F1. Reducing Cropland Nitrogen Losses to Surface Waters

Author: Dave Wall, MPCA

Technical support from: William Lazarus, David J. Mulla, Geoffrie Kraemer, and Karina Fabrizi (University of Minnesota)

Minnesota is one of a dozen states in the Mississippi River Basin developing a state-level action strategy to achieve and track measureable progress for reducing point and nonpoint nutrient losses. The strategy is driven by a need to reduce Minnesota's contribution of nitrogen (N) and phosphorus pollution to downstream waters such as the Gulf of Mexico and Lake Winnipeg, as well as in-state nutrient reduction needs to protect and improve Minnesota waters from excess nutrients. The strategy, when complete, is expected to identify how far we are progressing with current programs and efforts, and identify ways to reach milestone goals and targets. Scientific assessments are being used to develop priorities, targets, monitoring strategies, and ways to use existing and new programs to continue making long-term progress in reducing nutrient losses.

The strategy development effort is designed to align goals, identify the most promising strategies, and ensure that collective activities around the state are working to achieve our goals. The strategy will be used by agencies and organizations to focus and adjust state-level and regional programs, and will be considered by watershed managers and local water planners to translate ideas and priorities into effective local best management practice (BMP) implementation. In support of the Nutrient Reduction Strategy development, Minnesota is examining recently completed reports and tools estimating N load reductions from BMP adoption. Findings from these efforts are described for cropland sources in this chapter and for wastewater point sources in Chapter F2. The primary purposes of these two chapters are to consider the level of N reduction that can be achieved by individual BMPs and combinations of BMPs adopted on lands suitable for the practices.

This chapter is organized in the following sequence:

- Nitrogen reduction from individual BMPs and conservation practices adopted on treated acreages (i.e. percent reductions on a single field with the applied BMP).
- Statewide adoption scenarios for single practices if adopted everywhere suitable for the practice in the entire state.
- Nitrogen reduction expected from adopting multiple practices on land suitable for each BMP. More specifically, the following are evaluated:
    - BMP adoption levels needed to achieve a 30% and 45% reduction from cropland sources statewide.
    - BMP adoption levels needed to achieve 15% and 25% reductions from cropland sources in representative HUC8 watersheds located in different regions of southern Minnesota.

Where possible, we compared Minnesota results with results developed by Iowa State University, which used a different analytical approach than the Minnesota work.

Best management practices for nitrogen reduction

Best management practices and conservation practices are collectively referred to in this chapter as either “BMPs” or “Practices.” Four documents developed in 2012-13 summarize the effects of agricultural BMPs for reducing N to waters: 1) Minnesota BMP Handbook; 2) Nitrogen Fertilizer Management Plan; 3) University of Minnesota literature review; and 4) Iowa State University literature review.

Minnesota best management practice handbook

Miller et al. (2012) completed a Minnesota Agricultural Best Management Practice (BMP) handbook, which describes different BMPs and associated research findings concerning the effect that individual (BMPs) can be expected to have on reducing pollutants to surface waters, including N loads. The BMP Handbook can be found at:
www.eorinc.com/documents/AG-BMPHandbookforMN_09_2012.pdf

Nitrogen fertilizer management plan

The Minnesota Nitrogen Fertilizer Management Plan (NFMP) was written by the Minnesota Department of Agriculture. The NFMP describes and references Minnesota’s cropland N BMPs for groundwater protection, as required and defined in Minn. Stat. 103H.151. Fertilizer management BMPs for groundwater protection are also important for protecting surface waters, since a large fraction of surface water N comes from groundwater and saturated soils below cropland (see Chapters D1 and D4). While the NFMP focusses on groundwater protection, widespread adoption of the BMPs in the plan would be expected to result in considerable reductions of N into surface waters. The NFMP, which was still in draft at the time of this writing, can be found at
www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan.aspx

Literature review by Fabrizzi and Mulla (2012)

Several BMPs can be used either individually or in combination with other BMPs to reduce N entering waters from cropland sources. Two recent efforts were specifically aimed at estimating effects of N BMPs on surface water protection from field studies and literature reviews. Each is described, starting with a Minnesota analysis, which is then followed by an Iowa review.

Fabrizzi and Mulla (2012) conducted a literature review of the primary BMPs which can be used for reducing N from cropland (see Appendix F1-1). These BMPs were classified by the authors into three broad categories of BMPs: 1) Hydrologic, 2) Nutrient Management, and 3) Landscape Diversification (Figure 1).

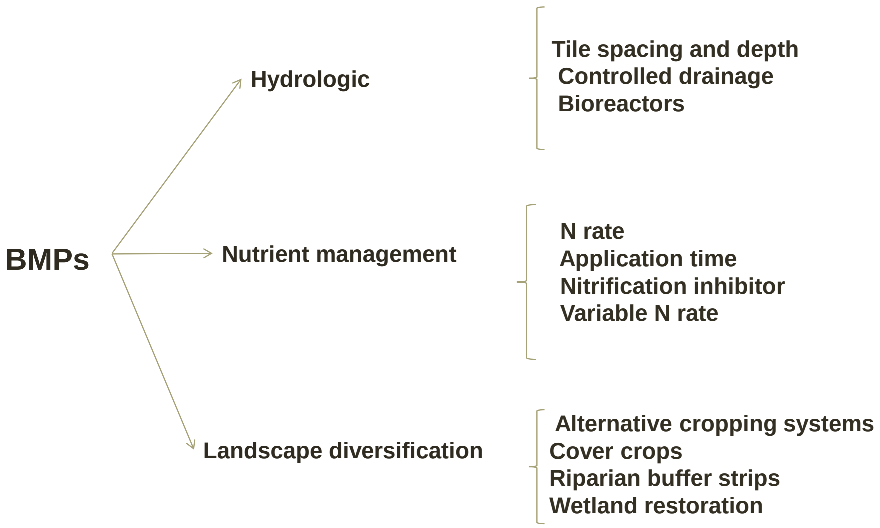

Figure 1. Categories of agricultural BMPs to reduce N loads as defined by Fabrizzi and Mulla (2012).

Table 1 shows the wide range in N reduction effectiveness from different BMPs. The results depend on many variables, such as climate, soils, research design, BMP design, baseline practices and conditions, etc. The wide range in N reductions shown in Table 1 is attributable to the fact that these results include findings from others states and from extreme climatic situations, and are not meant to represent average or typical removals. Lazarus et al. (2012) identified typical N removal percentages for these BMPs when implemented in Minnesota fields suitable for the individual BMP adoption. These results are shown in Table 1 as "N removal default in the NBMP spreadsheet." More information is provided on the NBMP spreadsheet later in this report, including background, assumptions, and how it can be downloaded from the Web.

Table 1. N reductions to waters in the tested/treated area as reported in a literature review by Fabrizzi and Mulla (2012) and compared with typical reduction rates used by Lazarus, Mulla et al., (2012) in the NBMP spreadsheet.

	Range in N reductions from literature review	N removal default in MN NBMP spreadsheet for treated areas	Notes for numbers with *
Tile depth and spacing	15-59%	NA	
Controlled drainage	14-96%	40%	
Bioreactors	10-99%	*13%	*Assumes 44% removal when fully treated, but only 30% of annual flow is treated
Reduced rates of application	11-70%	Varies by watershed and climate	
N application timing and inhibitors	10-58%	Varies by watershed and climate	
Wetlands	19-90%	50%	
Alternative cropping systems	5-98%	*95%	*Perennials replacing marginal land row crops
Riparian buffers	17-99%	*95%	*Perennials replacing row crops near waters
Cover crops	11-60%	*10%	*50% N leaching reduction when successfully established and 10% runoff N reduction. 20% establishment success rate assumed for MN average.

Other BMPs not included in Table 1 are continually being developed and improved. For example, saturated buffers established at field edges to treat tile drainage waters in the subsurface are currently being researched. Additionally, crop genetics research has improved the N use efficiency of crops, allowing farmers to harvest more crops for the same or less N fertilizer use (MDA, 2013). Enhanced fertilizers and other BMP improvements will likely continue to be developed.

Iowa literature review

Iowa recently completed an extensive review of Upper Midwest studies on the effectiveness of N removal when using various individual and collective BMPs. Their report, which was developed by a team of scientists from Iowa Universities led by Iowa State, can be found at www.nutrientstrategy.iastate.edu. Using a slightly different categorization scheme as Fabrizzi and Mulla (2012), Iowa evaluated three types of practices: 1) Nutrient Management, 2) Land Use, and 3) Edge of Field. Anticipated yield reductions or gains and BMP costs were evaluated in the Iowa study and are included in Iowa State University (2012).

The percent of nitrate reduction from each type of practice expected on fields potentially suitable for those practices in Iowa is summarized in Table 2. Similar to the Minnesota review, Iowa also found considerable variability in N reduction efficiency for individual types of practices described in the research literature. Energy crops, perennials, and buffer practices (e.g. changing from corn/soybeans to grasses or other perennials) had reasonably consistent nitrate reductions from study to study and field to field. However, most other practices had high standard deviations and coefficients of variation. All baseline assumptions and findings are reported in Iowa State University (2012).

Table 2. Iowa findings of BMP average nitrate reduction based on a review of research in the Upper Midwest (numbers extracted from Iowa State University, 2012). Reductions represent nitrate concentration reductions, except where noted as "load reduction."

Practice category	Practice	% Nitrate reduction from treated cropland
Change fertilizer timing	From fall to spring pre-plant	6
	From fall to spring pre-plant/sidedress 40-60 split	5
	From pre-plant application to sidedress	7
	From pre-plant to sidedress – soil test based	4
Change source from fertilizer to manure	From spring applied fertilizer to liquid swine manure	4
	From spring applied fertilizer to solid poultry litter	-3
Nitrogen application rate	From existing rates down to rates providing the maximum return to nitrogen value (133 lb/acre corn-soybean and 190 lb/acre on corn-corn)	10
Nitrification inhibitor	From fall applied without inhibitor to fall applied with Nitrapyrin	9
Cover crops	Rye cover crop on corn/soybean or corn/corn acres	31
	Oat cover crop on corn/soybean or corn/corn acres	28
Perennials	From spring applied fertilizer onto corn to perennial energy crops	72
	From spring-applied fertilizer onto corn to land in retirement (CRP)	85
Extended rotations	From continuous row crops to at least 2 years of alfalfa in a 4 or 5 year rotation (stateside estimates assume a doubling of current extended rotations)	42

Practice category	Practice	% Nitrate reduction from treated cropland
Tile drainage waters	Drainage water management – controlled drainage (nitrate load reduction)	33 (load reduction)
	Shallow drainage (nitrate load reduction)	32
	Wetland treatment (statewide estimate assumes 45% of row crops would drain to wetlands)	52
	Bioreactors (statewide estimate assumes bioreactors installed on all tile-drained acres)	43
	Buffers treating water that interacts with active zone below the buffer – load reductions depend on water amounts treated	91

Statewide adoption of individual best management practices

Nitrogen load reduction to waters estimates were made by Minnesota and Iowa for their respective states, while using different methods and assumptions. Iowa is similar enough to southern Minnesota that N reduction estimates from Iowa are included in this discussion for comparison purposes, although it should be noted that differences exist between Iowa and Minnesota climate, land uses, and amount of lands suitable for various BMPs. The climate, soils and landscape in the Red River Valley area are particularly different from Iowa.

Most of the practices can only be used under certain conditions, restricting suitable acreages across the state for each practice. Some examples of limitations include:

- Wetlands are best suited in areas of low slopes and high flow accumulation that were likely historic wetlands on the landscape.
- Controlled drainage is largely limited to tile-drained land with nearly flat slopes (i.e. less than 1% slopes).
- Bioreactors can only effectively treat limited quantities of water at a given time, and during high spring flows are less effective in removing nitrate.
- Climate can be a limiting factor for cover crops in certain areas.
- Changing timing of application from fall to spring is only applicable where fertilizer is currently being applied in the fall.

Because the BMPs for reducing N in waters only work in certain areas and situations, when we assess reductions across large watersheds, the capability of practices to reduce the percent of N loading to waters is not as high as for small areas where the BMP was used on all the land. For example, if a practice achieves a 50% N loss reduction to waters on the area where the BMP is applied, that practice adopted on suitable land throughout a watershed will result in less than a 50% N reduction in that watershed. In this section, we evaluate the adoption of individual BMPs if adopted on land assumed to be suitable for the BMP.

Uncertainties exist in the findings below for several reasons:

1. The literature review points to a wide range of BMP N reduction capabilities. The analyses below use average or representative values for N reduction to waters.

2. The results depend on the assumptions about which land is suitable for the BMPs. These assumptions can greatly affect the number of acres where the BMP can be adopted, and both Iowa and Minnesota use different assumptions about suitable acreages.
3. The N reduction estimates for certain BMPs, such as rate and timing of application, are dependent on the accuracy of the baseline assessments. Uncertainties exist concerning current fertilizer rates, particularly related to N crediting following manure applications.
4. The cost information is not static. Fertilizer costs, application costs, crop prices, and other factors vary from year to year.
5. There is uncertainty regarding the average nutrient reductions to groundwater which take place when adopting fertilizer rate reduction BMPs. Since groundwater can be a significant pathway of transporting nitrate to surface waters, uncertainty regarding leaching to groundwater can also affect the uncertainty of N reductions to surface water estimates.

Fortunately, we have research and survey information in Minnesota which narrows many of these uncertainties so that the final results are believed to provide an approximate estimate of large scale N reduction potential and associated costs. Each finding should be viewed as a rough estimate of the actual achievable reduction and the cost to achieve such reductions.

Iowa statewide adoption of individual best management practices

To support Iowa's Nutrient Reduction Strategy, scientists from Iowa universities estimated the likely nitrate load reductions to state waters which could be achieved through adoption of individual BMPs across the state on all land suitable for the particular BMPs (Table 3). The results show a wide range in estimated effects, from a 28% reduction for cover crops, down to a 0.1% reduction by changing fertilizer timing from fall to spring. The methods and assumptions are described in a report by Iowa State University (2012).

Table 3. Iowa findings of BMP N removal based on a review of research in the upper Midwest (numbers extracted from Iowa State University, 2012) and applied to land suited for those BMPs in Iowa. Negative costs represent a net dollar savings.

		% Nitrate reduction in treated area	Iowa statewide % nitrate reduction*	Cost $ per pound of N reduced
Change fertilizer timing	From fall to spring pre-plant	6	0.1	*
	From pre-plant application to sidedress	7	4	0.00
Nitrogen application rate	From existing rates down to rates providing the maximum return to nitrogen value (133 lb/acre corn-soybean and 190 lb/acre on corn-corn)	10	9	-0.58
Nitrification inhibitor	From fall applied without inhibitor to fall applied with nitrapyrin	9	1	-1.53
Cover crops	Rye cover crop on CS or CC acres	31	28	5.96
	Oat cover crop on CS or CC acres	28		
Perennials	From spring applied fertilizer onto corn to perennial energy crops (statewide estimate assumes 1987 levels of pasture/hay converted to Energy Crops)	72	18	21.46

		% Nitrate reduction in treated area	Iowa statewide % nitrate reduction*	Cost $ per pound of N reduced
Extended rotations	From continuous row crops to at least 2 years of alfalfa in a 4 or 5 year rotation (statewide estimates assume a doubling of current extended rotations)	42	3	2.70
Tile drainage waters	Drainage Water Management – controlled drainage	33	2	1.29
	Wetland treatment (statewide estimate assumes 45% of row crops would drain to wetlands)	52	22	1.38
	Bioreactors (statewide estimate assumes bioreactors installed on all tile-drained acres)	43	18	0.92
Buffers	Buffers treating water that interacts with active zone below the buffer	91	7	1.91

*Statewide percent reductions are lower than reductions at the place of adoption since statewide adoption estimates assume that the BMP cannot be used on all lands, but only on lands suitable for the BMP.

Iowa concluded that no single practice would achieve the hypoxia nutrient reduction goals (unless major land use changes occurred), but that a combination of practices would be needed to meet long term goals.

In Iowa, the N management practices which seem to be the most promising for nitrate reductions to waters are reduced N application rate and planting cover crops. Iowa estimated average N application to a corn following soybeans to be 151 pounds/acre, which compares to 133 pounds BMP rate (maximum return to N assuming$5.00/bushel corn and $0.50/pound N). Average N application rate to corn following corn was 201 pounds/acre, which compares to a 190 pound BMP rate. A 9% nitrate reduction to waters was estimated for the entire state of Iowa if fertilizer rate reductions were to occur on all corn ground. If rye cover crops were planted on all corn and soybean acres, an estimated 28% statewide nitrate reduction is estimated from this practice alone. Other BMPs also showed promise in reducing nitrate, including wetland treatment (22% reduction statewide), bioreactors (18% reduction statewide), and side-dressing N rather than spring pre-plant N (4% reduction statewide).

The researchers at Iowa State University concluded that there is limited potential for nitrate reduction with several other BMPs. Controlled drainage adoption is limited by the land area suitable for this practice (slopes less than 1%). Switching all fall applied fertilizer to spring (without a corresponding decrease in rate) showed little potential for nitrate reduction in the Iowa study.

Changes to perennial vegetation can result in dramatic reductions where adopted, but the level of reduction is dependent on the overall amount of land converted to perennial based systems. The cost per pound of nitrate reduced was found to be particularly high for land converting from row crops to perennial energy crops under the current market and subsidy framework, but was considerably lower for extended rotations.

Minnesota statewide adoption of individual best management practices

To evaluate the expected N reductions to Minnesota waters from individual practices adopted on all land statewide where the practice is suitable for adoption, we used the Nitrogen Best Management Practice watershed planning tool (NBMP or NBMP.xlsm). The NBMP spreadsheet was developed by the University of Minnesota (William Lazarus, David Mulla,et al.) to enable water resource planners developing either state-level or watershed-level N reduction strategies to gauge the potential for reducing N loads to surface waters from cropland, and to assess the potential costs of achieving various reduction goals. The tool merges information on N reduction with landscape adoption limitations and economics. The tool allows water resource managers and planners to approximate the percent reduction of N entering surface waters when either a single BMP or a suite of BMPs is adopted at specified levels across the watershed. The tool also enables the user to identify which BMPs will be most cost-effective for achieving N reductions.

NBMP spreadsheet background

NBMP compares the effectiveness and cost of BMPs that could be implemented to reduce N load entering surface waters from cropland in a watershed. The spreadsheet was not designed for individual land owner decisions, but rather for larger scale watershed or state level assessments. The NBMP.xlsm spreadsheet can be downloaded z.umn.edu/nbmp and more information about the development and use of the spreadsheet is found at faculty.apec.umn.edu/wlazarus/documents/nbmp_overview.pdf.

The spreadsheet contains data for 17 individual watersheds and for Minnesota as a whole. The watersheds that can be assessed individually with the tool at this time include 15 HUC8 watersheds which have high N loading, plus two HUC10 watersheds - Elm Creek and Rush River. The fifteen HUC8 watersheds include the: Lower Minnesota River, Minnesota River – Mankato, Blue Earth River, Le Sueur River, Minnesota River - Yellow Medicine River, Cannon River, Root River, Zumbro River, South Fork Crow River, Cedar River, Cottonwood River, Watonwan River, Des Moines River, Chippewa River, and North Fork Crow River.

The soil, crop, N loading data, and corn fertilizer response functions were provided by David Mulla as developed for work described in Chapter D4 of this report. Assumptions underlying the calculations, including land deemed suitable for each BMP are described in Table 4.

Table 4. Key assumptions in the NBMP spreadsheet for each N reduction practice (based on Lazarus et al. 2012 and personal communication with Lazarus 2013).

Nitrogen fertilizer rates and application timing
Current N rates based on 2010 statewide fertilizer use survey by University of Minnesota (Bierman et al., 2011) as compared to BMP rates based on current U of MN recommendations
U of MN recommendations vary by previous crop.
Corn acres include corn for grain and silage grown during a single year. Because soybeans are typically rotated with corn, the corn acreage during any one year is about half of the total corn/soybean acreage.
N fertilizer product prices vary. Farmer survey information was used to estimate the use of different types of fertilizer.
N fertilizer products change with the timing of application.
Solves for a point estimate of the profit-maximizing N rate based on the corn price and the N price (varies by application timing).
The point estimate of the profit-maximizing rate is increased for fall-application and reduced for spring preplant or sidedressing. Fall application rates were assumed to be 30 pound/acre higher than spring application rates.

The survey of current practices covered only non-manured land.

- Current N rates were adjusted assuming that farm operators are now taking credit for part of the estimated crop available N on manured land as follows:85% for swine, 75% for dairy, and 70% for poultry and beef.
- The manure N is credited in the BMP N rates.

The percent N load reduction to waters varies depending on current N application rate spatial averages for the agroecoregion.

Fall to spring preplant or prepland/sidedress

Switching from fall to spring/sidedressing reduces tile line N loading, but increases the N fertilizer price/pound and adds an extra fertilizer application cost.

This BMP only applies to corn grain and silage acres currently fertilized in the fall (based on farmer surveys as reported by Bierman et al. (2011)). “Sidedressing” here is actually a split application of spring preplant and sidedressing, with a default of 30% preplant and 70% sidedressed.

This BMP Only considers corn acreages for a single year, instead of using all land where corn is grown in the rotation.

The percent tile N load reduction varies between an average year, a wet year, and a dry year because the water volume in the tile line varies. The spreadsheet does not adjust N loading to waters from the surface runoff and groundwater pathways due to this timing BMP.

In a wet year, a percentage of the fertilizer N is lost and not available to the crop. Default is 10% less N available to the crop during the wet year.

Nitrification inhibitors are not a BMP option included with the version of the NBMP spreadsheet used for this analysis.

Riparian buffers

This data layer represents a 100 ft. buffer on either side of every stream on DNR’s 1:24,000 scale maps. It does not account for land that is already in a buffer condition; and therefore represents the maximum available land for buffering, not how much can be added to current buffers.

The annual cost per acre is based on an enterprise budget for a 10-year stand of switchgrass, not harvested.

Acres of buffers are assumed to come out of acres of corn and soybeans.

The N load from the buffer acres is assumed to be 5% of N loads from corn/soybeans.

Wetland restoration

Lands suitable for wetlands were assessed by first using a logistic regression model that utilizes the Compound Topographic Index (CTI) and hydric soil data to isolate areas of low slopes and high flow accumulation that were likely historic wetlands on the landscape. Once these areas are identified, the layer is further refined by intersecting likely historic wetlands with likely tile drained lands. These lands are isolated by finding Crop Data Layer 2009 crops that are likely drained (corn, beans, wheat, sugar beets) and intersecting them with poorly drained SSURGO soils and slopes of 0-3%.

Suitable acres are poorly drained soils with slopes 0-3% and crops that are likely to be drained.

Three types of land are involved: 1) Wetland pool (always flooded); 2) Grassed buffer around the pool that is sometimes flooded so is not available for crop production; and 3) Cropland that is treated by having its water flow into the wetland (assumes approximately 10:1 ratio of cropland to wetland/buffer area (9.87:1))

Costs considered include: 1) Establishment cost, related to the wetland pool and buffer acres annualized over the useful life of the wetland ; 2) Annual maintenance cost related to the pool and buffer acres, and 3) Opportunity cost of the crop returns lost on the pool and buffer acres.

A default 50% reduction in N loading is assumed on treated acres. The N loads on acres shifted to the wetland pool and grassed buffer are assumed to be zero.

Controlled drainage and bioreactors

This layer uses the likely tile drained land layer (poorly drained soils, 0-3% slope, and 2009 CDL corn, soybeans, wheat, or sugar beets). This layer is further refined with slopes using a 30 meter slope grid. The default is slopes less than 1%, on average. Suitable acres for controlled drainage can be adjusted to include an upper slope limit of 0.5% slope, 1% slope, or 2% slope [default is 1%].

Costs considered include an establishment cost, annualized over the useful life, and an annual maintenance cost, per treated acre.

For controlled drainage, a default 40% reduction is assumed in the tile line N load, with no change in leaching to groundwater and runoff N load. The tile line N load reduction can be changed by the user.

For tile line bioreactors, the tile line N load reduction in the treated flow varies based on loading density (treated acres/footprint), with a default of 44%. Only 30% of the drainage system water is assumed to be treated, however, due to factors such as spring overflow, so the default reduction is 13% of the overall tile line N load (44% times 30%).

Cover crops

Suitable acres include total of corn grain, corn silage, and soybean acres in the watershed.

Cover crops of cereal rye are seeded in September into standing corn and soybean crops, by air.

Only a percentage of the seeded acres achieve a successful stand. The default success rate is 20%.

A cost for a contact herbicide and custom application is included for the successfully-seeded acres.

The N loads in tile lines, leaching, and runoff are all reduced, but the runoff reduction is much less than the reductions in tile line and leaching N. On successfully-seeded acres, the tile line and leaching N loads are reduced by a default 50%, with a 10% reduction in the runoff N load. Considering the 20% success rate, the overall reductions/seeded acre are 10% for tile line and leaching N, with a 2% reduction in runoff N.

The corn yield is reduced by default on cover-cropped acres in a wet year, but not in an average year or a dry year.

Perennial energy crops

The default is “marginal land.” This is from a data layer that isolates National Land Cover Database (NLCD) 2006 cultivated land with Crop Productivity Index values of less than 60 to identify marginal cropland that be converted to perennial crops.

The annual net return/acre is based on an enterprise budget for a 10-year stand of switchgrass, with a user-specified crop price/ton. Default switchgrass price is $0.

Revenue losses from the previous crop are based on average crop yields for the agroecoregion – actual revenue loss is expected to be less than on average lands, where perennials are replacing other crops only on marginal cropland.

- If the grass price is high enough to cover the harvest cost, it is harvested and the net returns are based on the crop value minus an annualized establishment cost, annual maintenance cost, and harvesting cost.
- Otherwise, it is not harvested and the only costs are the annualized establishment cost and annual maintenance cost.

The N load from the perennial crop acres is assumed to be zero.

If the adoption rates entered for buffers, wetland treated acres, and perennial crops exceed total corn and soybean acres, the rates are reduced to equal that total, with the difference coming out of wetland or perennial crop acres, whichever is most costly.

The NBMP spreadsheet was designed so that effects of BMPs cannot be double counted. Since some of the BMPs affect the same acreage in a similar way when adoption rates are high, the spreadsheet only includes the most cost-effective practice(s) on the overlapping acreage.

The NBMP tool can be revised and assumptions changed as new information becomes available. We used a March 25, 2013, version of the spreadsheet to obtain most of the estimates described below, using the default assumptions, unless otherwise noted. Best management practice costs and other results are dependent on several variables which can and do change significantly over time (i.e. fertilizer prices, price of corn, price of equipment, etc.). Therefore, the reported cost estimates should not be viewed as a static number, but rather a number which will fluctuate over time. The results represent our best estimates at this point in time.

Additional BMPs exist for N reductions other than what are provided in the NBMP tool (i.e. tile spacing and depth, nitrification inhibitors, saturated buffers, etc.). The developers of the NBMP spreadsheet only included the BMPs which were believed to represent the combination of the most research-proven and effective BMPs for Minnesota waters at this time.

One BMP which can greatly reduce tile line nitrogen loads is installing tile drains at a shallower depth (i.e. 2.5 feet instead of 3.5 to 4.0 feet). This practice is not expected to reduce nitrate concentrations, but it can reduce the flow and thus reduce the load. The focus of this study was reducing nitrogen loads to surface waters from existing conditions. However, installation of shallower drain tiles should be considered for mitigating nitrogen losses to waters where new tile drains are installed.

Minnesota statewide estimates of nitrogen load reduction– from individual BMPs

We used the NBMP tool to estimate statewide N reductions for individual practices, if they were to be adopted on 100% of the suitable acreage in the state during an average precipitation year (Table 5). The most cost-effective BMPs include: optimal N rates, changing from fall to spring/preplant fertilizer timing, controlled drainage and wetland treatment. Since the acreages used for these BMPs would overlap in many cases, the cumulative potential reductions for the state cannot be determined by adding the individual BMPs in Table 5.

Table 5. Nitrogen reduction to waters estimated with the NBMP spreadsheet for individual BMPs, assuming adoption of the individual BMP on all suitable areas for the BMP in Minnesota and average precipitation conditions. A negative cost indicates a net savings.

N reduction BMP	N reduction to waters if adopted statewide (MN) on 100% of suitable acres	Cost - $ per pound of N reduced in water	Percent of land acres suitable for the BMP in a given year
Optimal N rates	9.8%	$-4.03	26.2%
Fall to spring N with lower rates	6.4%	$-0.67	10.5%
Fall to preplant/side-dressing with lower rates	6.7%	$1.41	10.5%
Wetland treatment	5.2%	$6.22	5.3%
Bioreactors	0.8%	$14.09	4.5%
Controlled drainage	2.3%	$2.35	4.5%
Riparian buffers – converting row crop to perennials	7.2%	$42.22	5.7%
Perennials – converting marginal row crops to perennials	11.1%	$38.24	8.3%
Cover crops	7.3%	$49.92	50.1%

The default for the NBMP spreadsheet for cover crops is a 20% successful establishment rate. If we were able to achieve a better average success rate, the potential to remove N would increase substantially. The NBMP tool shows that under a scenario of a 50% cover crop establishment success, the N reduction would increase from 7.3% to 18.3%. And if the cover crop establishment success were to increase to 75%, then the N reduction to waters statewide would increase to 27.4%.

The numbers change when using the BMPs during a wet or dry year (Table 6). For example, if fertilizer and manure N is lost due to a wet spring, the cost per pound of N reduced in waters increases for the wet year. The cost for wetland treatment per pound of N reduced decreases from $6 to $4 during a wet year. The cost for cover crops decreases during a wet year, from $49 to $30 per pound of N reduced.

Table 6. Comparison of wet (90th percentile annual precipitation), average and dry (10th percentile annual precipitation) year estimates of N reduction to waters if adopted on 100% of suitable acres in Minnesota, and the cost ($) per pound of N reduced in waters (rounded to nearest dollar). Wet year calculations assume a 10 percent loss of manure and fertilizer N due to additional denitrification and leaching.

N reduction BMP	Dry year N reduction (million lbs/year)	Average year N reduction (million lbs/year)	Wet year - N reduction (million lbs/year)	Dry year $ per pound of N reduced	Average year $ per pound of N reduced	Wet year - $ per pound of N reduced
Optimal N rates	11	21	27	-7.9	-3.9	-2.7
Fall to spring N with lower rates	8	14	17	-1	-0.5	-0.2
Fall to preplant/side-dressing with lower rates	8	15	18	3	1.6	1.7
Wetland treatment	4	12	21	19	6	4
Bioreactors	0.4	2	3	59	14	8
Controlled drainage	1	5	9	10	2	1
Riparian buffers – converting row crop to perennials	6	17	28	120	42	25
Perennials – converting marginal row crops to perennials	10	26	42	97	38	24
Cover crops	6	17	28	149	49	30

Comparing Iowa and Minnesota best management practice effects

Iowa and Minnesota have several similarities and differences regarding the N reduction and cost from individual BMPs applied to a given treated area or at the statewide scale (Table 7, Figures 2 and 3). Some of the differences are due to:

- Minnesota used GIS-based information to estimate land areas suitable for BMPs, whereas Iowa used a larger scale Major Land Resource Area approach;
- Several assumptions concerning the effectiveness of BMPs throughout the year were different between the states, based on differences in climate and other considerations; and
- Iowa focused on the subsurface pathways of N loss, whereas Minnesota also considered surface runoff pathways. This difference is relatively minor, since most N losses to surface waters occur through the subsurface.

Additionally, Minnesota and Iowa assumptions about the total number of acres that could be used for each individual BMP differed greatly. These differences were due to differences in assumptions and approaches used to determine suitable lands for each BMP, and due to real differences in land, landscape, and climate between the two states. The differences in statewide N reduction estimates in Table 7 can largely be explained by the above stated factors.

Table 7. Minnesota and Iowa estimates of percent N reduction in treated areas and collectively across the state on all lands deemed suitable for the BMPs (average precipitation years).

	N removal range in test area Fabrizi Mulla, 2012	MN NBMP reduction in BMP treated area (average precip yr)	Iowa average removal in BMP treated area	MN reduction statewide w/NBMP (average precip yr)	Iowa reduction statewide ISU, 2012	MN cost per lb N reduced in water (average precip yr)	Iowa cost per lb N reduced in water
	%	%	%	%	%	$/lb N	$/lb N
Tile line water							
Controlled drainage	14-96	44	33	2.3	2	2.30	1.29
Bioreactors	10-99	13*	43	0.8	18	14.09	0.92
Wetlands	19-90	50	52	5.3	22	6.09	1.38
N rates							
Reduced rates of application to MRTN	11-70	16	10	9.8	9	-3.92	-0.58
Timing of application							
Timing of application (general)	10-58						-
Preplant to sidedress			7		4		-
Fall to spring preplant			6		0.1		-
Fall to spring preplant with reduced rate		26		6.4		-0.53	
Fall to preplant / sidedress with reduced rates		29		6.7		1.60	
Fall with nitrification inhibitor	18		9		1		-1.53
Vegetation change							
Extended rotations			42		3		2.70
Alternative cropping systems	5-98						
Riparian buffers	17-99	95	91	7.2	7	42.22	1.91
Cover crops (rye)	11-60	10**	31	7.3	28	49.92	5.96
Perennials		95	72	11.1	18	38.24	21.46

*MN estimates assume that only 30 percent of the drainage into bioreactors is treated on an annual basis, reducing treatment from 44 to 13%.

**MN estimates assume that tile line and leached N is reduced by 50 percent in tile drained systems with cover crops, but that the establishment rate averages 20%, reducing the N removal rates to 10%.

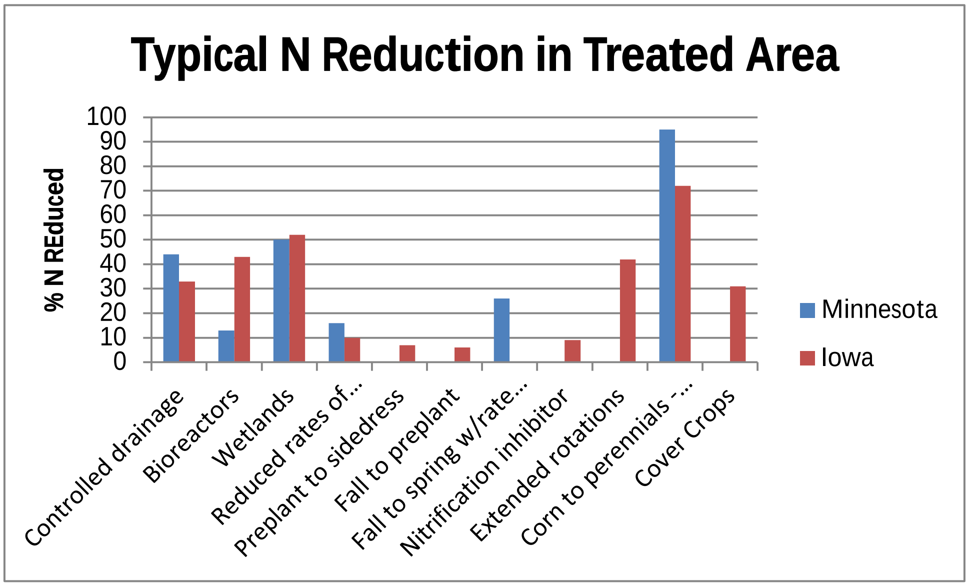

Figure 2. Minnesota and Iowa estimates of the average percent N load reduction in areas treated with the BMPs.

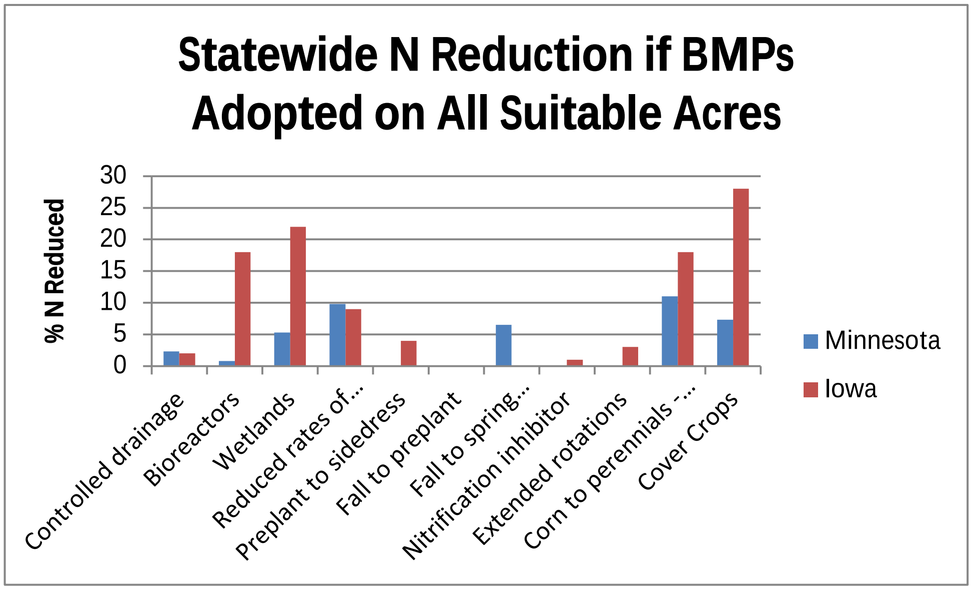

Figure 3. Minnesota and Iowa estimates of the average percent N load reduction statewide if the individual BMPs are adopted on all lands considered suitable for the BMP.

Both states consider that cover crops will reduce large quantities of N when successfully established. Iowa costs are much lower and N removal is much higher for cover crops. The higher Minnesota cost of cover crops compared to the Iowa estimates is largely due to the low assumed success rate (20%) in establishing cover crops in Minnesota. Climate is a factor, and additionally cover crops were assumed to be seeded by air in Minnesota while the Iowa costs assume seeding with a no-till drill after harvest. Aerial seeding requires a greater seeding rate and a higher seeding cost than the Iowa estimates assume. With increasing study of cover crops in Minnesota to develop better ways of more consistently establishing cover crops, the cost per pound of N reduced may potentially decrease. If Minnesota could successfully establish cover crops 75% of the time, the statewide N reduction to waters would be about the same as the Iowa estimates (28%).

Both states estimate a comparable level of treatment expected from controlled drainage BMPs, although Minnesota's estimates with this practice is slightly higher than Iowa. Both states estimate wetland treatment N removals near 50%, but Iowa assumes a higher ratio of cropland to wetland/buffer areas and Iowa determined that this BMP could be adopted in a larger fraction of the state than Minnesota estimates. Therefore the statewide N reduction estimates for wetlands are considerably lower in Minnesota.

Iowa estimates of N reduction from bioreactors is considerably higher than Minnesota estimates. Both states consider a similar average rate of reduction when bioreactors are treating tile waters (40-44% in Minnesota vs. 43% in Iowa), but Minnesota assumes that only 30% of the annual tile waters draining to bioreactors will be treated in a given year due to bioreactor limitations during high-flow seasons.

Both states indicate a similar level of statewide N reductions which can be achieved by reducing fertilizer rates to economically optimal rates. Minnesota estimates of cost savings per pound of N reduced to waters are considerably higher than Iowa estimates. Evaluation of this practice is highly dependent upon assumptions of: baseline conditions, price of corn, price of fertilizer, and climate.

Effects of changing fertilizer timing to closer to when crops need the nutrients are more pronounced in Minnesota estimates, especially in the fall to spring preplant scenario. Minnesota assumes a corresponding 30 pound N rate reduction in association with the change in timing, whereas Iowa did not assume a rate reduction with the change in fertilizer timing.

Iowa included an analysis of nitrification inhibitors, whereas the Minnesota NBMP analysis did not. Iowa assumes an average 9% nitrate reduction to waters on acres treated with inhibitors, but that overall statewide reductions to waters from inhibitors would only be 1%. Nitrification inhibitor use in Minnesota has been increasing during recent years. The Minnesota Department of Agriculture estimates use of inhibitors on over 1.2 million cropland acres in 2012, up from about 0.5 million acres in 2010 (Bruce Montgomery, personal communication).

Both states show reasonably similar N reduction expectations for riparian buffers and perennials. Minnesota's cost estimates are much higher for riparian buffers per pound of N reduced compared to Iowa, largely due to difference in the type of buffers being considered. Iowa focused on buffers which intercept shallow subsurface waters flowing toward the buffers, and therefore the treatment area for Iowa's buffers are larger than Minnesota estimates.

Statewide best management practices combinations needed for a 45% nitrogen reduction

Goals to reduce the Gulf of Mexico Hypoxic zone down to a 5,000 square kilometer area would require an estimated 45% reduction in N and phosphorus loads to the Gulf (see Chapter A2). Iowa and Minnesota used different methods and assumptions to arrive at estimates of BMP adoption levels (and associated costs) required to achieve a 45% N load reduction in surface waters.

Iowa State University (2012) developed several possible scenarios for Iowa to achieve 45% reductions from cropland (Table 8), equating to an overall 41% reduction of N loads from all sources. The scenarios have different up-front and annual costs for the BMPs. The scenarios represent hypothetical combinations of BMPs and do not necessarily represent the most optimal or achievable scenarios.

Table 8. Three Iowa BMP adoption scenarios predicted to achieve an estimated 45% nitrate-N loading reduction to Iowa surface waters from the cropland sources (adapted from Iowa State University, 2012).

	Initial cost (billion $)	Annual cost (billion $)
Scenario 1 · 100% agric. land with optimal N rate (maximum return to nitrogen) · 27% of agric. land draining into wetland treatment · 60% of tile drained land with bioreactor	3.2	0.76
Scenario 2 · 100% agric. land with optimal N rate (maximum return to N) · 95% of row crops with cover crops · 34% of agric. land in best-suited regions with wetlands · 5% of agric. land (additional) retired to perennial vegetation	1.2	1.2
Scenario 3 · 100% agric. land with optimal N rate (Maximum return to N) · 100% of fall N with nitrification inhibitor · 100% of spring N side-dressed · 70% of tiled land treated with bioreactor · 70% of suitable land with controlled drainage · 31.5% of agric. land draining into wetland treatment · 70% of agricultural streams with buffers	4.0	0.08

For Minnesota conditions, we used the NBMP tool previously described to estimate BMP adoption scenarios to achieve 30%, 35%, and 45% reductions for an average precipitation year (Table 9).

Both states show a very high level of BMP adoption needed to achieve a 45% load reduction. Minnesota estimates indicate that the 45% level of reduction is not achievable with current practices included in the NBMP spreadsheet, but could theoretically be achieved with future BMP improvements. Both Iowa and Minnesota show the cost range in billions of dollars to achieve N reductions at or approaching the 45% goal (Tables 8 and 9). The costs in Table 9 incorporate fertilizer savings, where savings are potentially achievable. Costs do not include government and private industry personnel costs to promote BMPs and assist with BMP implementation.

Table 9. Minnesota statewide BMP adoption levels estimated to achieve 30%, 35%, and 45% reductions of N into surface waters. Estimates were developed by using the Minnesota NBMP tool (Lazarus et al., 2012). Percentages of BMP adoption represent percentages of land well-suited for each BMP (i.e. 90% adoption – is 90% of land suitable for the BMP).

	% N reduction	Annual net cost billion $
30% reduction scenario · 90% corn land with optimal N rate (maximum return to N) · 45% fall N switched to spring; 45% fall N switched to preplant/sidedress · 70% of streams with riparian buffers growing perennial grasses 100 ft wide on each side of stream 80% (1.36 million acres) tiled land draining into wetland treatment and 10% into bioreactors · 70% of corn/soybean land with rye cover crop · 90% of suitable land with controlled drainage · 44% of all marginal cropland retired to perennial vegetation (all other marginal land was used for other lower cost BMPs)	30%	1.4
35% reduction scenario · 100% corn land with optimal N rate (maximum return to N) · 50% fall N switched to spring; other 50% fall N switched to preplant/sidedress · 100% of streams with riparian buffers growing 100 ft wide perennial grasses (1.7 mill. acres) · 80% (1.36 million acres) suitable tiled land draining into wetland treatment and 20% into bioreactors · 100% of corn/soybean land with rye cover crop (11.7 mill. acres) · 100% of suitable land with controlled drainage (1.34 mill. acres) · All marginal cropland retired to perennial vegetation (1.35 mill. acres)	35%	1.9
45% reduction scenario More development of BMPs is needed to achieve a 45% reduction. We cannot show a 45% statewide N reduction with the NBMP tool using the current assumptions and default values. We estimate that we can achieve a 45% reduction if we use the above 35% reduction scenario BMP adoption rates and additionally we modify the NBMP tool to assume: a) that we can find ways to improve establishment of cover crops, increasing from a 20% success rate to 60% success rate, and b) application rates to corn are reduced from 100% of optimal to 80% of optimal (80% of maximum return to N rate. With the better success of the cover crop establishment, the overall cost is reduced as compared to the 35% reduction scenario.	45%	*1.6

*this cost assumes that cover crop establishment success increases from 20% (current) to 60% (hypothetical)

To achieve the 35% reduction scenario, the N reduction BMPs would need to be applied to all cropland in the state that is suitable for the BMPs. Similar to Iowa's approach, the scenarios in Table 9 were not evaluated or considered for achievability, and we anticipate that the economic and social constraints would make these scenarios unrealistic at this time.

A 30% statewide N reduction to waters from cropland is theoretically achievable based the NBMP model results, but would require a very high adoption rate of optimal fertilizer management, tile drainage treatment and vegetation change BMPs. According to NBMP tool results, it appears that the first 13% N reduction to waters from cropland sources can potentially be made if optimal fertilizer/manure rate and timing BMPs are adopted on most (over 90%) of the state cropland (Figure 4). NBMP tool estimates indicate that this can be accomplished with a net cost savings (approximately $77 million) to producers during an average precipitation year, and a reduced savings during a wet year. The second tier of BMPs is tile drainage BMPs. An additional 5% N reduction to waters can be accomplished with a $73 million dollar annualized cost to install and maintain wetlands (80% of suitable acres), bioreactors (10% of suitable acres) and controlled drainage (90% of suitable acres). By changing or adding vegetation through another $1.4 billion annual investment, an additional 12% N reduction to waters can be accomplished. The vegetation changes to achieve the added 12% reduction include a rye cover crop on 70% of row crops; change existing crop to grasses on about 100 feet each side of 70% of the streams in the state; and change 44% of the other marginal croplands from corn to grasses. The costs of the vegetation changes are particularly sensitive to changing crop and fertilizer prices.

The N reduction potential and associated costs vary by watershed, and therefore the statewide numbers shown in Table 9 and Figure 4 are not applicable to individual watersheds.

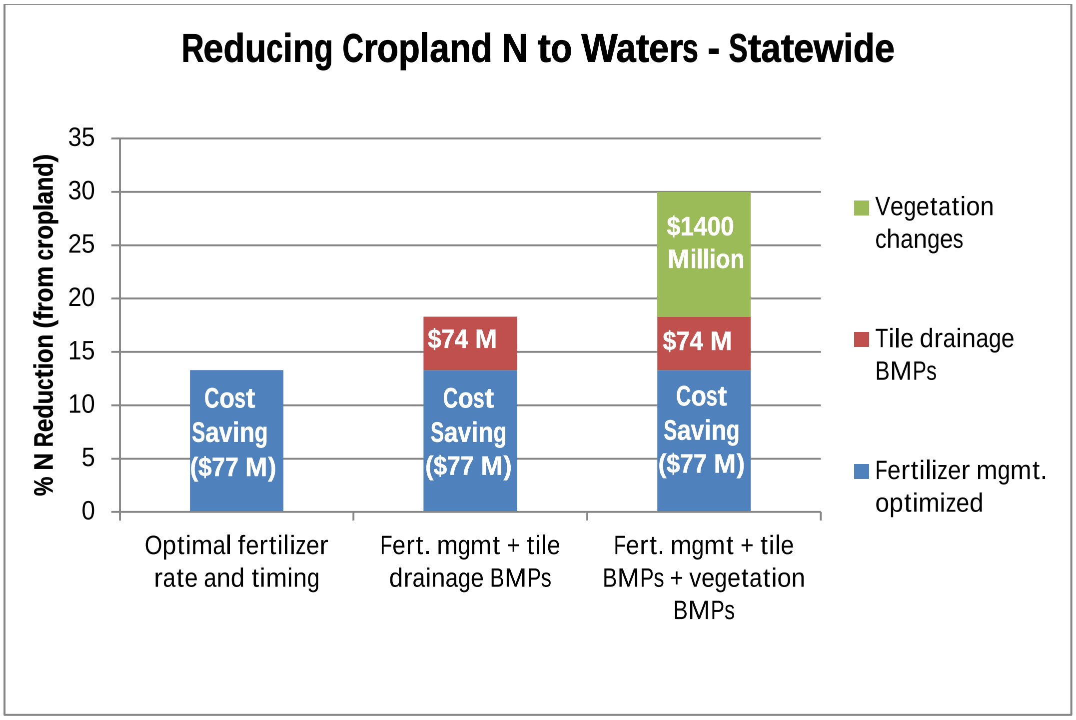

Figure 4. NBMP estimated Minnesota statewide N reductions to surface waters from cropland during an average precipitation year, using fertilizer management BMPs alone (left), fertilizer management with tile drainage BMPs (middle), and fertilizer management with both tile drainage and vegetation change BMPs (right). Cost estimates are incremental in millions of dollars annually calculated for conditions at the time of report writing and will change with fluctuating markets.

Watershed best management practice combinations to achieve 15% and 25% nitrogen load reductions

Since some BMPs are better suited for one region of the state over another, the N reduction potential and associated costs vary considerably across Minnesota. BMP adoption scenarios were developed separately for four watersheds using the NBMP tool, with the goal of showing potential scenarios for reducing watershed N load by approximately a) 15%, b) 25% and c) maximum reduction % under the adoption of BMPs as described in Tables 10-14. Numerous combinations of BMP adoption scenarios can be used to achieve the 15% and 25% reductions. The scenarios chosen below are weighted toward higher adoption of the more cost-effective BMPs at each site, but they are not completely cost-optimized. Each scenario includes a variety of BMPs, recognizing that different farmers will not all choose the same BMPs, and assuming that 100% adoption of any single BMP across a watershed is unrealistic. Nitrogen reduction BMP adoption scenarios for achieving 15% and 22% N load reductions in the Root River Watershed are shown in Table 10. The 25% reduction scenario could not be achieved in the Root River Watershed with 100% adoption of the listed BMPs.

Nitrogen reduction BMP adoption scenarios for achieving 15%, 25% and 38-39% N load reductions in the LeSueur River Watershed in south central Minnesota, Cottonwood Watershed in southwestern Minnesota, and North Fork Crow River Watershed in central Minnesota are shown in Tables 11, 12, and 13. To achieve the higher N load reductions, BMP adoption rates were greatly increased.

Table 10. Nitrogen reduction BMP adoption scenarios for achieving 15% and 22% N reductions in the Root River Watershed during an average precipitation year. All BMPs in the table combined must be adopted at the listed acreage amounts in order to achieve the 15 and 22% reductions.

Root River Watershed		**22% Maximum* N-reduction**	**25%**	**15%**
	Area of watershed suitable for BMP in a single year (% of watershed)	Acres treated with BMP during a given year to get 22% reduction	Acres treated with BMP during a given year to get 25% reduction	Acres treated with BMP during a given year to get a 15% reduction
Corn N rate reduced to optimal (from current avg. down to U of MN rec. avg. for a given year)	38.3	307,400	NA	261,300
Switch fall application to spring application and reduce rate 30 lb/acre (only on corn)	4.8	38,700	NA	31,000
Wetlands installed to treat tile line water (land draining into)	2.4	18,900	NA	5700
Bioreactors (land draining into)	1.4	11,200	NA	1100
Controlled drainage	1.4	11,200	NA	3900
Rye cover crop installed – (assumes 25% success rate for establishing cover crop)	58.6	391,800	NA	233,600
Marginal cropland planted to perennials	5.0	40,000	NA	2000
Avg. N reduced per watershed (million lbs/year)		3.1		2.1
Avg. cost per lb N reduced		7.4		5.0
Avg. annual net cost per watershed (million $/year)		22		10.4
Savings from fertilizer BMPs (million $/year)		+4		
Cost of tile drainage BMPs (million $/year)		0.6		
Cost of perennials and cover crops (million $/year)		26		

*Maximum reduction in NBMP tool with 100% adoption of the BMPs listed in this table.

Table 11. Nitrogen reduction BMP adoption scenarios for achieving 15%, 25% and 39% N reductions to surface waters in the LeSueur Watershed. All BMPs combined in the table must be adopted at the listed acreage amounts in order to achieve the 15%, 25% and 39% reductions.

LeSueur River Watershed		**39% *Maximum N-reduction**	**25%**	**15%**
	Area of watershed suitable for BMP in a single year (% of watershed)	Acres treated with BMP during a given year to achieve a 39% reduction	Acres treated with BMP during a given year to achieve a 25% reduction	Acres treated with BMP during a given year to achieve a 15% reduction
Corn N rate reduced to optimal (from current avg. down to U of MN rec. avg. for a given year)	49.3	274,300	225,000	205,800
Switch fall application to spring application and reduce rate 30 lb/acre (only on corn)	32.2	178,800	143,000	17,900
Wetlands installed to treat tile line water (acres draining into)	17.9	99,400	29,800	19,900
Bioreactors (acres draining into)	18.1	50,500	10,000	
Controlled drainage	18.1	50,500	30,300	
Rye cover crop installed – (assumes 25% success rate for establishing cover crop)	87.7	478,200	193,500	97,100
Marginal cropland planted to perennials	3.3	0 Marginal land used for other BMPs	900	
Avg. N reduced per watershed (million lbs/year)		3.3	2.1	1.3
Avg. cost per lb N reduced		$9.00	4.95	2.83
Avg. annual net cost per watershed (million $/year)		30	10.5	3.6
Savings from fertilizer BMPs (million $/year)		+4		
Cost of Tile drainage BMPs (million $/year)		6		
Cost of perennials and cover crops (million $/year)		27		

*Maximum reduction in NBMP tool with 100% adoption of the BMPs listed in this table.

Table 12. Nitrogen reduction BMP adoption scenarios for achieving 15%, 25% and 38% reductions to surface waters in the Cottonwood River Watershed All BMPs combined in the table must be adopted at the listed acreage amounts in order to achieve the 15%, 25% and 38% reductions.

Cottonwood River Watershed		**38% *Maximum N-reduction**	**25%**	**15%**
	Area of watershed suitable for BMP in a single year (% of watershed)	Acres treated with BMP during a given year to get 38% reduction	Acres treated with BMP during a given year to get 25% reduction	Acres treated with BMP during a given year to get a 15% reduction
Corn N rate reduced to optimal (from current avg. down to U of MN rec. avg. for a given year)	49.8	337,100	286,500	252,800
Switch fall application to spring application and reduce rate 30 lb/acre (only on corn)	27.6	186,700	140,000	26,100
Wetlands installed to treat tile line water (acres draining into)	12.0	78,200	32,600	16,300
Bioreactors (acres draining into)	11.5	38,900	7,800	
Controlled drainage	11.5	38,900	31,100	
Rye cover crop installed – (assumes 25% success rate for establishing cover crop)	92.2	591,400	247,800	124,500
Marginal cropland planted to perennials	3.7	25,300	1,300	
Avg. N reduced per watershed (million lbs/year)		2.6	1.7	1.0
Avg. cost per lb N reduced		$18.5	8.4	5.4
Avg. annual net cost per watershed (million $/year)		47	14.0	5.4
Savings from fertilizer BMPs (million $/year)		+3		
Cost of Tile drainage BMPs (million $/year)		6		
Cost of perennials and cover crops (million $/year)		44		

*Maximum reduction in NBMP tool with 100% adoption of the BMPs listed in this table.

Table 13. Nitrogen reduction BMP adoption scenarios for achieving 15%, 25% and 38% reductions to surface waters in the North Fork Crow River Watershed. All BMPs combined in the table must be adopted at the listed acreage amounts in order to achieve the 15%, 25% and 38% reductions.

North Fork Crow River Watershed		**38% *Maximum N-reduction**	**25%**	**15%**
	Area of watershed suitable for BMP in a single year (% of watershed)	Acres treated with BMP during a given year to get 38% reduction	Acres treated with BMP during a given year to get 25% reduction	Acres treated with BMP during a given year to get a 15% reduction
Corn N rate reduced to optimal (from current avg. down to U of MN rec. avg. for a given year)	33.6	196,900	177,200	161,500
Switch fall application to spring application and reduce rate 30 lb/acre (only on corn)	13.1	76,700	61,400	46,000
Wetlands installed to treat tile line water (acres draining into)	7.8	36,100	29,700	7,300
Bioreactors (acres draining into)	5.1	14,900	3000	
Controlled drainage	5.1	14,900	19,400	4500
Rye cover crop installed – (assumes 25% success rate for establishing cover crop)	58.3	260,000	210,200	50,600
Marginal cropland planted to perennials	13.4	78,400	15,700	3900
Avg. N reduced per watershed (million lbs/year)		25	1.3	0.8
Avg. cost per lb N reduced		23.4	13.7	3.51
Avg. annual net cost per watershed (million $/year)		47	18	2.8
Savings from fertilizer BMPs (million $/year)		+3		
Cost of Tile drainage BMPs (million $/year)		1		
Cost of perennials and cover crops (million $/year)		49		

*Maximum reduction in NBMP tool with 100% adoption of the BMPs listed in this table.

The costs per pound of N reduced increase significantly when achieving higher and higher N reductions (Figure 5). The first 10-20% reductions can largely be achieved with lower cost BMPs and cost-saving optimal fertilizer management BMPs. Further reductions can be achieved by increasing adoption of the more costly tile-drainage management and treatment BMPs. The last 7-20% reductions can be achieved by the most costly BMPs, which involve replacing row crops with perennial vegetation (on marginally productive soils) and establishing cover crops.

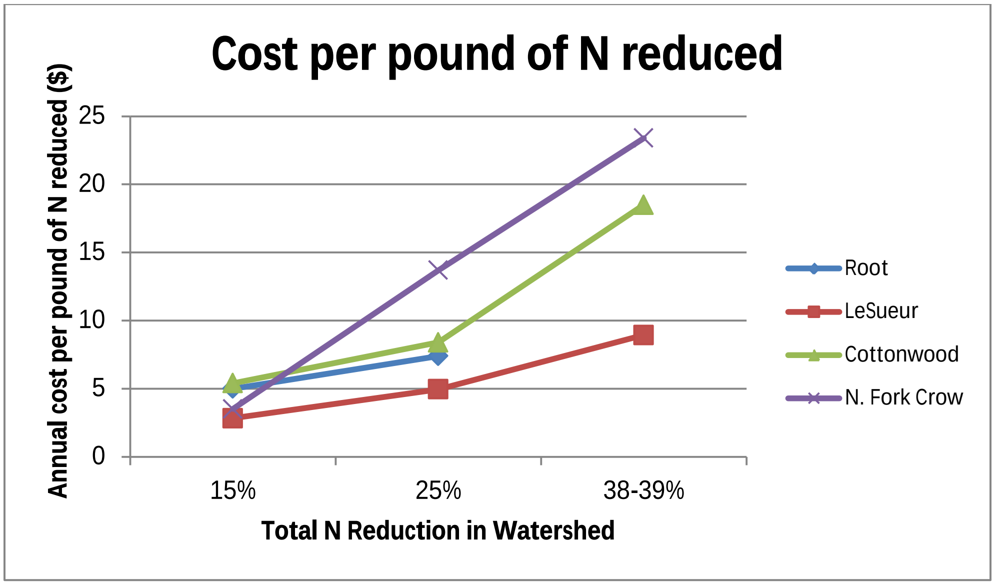

Figure 5. Average estimated net costs per pound of N reduced to waters from four watersheds when achieving N reduction goals of 15%, 25% and 38 to 39% (derived from NBMP tool as presented in Tables 10-13). The 25% reduction scenario for the Root River is actually a 22% reduction, since the 25% reduction could not be achieved with the selected BMPs.

The LeSueur and Cottonwood River Watersheds can achieve a higher estimated N reduction as compared to the Root River Watershed, according to NBMP tool results (Figure 6). This is partly due to a couple of key differences among the watersheds. The Root River Watershed has much less tile-drainage as compared to the other two watersheds, and therefore the BMPs to manage or treat tile-drainage cannot be implemented as much in the Root River Watershed. Additionally, there is little opportunity to switch from fall to spring fertilizer applications in the Root River Watershed, since most farmers in this region are currently applying fertilizer in the spring months. Farmers in the south-central and southwestern watersheds generally have more fall application.

Nitrification inhibitors are being used more frequently with fall applications in these areas to reduce N leaching losses in the fall and early spring months, and sales of these products more than doubled between 2010 and 2012 (personal communication with Bruce Montgomery, MDA). Nitrification inhibitors are not yet included as a BMP in the NBMP tool.

The North Fork of the Crow River can achieve N reduction percentages comparable to the LeSueur and Cottonwood Watersheds (Figure 6). But in order to achieve a 38% reduction in the North Fork of the Crow, a relatively large amount of marginal cropland (13% of the watershed) would need to be converted to perennial vegetation. More marginal cropland is available in this watershed as compared to the LeSueur and Cottonwood Watersheds.

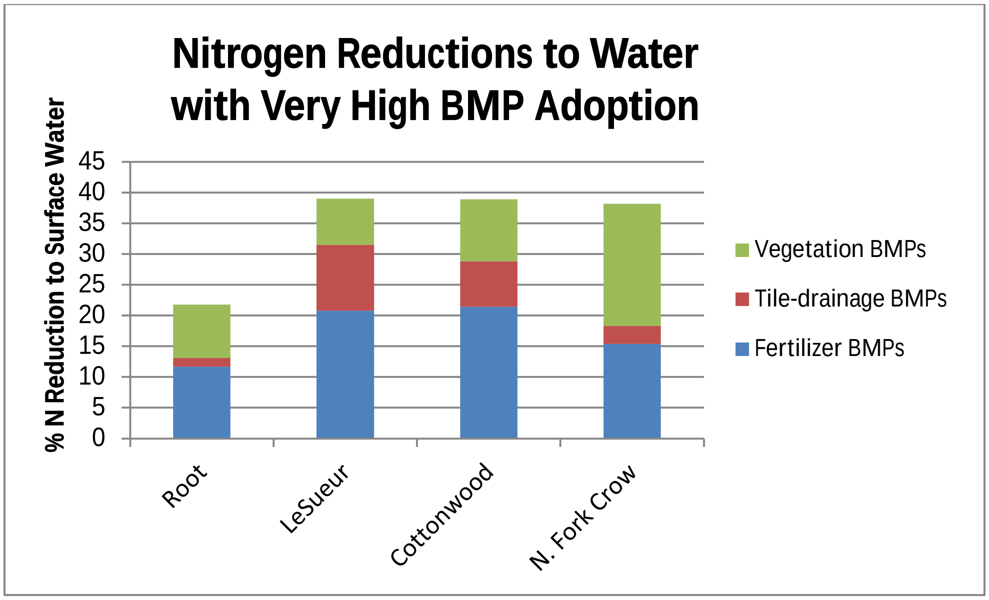

Figure 6. Nitrogen reductions to surface waters (%) in four watersheds which may be achieved by adopting BMPs on 100% of the suitable lands as shown in tables 10-13. The total percentage reduction and reductions from each of the three major BMP categories were estimated with the NBMP tool.

SPARROW model nitrogen reduction scenarios

The SPARROW modeling conducted for this study, as described in Chapter B4, was used to predict expected statewide delivered total nitrogen (TN) load reductions with different source reduction scenarios (Table 13). Based on these results, 30% reductions to both point source and fertilizers applied to land would result in an estimated 11.2% TN load reduction at the state borders. The agricultural fertilizer category does not include manure sources or any other agricultural N sources except for commercial fertilizer. Similar to results obtained from the NBMP spreadsheet, the SPARROW model scenarios suggest that statewide total N reductions in excess of 10 to 15% will be very difficult to achieve by only reducing N additions to soils.

Table 13. Estimated effects of statewide total N load reductions in streams with source reductions in agricultural fertilizer and urban point sources by 10%, 20% and 30% as estimated with the MRB SPARROW model.

	10% source reduction	20% source reduction	30% source reduction
Point source	-0.7% TN	-1.2% TN	-2.0% TN
Agricultural fertilizer	-3.1% TN	-6.1% TN	-9.2% TN
Total	-3.8% TN	-7.3% TN	-11.2% TN

Social constraints to cropland best management practice adoption

Based on farmer interview research conducted by Davenport and Olson (2012) in two highly agricultural and heavily tile-drained watersheds (Rush River and Elm Creek), certain BMPs have a greater acceptance by farmers than other BMPs (see report at Nitrogen Use and Determinants of Best Management Practices: A Study of Rush River and Elm Creek Agricultural Producers). While the Davenport and Olson study of farmer and resource manager viewpoints about N reduction BMPs was limited to two watersheds and a limited numbers of farmers, the results identified social constraints which may also exist in other areas. For example, planting perennial crops for energy or forage shows great promise for reducing nitrate losses, but is not popular due to economic constraints (i.e. current poor market for these crops). Planting riparian buffers along waters is a more accepted practice by farmers, but research shows that it takes large acreages to have a significant effect on reducing N loads. Economic considerations of BMP implementation were the most influential constraints to adoption, including considerations such as cost of the BMP, any associated loss of crop production, land values, and crop prices. Yet, agricultural producer decisions about their farms and BMP adoption are also affected by farm culture, knowledge (education), influence of agricultural professionals, and values such as stewardship, civic responsibility, and human health. Davenport and Olson concluded that the BMPs considered by the interviewed farmers to have the greatest likelihood of adoption at this time are buffer strips along waters, optimal rates as defined by the University of Minnesota, and cover crops.

More information about farmer nutrient management practices and considerations are described in Minnesota Department of Agriculture's Farm Nutrient Management Assessment Program reports found at www.mda.state.mn.us/protecting/soilprotection/fanmap.aspx

Discussion/conclusions

Information on cropland BMPs presented in this chapter can be considered for larger geographic scale planning purposes (i.e. HUC8 watersheds and larger), but is not intended for small scale strategy development. The potential reductions from BMPs and the costs to achieve those reductions are dependent on: a) the accuracy of baseline assumptions about N fertilizer rates/timing; b) accuracy of in-field N leaching and runoff estimates; c) accuracy of assumptions about land suitable for the BMPs; d) annual and regional climate variability; e) ability and willingness of farmers to manage and maintain the BMPs; and f) many other factors. Therefore all N reduction estimates and costs should be viewed as rough approximations for program planning purposes.

Scale of reductions

Based on Chapters B2 to B4, large portions of southern Minnesota contribute high N loads to surface waters (yields exceeding 10 pounds/acre), especially south-central Minnesota, but also portions of southeast and southwest Minnesota. A 45% reduction in the highest single HUC8 watershed in the state will only result in about a 3% loading reduction to state rivers. Little cumulative state-level progress will be made unless multiple watersheds (i.e. the top 10 to 20 N loading watersheds) all work to reduce N levels. Meaningful N reductions to surface waters at regional scales cannot be achieved by solely targeting small "hot spots" based on geologically sensitive areas or by targeting "bad actors."

Priority areas

At the state level, Minnesota will not make meaningful progress in reducing large-scale N loads unless BMPs are adopted on acreages where there is a combination of: high N sources to the land; a seasonally inefficient plant root system which allows considerable vertical movement of the source N; and a way of readily transporting the leached N to surface waters. This pertains mostly to row crops planted on tile-drained lands, but also includes row crops in the karst region and sandy soils.

Magnitude and cost of reductions

Based on the statewide results from the NBMP tool, up to an estimated 13% reduction in river N loads can potentially be achieved through widespread implementation of optimal fertilizer rate and timing practices. These results are similar to Iowa's estimated reductions from optimal fertilizer rates and timing BMPs. To achieve a 25% N load reduction statewide, a suite of more costly BMPs would also be needed (in addition to the optimal fertilizer rate/timing BMPs). The NBMP spreadsheet indicated that a

25% N loading reduction in Minnesota surface waters is theoretically achievable statewide under very high BMP adoption rates of a variety of field and off-field practices. The cost per pound of N reduced in waters varies from one part of the state to the other, and increases significantly in all watersheds when achieving 25% reductions as compared to 15% reductions. A 30 to 35% statewide reduction of cropland N losses to waters was projected to cost between 1 and 2 billion dollars per year with current crop prices and without further improvements in N reduction BMPs.

Reduction strategy considerations

- *Optimal in-field N management* - N reduction strategies should start by optimizing in-field nutrient management, including: fertilizer and manure rates, fertilizer types, timing of application or use of nitrification inhibitors, plant genetic improvements, etc. These types of practices can reduce N transport to waters significantly and typically have the least cost, potentially saving money in reduced fertilizer costs and/or increased crop yields. Many farmers are already using these BMPs, including use of nitrification inhibitors. Yet farmer survey results incorporated into the NBMP tool indicate that further reductions are potentially achievable, on average.
- *Multiple purpose BMPs* – While this study largely isolates N and N removal BMPs, we recognize that many BMPs provide other benefits apart from reducing N. Any evaluation of recommended practices to reduce N should consider the complete costs and benefits of the BMP. For example, BMPs such as constructed wetlands and controlled drainage could potentially help reduce peak river flows through temporary storage of water. Wetlands and riparian buffers have a potential to create wildlife habitat. Cover crops have added benefits of reducing wind and water erosion and potentially improving soil health. Nitrification inhibitors and spring/sidedress fertilizer applications can improve N use efficiency.
- *BMP combinations* – No single type of BMP is expected to achieve large scale measurable reductions in Minnesota River N levels. Instead, we will need to consider a sequential combination of BMPs which includes in-field nutrient management, tile drainage water treatment and management, and vegetation/landscape diversification. We have enough information to make progress in reducing N in waters with existing BMPs. With continued research and development, further N reductions may be more feasible in the future.
- *In-field alternative vegetation* – Several types of in-field vegetation can achieve large N reductions, including extended rotations involving perennials, cover crops, and perennial energy crops or grasses on marginal lands. It is particularly difficult to achieve N reductions of more than 10 to 15% in minimally-tiled watersheds unless in-field alternative vegetation BMPs are used.

    - Cover crops deserve further study in Minnesota due to the potential desirable effects of significantly reducing nitrate leaching, reducing phosphorus and sediment in runoff, reducing pesticides, and improving soil health. Yet the NBMP tool indicated that cover crops are a costly practice per pound of N reduced, and more work is needed to determine the best ways of seeding and managing cover crops in Minnesota's northern climate. If Minnesota can become more successful at establishing and managing cover crops (e.g. 50-75% success rate) this practice, if widely adopted, could reduce N in rivers by as much as 17-27%.

    - Perennial vegetation provides considerable N reductions to underlying groundwater and tile drainage waters. However, the crop revenue losses when converting row crops to perennials, especially during times of high grain prices, makes this practice less likely to be accepted on a widespread scale at this time. If more profitable markets open up for perennial energy crops or forage crops on marginally productive cropland, then this practice will be a more feasible part of N reduction strategies.

    - Converting riparian cropland to perennial buffers will not achieve substantial N reductions by filtering surface runoff, but this can be an effective practice to reduce N leaching on the land where the vegetation change occurs.

- *Tile drainage treatment and management* – Tile line water treatment BMPs are also part of the sequential combination of BMPs needed in many areas to achieve measurable N reductions to waters. Constructed wetlands should be considered in riparian and marginal lands, especially where multiple purpose benefits can be achieved through their use. Bioreactors were found to be more expensive (per pound of N reduced) than wetlands in the Minnesota evaluation, but could be more effective if improvements can be made to treat waters during high-flow times of the year. Bioreactors may be more acceptable in certain areas, such as upland areas where wetland treatment is less feasible. Care must be taken to ensure that BMPs relying on denitrification for N removal do not cause unintended consequences, such as release of metals in waters or greenhouse gasses to the atmosphere.

  One BMP which can greatly reduce tile line nitrogen loads is installing tile drains at a shallower depth. This BMP is not generally considered a BMP for reducing N loads from existing conditions, but it can be a preventative measure to reduce the increase of N loads to surface waters in areas where new tile drainage is installed.

Recommendations for further study

- Develop a cost/benefit planning tool which considers benefits of multiple purpose BMPs, so that planning decisions can be based on a more holistic approach to improving environmental and farm quality, rather than focusing on a single contaminant.
- Research and demonstrate ways to successfully and profitably establish and grow cover crops in Minnesota.
- Research and demonstrate ways to successfully and profitably grow perennial forage and energy crops which have low N losses to waters.
- Further our understanding of how to avoid unintended consequences of adopting BMPs.
- Continue efforts to understanding barriers to adoption of all types of BMPs by discussing with farmers and crop consultants. Refine the existing NBMP tool in the following ways:
    - Verify BMP installation and maintenance cost estimates where developed on limited information.
    - Update with new N fertilizer use surveys and land application of manure data, including how well manure is credited when determining fertilizer rates and current practices related to timing of application.
    - Add nitrification inhibitors as an added BMP option.
    - Continue to add BMP options to the spreadsheet when research demonstrates promising technologies.
    - Annually update default numbers to the latest fertilizer and crop prices.

- Continue researching improved ways of reducing N loads to surface waters. Saturated buffers show some promise but may need further research and demonstration.
- Continue to evaluate BMPs relying on denitrification processes (i.e. bioreactors and wetlands) to ensure prevention of unintended consequences.
- Evaluate the costs of the BMPs compared to the environmental costs without improvements. Consider full cost accounting studies.
- Conduct further analysis using the NBMP tool, testing its use at the watershed scale.

References

Bierman, P., C. Rosen, R. Venterea, and J. Lamb. 2011. Survey of nitrogen fertilizer use on corn in Minnesota. Minnesota Department of Agriculture. Summary Report. 24 pp.

Fabrizzi, K., and D. Mulla. "Effectiveness of Best Management Practices for Reductions in Nitrate Losses to Surface Waters In Midwestern U.S. Agriculture. Report submitted to the Minnesota Pollution Control Agency as part of a comprehensive report on nitrogen in Minnesota Surface Waters." September 2012. Appendix F1-1 to this report.

Iowa State University. 2012. Iowa Science Assessment of Nonpoint Source Practices to Reduce Nitrogen and Phosphorus Transport in the Mississippi River Basin. Draft July 2012. Section 2 of the Iowa Nutrient Reduction Strategy developed by Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and Iowa State University College of Agriculture and Life Sciences.

Lazarus, William, Geoff Kramer, David Mulla, and David Wall. 2012. Watershed Nitrogen Reduction Planning Tool (NBMP.xlsm) for Comparing the Economics of Practices to Reduce Watershed Nitrogen Loads. University of Minnesota, St. Paul. 49 pp.

Miller, T.P., J.R. Peterson, C.F. Lenhart, and Y. Nomura. 2012. The Agricultural BMP Handbook for Minnesota. Minnesota Department of Agriculture.