Author	C Deklein
Author	R Muirhead
Publication	Journal of Environmental Management
Volume	87
Issue	4
Pages	609-622
Date	06/2008
Journal Abbr	Journal of Environmental Management
DOI	10.1016/j.jenvman.2006.07.017
ISSN	03014797
Short Title	Prioritisation of farm scale remediation efforts for reducing losses of nutrients and faecal indicator organisms to waterways
URL	http://linkinghub.elsevier.com/retrieve/pii/S0301479707003775
Accessed	Tuesday, July 05, 2011 12:22:09 PM
Library Catalog	CrossRef

Tags:

bacteria costs field border manure and agricultural waste storage manure management nitrogen nutrient management_method phosphorus waste water treatment strip water/sediment control basin

Notes:

The farm scale sites are those in temperate climates where cows can graze pastures mostly all year round. Modeling is the method of estimation of pollutant reductions from BMPs.

Linkages between land management activities and water quality in an intensively farmed catchment in southern New Zealand

Type	Journal Article
Author	R.M. Monaghan
Author	R.J. Wilcock
Author	L.C. Smith
Author	B. Tikkisetty
Author	B.S. Thorrold
Author	D. Costall
Publication	Agriculture, Ecosystems & Environment
Volume	118
Issue	1-4
Pages	211-222
Date	01/2007
Journal Abbr	Agriculture, Ecosystems & Environment
DOI	10.1016/j.agee.2006.05.016
ISSN	01678809
URL	http://linkinghub.elsevier.com/retrieve/pii/S0167880906001721
Accessed	Tuesday, July 05, 2011 11:59:30 AM
Library Catalog	CrossRef

Tags:

bacteria costs manure and agricultural waste storage manure management nitrogen nutrient management_amount nutrient management_method phosphorus

Notes:

The water quality effects of implementing BMPs in a catchment in New Zealand iis evaluated using modeling. The BMPs include covered feedpad wintering systems, nitrification inhibitor use, deferred irrigation and low rate application of farm dairy effluent, and limiting soil Olsen P. In addition, the study undergoes an interesting exercise of linking the stream water quality data to land management practices in the catchment using a nutrient budget model (OVERSEER).

Denitrification activity, wood loss, and N2O emissions over 9 years from a wood chip bioreactor

Type	Journal Article
Author	Thomas B. Moorman
Author	Timothy B. Parkin
Author	Thomas C. Kaspar
Author	Dan B. Jaynes
Publication	Ecological Engineering
Volume	36
Pages	1567-1574
Date	2010

Tillage Effects on Subsurface Drainage

Type	Journal Article
Author	Toshitsugu Moroizumi
Author	Haruhiko Horino
Publication	Soil Science Society of America Journal
Volume	68
Pages	1138-1144
Date	2004

ASSESSMENT OF MANAGEMENT ALTERNATIVES ON A SMALL AGRICULTURAL WATERSHED

Type	Document
Author	S. Mostaghimi
Author	S.W. Park
Author	R.A. Cooke
Author	S.Y. Wang
Date	1997

Tags:

conservation cover manure and agricultural waste storage manure management MN nitrogen No till / minimum till / strip till phosphorus sediment

Notes:

A watershed in Virginia was modeled using AGNPS; calibration used 2 years of hydrologic and water quality data. Pollutant loading under various scenarios was modeled including, but not limited to, BMP scenarios. The watershed appears to have had a good water quality monitoring network for a 4-square mile watershed. A scenario of no-till, conservation reserve program, and manure storage practices were run individually and then in combination. Mass pollutant reductions are reported in a table; ranges of percent reductions are discussed in the text.

Erosion and Subsequent Transport State of Escherichia coli from Cowpats

Type	Journal Article
Author	Muirhead, R.W.
Author	Robert Peter Collins
Author	Philip James Bremer
Publication	American Society for Microbiology
Volume	71
Issue	6
Date	June 2005

Tags:

bacteria Lab manure and agricultural waste storage manure management

Notes:

This study undertakes the important analysis of the fate and transport of E. coli. In this case, cow patties were exposed to simulated rainfall in the laboratory. E. coli in the cow patties and the runoff were measured and reported and results were synthesized.

The State of Minnesota's Soil: Impact of Soil and Landscape Factors on Water Quality

Type	Presentation
Presenter	J. Mulla
Date	N.D.
Extra	Dept. Soil, Water and Climate - University of MN

Limitations of Evaluating the Effectiveness of Agricultural Management Practices at Reducing Nutrient Losses to Surface Waters

Type	Report
Author	D. J Mulla
Author	A. S. Birr
Author	N. R. Kitchen
Author	M. B. David
Report Number	14
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Date	2008
Pages	24

Tags:

MN

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. A discussion of the BMP assessment methods, the limitations and what has been improved, new technologies, the appropriate scales and techniques to use for the assessments so that BMPs can be implemented more effectively. Many examples come from Minnesota.

Evaluating the effectiveness of agricultural management practices at reducing nutrient losses to surface waters.

Type	Journal Article
Author	D.J. Mulla
Author	A.S. Birr
Author	N. Kitchen
Author	M. David
Date	N.D.

Tags:

agricultural All BMPs contour buffer strips MN nutrient management

Notes:

There are several very good references in this publication. In addition, percent reductions are summarized/estimated for several different BMPs.

Fish habitat requirements as the basis for rehabilitation of eutrophic lakes by oxygenation

Type	Journal Article
Author	Muller, R.
Publication	Fisheries Management and Ecology
Pages	251-260
Date	2004

Notes:

This study is more of a limnology study and not an ag BMP study.

Optimizing irrigation management for pollution control and sustainable crop yield

Type	Journal Article
Author	Ghassan R. Musharrafieh
Author	Richard C. Peralta
Author	Lynn M. Dudley
Author	Ronald J. Hanks
Publication	Water Resources Research
Volume	31
Issue	4
Pages	1077-1086
Date	1995 April

A Comparison of Water Chemistry and Biological Integrity in Creel Ditch Before and After Two-Stage Ditch Construction

Type	Report
Author	Melody L. Myers-Kinzie
Author	Greg R. Bright
Date	2009 December

Phosphorus removal in created wetland ponds receiving river overflow

Type	Journal Article
Author	Mitsch, WJ Nairn, RW
Publication	Ecological Engineering
Volume	14
Pages	107-126
Date	2000
URL	www.elsevier.com:locate:ecoleng

Tags:

wetland, creation

Notes:

Phosphorus removal in created wetland ponds receiving river overflow

Type	Journal Article
Author	Mitsch, W Nairn, W
Publication	Ecological Engineering
Volume	14
Pages	107-126
Date	2000

Effects of changes in N-fertilizer management on water quality trends at the watershed scale

Type	Journal Article
Author	V. Nangia
Author	P.H. Gowda
Author	D.J. Mulla
Publication	Agricultural Water Management
Volume	97
Pages	1855-1860
Date	2010
Extra	Minnesota, Near St. Peter (Seven-Mile creek watershed)

Tags:

agricultural best management practice BMP manure management MN nitrogen nutrient management_amount nutrient management_timing

Notes:

This study was conducted at the watershed scale. Instead of field-scale data (as was used in Nangia et al 2008 Water Quality Modeling of Fertilizer Managemetn Impacts on Nitrate Losses in Tile Drains at the Field Scale), data from two watersheds is used to calibrate the ADAPT model. The ADAPT model was then run continuously from 1955-2004 at various nitrogen application rates and timing.

Evaluation of predicted long-term water quality trends to changes in N fertilizer management practices for a cold climate

Type	Journal Article
Author	V. Nangia
Author	P.H. Gowda
Author	D.J. Mulla
Author	K. Kuehner
Publication	American Society of Agricultural Engineers Paper number 05226
Pages	1-12
Date	2005
Extra	Minnesota, Near St. Peter (Seven Mile Creek Watershed)

Tags:

agricultural manure management MN nitrogen nutrient management nutrient management_amount nutrient management_timing

Notes:

Refer to Nangia et al. (2010) Effects of Changes in N-Fertilizer Management on Water Quality Trends at the Watershed Scale. This is a conference proceeding of the same study, but prior to the peer reviewed publication. The model was developed based on data from 2000-2004.

Modeling nitrate-nitrogen losses in response to tile drain depth and spacing in a cold climate

Type	Journal Article
Author	V. Nangia
Author	P.H. Gowda
Author	D.J. Mulla
Author	G.R. Sands
Publication	American Society of Agricultural Engineers Meeting Presentatation
Pages	1-12
Date	2005
DOI	ASAE paper number: 052022
Extra	Minnesota, near St. Peter

Tags:

agricultural manure management MN nitrogen nutrient management tile system design

Notes:

Refer to Nangia et al. (2010) Modeling Impacts of Tile Drain Spacing and Depth on Nitrate-Nitrogen Losses. This is a conference proceeding of the same study, but prior to the peer reviewed publication.

Water Quality Modeling of Fertilizer Management Impacts on Nitrate Losses in Tile Drains at the Field Scale

Type	Journal Article
Author	V. Nangia
Author	P.H. Gowda
Author	D.J. Mulla
Author	G.R. Sands
Publication	Journal of Environmental Quality
Volume	37
Pages	296-307
Date	2008
Extra	Minnesota, near St. Peter (Seven-mile Creek Watershed)

Tags:

agricultural bacteria buffer fecal MN nitrogen nutrient management nutrient management_amount nutrient management_timing

Notes:

Continuous modeling (ADAPT model) over a 50-year period to determine the effects of fertilizer rate and timing on nitrogen export. This study was done in a similar manner to Nangia et al. (2008), but studies fertilizer instead of drain tile spacing. Again the study is based on modeling a site in Minnesota. The model was developed based on data from 1999-2003.

Modeling Impacts of Tile Drain Spacing and Depth on Nitrate-Nitrogen Losses

Type	Journal Article
Author	V. Nangia
Author	P.H. Gowda
Author	D.J. Mulla
Author	G.R. Sands
Publication	Vadose Zone Journal
Volume	9
Issue	1
Pages	61-72
Date	2010
Extra	Minnesota, St. Peter

Tags:

agricultural best management practice manure management MN nitrogen nutrient management tile system design

Notes:

Continuous modeling (ADAPT model) over a 50-year period to determine the effects of various horizontal and vertical drain tile spacing. Data from two 10-ha sites in Minnesota were used for model calibration.

2011 Accomplishment Report

Type	Document
Author	Natural Resources Conservation Service
Date	2011

2011 MINNESOTA EQIP CONSERVATION PRACTICE PAYMENT SCHEDULE

Type	Document
Author	Natural Resources Conservation Service
Date	2011 February

Soil and Water Assessment Tool

Type	Document
Author	S.L. Neitch
Author	J.G. Arnold
Author	J.R. Kiniry
Author	J.R. Williams
Date	2011 September

Long-term wastewater treatment effectiveness of a Northern wisconsin Peatland

Type	Journal Article
Author	D.S. Nichols
Author	D.A. Higgins
Publication	Journal of Environmental Quality
Volume	29
Pages	1703-1714
Extra	Wisconsin, Drummond

Tags:

bacteria buffer MN nitrogen phosphorus sediment waste water treatment strip wetland, constructed wetland, creation wetland, enhancement wetland, restoration WI

Notes:

Secondary effluent may be higher in concentration than typical agricultural runoff. Animal feeding operations may have runoff at more comparable bacteria levels, in which case this Wisconsin study might be of interest. Waste water goes through a series of lagoons prior to discharge to the bog. It is possible that results are applicable to wetland systems used for water quality treatment from agricultural runoff.

Evaluation of Buffer Width on Hydrologic Function, Water Quality,

and Ecological Integrity of Wetlands

Type	Report
Author	John Nieber
Author	Caleb Arika
Author	Chris Lenhart
Author	Mikhail Titov
Date	2011 February

Drainage water management impact on farm profitability

Type	Journal Article
Author	A.P. Nistor
Author	J. Lowenberg-DeBoer
Publication	Soil and Water Conservation Society
Volume	62
Issue	6
Pages	443-446
Date	2007 November/December

Developing Watershed-Scale Tools: A Case Example in the Wisconsin Buffer Initiative

Type	Report
Author	P. Nowak
Author	J. Norman
Author	D. J. Mulla
Report Number	13
Date	2008

Tags:

MN

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. A discussion highlighting the importance of the spatial congruence between 1.) the jurisdictional boundaries, 2.) the special dimension of degradation processes within a watershed, and 3.) the specific spaces addressed by the remedial practices. A case study in WI shows challenges in decision making processes to develop effective watershed management tools among political, administrative, academic, and civic groups.

Chloride, sodium, potassium and faecal bacteria levels in surface runoff and subsurface percolates from grassland plots amended with cattle slurry

Type	Magazine Article
Author	Nunez-Delgado, Avelino
Author	Eugenio Lopez-Periago
Author	Francisco Dıaz-Fierros Viqueira
Publication	Biosource Technology
Date	October 2001

Tags:

bacteria filter strips nutrient management_method

Notes:

Cattle slurry and inorganic fertilizer are compared for transport of pollutants, including bacteria, through filter strips. Various distances along the filter strips are monitored. This study was data intensive.

Benefits of Wetland Buffers: A Study of Functions, Values and Size prepared for the Minnehaha Creek Watershed District

Type	Report
Author	Gary Oberts
Author	Andrea Plevan
Institution	Emmons & Olivier Resources, Inc.
Date	December 6 2001

Tags:

agricultural bacteria best management practice BMP buffer fecal filter strip livestock access control livestock riparian pasture MN nitrogen nutrient management phosphorus sediment

Notes:

This literature review and guidance document assesses the latest research in buffer treatment efficiencies and design width. Ultimately, explicit design recommendations are made. A summary table of water quality findings and their respective citations provides a useful tool for buffer design guidance and performance characteristics. The report also visits concepts of rules and regulations for buffers.

Water Balance and Nitrate Leaching under Corn in Kura Clover Living Mulch

Type	Journal Article
Author	T. E. Ochsner
Author	K. A. Albrecht
Author	T. W. Schumacher
Author	J. M. Baker
Author	R. J. Berkevich
Publication	Argonomy Journal
Volume	102
Issue	4
Pages	1169-1178
Date	2010

Sediment control practies for surface tile inlets

Type	Journal Article
Author	E. B. Oolman
Author	B. N. Wilson
Publication	American Society of Agricultural Engineers
Volume	19
Issue	2
Pages	161-169
Date	2003
Extra	Minnesota, Vernon Center

Tags:

agricultural Alternative tile inlets best management practice buffer costs filter strip MN No till / minimum till / strip till sediment

Notes:

Standpipes, buffers, and no-till farming were evaluated for removing sediment from flow through surface tile inlets. Two sites in Minnesota are modeled using continuous simulation. Simulation parameters appear well cited.

This study evaluated five different practices for tile surface inlets. The five practices are: 1) conventional tillage with flush inlet pipes, 2) conventional tillage with grass buffer, 3) conventional tillage with slot-free slotted pipe, 4) conventional tillage with 1-ft slotted pipe, and 5) no-till with flush pipe inlet. Two intake locations were modeled: a 2.7 acre intake in Vernon Center (near Mankato) and a 7.4 acre site in Martin County. Four hundred years of runoff and erosion were simulated at each site.

The authors' results show that the most sediment entrering the depression was the no-till, a 90% reduction compared to conventional tillage. Of the management options with conventional tillage, the slot-free standpipe resulted in the best sediment traping eficiency (about 72% effective). However, the slot free stand pipe results in ponded water up to the top of the stand pipe, so there could be some crop impact. The slotted standpipe was 69% effective. Give tha tteh slotted standpipe results in less ponded area, it is preferred over the non-slotted standpipe. Both standpipe options performed better than the grass buffer.

For both sites, slotted standpipes reduced sediment load entering the tile system by about 50% compared to a flush pipe.

Influence of Alternative and conventional farming practies on subsurface drainage and water quality

Type	Journal Article
Author	K.A. Oquist
Author	J.S. Strock
Author	D.J. Mulla
Publication	Journal of Environmental Quality
Volume	36
Pages	1194-1204
Date	2007
Extra	Minnesota, Lamberton

Tags:

agricultural manure management MN nitrogen nutrient management nutrient management_method phosphorus

Notes:

Alternative and conventional farming practices were compared with respect to subsurface drainage and nitrogen and phosphorus loss through subsurface drainage. Unfortunately, the impact of individual farming practices on water quality was not measured; this may preclude extrapolation of findings to specific BMPs.

Economic and Environmental Impacts of Alternative Practices on Dairy Farms in an Agricultural Watershed

Type	Document
Author	E. Osei
Author	P.W. Gassman
Author	R.D. Jones
Author	S.J. Pratt
Author	L.M. Hauck
Author	L.J. Beran
Author	W.D. Rosenthal
Author	J.R. Williams
Publisher	Soil and Water Conservation Society
Date	2000

Tags:

costs manure and agricultural waste storage nutrient management_method phosphorus

Notes:

Phosphorus loss and economics associated with phosphorus-based manure applications and composting of solid manure were evaluated in this study. The models APEX and SWAT were used to simulate a north central Texas watershed and its dairy farms.

Applicability of targeting vegetative filter strips to abate fecal bacteria and sediment yield using SWAT

Type	Journal Article
Author	P Parajuli
Author	K Mankin
Author	P Barnes
Publication	Agricultural Water Management
Volume	95
Issue	10
Pages	1189-1200
Date	10/2008
Journal Abbr	Agricultural Water Management
DOI	10.1016/j.agwat.2008.05.006
ISSN	03783774
URL	http://linkinghub.elsevier.com/retrieve/pii/S0378377408001303
Accessed	Tuesday, July 05, 2011 12:46:07 PM
Library Catalog	CrossRef

Tags:

bacteria filter strips sediment

Notes:

A SWAT model was created for a northeast Kansas watershed to evaluate the sediment and bacteria removal effectiveness of filter strips at various lengths (0, 10, 15, and 20 meters). In addition, the modeling evaluates the treatment benefits of filter strips using both targeted and random implementation approaches. Targeted approaches seek more pollution control in areas where it is most cost-effective as opposed to a random approach, which undergoes implementation on a first-come, first-served basis. Targeting critical areas for pollution reduction was more cost-effective and beneficial than random implementation.

SEEPAGE FROM EARTHEN ANIMALWASTE PONDS AND LAGOONS— AN OVERVIEW OF RESEARCH RESULTS AND STATE REGULATIONS

Type	Journal Article
Author	D. B. Parker
Author	D. D. Schulte
Author	D. E. Eisenhauer
Publication	American Society of Agricultural Engineers
Volume	42
Issue	2
Pages	485-493
Date	1999

Simulation of controlled drainage in open-ditch drainage systems"

Type	Document
Author	J.E. Parsons
Author	R.W. Skaggs
Author	C.W. Doty
Publisher	Elsevier Science Pubhshers B.V., Amsterdam
Date	1990

REEXAMINING BEST MANAGEMENT PRACTICES FOR IMPROVING WATER QUALITY IN URBAN WATERSHEDS

Type	Journal Article
Author	S. R. Pennington
Author	M. D. Kaplowitz
Author	S. G. Witter
Publication	Journal of American Water Resources Association
Pages	1027-1041
Date	2003 October

Tags:

bacteria nitrogen phosphorus sediment basin vegetated treatment area water/sediment control basin wetland, constructed

Notes:

The purpose of this paper is to compare removal efficiencies of urban structural BMPs with the percent removal of pollutants required as part of the TMDL program in Michigan. The following BMPs were examined for removal efficiencies: dry ponds, wet ponds, wetlands, filtering practices (excluding vertical sand filters and filter strips), infiltration practices, and swales. Some of these findings may be adaptable to agricultural applications. The following pollutants are considered: organic carbon, bacteria, total phosphorus, nitrogen species, sediment, and metals.

Conservation Drainage Practices for Agriculture

Type	Presentation
Presenter	Joel Peterson
Date	2009
Place	2009 Minnesota Association of Watershed Districts Meeting

Tags:

agricultural Alternative tile inlets best management practice BMP buffer controlled subsurface drainage culvert sizing filter strip MN nitrogen nutrient management sediment basin side inlet controls tile system design two-stage ditch water/sediment control basin wetland, restoration wood chip bioreactor

Notes:

Design guidance and benefits of culvert sizing, side inlet controls, wetland restoration (including nitrate treatment effectiveness), wood chip bioreactors, controlled subsurface drainage and tile system design, two-stage ditch, alternative tile inlets, and surge ponds. Local examples are made available. This guidance is practical, and not necessarily based on reference literature but, rather, on-the-ground experience.

Nonpoint source pollution impacts of alternative agricultural management practices in illinois: A simulation study

Type	Document
Author	Donald L. Phillips
Author	Paul D. Hardin
Author	Verel W. Benson
Author	Joseph V. Baglio
Publisher	Soil and Water Conservation Society
Date	1993

Tags:

conservation crop rotation IL MN nitrogen No till / minimum till / strip till phosphorus sediment yield

Notes:

A statistically representative sample of Illinois croplands were modeled in order to simulate environmental effects (especially nitrogen, phosphorus and yield) of no till and various crop rotations. Results are not reported in terms of treatment efficiencies of nitrogen and phosphorus, but these efficiencies can be calculated from the reported results.

Mustinka River Turbidity TMDL Implementation Plan

Type	Report
Author	Plevan, Andrea
Author	Tom Miller
Author	Jason Naber
Author	Charlie Anderson
Contributor	Joe Roeschlein
Contributor	Pete Waller
Institution	Emmons & Olivier Resources, Inc.
Date	November 2010

Tags:

All BMPs costs MN

Notes:

This report is helpful for general descriptions of agricultural BMPs, and the descriptions are specific to Minnesota. There is a valuable table of unit costs for all of the agricultural BMPs discussed. However, most of the costs are based on EQIP cost estimates which may or may not account for full project costs. Relative pollutant removal, in general, is also summarized in the same table.

FARM-LEVEL MANAGEMENT OF DEEP PERCOLATION EMISSIONS IN IRRIGATED AGRICULTURE

Type	Journal Article
Author	Judith F Posnikoff
Author	Keith C. Knapp
Publication	Jouranl of the American Water Resources Association
Volume	33
Issue	2
Pages	375-386
Date	1997 April

Terrace Maintenance

Type	Document
Author	Powell, G. Morgan
Author	McVay, Kent A.
Publisher	Kansas State University
Date	2004 July

Notes:

A description of terrace maintenance for three kinds of terrace commonly used in Kansas: broad-base, grass-back, and level flat-channel terrace.

Managing Farming Systems for Nitrate Control: A Research Review from Management Systems Evaluation Areas

Type	Journal Article
Author	J. F. Power
Author	Richard Wiese
Author	Dale Flowerday
Publication	J. Environmental Quality
Volume	30
Pages	1866-1880
Date	2001 November-December

Effects of Liquid Manure Storage Systems on Ground Water Quality

Type	Report
Author	Ground Water Monitoring and Assessment Program
Date	2001 April
Short Title	Summary Report

A VSA-Based Strategy for Placing Conservation Buffers in Agricultural Watersheds

Type	Journal Article
Author	Zeyuan Qiu
Publication	Environmental Management
Volume	32
Issue	3
Pages	299-311
Date	9/2003

Journal Abbr	Environmental Management
DOI	10.1007/s00267-003-2910-0
ISSN	0364-152X
URL	http://www.springerlink.com/openurl.asp?genre=article&...
Accessed	Wednesday, June 29, 2011 4:20:57 PM
Library Catalog	CrossRef

Tags:

costs field border filter strips nitrogen pesticides phosphorus

Notes:

Conservation buffers are strategically placed in a representative field in Missouri based on Variable Source Area (VSA) hydrology as compared to placing them along the edge of the field. A VSA is the area that contributes storm flow runoff via overland flow and, based on the watershed's topography, varies from less than 1% of a watershed's area during small storms to more than 50% during large storms. Locating conservation buffers in VSAs is more effective and cost-effective than placing them along the edge of the field.

Real-time treatment of dairy manure: Implications of oxidation reduction potential regimes to nutrient management strategies

Type	Journal Article
Author	Asif Qureshi
Author	K. Victor Lo
Author	Ping H. Liao
Author	Donald S. Mavinic
Publication	Bioresource Technology
Volume	99
Issue	5
Pages	1169-1176
Date	3/2008
Journal Abbr	Bioresource Technology
DOI	10.1016/j.biortech.2007.02.046
ISSN	09608524
Short Title	Real-time treatment of dairy manure
URL	http://linkinghub.elsevier.com/retrieve/pii/S0960852407002349
Accessed	Tuesday, July 05, 2011 12:47:35 PM
Library Catalog	CrossRef

Tags:

manure and agricultural waste storage nitrogen nutrient management_method oxygen phosphorus

Notes:

This study evaluates winter time treatment of dairy manure. The chemical processes of the sequencing batch reactor (SBR) are studied under operating conditions. Nitrogen and phosphorus removal efficiencies and dissolved oxygen, oxygen reduction potential, and chemical oxygen demand are tracked and reported.

EVALUATION OF CONTROLLED DRAINAGE EFFICIENCY IN LITHUANIA

Type	Journal Article
Author	EDMUNDAS RAMOSKA
Author	NIJOLE BASTIENE
Author	VALENTINAS SAULYS
Publication	Irrigation and Drainage
Volume	60
Pages	196-206
Date	2011
DOI	10.1002/ird.548

Terracing Farm Lands

Type	Document
Author	C.E. Ramser
Date	1918 August
Short Title	Farmer's Bulletin 997

Effect of fall tillage following soybeans and the presence of gravel filters on runoff losses of solids, organic matter, and phosphorus on a field scale

Type	Thesis
Author	A. Z. H. Ranaivoson
University	University of Minnesota

# of Pages 236

Notes:

Ranaivoson analyzed the hydrology and trapping efficiency of gravel filters under runoff events. The trapping efficiency of the gravel ranged from 14 to 32%. The concentration of both soluble N and P increased over the duration of the event to water ponding played a significant role in releasing soluble phosphorus. According to the author, hundreds of gravel inlets have replaced open tile inlets. Study sites were located in LeSeuer and Watonwan Counties.

N and P dynamics were influenced by the presence of a pond near the gravel inlet.

Ranaivoson found that at the LeSeuer site, 37% of the gravel filter void volume was filled (in 2002), wich is considered to be a minimum value.

Annual sediment loading entering the site was 295 kg/ha versus 227 kg/ha leaving the site on an annual basis. Average sediment concentration was 238 mg/L entering the gravel inlet and 183 mg/L exiting, which is a reporting 22% trapping efficiency. These numbers are substantially lower than those reported elsewhere (Gieseke, Wilson). Trapping efficiency of COD, TP, and particulate P during four events in 2002 was 24, 14, and 32%, respectively. Under ponded conditions, the concentration of soluble P has been shown to increase, related to the amount of residue (current study and Ginting et al.). Therefore, while it appears there is still a net benefit of TP trapping efficiency, the result may not be as great as that of total solids.

Potential to Reduce Contaminants in Field Drainage with Anaerobic Woddchip Bioreactors Under Minnesota Conditions

Type	Presentation
Presenter	Andry Ranaivoson
Presenter	John Moncri
Presenter	Rod Venterea
Presenter	Mark Dittrich
Presenter	Yogesh Chander
Date	n.d.

Notes:

A presentation on woodchip bioreactors that presents pollutant reductions from field sites in Minnesota.

Impact of Long-Term tillage systems for continuous corn on nitrate leaching to tile Drainage.

Type	Journal Article
Author	G.W. Randall
Author	T.K. Iragavarapu
Publication	Journal of Environmental Quality
Volume	24
Pages	360-366
Date	1995
Extra	Minnesota, Waseca

Tags:

agricultural best management practice BMP MN mulch till nitrogen No till / minimum till / strip till nutrient management Ridge Till tile yield

Notes:

This study, being conducted in Minnesota and having a long period of record (1982-1992), is a valuable resource. The main conclusion of the study is that nitrate losses in tile drainage are highly dependent on precipitation during the growing season and much less dependent on tillage. This paper provides useful regression equations for predicting nitrogen losses based on residual soil nitrogen and rainfall.

Nitrate Nitrogen in Surface Waters as Influenced by Climatic Conditions and Agricultural Practices

Type	Journal Article
Author	Gyles W. Randall
Author	David J. Mulla
Publication	Journal of Environment Quality
Volume	30

Pages 337-344
Date 2001

Notes:

A literature review discussing recent findings on nitrate-N loss in tile drainage and the importance of adopting conservation practices such as crop rotation and nutrient management. Six steps of minimizing nitrate-N loss to surface water were suggested.

Nitrogen Application Timing, Forms, and Additives

Type	Report
Author	G. W. Randall
Author	J. E. Sawyer
Report Number	6
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Institution	ASABE
Date	2008
Pages	13

Tags:

MN

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. A compiled data of recent studies showing the effect of different nitrogen reduction methods (amount, timing, and additives) in runoff and the corresponding crop yields. A good portion of data come from Minnesota.

NITROGEN APPLICATION TIMING, FORMS, AND ADDITIVES

Type	Document
Author	Gyles Randall
Author	John Sawyer
Date	N.D.

Nitrate Losses in Subsurface Drainage from a Corn–Soybean Rotation as Affected by Fall and Spring Application of Nitrogen and Nitrapyrin

Type	Journal Article
Author	G. W. Randall
Author	J. A. Vetsch
Publication	Journal of Environment Quality
Volume	34
Pages	590-597
Date	2005

Notes:

A seven-year study in Waseca, MN, on a poorly drained clay loam glacial till soil, a continuous work of Randall et al. (2003). Nitrate loadings in the subsurface tile drainage were compared among four anhydrous ammonia treatments: Fall N, Fall N + nitrification inhibitor, nitrapyrin (NP), spring preplant N, and spring N +NP. Timing of N fertilizer had a greater influence than NP use in the fall.

Impact of Nitrogen and Tillage Management Practices on Corn Production and Potential Nitrate Contamination of Groundwater in Southeastern Minnesota

Type	Conference Paper
Author	G. W. Randall
Author	J. L. Anderson
Author	G. L. Malzer
Author	B. W. Anderson
Date	1993 February
Conference Name	Agricultural Research To Protect Water Quality
Place	Minneapolis, Minnesota USA
Publisher	Soil and Water Conservation Society
Pages	172-175

Notes:

A study measuring the impact of using manure, N Serve, side dress, and different timing of N fertilizer application. Results were discussed based on the corn grain yield and nitrate concentration in the soil and soil water.

Nitrate and Pesticide Losses to Tile Drainage, Residual Soil N, and N Uptake as Affected by Cropping Systems

Type	Conference Paper
Author	G. W. Randall
Author	D. J. Fuchs
Author	W. W. Nelson
Author	D. D. Buhler
Author	M. P. Russelle
Author	W. C. Koskinen
Author	J. L. Anderson
Date	1993 February
Conference Name	Agriculture Research To Protect Water Quality
Place	Minneapolis, Minnesota USA
Publisher	Soil and Water Conservation Society
Pages	468-470

Notes:

A study in Minnesota on the effect of cropping systems on nitrate loss in the drainage system. Continuous corn was compared with a corn-soybean sequence, alfalfa, and continuous CRP (Conservation Research Program) species.

Nutrient Losses in Subsurface Drainage Water from Dairy Manure and Urea Applied for Corn

Type	Journal Article
Author	G. W. Randall
Author	T. K. Iragavarapu
Author	M. A. Schmitt
Publication	Journal of Environment Quality
Volume	29
Pages	1244-1252
Date	2000

Notes:

A four-year nutrient management study in Waseca, MN, on a poorly drained clay loam glacial till soil.

Total P, ortho-P, NH_4-N, and bacteria concentrations and nitrate load in drainage water were measured on the plots where liquid dairy manure was fall applied or urea was spring applied annually based on the same amount of the total available N.

Nitrate losses through subsurface tile drainage in conservation reserve program, alfalfa, and row crop systems

Type	Journal Article
Author	G.W. Randall
Author	D.R. Huggins
Author	M. P. Russelle
Author	D. J. Fuchs
Author	W. W. Nelson
Author	J. L. Anderson
Publication	Journal of Environmental Quality
Volume	26
Pages	1240-1247
Date	1997
Extra	Minnesota, Lamberton

Tags:

agricultural best management practice conservation cover conservation crop rotation MN nitrogen nutrient management tile yield

Notes:

This study evaluates differences between annual crops (corn and soybeans) and perennial crops (alfalfa and Conservation Reserve Program) with respect to biomass yields, nitrogen uptake, residual soil nitrogen, soil water content, and nitrate losses to drain tile. Each system has subsurface drain tile. Alfalfa and CRP is shown to be the best for water quality.

Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by time of nitrogen application and use of nitrapyrin

Type	Journal Article
Author	G.W. Randall

Author	J.A. Vetsch
Author	J.R. Huffman
Publication	Journal of Environmental Quality
Volume	32
Pages	1764-1772
Date	2003
Extra	Minnesota, Waseca

Tags:

agricultural MN nitrogen nutrient management nutrient management_method nutrient management_timing tile

Notes:

This paper tracks the nitrogen losses from corn and soybean agriculture after four different anyhyrous ammonia treatments replicated four times. The replication and period of record (1987-1994) give this data strength. This study was conducted in Minnesota, giving it additional value. The study shows the significant impact of temporal distribution of precipitation on nitrogen losses.

Best Management Practices for Nitrogen Use in SOUTHEASTERN MINNESOTA

Type	Journal Article
Author	Gyles Randall
Author	George Rehm
Author	John Lamb
Publication	University of Minnesota Extension
Date	2008

EFFECTIVENESS OF SEDIMENTATION BASINS THAT DO NOT TOTALLY IMPOUND A RUNOFF EVENT

Type	Journal Article
Author	J. Rauhofer
Author	A. R. Jarrett
Author	R. D. Shannon
Publication	American Society of Agricultural Engineers
Volume	44
Issue	4
Pages	813-818
Date	2001
ISSN	0001–2351

Feedlot Inventory Guidebook

Type	Book
Author	Minnesota Board of Water and Soil Resources
Publisher	Minnesota Department of Natural Resources, Office of Planning
Date	1991 June

LOW-DROP GRADE-CONTROL STRUCTURE

Type	Journal Article
Author	C. E. Rice
Author	K. C. Kadavy
Publication	American Society of Agricultural Engineers
Volume	41
Issue	5
Pages	1337-1343
Date	1998

Management and maintenance of earthen manure structures: Implications and opportunities for water quality protection

Type	Journal Article
Author	T.L. Richard
Author	C.C. Hinrichs
Publication	Applied Engineering in Agriculture
Volume	18
Issue	6
Pages	727-734
Date	2002
Extra	Iowa, throughout state

Tags:

agricultural bacteria best management practice fecal IA manure and agricultural waste storage manure management nutrient management

Notes:

Results of on-site surveys of earthen berm structures for manure management are reported and summarized. The surveys illustrate the failure mechanisms and broad evidence of water quality risks of earthen berm storage structures. Earthen structure publications from technical, educational, and policy perspectives were reviewed for adequacy of management and maintenance guidance. This document directly identifies the current, practical needs for earthen berm management and maintenance in order to reduce water quality risk.

Buffered Wetlands in agricultural landscapes in the prairie pothole region: environmental Agronomic and economic evaluations

Type	Journal Article
Author	D. H. Rickerl
Author	L. L. Janssen
Author	R. Woodland
Publication	Journal of Soil and Water Conservation
Volume	55
Issue	2
Pages	220-225
Date	2000
Extra	South Dakota, Lake County

Tags:

agricultural best management practice buffer costs field border filter strip MN no-till nutrient management riparian vegetation SD wetland, enhancement wetland, restoration yield

Notes:

The economic value of buffering wetlands as opposed to farming through them is identified for three different farming systems: no-till, conventional, and organic. Different wetland buffer strategies are included in the analysis (including participation in the Wetland Reserve Program or Conservation Reserve Program). There is some, though limited, discussion of environmental effects of farming wetlands. Study results are from a site in South Dakota.

WATER BALANCE INVESTIGATION OF DRAINAGE WATER MANAGEMENT IN NON WEIGHING LYSIMETERS

Type	Journal Article
Author	K. D. Riley
Author	M. J. Helmers
Author	P. A. Lawlor
Author	R. Singh
Publication	American Society of Agricultrual and Biological Engineers
Volume	25
Issue	4
Pages	507-514
Date	2009
ISSN	0883-8542

Nitrate removal rates in woodchip media of varying age

Type	Journal Article
Author	W.D. Robertson
Publication	Ecological Engineering
Volume	36
Pages	1518-1587
Date	2010
DOI	10.1016/j.ecoleng.2010.01.008

Rates of Nitrate and Perchlorate Removal in a 5-Year-Old Wood Particle Reactor Treating Agricultural Drainage

Type	Journal Article
Author	W.D. Robertson
Author	C.J. Ptacek
Author	S.J. Brown
Publication	Ground Water Monitoring & Remediation
Volume	29
Issue	2
Pages	87-94
Date	2009 Spring
URL	NGWA.org

Phosphorus Relationships in Runoff from Fertilized Soils

Type Journal Article
Author M.J.M. Romkens
Author D.W. Nelson
Publication Journal of Environmental Quality
Volume 3
Issue 1
Pages 10-13
Date 1974

FECAL COLIFORM TRANSPORT AS AFFECTED BY SURFACE CONDITION

Type Document
Author Roodsari, R. M.
Author D. R. Shelton
Author A. Shirmohammadi
Author Y. A. Pachepsky
Author A. M. Sadeghi
Author J. L. Starr
Publisher American Society of Agricultural Engineers
Date 2005

Tags:

bacteria filter strips

Notes:

In Maryland, a two-sided lysimeter with four individual plots simulating filter strips was studied for runoff of manure. Manure was applied at the top of each plot. Results are indicative of filter strip performance under land application of manure.

Tile Drainage in Wisconsin: Understanding and Locating Tile Drainage Systems

Type Report
Author Matthew D. Ruark
Author John C. Panuska
Author Eric T. Cooley
Author Joe Pagel
Series Title Tile Drainage in Wisconsin
Institution Discovery Farms University of Wisconsin Extension
Date 2009
Pages 4

Tags:

agricultural manure management nutrient management tile WI

Notes:

This is a fact sheet out of Wisconsin's Discovery Farms project. It provides a description of tile drainage in Wisconsin and methods to locate tile drains. The fact sheet is very general in nature and is specifically designed for Wisconsin.

BIORETENTION COLUMN STUDY: FECAL COLIFORM AND TOTAL SUSPENDED SOLIDS REDUCTIONS

Type Document
Author Rusciano, G.M.
Author C. C. Obropta
Publisher ASABE
Date 2007 May

Tags:

bacteria Lab sediment sediment basin vegetated treatment area waste water treatment strip water/sediment control basin

Notes:

This laboratory study identified bacteria and sediment treatment efficiencies of bioretention media. Columns of media were dosed with diluted manure slurry. Though the study simulated typical New Jersey rainfall conditions, results are likely extractable to Minnesota.

Predicting the impact of drainage depth on water quality in a cold climate

Type Journal Article
Author G.R. Sands

Author	L.M. Busman
Author	C.-X. Jin
Author	W.E. Rugger Jr.
Publication	American Society of Agricultural Engineers Conference proceedings
Pages	070-083
Date	2004
DOI	ASAE publication number 701P0304
Extra	Minnesota, Waseca

Tags:

agricultural buffer filter strip MN nitrogen nutrient management tile system design

Notes:

Nitrogen results are not easily extractable for specific tile system designs. Vertical and horizontal spacing of tiles is tested. The study entails a field experiment as well as uncalibrated modeling. The experimental data is likely more valuable than the modeling results.

The impact of drainage depth on water quality in a cold climate

Type	Journal Article
Author	G.R. Sands
Author	L.M. Busman
Author	W.E. Rugger Jr.
Author	B. Hansen
Publication	American Society of Agricultural Engineers Meeting Presentation
Pages	1-11
Date	2003
DOI	032365
Extra	Minnesota, Waseca

Tags:

agricultural buffer MN nitrogen nutrient management tile system design

Notes:

Refer to Sands et al. (2004) *Predicting the impact of drainage depth on water quality in a cold climate*. This is an early version of the 2004 study.

The effects of subsuface drainage depth and intensity on nitrate loads in the northern cornbelt

Type	Journal Article
Author	G.R. Sands
Author	I. Song
Author	L.M. Busman
Author	B.J. Hansen
Publication	Transactions of the American Society of Agricultural and Biological Engineers
Volume	51
Issue	3
Pages	937-946
Date	2008
Extra	Minnesota, Waseca

Tags:

agricultural buffer MN nitrogen nutrient management tile system design

Notes:

This study takes place over a 5 year period and evaluates vertical and horizontal spacing of tile systems. This is a long term study and one of many publications of its kind from G.R. Sands.

Nitrogen Rates

Type	Report
Author	J. E. Sawyer
Author	G. W. Randall
Report Number	5
Series Title	Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop
Date	2008
Pages	13

Tags:

MN

Notes:

A chapter from the Final Report on Gulf Hypoxia and Local Water Quality Concerns Workshop. A review of the effect of N application rate for growing corn in relation to nitrate in runoff from tile drainage, economic return, and potential nitrate reduction.

Water quality from erosion control structures in Nebreska

Type	Journal Article
Author	J. S. Schepers
Author	D. D. Francis
Author	L. N. Mielke
Publication	Journal of Environmental Quality
Volume	14
Issue	2
Pages	186- 190
Date	1985

Notes:

The objective of this study was to evaluate the chemical and sediment loss characteristics of discharge from underground tile outlet terraces and sediment basins and to compare these concentrations to a nearby stream.

Five sites were part of the study, which took place in northeastern Nebraska, which shares a climate similar to southwestern Minnesota. The authors noted that there were few runoff events at all of the study sites. The authors also noted that total P and TKN concentrations were positively correlated with suspended solids concentrations.

Initial sediment concentrations were 40 to 50 times greater than those measured in a nearby stream. Peak sediment concentrations ranged from 4 to 76 mg/L.

The authors observed that most larger particles settle out in a depression as soon as a pond of water forms around the riser inlet.

Denitrifying bioreactors—An approach for reducing nitrate loads to receiving waters

Type	Journal Article
Author	Louis A. Schipper
Author	Will D. Robertson
Author	Arthur J. Gold
Author	Dan B. Jaynes
Author	Stewart C. Cameron
Publication	Ecological Engineering
Volume	36
Pages	1532-1543
Date	2010

A manure management survey of Minnesota swine producers: summary of responses

Type	Journal Article
Author	D. R. Schmidt
Author	L. D. Jacobson
Author	M. A. Schmidt
Publication	American Society of Agricultural Engineers
Volume	12
Issue	5
Pages	591-594
Date	1996
Extra	Minnesota - Survey

Tags:

agricultural bacteria best management practice fecal manure and agricultural waste storage manure management MN nutrient management

Notes:

This study is good for guiding what Minnesota needs to improve on with respect to manure management.

Filter Strip Performance and Processes for Different Vegetation, Widths, and Contaminants

Type	Journal Article
Author	T.J. Schmitt
Author	M. G. Dosske
Author	K. D. Hoagland
Publication	Journal of Environment Quality
Volume	28
Pages	1479-1489
Date	1999

Tags:

filter strips nitrogen pesticides phosphorus sediment soluble phosphorus

Notes:

This article discusses chemical and physical processes that account for the pollutant removal results experienced (settling, infiltration, dilution). Trees and shrubs were included in the filter strips; and vegetation types and age were varied. This study took place in Nebraska. Synthetic runoff as well as simulated direct rainfall feed the filter strips; adding the naturally-occurring component of dilution. The study reports percent reductions explicitly, which is helpful for extrapolating the results.

Choosing Terrace Systems

Type	Document
Author	R. W. Schottman
Author	J. White
Date	1993 October

Tags:

costs terrace yield

Notes:

Terrace methods are identified in order of increasing cost and design complexity. The methods are based on a case study of a farm in northeast Missouri. The following terrace methods are described: constant grade, broad-based with reduced curves and point rows, narrow rows and advanced technology. This article is more narrative in nature.

The cost of cleaner water: Assessing agricultural pollution reduction at the watershed scale

Type	Document
Author	S. Secchi
Author	P.W. Gassman
Author	M. Jha
Author	L. Kurkalova
Author	H.H. Feng
Author	T. Campbell
Author	C.L. Kling
Date	2007

Tags:

conservation cover contour farming costs grassed waterways IA nitrogen No till / minimum till / strip till nutrient management_amount phosphorus sediment terrace

Notes:

This is one of few articles that specifically addresses grassed waterways. However, percent reductions for water quality treatment are not separated for individual practices. In addition, percent reductions are based on modeling only.

Lake Pepin Watershed TMDL: Eutrophication and Turbidity Impairments Project Overview

Type	Document
Author	Norman Senjem
Date	2007 April

Water quality and restoration in a coastal subdivision stormwater pond

Type	Journal Article
Author	L Serrano
Author	M Delorenzo
Publication	Journal of Environmental Management
Volume	88
Issue	1
Pages	43-52
Date	2008 July
Journal Abbr	Journal of Environmental Management
DOI	10.1016/j.jenvman.2007.01.025
ISSN	03014797
URL	http://linkinghub.elsevier.com/retrieve/pii/S0301479707000576
Accessed	Tuesday, July 05, 2011 3:32:59 PM
Library Catalog	CrossRef

Tags:

sediment basin water quality water/sediment control basin

Notes:

This article is related to stormwater ponds in residential subdivisions. It may or may not be adaptable to sediment basins in agricultural settings.

Determining Environmentally Sound Soil Phosphorus Levels

Type	Journal Article
Author	A. Sharpley
Author	T. C. Daniel
Author	J. T. Sims
Author	D. H. Pote
Publication	Soil and Water Conservation Society
Volume	51
Issue	2
Pages	160-166
Date	1996

Notes:

A literature review, which assesses the validity of the use of soil P test as an indicator of P loss in runoff. It calls for the integrated assessment of soil P test with estimates of potential runoff and erosion losses and local climatic, topographic, and agronomic factors.

Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus and Sediment in the Chesapeake Bay Watershed

Type	Report
Author	Dr. Thomas Simpson
Author	Sarah Weammert
Institution	University of Maryland Mid-Atlantic Water Program
Date	December 2009

Tags:

agricultural bacteria best management practice BMP buffer filter strip livestock access control livestock riparian pasture manure management nutrient management rotational grazing

Notes:

An extensive description of a large array of BMPs used in Chespeake Bay Watershed. Effectiveness of each BMP is studied and estimated in detail, reflecting the local conditions and variation in hydrologic flow, soil conditions, types of vegetation, and BMP design.

Potential Impact of Climate Change on Subsurface Drainage in Iowa's Subsurface Drained Landscapes

Type	Journal Article
Author	R. Singh
Author	M. J. Helmers
Author	Amy L. Kaleita
Author	Eugene S. Takle
Publication	Journal of Irrigation and Drainage Engineering
Date	2009
DOI	doi:10.1061/(ASCE)IR.1943-4774.0000009

Predicting effects of drainage water management in Iowa's subsurface drained landscapes

Type	Journal Article
Author	R. Singh
Author	M.J. Helmers
Author	W.G. Crumpton
Author	D.W. Lemke
Publication	Agricultural Water Management
Volume	92
Pages	162-170
Date	2007
Extra	Iowa

Tags:

agricultural IA MN nutrient management tile tile system design yield

Notes:

This article addresses volumes and not water quality. It is based on modeling of different vertical and horizontal spacings of tile systems.

The effects of increased runoff and excess water on crop production are considered as the result of various tile system designs.

EFFECTS OF SUBSURFACE DRAIN DEPTH ON NITROGEN LOSSES FROM DRAINED LANDS

Type	Journal Article
Author	R. W. Skaggs
Author	G. M. Chescheir III
Publication	American Society of Agricultural Engineers
Volume	46
Issue	2
Pages	237-244
Date	2003

EFFECT OF CONTROLLED DRAINAGE ON WATER AND NITROGEN BALANCES IN DRAINED LANDS

Type	Journal Article
Author	R. W. Skaggs
Author	M. A. Youssef
Author	J. W. Gilliam
Author	R. O. Evans
Publication	American Society of Agricultural and Biological Engineers
Volume	53
Issue	6
Pages	1843-1850
Date	2010
ISSN	2151-0032

Nutrient losses from row crop agriculture in Indiana

Type	Journal Article
Author	D.R. Smith
Author	S.J. Livingston
Author	B.W. Zuercher
Author	M. Larose
Author	G.C. Heathman
Author	C. Huang
Publication	Journal of Soil and Water Conservation
Volume	63
Issue	6
Pages	396-409
Date	11/2008
Journal Abbr	Journal of Soil and Water Conservation
DOI	10.2489/jswc.63.6.396
ISSN	1941-3300
URL	http://www.jswconline.org/cgi/doi/10.2489/jswc.63.6.396
Accessed	Tuesday, April 26, 2011 4:28:01 PM
Library Catalog	CrossRef

Tags:

filter strips nitrogen phosphorus soluble phosphorus

Notes:

Watersheds with filter strips were monitored. Specific treatment efficiencies of BMPs are not extractable from the study, but watershed-wide results are provided over multiple years. Regression equations were developed for nutrient load and concentrations.

Forum on Minnesota Irrigated Agriculture

Type	Report
Author	East Otter Tail Soil
Author	Water Conservation District
Date	2011 March 8
Pages	1-22

Culvert Sizing for Flood Damage Reduction

Type	Document
Author	Jim Solstad
Author	Al Kean
Author	Charlie Anderson
Date	2007 October

Culvert Sizing for Flood Damage Reduction

Type	Report
Author	Solstad, Jim
Author	Al Kean
Author	Charlie Anderson
Report Type	Red River Basin Flood Damage Reduction Work Group Technical and Scientific Advisory Committee Technical Paper No. 15
Date	2007 October

Tags:

culvert sizing MN

Notes:

Preliminary technical culvert sizing guidelines, which are very detailed, for flood damage reduction and prevention in the Red River Basin, which includes portions of Minnesota. Guidance is specifically for culverts discharging waters from agricultural drainage areas. Much of this technical report is about the modeling conducted to develop the preliminary guidelines.

Treatment of Parking Lot Stormwater Using a StormTreat System

Type	Journal Article
Author	Rebecca S. Sonstrom
Author	John C. Clausen
Author	David R. Askew
Publication	Environmental Science & Technology
Volume	36
Issue	20
Pages	4441-4446
Date	2002 October
Journal Abbr	Environ. Sci. Technol.
DOI	10.1021/es020797p
ISSN	0013-936X
URL	http://pubs.acs.org/doi/abs/10.1021/es020797p
Accessed	Tuesday, July 05, 2011 3:32:17 PM
Library Catalog	CrossRef

Tags:

clean runoff water diversion sediment basin water quality wetland, creation

Notes:

A commercial application of a proprietary water quality treatment chamber. Bypass flow was not monitored, but percent reduction of pollutants in water that travels through the system is reported for a variety of constituents. The system incorporates a wetland-style treatment function.

Impacts of rotational grazing and riparian buffers on physicochemical and biological characteristics of southeastern minnesota, usa, streams

Type	Journal Article
Author	laurie a. sovell
Author	bruce vondracek
Author	julia a. frost
Author	karen g. mumford
Volume	26
Issue	6
Pages	629-641
Date	2012 April 11
DOI	10.1007/s002670010121

BEST MANAGEMENT PRACTICES FOR PATHOGEN CONTROL IN MANURE MANAGEMENT SYSTEMS

Type	Document
Author	Spiehs, Mindy
Author	Sagar Goyal
Date	2011 June 23

Tags:

bacteria manure and agricultural waste storage MN nutrient management_amount nutrient management_method nutrient management_timing

Notes:

A wide variety of methods for reducing pathogens from manure in runoff are identified. Diet, manure collection and storage techniques, methods of biological treatment of manure, and land application methods are identified. The article is heavily referenced and appears to be a reliable collection of techniques. In addition, this document comes out of the University of Minnesota and, therefore, is particularly relevant for Minnesota.

The effects of minimal tillage, contour cultivation and in-field vegetative barriers on soil erosion and phosphorus loss

Type	Journal Article
Author	C.J. Stevens
Author	J.N. Quinton
Author	A.P. Bailey
Author	C. Deasy
Author	M. Silgram
Author	D.R. Jackson
Publication	Soil and Tillage Research
Volume	106
Issue	1
Pages	145-151
Date	12/2009
Journal Abbr	Soil and Tillage Research
DOI	10.1016/j.still.2009.04.009
ISSN	01671987
URL	http://linkinghub.elsevier.com/retrieve/pii/S0167198709001007
Accessed	Friday, July 01, 2011 10:37:20 AM
Library Catalog	CrossRef

Tags:

contour farming contour stripcropping costs filter strips No till / minimum till / strip till phosphorus sediment soluble phosphorus vegetated treatment area

Notes:

Implementation costs of experimental practices are evaluated as a part of this study, but they are evaluated in British pounds. The study makes a valuable comparison of contour farming and vegetative buffers. Mixed direction tillage and minimum tillage are also evaluated at the field scale.

Runoff transport of faecal coliforms and phosphorus released from manure in grass buffer conditions

Type	Journal Article
Author	W.L. Stout
Author	Y.A. Pachepsky
Author	D.R. Shelton
Author	A.M. Sadeghi
Author	L.S. Saporito
Author	A.N. Sharpley
Publication	Letters in Applied Microbiology
Volume	41
Issue	3
Pages	230-234
Date	09/2005
Journal Abbr	Lett Appl Microbiol
DOI	10.1111/j.1472-765X.2005.01755.x
ISSN	0266-8254
URL	http://doi.wiley.com/10.1111/j.1472-765X.2005.01755.x
Accessed	Friday, July 01, 2011 10:55:29 AM
Library Catalog	CrossRef

Tags:

bacteria filter strips Lab phosphorus

Notes:

This study found that fecal coliform and total phosphorus transport through laboratory scale grass filter strips were highly correlated. If these results hold in unsaturated conditions and over longer distances, it could mean that total phosphorus could be used as an indicator for manure-born fecal coliform in runoff. These results appear very preliminary and not yet conclusive. Percent removal of fecal coliform and total phosphorus is reported.

Hydrologic Trends in Minnesota Water Resources

Type	Presentation
Presenter	Andrew Streitz
Date	March 28, 2011
Place	Red River Basin Team Meeting, Detroit Lakes

Tags:

MN

Notes:

A presentation of statistics illustrating significant increase in water appropriations, significant decrease in summer steam flow, and how the two trends may be related.

Controlled Drainage for Agronomic and Environmental Benefits

Type	Journal Article
Author	J.S. Strock
Author	G.R. Sands
Publication	University of Minnesota Extension
Date	N.D.
Extra	Minnesota, Tracy

Tags:

agricultural best management practice controlled subsurface drainage MN nitrogen nutrient management phosphorus soluble phosphorus

Notes:

Two years of data are provided in this non-peer reviewed article. However, Strock and Sands are reputable researchers in this field. A control and treatment site are both monitored for nutrients and flow.

Managing natural processes in drainage ditches for nonpoint source nitrogen control.

Type	Journal Article
Author	J.S. Strock
Author	C.J. Dell
Author	J.P. Schmidt
Publication	Journal of Soil and Water Conservation
Volume	62
Issue	4
Pages	188-196
Date	2007
Extra	Minnesota, Lamberton

Tags:

agricultural bacteria best management practice BMP buffer controlled subsurface drainage culvert sizing filter strip MN nutrient management

Notes:

This study reports nitrogen results from flow control in vegetated open ditches from the first year of observation. Results are not conclusive, but nitrogen cycling in ditch systems is discussed and helpful graphics are provided. It is a paired field study that takes place in Minnesota.

Cover Cropping to Reduce Nitrate Loss through Subsurface Drainage in the Northern U.S. Corn Belt

Type	Journal Article
Author	J.S. Strock
Author	P. M. Porter
Author	M. P. Russelle
Publication	Journal of Environmental Quality
Volume	33
Pages	1010-1016
Date	2004
Extra	Minnesota, Lamberton

Tags:

agricultural best management practice cover crop manure management MN nitrogen nutrient management tile yield

Notes:

The effects of a winter rye cover crop on nitrogen transport and crop yield are evaluated at a field site in Minnesota. The study includes 3 years of data from four different crop phases. Results are conclusive.

Performance of Stormwater Retention Ponds and Constructed Wetlands in Reducing Microbial Concentrations

Type	Document
Author	S. Struck
Author	A. Selvakumar
Author	Michael Borst

Publisher	EPA
Date	September 2006

Tags:

bacteria Lab wetland, constructed wetland, creation wetland, enhancement wetland, restoration

Notes:

The EPA investigated the fate of bacteria indicator organisms, as surrogates for pathogens, in stormwater runoff discharging to constructed wetlands and retention ponds. This research used pilot-scale and bench-scale (laboratory) systems. The results from constructed wetlands BMPs, in particular, are likely adaptable to constructed wetlands implemented in agricultural systems; results may be helpful in this respect.

Prediction of Effluent Quality from Retention Ponds and Constructed Wetlands for Managing Bacterial Stressors in Storm-Water Runoff

Type	Journal Article
Author	Scott D. Struck
Author	Ariamalar Selvakumar
Author	Michael Borst
Publication	Journal of Irrigation and Drainage Engineering
Volume	134
Issue	5
Pages	567
Date	2008
Journal Abbr	J. Irrig. and Drain. Engrg.
DOI	10.1061/(ASCE)0733-9437(2008)134:5(567)
ISSN	07339437
URL	http://link.aip.org/link/JIDEDH/v134/i5/p567/s1&Agg=doi
Accessed	Tuesday, July 05, 2011 3:20:10 PM
Library Catalog	CrossRef

Tags:

bacteria Lab wetland, constructed wetland, creation wetland, enhancement wetland, restoration

Notes:

The EPA investigated the fate of bacteria indicator organisms, as surrogates for pathogens, in stormwater runoff discharging to constructed wetlands and retention ponds. This research used pilot-scale and bench-scale (laboratory) systems. The results from constructed wetlands BMPs, in particular, are likely adaptable to constructed wetlands implemented in agricultural systems; results may be helpful in this respect.

Methods of Data Collection, Sample Processing, and Data Analysis for Edge-of-Field, Streamgaging, Subsurface-Tile, and Meteorological Stations at Discovery Farms and Pioneer Farm in Wisconsin, 2001–7

Type	Report
Author	Todd D. Stuntebeck
Author	Matthew J. Komiskey
Author	David W. Owens
Author	David W. Hall
Institution	USGS
Date	2007

Tags:

agricultural best management practice buffer filter strip manure management nutrient management WI

Notes:

This report describes methods to collect, process, and analyze water-quantity, water-quality, and meteorological data for edge-of-field, streamgaging, subsurface-tile, and meteorological stations for 6 years at Discovery Farms and Pioneer Farm in Wisconsin. The report identifies the equipment used; event-monitoring and sample collection procedures; station maintenance; sample handling and processing procedures; water quantity, water quality, and precipitation data analyses; and procedures for determining estimated constituent concentrations for runoff events that were not sampled. The study areas are described, but no results are presented in this document.

Precipitation-Runoff Relations and Water-Quality Characteristics at Edge-of-Field Stations, Discovery Farms and Pioneer Farm, Wisconsin, 2003-08

Type	Report
Author	Todd D. Stuntebeck

Author	Matthew J. Komiskey
Author	Marie C. Peppler
Author	David W. Owens
Author	Dennis R. Frame
Report Type	Scientific Investigations Report 2011-5008
Place	Wisconsin
Institution	USGS
Date	2011
Pages	1-46

Notes:

A six-year study in southern Wisconsin measuring runoff quality all year round including winter months from several private livestock farms where various conservation measures were adopted. The annual and overall mean data show nice trends in runoff volume and concentrations of suspended sediment, total nitrogen, dissolved and particulate phosphorus. About 50% of overall mean annual runoff occurred during the frozen-ground period, accompanied by significantly high total N and dissolved P concentration in runoff.

Converting Cropland to Perennial Grassland

Type	Document
Author	Sullivan, Preston
Author	Rinehart, Lee
Date	2010

Tags:

conservation cover conservation crop rotation costs yield

Notes:

This is a guidance document for pasture establishment. The target audience is the landowner embarking on or considering pasture establishment. For that reason, the narrative guidance and cost comparisons are useful for their on-the-ground details and the fact that they already represent a synthesis, presumably, of the research available at the time of publication. Implementation, more than water quality, is addressed in this document.

Watershed evaluation of beneficial management practices

Type	Document
Author	Mark Sunohara
Publisher	Drainage Management Systems
Date	2008

Tags:

best management practice BMP buffer nitrogen nutrient management tile water quality yield

Notes:

This article identifies an ongoing project in Canada that installs inline water level control structures to tile drained fields. Paired watersheds, a conventional drainage system and a controlled system, are studied. Nitrogen and crop yield benefits are identified.

Phosphorus loss to runoff water twenty-four hours after application of liquid swine manure or fertilizer.

Type	Journal Article
Author	H. Tabbara
Publication	Journal of Environmental Quality
Volume	32
Pages	1044-1052
Date	2003
Extra	Iowa, Ames

Tags:

agricultural best management practice BMP filter strip IA manure management nutrient management nutrient management_method nutrient management_timing phosphorus sediment soluble phosphorus

Notes:

This study was conducted on field plots in Iowa. Simulated rainfall was applied to plots 24 hours after liquid swine manure was incorporated. The study did not have a control plot, but measured the phosphorus (multiple forms) and sediment loss to runoff.

Effect of tillage and water table control on evapotranspiration, surfcae

runoff, tile drainage and soil water content under maize on a clay loam soil

Type	Journal Article
Author	C.S. Tan
Author	C.F. Drury
Author	J.D. Gaynor
Author	T.W. Welacky
Author	W.D. Reynolds
Publication	Agricultural Water Management
Volume	54
Pages	173-188
Date	2002

Effect of Controlled Drainage and tilage on Soil Structure and Tile Drainage Nitrate Loss at the Field Scale

Type	Journal Article
Author	C.S. Tan
Author	C.F. Drury
Author	M. Soultani
Author	I.J. van Wesenbeeck
Author	H.Y.F. Ng
Author	J.D. Gaynor
Publication	Water Science & Technology
Volume	28
Issue	4-5
Pages	103-110
Date	1998

The Two-Stage Ditch and Nitrogen Dynamics

Type	Document
Author	Jennifer Tank
Publisher	University of Notre Dame
Date	N.D.

Identifying Pathways and Processes Aff ecting Nitrate and

Orthophosphate Inputs to Streams in Agricultural Watersheds

Type	Journal Article
Author	Anthony J. Tesoriero
Author	John H. Duff
Author	David M. Wolock
Author	Norman E. Spahr
Author	James E. Almendinger
Publication	Journal of Environment Quality
Volume	38
Pages	1892-1900
Date	2009 October-September

Tillage and Nutrient Source Effects on Water Quality and Corn Grain Yield from a Flat Landscape

Type	Journal Article
Author	D.P. Thoma
Author	S.C. Gupta
Author	J.S. Strock
Author	J.F. Moncrief
Publication	Journal of Environmental Quality
Volume	34
Pages	1102-1111
Date	2005
Extra	Minnesota, Lamberton

Tags:

agricultural best management practice manure management MN nitrogen nutrient management phosphorus tile yield

Notes:

This study was conducted on sixteen 9.1 m by 18.2 m plots in Minnesota and assessed the water quality (nitrogen and phosphorus) effects of fall chisel or moldboard plow tillage treatments and fall injected liquid hog manure or spring incorporated urea nutrient treatments. The effects of leaving residue at the soil surface was evaluated under these treatments. Surface inlet flow and tile drainage were monitored and reported.

Letter: Duration of action of AH8165

Type	Journal Article
Author	J A Thornton
Author	M J Harrison
Publication	British Journal of Anaesthesia
Volume	47
Issue	9
Pages	1033
Date	1975 September
Journal Abbr	Br J Anaesth
ISSN	0007-0912
Short Title	Letter
URL	http://www.ncbi.nlm.nih.gov/pubmed/28
Accessed	Tuesday, July 05, 2011 12:07:26 PM
Library Catalog	NCBI PubMed
Extra	PMID: 28

Tags:

Dose-Response Relationship, Drug Hemodynamics Humans Pyridinium Compounds Time Factors

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SIMULATING THE LONG TERM PERFORMANCE OF DRAINAGE WATER MANAGEMENT ACROSS THE MIDWESTERN UNITED STATES

Type	Journal Article
Author	K. R. Thorp
Author	D. B. Jaynes
Author	R. W. Malone
Publication	American Society of Agricultural and Biological Engineers
Volume	51
Issue	3
Pages	961-976
Date	2008

Simulated long-term effects of nitrogen fertilizer application rates on corn yield and nitrogen dynamics

Type	Journal Article
Author	K.R. Thorp
Author	R.W. Malone
Author	D.B. Jaynes
Publication	Transactions of the American Society of Agricultural and Biological Engineers
Volume	50
Issue	4
Pages	1287-1303
Date	2007
Extra	Iowa, Story city

Tags:

agricultural buffer IA manure management MN nutrient management_amount yield

Notes:

A long data record was used for calibrating a model that simulates corn yield and nitrogen runoff for nitrogen fertilizer application rates. The model does not vary based on timing of nitrogen application but the rate of application. Nitrogen application is assumed to occur as an injection of anhydrous ammonia on April 16th of years that corn is planted.

Effectiveness of Best Management Practices for Bacteria Removal

Type	Report
Author	Tilman, Lisa
Author	Andrea Plevan
Author	Pat Conrad
Institution	Emmons & Olivier Resources, Inc.
Date	2011 June

Tags:

bacteria BMPs MN

Notes:

This report is a synthesis of bacteria removal mechanisms and treatment efficiencies. Some applications are urban, but a variety of the BMPs are applicable to agricultural systems as well.

Five Reasons to Choose Native Grass Releases

Type	Document
Author	Tober, Dwight
Author	Wayne Duckwitz
Author	Nancy Jensen
Author	Mike Knudson
Publisher	Natural Resources Conservation Service
Date	2008 January

Tags:

conservation cover MN ND

Notes:

This is an educational and promotional piece for landowners regarding native grass restoration: benefits and implementation guidance.

Methods to prioritize placement of riparian buffers for improved water quality

Type	Journal Article
Author	M. D. Tomer
Author	Michael G. Dosskey
Author	Michael R. Burkart
Author	Matthew J. Helmers
Author	Dean E. Eisenhauer
Date	2008 May 03
DOI	10.1007/s10457-008-9134-5

Assessment of the Iowa River's South Fork watershed: Part 2. Conservation practices

Type	Journal Article
Author	M.D. Tomer
Author	T.B. Moorman
Author	D.E. James
Author	G. Hadish
Author	C.G. Rossi
Publication	Journal of Soil and Water Conservation
Volume	63
Issue	6
Pages	371-379
Date	11/2008
Journal Abbr	Journal of Soil and Water Conservation
DOI	10.2489/jswc.63.6.371
ISSN	1941-3300
Short Title	Assessment of the Iowa River's South Fork watershed
URL	http://www.jswconline.org/cgi/doi/10.2489/jswc.63.6.371
Accessed	Tuesday, April 26, 2011 4:18:00 PM
Library Catalog	CrossRef

Tags:

BMPs IA

Notes:

This study provides an inventory of conservation practices and demonstrated inadequacies of them for an Iowa watershed. It is unclear how much can be extrapolated to other watersheds due to the fact that the study is an inventory. However, the study highlights the need for conservation practices to target the most important pollutant pathway of the watershed.

Assessment of the Iowa River's South Fork watershed: Part 1. Water quality

Type	Journal Article
Author	M.D. Tomer
Author	T.B. Moorman
Author	C.G. Rossi
Publication	Journal of Soil and Water Conservation
Volume	63
Issue	6
Pages	360-370
Date	11/2008
Journal Abbr	Journal of Soil and Water Conservation
DOI	10.2489/jswc.63.6.360
ISSN	1941-3300
Short Title	Assessment of the Iowa River's South Fork watershed
URL	http://www.jswconline.org/cgi/doi/10.2489/jswc.63.6.360
Accessed	Tuesday, April 26, 2011 4:18:35 PM
Library Catalog	CrossRef

Tags:

bacteria IA nitrogen phosphorus tile

Notes:

A watershed in Iowa is studied to understand the variable delivery mechanisms and timing of nitrogen, phosphorus and bacteria runoff. Data for nitrogen and phosphorus provided valuable information, and a valuable discussion ensues in the report; data regarding bacteria delivery and timing was not as conclusive.

PERSPECTIVES ON THE HISTORY OF SOIL EROSION CONTROL IN THE EASTERN UNITED STATES

Type	Journal Article
Author	Stanley W. Trimble
Publication	Agricultural History
Volume	59
Issue	2
Pages	162-180
Date	1985 April
URL	http://www.jstor.org/stable/3742382 .

SIMULATION OF CONSERVATION PRACTICES USING THE APEX MODEL

Type	Journal Article
Author	P. Tuppad
Author	C. Santhi
Author	X. Wang
Author	J. R. Williams
Author	R. Srinivasan
Author	P. H. Gowda
Publication	American Society of Agricultrual and Biological Engineers
Volume	26
Issue	5
Pages	779-794
Date	2010

Simulation of Agricultural Management Alternatives for Watershed Protection

Type	Journal Article
Author	Pushpa Tuppad
Author	Narayanan Kannan
Author	Raghavan Srinivasan
Author	Colleen G. Rossi
Author	Jeffrey G. Arnold
Publication	Water Resources Management
Volume	24
Issue	12
Pages	3115-3144
Date	2/2010
Journal Abbr	Water Resour Manage
DOI	10.1007/s11269-010-9598-8
ISSN	0920-4741
URL	http://www.springerlink.com/index/10.1007/s11269-010-9598-8
Accessed	Friday, July 01, 2011 10:36:54 AM
Library Catalog	CrossRef

Tags:

All BMPs Model

Notes:

A Texas watershed is modeled using SWAT to simulate the performance of a variety of agricultural BMPs. Results appear minimally applicable to Minnesota. Figure 4 provides nice summary tables for sediment, nitrogen, and phosphorus results, the relative results of which may be applicable.

INFLUENCE OF SEAL AND LINER HYDRAULIC PROPERTIES ON THE SEEPAGE RATE FROM ANIMAL WASTE HOLDING PONDS AND LAGOONS

Type	Journal Article
Author	J. S. Tyner
Author	J. Lee
Publication	American Society of Agricultural Engineers
Volume	47
Issue	5
Pages	1739-1745

Date 2004
ISSN 0001–2351

Agroforestry Practices, Runoff, and Nutrient Loss: A Paired Watershed Comparison

Type Document
Author Ranjith P. Udawatta
Author J. John Krstansky
Author Gray S. Henderson
Author Harold E. Garrett
Date 2002

Tags:

contour stripcropping field border filter strips nitrogen phosphorus sediment

Notes:

This study took place in northeast Missouri at a research center. Runoff, sediment loss, and nutrient loss from corn-soybean rotations was determined for three watersheds implementing either agroforestry, contour grass filter strips or control practices. Results are favorable for agroforestry and contour stripcropping.

CORE4 Conservation Practices Training Guide: The common sense approach to natural resource conservation

Type Document
Author United States Department of Agriculture
Publisher CORE4 Conservation Practices
Date 1999 August

Notes:

Chapter 3b Contour Buffer Strips provides 15-pages of useful information for buffer strip design, implementation, and maintenance. Diagrams and charts are provided for establishing field layouts, handling reverse curves, and using vegetative barriers. The contour buffer strip practice is one of 10 buffer practices described in detail, including: alley cropping, cross wind trap strips, field borders, filter strips, grassed waterway with vegetated filter, herbaceous wind barriers, riparian forest buffers, vegetative barriers, and windbreak/shelterbelt.

Conservation Buffers to Reduce Pesticide Losses

Type Document
Author United States Department of Agriculture
Publisher United States Department of Agriculture
Date 2000 March

Conservation Buffers to Reduce Pesticide Losses

Type Document
Author United States Department of Agriculture
Date 2000 March

Part 654 Stream Restoration Design National Engineering Handbook

Type Document
Author United States Department of Agriculture
Date 2007 August
Short Title Two-Stage Channel Design

Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Upper Mississippi River Basin

Type Report
Author United States Department of Agriculture
Date 2010 June
Pages 1 - 146

Key Findings from the CEAP Cropland Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Great Lakes Region

Type Document
Author United States Department of Agriculture
Date 2011 September

Summary of Findings from the CEAP Cropland Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Great Lakes Region

Type Document
Author United States Department of Agriculture
Date 2011 September

Managing Cover Crops Profitably

Type Book
Author United States Department of Agriculture
Edition Third
Publisher Sustainable Agricutlure Network, Beltsville, MD

Constructed Basins for Agricultural Water Treatment in Minnesota

Type Document
Author University of Minnesota
Publisher University of Minnesota Southwest Research & Outreach Center College of Food, Agriculture, and Natural Resource Sciences
Date N.D.

4th Drainage Water Management Field Day

Type Document
Author University of Minnesota Southwest Research & Outreach Center
Date 2011 August 23

Conservation Practice Physical Effects (CPPE) Matrix

Type Document
Author USDA
Date n.d.

Tags:

All BMPs buffer filter strip livestock access control livestock riparian pasture manure management MN nutrient management

Notes:

Matrix of physical effects of NRCS conservation practices. Extent of physical effects are categorized on a qualitative scale.

CORE4 Conservation Practices Training Guide The Common Sense Approach to Natural Resource Conservation

Type Document
Author USDA
Publisher USDA
Date August 1999

Tags:

agricultural All BMPs bacteria best management practice buffer conservation crop rotation costs filter strip livestock access control livestock riparian pasture manure and agricultural waste storage manure management mulch till No till / minimum till / strip till nutrient management Ridge Till Seasonal Till

Notes:

Although 10 years old, this guide addresses most agricultural BMPs in today's toolbox of BMPs. Categories of BMPs, each having specific BMPs, are: conservation tillage, nutrient management, pest management, and buffer practices. A section on integration of multiple practices is a practical tool that is typically overlooked in individual studies and guidance documents. The economics of each category of BMP is discussed.

Chapter 3b Contour Buffer Strips provides 15-pages of useful information for buffer strip design, implementation, and maintenance. Diagrams and charts are provided for establishing field layouts, handling reverse curves, and using vegetative barriers. The contour buffer strip practice is one of 10 buffer practices described in detail, including: alley cropping, cross wind trap strips, field borders, filter strips, grassed waterway with vegetated filter, herbaceous wind barriers, riparian forest buffers, vegetative barriers, and windbreak/shelterbelt.

Conservation Buffers to Reduce Pesticide Losses

Type	Document
Author	USDA
Publisher	NRCS
Date	March 2000

Minnesota 2008 Cropland Data Layer

Type	Map
Cartographer	USDA
Publisher	USDA
Date	2008

Tags:

MN

Notes:

2008 Minnesota crop data layer from NRCS.

User's Manual for PLOAD version 3.0 An ArcView GIS Tool to Calculate Nonpoint Sources of Pollution in Watershed and Stormwater Projects

Type	Document
Author	USEPA
Publisher	USEPA
Date	January 2001

Tags:

agricultural bacteria best management practice BMP buffer fecal water quality

Notes:

Event mean concentrations (EMCs) of many different land use types from many different studies are compiled in a set of tables. Typically 'agriculture' lumps cropland and pasture, but not in all cases.

Nitrogen and Phosphorus in Streams in Agricultural Watersheds

Type	Document
Author	USEPA
Publisher	USEPA
Date	2010 May 4

Tags:

agricultural nitrogen phosphorus

Notes:

The MPCA reports on nitrogen and phosphorus data in streams in 36 of the major river basins sampled by the National Water Quality Assessment (NAWQA) program of the U.S. Geological Survey. Data is general and not specific to types of agricultural practices or BMPs.

Evaluating the effectiveness of restored wetlands for reducing nutrient losses from agricultural watersheds

Type	Magazine Article
Author	Van der Valk, Allan G.
Author	William G. Crumpton
Publication	Leopold Center for Sustainable Agriculture
Volume	13
Date	2004

Tags:

agricultural best management practice buffer conservation cover IA nitrogen nutrient management phosphorus tile wetland, constructed wetland, creation wetland, enhancement wetland, restoration

Notes:

Restored wetlands in the Iowa Great Lakes Watershed are evaluated for vegetation and nutrient removal from row crop runoff. Data is reported from a period of relative drought, which skews the results.

BIODEGRADATION OF TREATED POLYLACTIC ACID (PLA) UNDER ANAEROBIC CONDITIONS

Type	Journal Article
Author	Vargas, L. F.
Author	B. A. Welt
Author	A. Teixeira
Author	P. Pullammanappallil
Author	M. Balaban
Author	C. Beatty
Publication	American Society of Agricultural and Biological Engineers
Volume	52
Issue	3
Pages	1025-1030
Date	2009

Notes:

A study evaluating degradability of polylactic acid (plant derived plastic) in anaerobic condition and its potential for energy recovery from the degradation.

Corn production as affected by nitrogen application timing and tillage

Type	Journal Article
Author	J.A. Vetsch
Author	G.W. Randall
Publication	Agronomy Journal
Volume	96
Pages	502-509
Date	2004
Extra	Minnesota, Waseca

Tags:

agricultural best management practice BMP MN nitrogen No till / minimum till / strip till nutrient management Ridge Till Seasonal Till yield

Notes:

The purpose of this study was to determine the effects of tillage types and nitrogen application timing on corn production. The study took place in Minnesota at an experimental research site. The study appears to be thorough and locally relevant. Tillage practices tested include no tillage, strip-till, one-pass, and chisel plow. Nitrogen management applications include fall/in-row, spring/mid-row, and a control application.

Corn and soybean production as affected by tillage systems

Type	Journal Article
Author	J.A. Vetsch
Author	G.W. Randall
Author	J.A. Lamb
Publication	American Society of Agronomy
Volume	99
Pages	952-959
Date	2007
Extra	Minnesota, Waseca

Tags:

best management practice costs MN No till / minimum till / strip till Ridge Till Seasonal Till tile yield

Notes:

In this study, corn and soybean production is evaluated against various tillage systems: no-till, zone-till, strip-till, chisel plow, and spring field cultivate. This Minnesota study is thorough and appears valuable to consideration of tillage systems in Minnesota. Findings are expressed in terms of yield and economic return.

CONSERVATION INNOVATION GRANTS

Type	Document
Author	Jan Voit
Date	2007-2009
Short Title	Biannual Progress Report

Evaluation of soluble phosphorus loading from manure-applied fields under various spreading strategies

Type	Document
Author	M.T Walter
Author	E.S. Brooks
Author	T.S. Steenhuis
Author	C.A. Scott
Author	J. Boll
Publisher	Soil and Water Conservation Society
Date	2001

Tags:

nutrient management_timing soluble phosphorus

Notes:

This study supports earlier research by Walter that the timing and location of manure spreading strongly influences soluble phosphorus transport. The study was conducted through modeling using hydrologic model and an empirical model for soluble phosphorus concentration in runoff. The study shows the effects of historic soil phosphorus on the capacity for reductions in soluble phosphorus export to streams and shows soluble phosphorus export based on the timing and location (e.g. in hydrologically sensitive areas) of manure applications. The modeling approach is recognized as useful for relative rather than absolute quantities of soluble phosphorus delivery.

The Nature Conservatory: Protecting Nature. Preserving life.

Type	Presentation
Presenter	Kent Wamsley
Date	N.D.

Improving the function of Agriculture drainage ditches

Type	Presentation
Presenter	Kent Wamsley
Date	N.D.

Improving the Design of Agricultural Drainage Ditches

Type	Document
Author	Andy Ward
Author	Dan Mecklenburg
Date	N.D.
Short Title	Can ditches be self-maintaining?

A COMPARISON OF SINGLE-CELL AND MULTICELL CULVERTS FOR STREAM CROSSINGS

Type	Journal Article
Author	Rebecca S. Wargo
Author	Richard N. Weisman
Publication	Journal of the American Water Resource Association
Pages	989-995
Date	2006 August

Effects of a livestock manure windrow composting site with a fly ash pad surface and vegetative filter strip buffers on sediment, nitrate, and phosphorus losses with runoff

Type	Journal Article
Author	D.F. Webber
Author	S. K. Mickelson
Author	T.L. Richard
Author	H.K. Ahn
Publication	Journal of Soil and Water Conservation
Volume	64
Issue	2
Pages	163-171
Date	2009
Extra	Iowa, Ames

Tags:

agricultural best management practice buffer filter strip IA livestock access control livestock exclusion - fencing livestock riparian pasture manure and agricultural waste storage manure management nitrogen nutrient management phosphorus sediment

Notes:

This field study took place in Iowa. Manure composting with downstream vegetated filter strips are evaluated for treating sediment and nutrient losses in runoff. A fly ash composting pad surface was used and evaluated. A compost nutrient balance was analyzed to show chemical and physical conversion taking place during composting.

Nitrate and water present in and flowing from root-zone soil

Type	Journal Article
Author	D.A.J. Weed
Author	R.S. Kanwar
Publication	Journal of Environmental Quality
Volume	25
Pages	709-719
Date	1996
Extra	Iowa, Nashua

Tags:

best management practice IA mulch till nitrogen No till / minimum till / strip till Ridge Till tile

Notes:

This study took place at an experimental research site in Iowa. The study identified the effect of tillage and crop rotation on the amount of nitrogen and water present in the soil and subsurface drainage systems. Tillage and crop rotation were found to show only slight effects.

Agriculture's Contribution to Restoring Minnesota's Wetlands

Type	Document
Author	Barbara Weisman
Author	Chris Radatz
Publisher	The Minnesota Department of Agriculture and the Minnesota Farm Bureau Federation
Date	July 2007

Tags:

agricultural conservation cover MN wetland, enhancement wetland, restoration

Notes:

This is a factsheet put out by the Minnesota Department of Agriculture on the voluntary wetland restoration and protection that has occurred on private farmland in Minnesota. It appears to be updated through 2007.

Post-CRP Management Options & Issues

Type	Document
Author	Weisman, Barbara
Date	2011 June 14

Tags:

MN

Notes:

A fact sheet describing management options for post-CRP land.

Effects of controlled drainage on N and P losses and N dynamics in a loamy sand with spring crops

Type	Journal Article
Author	Ingrid Wesstrom
Author	Ingmar Messing
Publication	Agricultural Water Management
Volume	87
Pages	229-240
Date	2007

The effects of controlled drainage on subsurface outflow from level agricultural fields

Type	Journal Article
Author	Ingrid Wesstrom
Author	Gunnar Ekbohm
Author	Harry Linner
Author	Ingmar Messing
Publication	Hydrological Processes

Volume 17
Pages 1525-1538
Date 2003

Controlled drainage - effects on drain out¯ow and water quality

Type Journal Article
Author Ingrid Wesstrom
Author Ingmar Messing
Author Harry Linner,
Author Jan Lindstrom
Publication Agricultural Water Management
Volume 47
Pages 85-100
Date 2001

SWINE-LAGOON SEEPAGE IN SANDY SOIL

Type Journal Article
Author p. W. Westerman
Author R. L. Huffman
Author J. S. Feng
Publication American Society of Agricultural Engineers
Volume 38
Issue 6
Pages 1749-1760
Date 1995

Responses of Spring Wheat and Soybean to Subsurface Drainage in Northwest Minnesota

Type Journal Article
Author J. J. Wiersma
Author G. R. Sands
Author H. J. Kandel
Author A. K. Rendahl
Author C. X. Jin
Author B. J. Hansen
Publication Agronomy Journal
Volume 102
Issue 5
Pages 1399-1406
Date 2010

Identifying sediment sources in the Minnesota River Basin

Type Journal Article
Author Peter Wilcock
Date 2010 August 10

Climate change mitigation for agriculture: water quality benefits and costs

Type Journal Article
Author Robert Wilcock
Author Sandy Elliott
Author Neale Hudson
Author Stephanie Parkyn
Publication Water Science & Technology
Volume 58
Issue 11
Pages 2093-2099
Date 2008

Four steps to rotational grazing

Type Document
Author J. Craig Williams
Author Marvin H. Hall
Publisher Penn State University
Date 1994

Tags:

agricultural rotational grazing

Notes:

This is a guidance document that came out of the Penn State College of Agricultural Sciences, Cooperative Extension. The goal of the guidance is to estimate acreage required for forage needs and paddock capacity in order to optimize pasture utilization and animal performance. The guidance does not explicitly indicate whether it's designed for water quality benefits.

Evaluations of alternative designs for surface tile inlets using prototype studies

Type	Document
Author	B.N. Wilson
Author	H.V. Nguyen
Author	U.V. Singh
Author	S. Morgan
Author	P. van Buren
Author	D. Mickelson
Author	E. Jahnke
Author	B. Hansen
Publisher	MDA
Date	1999

Notes:

This study assessed the trapping efficiency of two types of pipe systems (flush and slotted pipe) and three different sized aggregate materials (blind inlets) for trapping efficiency.

The most effective inlet was the finest aggregate blind inlet, with a d50 of about 12 mm or ½", of 95%. The other aggregates had trap efficiencies of 93 and 90%, with d50 sizes of about 13 and 16 mm, respectively. The slotted pipe had a trapping efficiency of 91.5%, while the flush pipe had an efficiency of 83.1%.

The surprisingly large efficiency of the flush pipe was an artifact of the incoming sediment load particle size distribution, which, with a d_{50} of 0.4 mm, likely had a large sand or aggregate content.

Conservation practices and gully erosion contributions in the Topashaw Canal watershed

Type	Journal Article
Author	G.V. Wilson
Author	F.D. Shields Jr.
Author	R.L. Bingner
Author	P. Reid-Rhoades
Author	D.A. DiCarlo
Author	S.M. Dabney
Publication	Journal of Soil and Water Conservation
Volume	63
Issue	6
Pages	420-429
Date	2008 November/December

Nitrogen balance in and export from agricultural fields associated with controlled drainage systems and denitrifying bioreactors

Type	Journal Article
Author	Krishna P. Woli
Author	Mark B. David
Author	Richard A. Cooke
Author	Gregory F. McIsaac
Author	Corey A. Mitchell
Publication	Ecological Engineering
Volume	36
Pages	1558-1566
Date	2010

Metamodeling Potential Nitrate Water Pollution in the Central United States

Type	Journal Article
Author	JunJie Wu
Author	Bruce A. Babcock
Publication	Journal of Environment Quality
Volume	28
Pages	1916-1928
Date	1999

Effectiveness of Vegetated Buffer Strips in Controlling Pollution from

Feedlot Runoff

Type	Journal Article
Author	R. A. Young
Author	T. Huntrods
Author	W. Anderson
Publication	Journal of Environmental Quality
Volume	9
Issue	3
Pages	483-487
Date	1980
Extra	Minnesota, Stevens County

Tags:

agricultural bacteria best management practice buffer contour buffer strips contour stripcropping fecal filter strip manure and agricultural waste storage manure management MN nitrogen nutrient management phosphorus sediment stripcropping vegetated treatment area

Notes:

This is a thorough water quality treatment study on cropped buffer strips receiving feedlot runoff. Many water quality constituents are monitored including water, sediment, nutrients, and bacteria.

Cost Effectiveness of agricultural BMPs for sediment reduction in the Mississippi Delta

Type	Journal Article
Author	Y. Yuan
Author	S.M. Dabney
Author	R.L. Bingner
Date	2002

Tags:

All BMPs costs sediment yield

Notes:

The AnnAGNPS 2.1 pollutant loading model was used to evaluate agricultural BMP sediment removal efficiency from a Mississippi River watershed in the state of Mississippi. Relative treatment efficiencies between BMPs is helpful information. In addition, a clear trend is exhibited in sediment yield reduction between no-till, conventional till, and reduced till practices. Each of these tillage practices were implemented in addition to one of the following BMPs: winter weeds, cover crop, filter strip, pipe, SB riser, impoundment, and various combinations of these.

Distribution of Pathogenic Indicator Bacteria in Structural Best Management Practices

Type	Journal Article
Author	X. Zhang
Author	M. Lulla
Publication	Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances & Environmental Engineering
Volume	41
Issue	8
Pages	1421-1436
Date	8/2006
Journal Abbr	Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances & Environmental Engineering
DOI	10.1080/10934520600753971
ISSN	1093-4529
URL	http://www.informaworld.com/openurl?genre=article&...
Accessed	Tuesday, July 05, 2011 3:11:12 PM
Library Catalog	CrossRef

Tags:

bacteria sediment sediment basin side inlet controls water/sediment control basin

Notes:

Vortechs structural best management practices were tested for bacteria distribution and survivability in sump water and sediments. The study took place in Rhode Island. The study showed that bacteria concentrations surged one day after rainfall ceased and that most of the bacteria were associated with smaller particles. The field conditions were more urban in nature, but results may be extractable for rural areas.

Evaluation of Pathogenic Indicator Bacteria in Structural Best

Management Practices

Type	Journal Article
Author	Xiaoqi Zhang
Author	Mukesh Lulla
Publication	Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances & Environmental Engineering
Volume	41
Issue	11
Pages	2483-2493
Date	11/2006
Journal Abbr	Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances & Environmental Engineering
DOI	10.1080/10934520600927484
ISSN	1093-4529
URL	http://www.informaworld.com/openurl?genre=article&...
Accessed	Tuesday, July 05, 2011 3:14:02 PM
Library Catalog	CrossRef

Tags:

bacteria sediment sediment basin side inlet controls water/sediment control basin

Notes:

Vortechs structural best management practices were tested for bacteria removal efficiency, re-suspension, and survivability. The study took place in Rhode Island. Bacteria resuspension was associated with sediment resuspension. The study showed partial removal of bacteria and low survivability in sump water. The field conditions were more urban in nature, but results may be extractable for rural areas.

Tillage and Nutrient Source Effects on Surface and Subsurface Water Quality at Corn Planting

Type	Journal Article
Author	Suling L. Zhao
Author	Satish C. Gupta
Author	David R. Huggins
Author	John F. Moncrief
Publication	Journal of Environmental Quality
Volume	30
Pages	998-1008
Date	2001

Notes:

A study in Lamberton, MN, on a clay loam soil simulating 75-year rainstorm. Four sets of treatments were compared using two tillage systems and two nutrient sources: Moldboard plow or ridge till, and urea or manure. NH_4^+-N, NO_3^-N, soluble P, and total P were measure from surface runoff and subsurface tile drainage.

Cost effectiveness of conservation practices in controlling water erosion in Iowa

Type	Journal Article
Author	X. Zhou
Author	M. Al-Kaisi
Author	M.J. Helmers
Publication	Soil & Tillage Research
Volume	106
Pages	71-78
Date	2009

Cost effectiveness of conservation practices in controlling water erosion in Iowa

Type	Journal Article
Author	X. Zhou
Author	M. Al-Kaisi
Author	M.J. Helmers
Publication	Soil & Tillage Research
Pages	71-78
Date	2009
DOI	10.1016/j.still.2009.09.015

Odor and aeration efficiency affected by solids in swine manure during post-aeration storage

Type	Journal Article

Author	J. Zhu
Author	Z Zhang
Author	C. Miller
Publication	Transactions of the American Society of Agricultural and Biological Engineers
Volume	51
Issue	1
Pages	293-300
Date	2008
Extra	Minnesota, Jackson County

Tags:

agricultural bacteria manure and agricultural waste storage MN

Notes:

This is about odor-free storage of manure. It's not exactly related to water quality.

Are you covered? Stop soil erosion on canning crop acres

Type	Document
Author	Mark Zumwinkle
Publisher	MDA
Date	2005 March

Tags:

MN

Notes:

A factsheet describing cover crops farmers can grow following the harvest of canning or row crops.

Living Mulch Literature Review

Type	Document
Author	Zumwinkle, Mark
Publisher	MDA
Date	N.D.

Tags:

mulch till

Notes:

This is research done by the MDA, Mark Zumwinkle. It appears to be thorough and well researched. A kind of all-you-need-to-know about mulch till. However, findings are buried in a lot of narrative.