Watershed Nitrogen Reduction Planning Tool (NBMP.xlsm) for Comparing the Economics of Practices to Reduce Watershed Nitrogen Loads

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Introduction

The Watershed Nitrogen Reduction Planning Tool (file name NBMP.xlsm) Excel spreadsheet was developed under a contract between the Minnesota Pollution Control Agency and the University of Minnesota, as part of a comprehensive study of surface water nitrogen conditions, sources, pathways to waters, trends and solutions. The project purpose was to develop a framework for a watershed nitrogen planning aid that could be used to compare and optimize selection of "Best Management Practices" (BMPs) for reducing the nitrogen load from the highest contributing sources and pathways in a watershed. NBMP.xlsm is intended to serve as that framework. It compares the effectiveness and cost of potential BMPs that could be implemented to reduce the nitrogen load entering surface waters from cropland in a watershed.

This spreadsheet is intended for use by resource planners evaluating how nitrogen loads in the watershed can be reduced by a certain amount. Such resource planners would normally not be the crop producers who would actually be deciding whether or not to implement any of the practices listed. One use for the spreadsheet might be to help decide the levels of subsidies or other incentives to offer to the producers who would be making such implementation decisions.

The link to download the NBMP.xlsm spreadsheet is http://z.umn.edu/nbmp. You will be prompted to enter your contact information. In addition to NBMP.xlsm, that website also links to a separate FERTTIMING.xlsm spreadsheet contains detailed calculations of the economic impacts of shifting from fall application of nitrogen fertilizer to spring preplant or sidedressing applications.

Important note: NBMP.xlsm includes a number of macros and functions written in Excel's VBA programming language to help automate various calculations and to help navigate to different parts of the calculations, so clicking that button allows them to run. In order to run the NBMP.xlsm spreadsheet effectively, you will need to "enable macros" and have Excel Solver installed on your computer. If you were not prompted to "Enable Content" when you first open the spreadsheet, then you will need to

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change your "Macro Security" level to "Disable macros WITH notification". Then, save the spreadsheet and open it again, and this time enable macros at the prompt.

To install Solver, first save and close the NBMP.xlsm spreadsheet. Then select File, Options, and Add-ins in Excel. If you don't see "Solver Add-in" under Active Application Add-ins, make sure "Excel Add-ins" is showing in the "Manage:" box at the bottom, and click "Go...". Then, check the box next to "Solver Add-in" in the list of Add-ins available. Finally, re-open the NBMP.xlsm spreadsheet.

Excel 2013 is the version we use with these spreadsheet. Excel 2010 and 2007 will probably work, but no guarantees. Earlier versions of Excel than 2007 will definitely NOT work. It has NOT been tested on an Apple Macintosh computer.

Two geographic units that are important for users to understand when using the spreadsheet are watersheds and agroecoregions. The spreadsheet does its analysis for a watershed that the user selects. The spreadsheet contains data for 68 HUC8 watersheds and for Minnesota as a whole. It also contains data for the portions of the ten major river basins that at least partially in Minnesota as well as the part of the overall Mississippi River basin in Minnesota. The soil, crop, and nitrogen loading data in the spreadsheet are initially calculated for each of 36 separate agroecoregions. Agroecoregions are units having relatively homogeneous climate, soil and landscapes, and land use/land cover. Agroecoregions (referred to simply as “regions” below) can be associated with a specific set of soil and water resource concerns, and with a specific set of management practices to minimize the impact of land use activities on soil and water resource quality. A watershed typically includes parts of several regions. When the user selects a watershed for analysis, the spreadsheet retrieves the acres of each region in that particular watershed, along with the soil, crop, and nitrogen data for those regions. Three other agroecoregions contained in Minnesota are not included in this spreadsheet because they contained little cropland.

The soil, crop, and nitrogen loading data and the corn fertilizer response function were provided by David Mulla and his staff and are described in Mulla et al. (2012). The loading calculations can be found in chapter D4 of the main MPCA report “Nitrogen in Minnesota Surface Waters (wq-s6-26a)” linked from the MPCA website shown above. The MPCA’s analysis of possible reductions and costs using the NBMP.xlsm spreadsheet can be found in chapter F1. Other information came from various other sources that are listed in the “Sources” sheet of the spreadsheet and are discussed in more detail in the Appendix. More information about the sources is contained in a separate literature review section of the project final report (Fabrizzi, K. and D. Mulla, 2012). The spreadsheet is continually being improved over time, so the results from the current version will be slightly different from what is shown in that chapter. Probably the biggest change is that corn and soybean yields are now differentiated between marginal and non-marginal land in each agroecoregion, so replacing those crops with a perennial crop now appears less costly than in the earlier results, which were based on average yields in the agroecoregion.

Assumptions underlying the calculations are described in Tables 1 and 2 below.

The process for developing the spreadsheet was that first author Lazarus developed prototypes which were then reviewed by the project team at numerous meetings between late 2011 and 2014. Kramer contributed mainly to the drainage aspects including tile line bioreactor and controlled drainage components. Individuals involved in the development included Dave Wall (Minnesota Pollution Control Agency), David Mulla, Karina Fabrizzi, and Jacob Galzki (University of Minnesota Department of Soil, Water, and Climate), Geoff Kramer (Department of Biosystems and Bioproducts Engineering), Mae Davenport and Bjorn Olson (Department of Forest Resources), and Joshua Stamper (Minnesota Department of Agriculture).

The spreadsheet compares various individual practices and combinations of those practices against a baseline of current practices developed by Professor Mulla and his staff and discussed in (Mulla et al. 2012). The model is watershed-scale rather than farm-level. The practices considered in the model include:

1) Reducing the fertilizer N rate on corn grain and silage acres to a target N rate,
2) Including a nitrification inhibitor with fall N applications,
3) Switching fall N applications to spring preplant,
4) Switching fall N applications to a split spring replant and dressing application,
5) Restoring wetlands,
6) Installing tile line bioreactors,
7) Installing controlled drainage,
8) Installing saturated buffers,
9) Adding riparian buffers,
10) Planting a rye cover crop on corn grain, soybeans, small grains, peas, sweet corn, sugar beets, and/or dry edible beans, and
11) Planting a perennial crop on corn and soybean acres.

All possible combinations of those practices are compared in the model except that:

- A nitrification inhibitor is not used in combination with switching to spring or sidedressed N applications,
- Either spring preplant or sidedressing is only done in combination with reducing the N rate,
- Spring preplant is not combined with sidedressing except when combined with all of the other BMPs,
- Controlled drainage is not combined with bioreactors except when combined with all of the other BMPs,
- Restoring wetlands is not combined with planting a perennial crop except when combined with all of the other BMPs, and
- Perennial crops and bioreactors are included only by themselves or in combination with all of the BMPs together.

The individual practices plus the combinations add up to 198 total scenarios for comparison.

This document is organized into three sections. The first section contains two tables that summarize the many assumptions involved in the analysis. The section goes through the individual sheets of the spreadsheet and discusses key things to know about each sheet. The third section discusses the assumptions and calculations involved with each BMP in more detail.

Key Assumptions

Table 1. Assumptions Underlying the Suitable Acre Values Shown in Column E of the Spreadsheet

BMP	Suitable Acres
Corn Grain & Silage Acres Receiving the Target N Rate	Total corn grain and silage acres in the watershed during any given 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 inhibitor	Fall-applied corn N fertilizer not already applied with inhibitor. The N fertilizer rate/acre is kept the same as on fall-applied N not applied with inhibitor.
Fall N applications switched to spring, % of fall-app. Acres	Corn grain and silage acres currently fertilized in the fall in accordance with 2010 fertilizer survey. Only considers corn acreages for a single year, instead of using all land where corn is grown in the rotation.
Fall N applications switched to sidedressing, % of fall-app. Acres	Corn grain and silage acres currently fertilized in the fall ("sidedressing" here is actually a split application of spring preplant and sidedressing, with the shares entered in cell E55 of the "Fert timing" sheet. The default is 30% preplant and 70% sidedressed.)
Riparian Buffers	This data layer represents a 30 m buffer on either side of every stream on DNRs 1:24,000 scale maps. Land already in buffers is netted out of the suitable acres. The suitable acres are separated into marginal and nonmarginal land using the same Crop Productivity Index as for perennial crops, as discussed below. The marginal land is allocated to buffers first, and then nonmarginal land is allocated to reach the total treated acres.
Restored wetlands	This data layer first uses 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 CDL 2009 crops that are likely drained (corn, beans, wheat, and sugarbeets) and intersecting them with poorly drained SSURGO soils and slopes of 0-3%.
Controlled Drainage	This layer again uses the likely tile drained land layer (poorly drained soils, 0-3% slope, and 2009 CDL corn, soybeans, wheat, or sugarbeets). This layer is further refined with slopes using a 30m slope grid. The default is the average for slopes less than 1%, selected in cell C37. Slopes less than 2% and less than 0.5% can also be selected as alternative scenarios.
Rye cover crop	Acres of corn grain, soybeans, corn silage, wheat, barley, oats, sweet corn, peas, dry edible beans, sugar beets, and potatoes in the watershed.
Perennial Crops	The default is "Marginal land", as selected in cell B19. This is from a data layer that isolates NLCD 2006 cultivated land with Crop Productivity Index values of less than 60 to identify marginal cropland that could be converted to perennial crops. If "all corn & soy" is selected, this is all corn grain, corn

	silage, and soybean acres.

Table 2. Other Key Assumptions in the Watershed Nitrogen Planning Tool Spreadsheet

N fertilizer rates and application timing
Current N rates based on a 2010 statewide fertilizer use survey by University of Minnesota vs. BMP rates based on current U of MN recommendations, assuming a corn price of $4.50/bushel. N fertilizer ingredient prices are for $0.52/lb for NH3, $0.62/lb for urea, and $0.65/lb for 32% liquid N (see the N rate sheet.) Farmer survey information was used to estimate use of different types of N fertilizer.
U of MN recommendations vary by previous crop.
N fertilizer products vary by application timing. Fall applications are assumed to be NH3. Sidedressed applications are 32% liquid. Spring applications are mainly urea but with some NH3 depending on the region. See the "N Fertilizer Product Mix and Application Timing by Agroecoregion" section below for more details.
Target N fertilizer rates on corn are based on profit-maximizing point estimates calculated based on a yield response function from Mulla and on the corn and fertilizer prices listed above. Since Fall application rates were assumed to be 30 lb/acre higher than spring preplant and sidedressed application rates. The price differences between the different N fertilizer products cause the target rates for spring preplant and sidedressed application to be slightly less than fall applications. For the statewide scenario, the difference between fall and spring preplant is five pounds, and seven pounds between fall and sidedressing. In addition to those price-related differences, the fall rate is assumed to be 20 lb higher than the spring and sidedressed rate to make up for extra losses over the winter. That is, the fall-applied target rate is increased by an extra 5 lb (25% of the 20 lb difference) while the spring and sidedressed rates are and reduced by 15 lb (the other 75% of the 30 lb).
The survey of current practices covered only non-manured land, so … • Current N rates were adjusted assuming that farm operators are now taking credit for 50-70% of the estimated crop available N on manured land (See the Current sheet, cells B105:B109). • All of the manure is credited in the BMP N rates.
Switching from fall to spring or sidedressing reduces tile line N loading, but increases the N fertilizer price/lb and adds an extra fertilizer application cost.
The sidedressing BMP considered is actually a split of spring preplant and 30% sidedressing, NOT 100% sidedressing.
The percent N load reduction varies depending on current N application rate for the agroecoregion. The current version is based on 2010 fertilizer survey use data.
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.
In a wet year, a (user-specified) percentage of the fertilizer N is lost to the corn crop. The corn yield response function is kept the same for wet and dry years and the target N rate is kept the same, but since the amount fertilizer N actually reaching the crop is reduced in wet years by the lost amount, that reduces the corn yield predicted by the yield response function. The default wet year loss is 25%, and is entered in Main calcs!C20. See the graph below for a graphical representation.
Riparian Buffers
The annual cost/A 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 zero.
Suitable acres are poorly drained soils with slopes 0-3% and crops that are likely to be drained.

Table 2 (continued)

Wetland Restoration
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 3) Cropland that is treated by having its water flow into the wetland Costs considered include: 1) Establishment cost, annualized over the useful life, related to the wetland pool and buffer acres 2) Annual maintenance cost related to the pool and buffer acres 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
Suitable acres for controlled drainage can be set at up to 0.5% slope, 1% slope, or 2% slope. [default is 1%] Suitable acres for bioreactors are set at up to 1% slope.
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 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 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%). The 30% default is from Stock (Strock 2012).
Cover Crops
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.

Table 2 (continued)

Perennial Energy Crops
Suitable acres can be based either on marginal cropland (Crop Productivity Index < 60), or all corn and soybean acres.
The annual return/acre is based on an enterprise budget for a 10-year stand of switchgrass, with a user-specified crop price/ton. The price/ton default is zero, since no biomass energy processing plants are currently operating in Minnesota. "Net return/acre" is defined in general as the switchgrass market revenue/acre (price times yield) for energy minus the annualized establishment costs (seed, fertilizer, chemicals, machinery, and labor) amortized over the assumed ten-year stand life AND minus costs to harvest and transport to a processing plant IF AND ONLY IF the crop market revenue is sufficient to cover the harvest and transport costs. • If the grass price is high enough to cover the harvest cost, it is assumed to be harvested and the net returns are based on the crop value minus an annualized establishment cost, annual maintenance cost, and harvesting and transport cost. The processing plant is assumed to be 25 miles from the field. • Otherwise, it is not harvested and the only costs are the annualized establishment cost and annual maintenance cost. If the crop price is set to zero (the default) or a level too low to cover harvesting and transport costs, the crop is assumed not to be harvested. In that case, the annual net revenue/acre is set equal to the negative of the annualized establishment cost ONLY.
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. See the "Interactions between acres of riparian buffers, perennial crops, and wetlands" section below for more details.
Corn and soybean yields on marginal land are assumed to be 67% of yields on non-marginal land in each region. Costs of shifting this marginal land to a perennial crop are based on the lost corn and soybean income calculated at these lower marginal land yields.

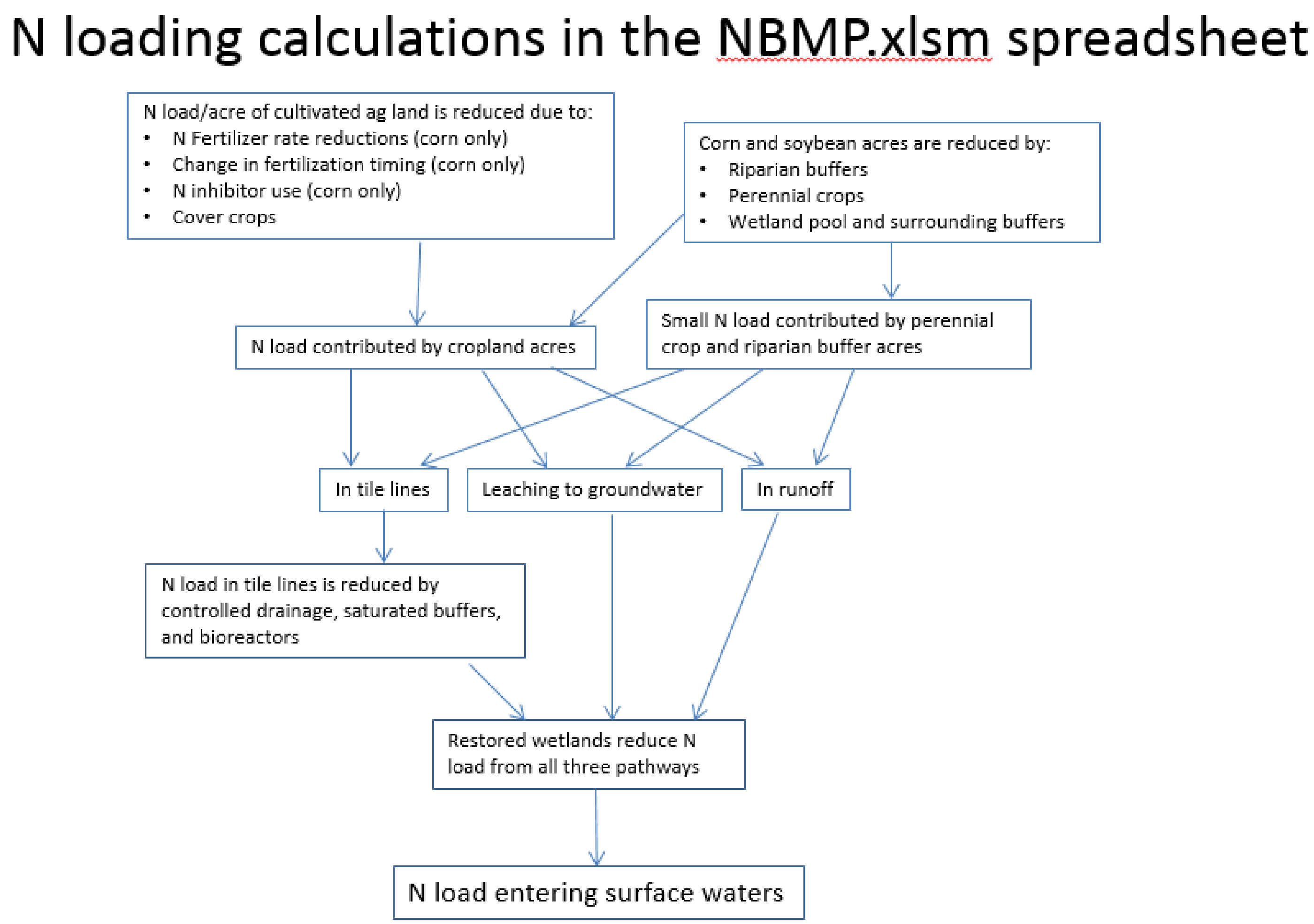


Figure 1. Illustration of the Order of the N Loading Calculations in the NBMP.xlsm Spreadsheet and How Adoption of One BMP May Affect the Amount of N Reaching Another BMP and Its Cost-Effectiveness

How to use the Tool

Note: Copies of the key graphs and tables are included below, but they are only examples. Obviously, the nature of a spreadsheet planning tool is that the results will vary based on data entered and selections made by the user, so readers are cautioned to not assign any particular importance to the results shown here.

Using the model involves three steps. The first step is to select a watershed, enter hypothetical adoption rates for each BMP, and compare the effectiveness and cost of the individual BMPs. The second step is to compare suites of the BMPs that would attain any given reduction in the N load at minimum cost. The third step is to "drill down" to the details and assumptions behind the models of effectiveness and costs of any particular BMP and make any adjustments to reflect your particular situation.

The main screen is shown in Figure 2 below. Row 6 contains a dropdown list of the watersheds that you can select from and the acreage of the watershed currently selected. Below that box is a list of the BMPs that are modeled. Input cells are formatted in yellow. Calculated cells are in white. The spreadsheet is password-protected to help avoid inadvertent changes to the calculation formulas.

The statewide total data is shown. The data includes crop acreages, yields, and other information for ten different crops: corn grain and silage, soybeans, the small grains of spring wheat, barley, and oats, sugar beets and potatoes, and alfalfa and other hay. Total crop acres and average N fertilization rates are also included for sweet corn, peas, and dry edible beans because the impact of cover crops on N loads are calculated for those crops, but the other information is not included for those three short-season crops.

	A	B	C	D	E	F	G
1	Step 1. Select a watershed, enter adoption rates for each BMP, and view effectiveness and cost in the two top graphs and the table. Change the weather scenario if desired.						Last modified or
2	Note: The acres shown below for the watershed or state are ALL acres, including ag land, forests, impervious urban and suburban						
3	land, and pasture and grasslands, NOT just cropland.						
4							
5			50.297	million acres in watershed or state			acres treated (mill.)
6	Watershed	Statewide 1	% suitable	% adoption	% treated	% treated, combined	combined
7	Corn acres receiving target N rate, no inhibitor or timing shift		15.5%	90%	13.9%	13.5%	6.78
8	Fall N target rate acres receiving N inhibitor		4.6%	0%	0.0%	0.0%	0.00
9	Fall N applications switched to spring, % of fall-app. acres		4.6%	45%	2.1%	2.0%	1.01
10	Fall N switch to split spring/sidedressing, % of fall acres		4.6%	45%	2.1%	2.0%	1.01
11	Restored wetlands		3.2%	50%	1.6%	1.6%	0.79
12	Tile line bioreactors		2.7%	20%	0.5%	0.0%	0.00
13	Controlled drainage		2.7%	50%	1.3%	0.7%	0.34
14	Saturated buffers		2.7%	50%	1.3%	1.3%	0.67
15	Riparian buffers		0.9%	70%	0.6%	0.5%	0.28
16	Corn grain &soybean acres planted w/cereal rye cover crop		29.2%	10%	2.9%	2.8%	1.42
17	Short season crops planted to a cereal rye cover crop		5.5%	50%	3.0%	2.7%	1.38
18	Perennial crop % of corn & soybean area	marginal only	3.3%	10%	0.3%	0.3%	0.13
19	Weather scenario	Average weather - all of preplant N is available	ll of preplar	1			
20	For wet spring scenario 2, fertilizer & manure N lost		30%				
21							
22	N load reduction with these adoption rates:		23.0%	of all nonpoint source load			
23			25.6%	of cultivated ag land source load			
24	Treatment cost before fertilizer cost savings & corn yield impacts		$233.81	million/year			
25	N fertilizer cost savings & corn yield impacts		-$120.05				
26	Net BMP treatment cost:		$113.75	million/year			

Figure 2. Main Screen of NBMP.xlsm Spreadsheet

After selecting a watershed, the next step is to specify how much of each BMP you think is reasonable or that you wish to consider for implementation in the watershed. For example, if you (as the resource planner) think that a particular BMP is likely to be adopted widely by producers farming in the watershed, enter a high percentage rate. Enter a lower rate for other BMPs that you think would be unpopular because of cost or whatever reason. Rely on your knowledge of the local situation and on studies such as Davenport and Olson for these adoption rates (Davenport and Olson 2012). You enter the percent adoption rates in column D. Column C shows a measure of suitable acreage associated with each BMP that is based on GIS watershed analyses and an assessment of watershed acreage for which that BMP can realistically be adopted, as a percentage of total watershed acreage. The adoption rates in column D represent a percentage of that maximum suitable acreage. The first four BMPs all relate to N fertilizer, and they are limited to the acreage of corn grain and silage, even though we recognize that other crops also receive N fertilizer as well. Since corn and soybeans are often in rotation together, the maximum acreage in corn in any given year is typically less than 50% across the watershed. Riparian buffers, restored wetlands, controlled drainage, saturated buffers and tile line bioreactors have suitable acreages related to slope and other geographic mapping data. Seeding a cereal rye cover crop by air into corn and soybeans, and short-season crops, or converting corn and soybean acres to a perennial crop such as switchgrass, are limited to either a) marginal land in corn and soybeans, or b) the total of corn, soybean and short-season crop acres, depending on the option selected in cell A18.

Column E shows the percentage of the watershed would be treated based on the suitable acres and adoption rate entered. However, some of the BMPs compete for the same acres, so that treated acres under some combinations of BMPs will not necessarily be equal to the sum of results from the individual BMPs considered alone. Figure 1 above illustrates the order of calculation of the load reductions from each BMP. Changing the adoption rate of one BMP may affect the amount of N reaching another BMP, which affects the amount of N removed by that later BMP and which in turn affects its cost-effectiveness in removing a percentage of the N reaching it at a given per-acre cost. For example, corn and soybean acres planted with a cover crop will be reduced when corn and soybean acres are shifted to a perennial crop or riparian buffers. Column F and G show treated percentage and absolute acres of each BMP respectively under a combination of all of the BMPs entered. The percent load reduction that the combination of BMPs entered will provide is shown in C22.

There are many data entry cells scattered around the various sheets in the spreadsheet, but for convenience a few data items that have played key roles in our sensitivity analyses to date are shown in A32:C40 just below the main screen.

Click the "Recalculate" button after making any changes in the data entry cells. Most changes will be fully incorporated with one recalculation, but a few may require two clicks to fully recalculate.

The graph starting at cell H3 shows the effectiveness and cost of the BMPs for the watershed and the adoption rate you have chosen (see Figure 3). The red bars show effectiveness, which are keyed to the left vertical axis. Effectiveness is shown as a percent of the N load reduced in the watershed surface waters due to that BMP, in the absence of any of the other BMPs. (Suites or combinations of the BMPs are evaluated in step 2 of the analysis as discussed below.) The blue line shows cost/lb of N removed, which relates to the right vertical axis. Both the effectiveness and cost will change with the adoption rate you enter. The graph shows that for the Statewide watershed and at the adoption rates entered, reducing fertilizer N rates on corn and switching to spring preplant or sidedressed application provide significant N reductions at relatively low cost, while riparian buffers, cover crops, and perennial crops are relatively expensive for the reductions attained. For example, converting 50% of the suitable acres to wetlands would reduce the N load by a little more than 2%, at a cost of around $0.50/lb of N load reduced. Column E shows that 1.6% of the acreage in the watershed would be treated by the restored wetlands. In the case of the wetlands BMP, this 1.6% refers to the area draining into the wetland. Only a small percentage of this acreage is actually taken out of crop production and converted to wetland. See the Wetlands sheet for the details.

Figure 4 is a model output graph which shows the N reductions and cost/acres TREATED, as opposed to acres of WATERSHED shown in Figure 3. The columns in the graphs and table can be sorted in a number of different ways. Here they are sorted by effectiveness per acre of watershed.

Table 3 shows the numbers which correspond to the graph in Figures 3 and 4.

Scroll down to row 49 for step 2 of the analysis, as shown in Figures 5 and 6 below. The Step 2 video http://z.umn.edu/nbmpv2 discusses that step. The spreadsheet looks at 198 different combinations or suites of the 12 BMPs, and selects only those combinations that are "efficient" in providing greater N reductions than any other combinations that cost the same amount or less. These "Frontier scenarios" are displayed in the graph starting at F54, sorted from low to high "Cost/lb of N removed". The bars of the graph shown in Figure 6 are color-coded to the legend below it. For example, the first green bar shows the result of reducing the corn N fertilizer rate to a target rate on 90% of the corn acreage. The horizontal axis shows that just that one BMP would reduce the N load by around 12%, which matches what the top graph (Figure 3) showed. The green bar goes up rather than down, showing that reducing the N rate would actually save money rather than costing money. There are red and blue bars extending downward, showing that greater reductions involving a combination of practices would start to increase costs.

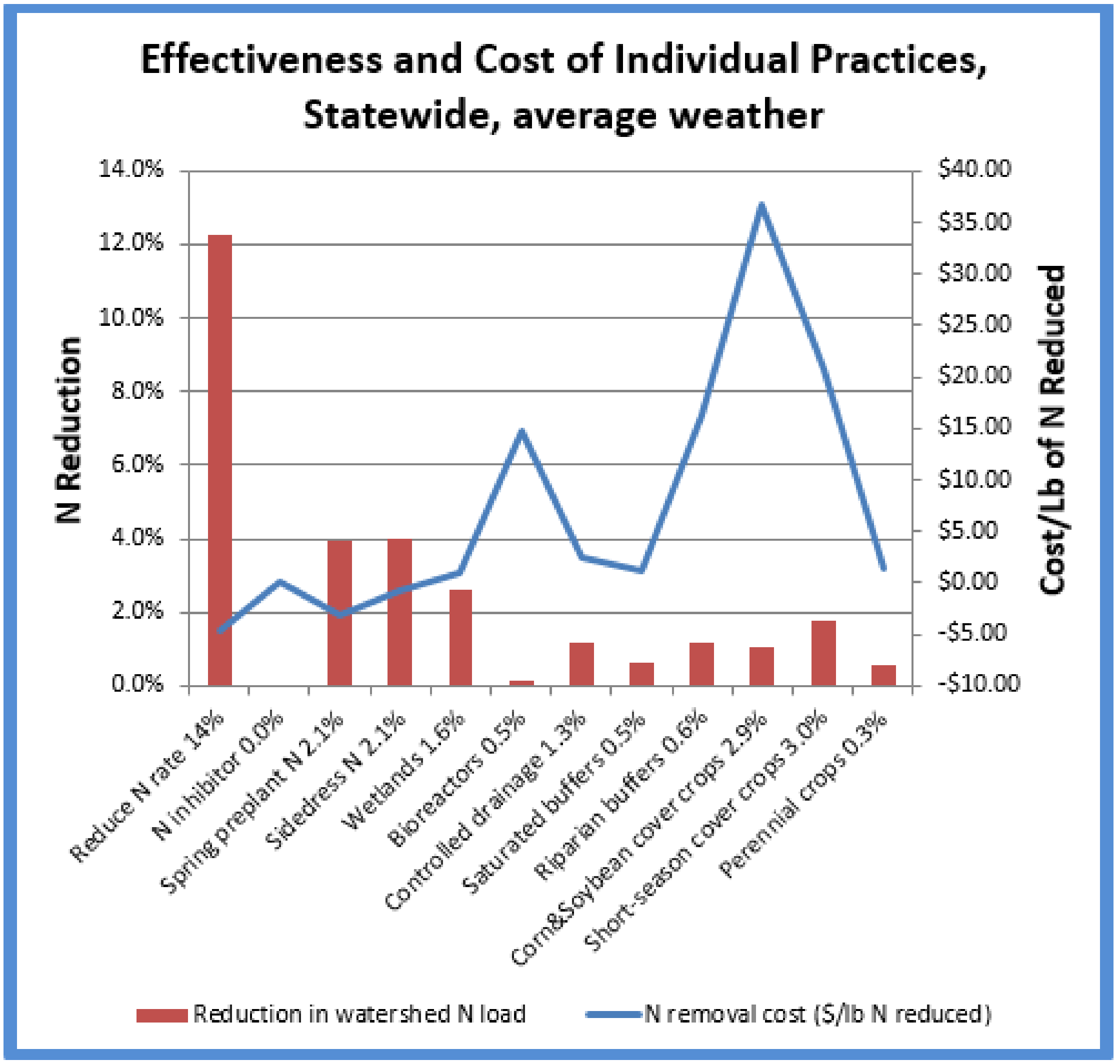


Figure 3. Graph Comparing the Effectiveness and Cost of Individual BMPs, Showing Results for the overall state. The numbers at the end of each practice description are the assumed percentages of the watershed treated.

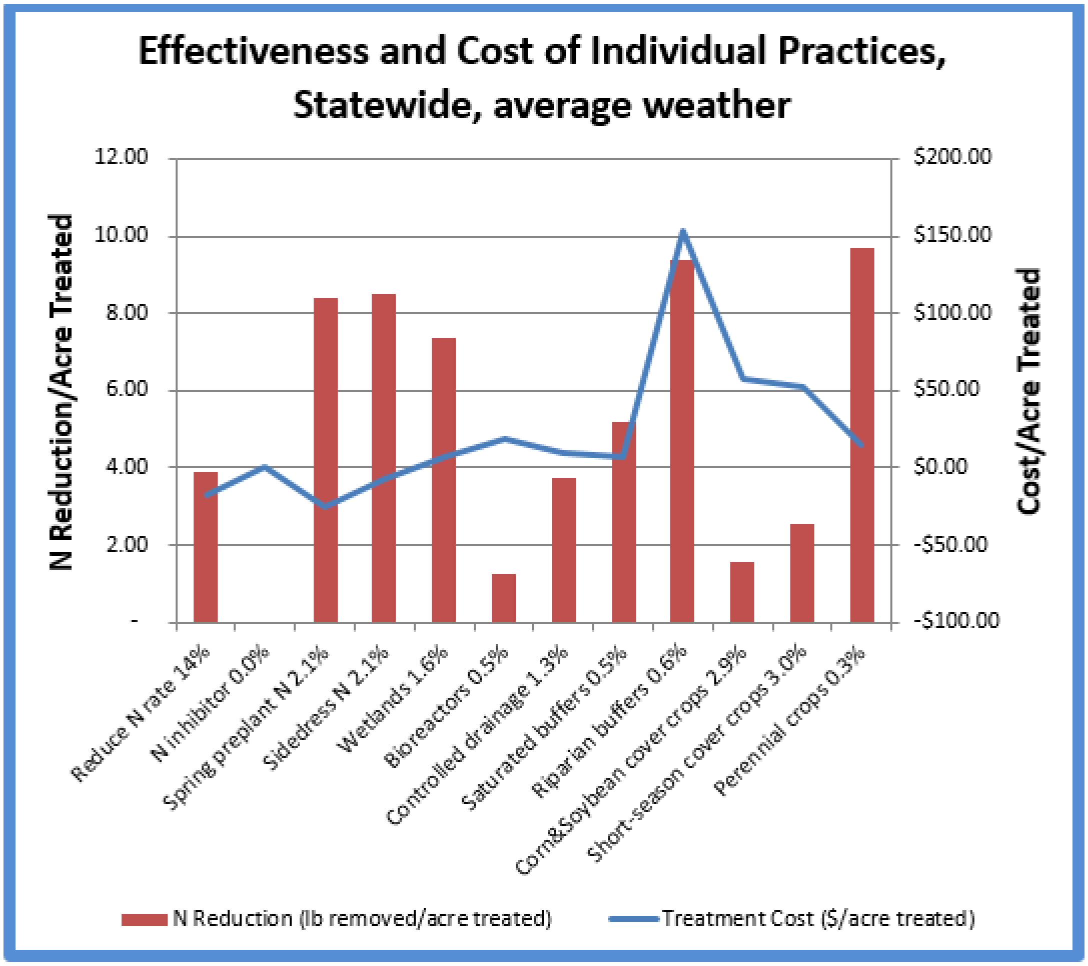


Figure 4. Graph Comparing the Effectiveness (lb N Reduced from Surface Waters) and Cost of Individual BMPs Per Acre Treated, Showing Results for the overall state.

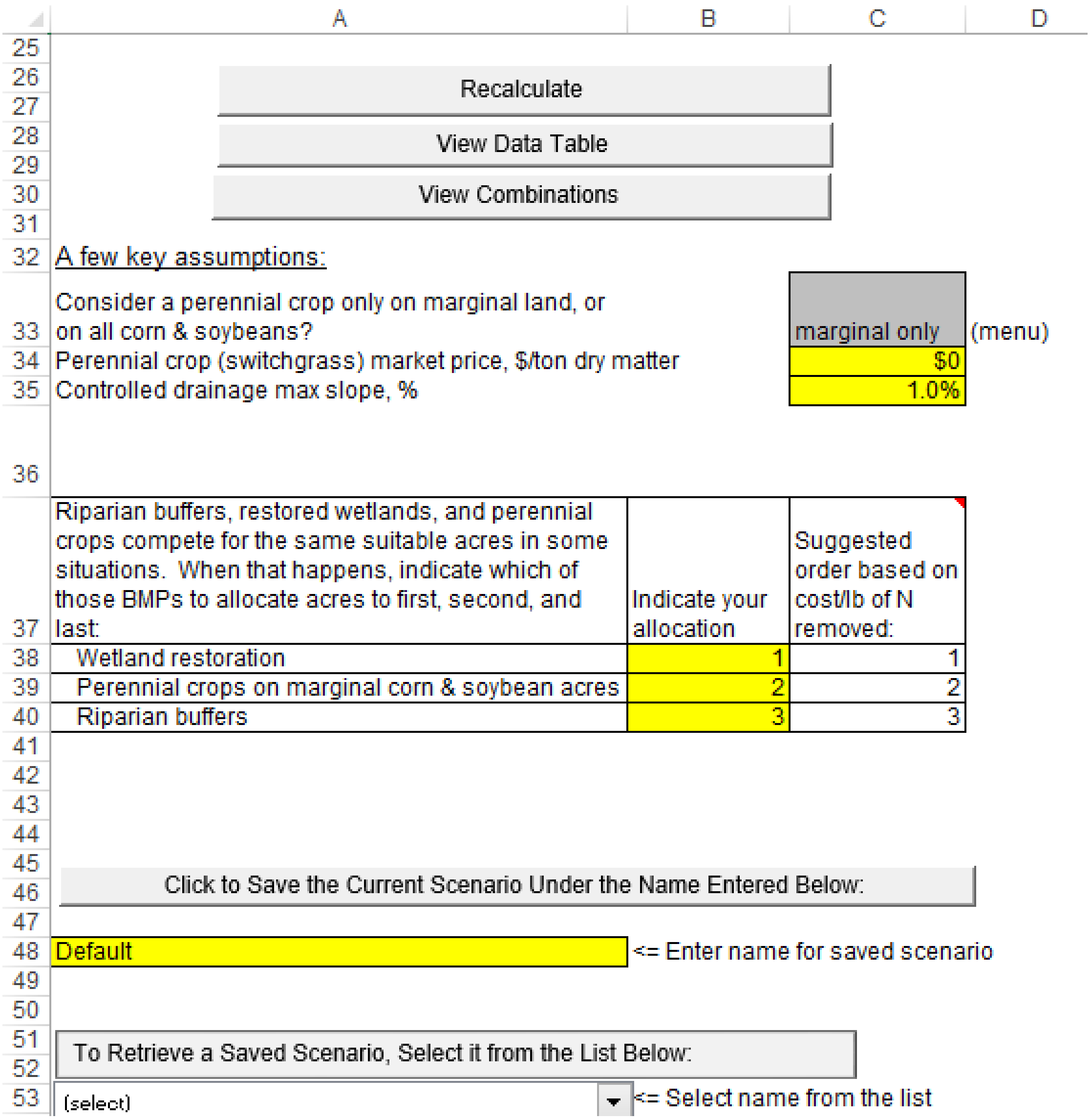
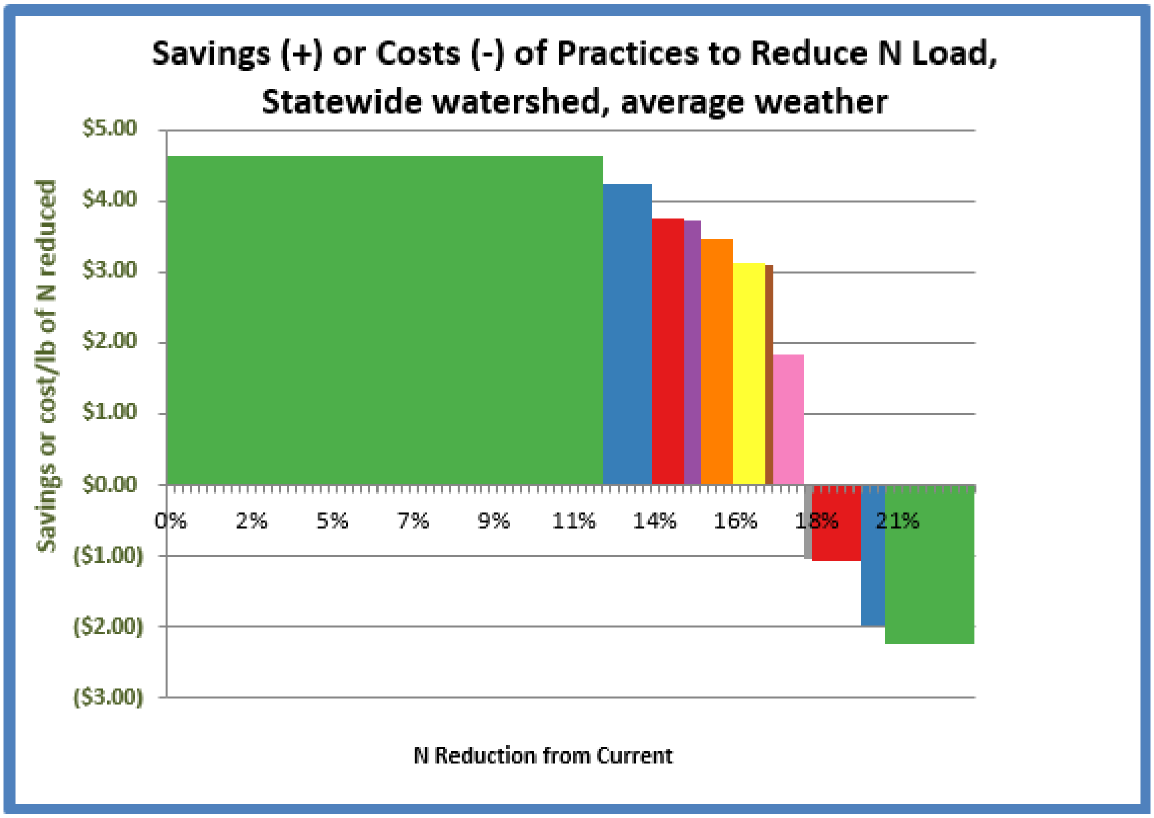


Figure 5. Screen Showing the Recalculate and Viewing Buttons, Cells to View or Change a Few Key Assumptions, and An Area for Saving and Reloading Input Data for Scenarios the User May Wish to Return to at a Later Time.

Table 3. Comparison of the cost and effectiveness of the individual BMPs when adopted at the rates shown in Figure 2, in an average weather year, sorted by BMP category (fertilizer optimization in blue, drainage-related in pink, and vegetation changes in green).

	Treatment Scale			Watershed Scale					Corn & soybean acres withdrawn from production			
BMP with Percent of Watershed Treated	Treatment Cost ($/acre treated)	N Reduction (lb removed/acre treated)	N removal cost ($/lb N removed)	Percentage of watershed treated	Total treatment cost ($ 000)	Total N reduction, watershed (000 lb)	Treatment Cost ($/acre of watershed)	Reduction in watershed N load	Individual BMPs	BMPs in combination	% current corn & soy acres, in combination	Percent of watershed, in combination
Reduce N rate 14%	$ (17.87)	3.8706	$ (4.62)	13.9%	$ (125,243)	27129.80	$ (2.49)	12.3%	0	0	0.0%	0.0%
N inhibitor 0.0%	$ -	0.0000	$ -	0.0%	$ -	0.00	$ -	0.0%	0	0	0.0%	0.0%
Spring preplant N 2.1	$ (25.57)	8.3711	$ (3.05)	2.1%	$ (26,398)	8641.68	$ (0.52)	3.9%	0	0	0.0%	0.0%
Sidedress N 2.1%	$ (6.75)	8.5253	$ (0.79)	2.1%	$ (6,968)	8795.99	$ (0.14)	4.0%	0	0	0.0%	0.0%
Wetlands 1.6%	$ 7.33	7.3428	$ 1.00	1.6%	$ 4,940	333.16	$ 0.12	2.6%	72,950	72,950	0.5%	0.1%
Bioreactors 0.5%	$ 18.40	1.2410	$ 14.83	0.5%	$ 6,101	2516.55	$ 0.10	0.2%	0	0	0.0%	0.0%
Controlled drainage 1	$ 9.09	3.7495	$ 2.42	1.3%	$ 4,381	3488.86	$ 0.12	1.1%	0	0	0.0%	0.0%
Saturated buffers 1.3	$ 6.53	5.1982	$ 1.26	1.3%	$ 42,748	2627.89	$ 0.09	1.6%	0	0	0.0%	0.0%
Riparian buffers 0.6%	$ 152.89	9.3984	$ 16.27	0.6%	$ 5,810	5822.43	$ 0.85	1.2%	279,610	275,818	1.9%	0.5%
Corn&Soybean cover	$ 56.93	1.5527	$ 36.67	2.9%	$ 83,582	2279.59	$ 1.66	1.0%	0	0	0.0%	0.0%
Short-season cover c	$ 52.92	2.5514	$ 20.74	3.0%	$ 80,781	3894.73	$ 1.61	1.8%	0	0	0.0%	0.0%
Perennial crops 0.3%	$ 14.32	9.6847	$ 1.48	0.3%	$ 1,880	1271.19	$ 0.04	0.6%	131,258	127,352	0.9%	0.3%
Note: Some of the BMPs are mutually exclusive, so don't attempt to add them up for a cumulative total.												
Cumulative total	**NA**	**NA**	**$2.24**	**NA**	**$113,754**	-	**$2.26**	**23.0%**	**NA**	476,120	**NA**	0.9%

Note that only a percentage of marginal land (as described on page 5) is assumed to be available for planting to a perennial crop. A negative number in a cost column means that the BMP will result in a cost savings rather than a cost increase. The number by the BMP description is the percentage of the watershed treated. Note that these BMPs are color-coded into three groups, as indicated by the legend shown in S39:U51 next to this table.



Key to graph colors by BMP (left to right, the numbers are percent of the watershed, from above)

Reduce N rate 14%

reduce N rate 14%,spring preplant N 2.1%

reduce N rate 14%,spring preplant N 2.1%,controlled drainage 1.3%

reduce N rate 14%,spring preplant N 2.1%,saturated buffers 1.3%

reduce N rate 14%,spring preplant N 2.1%,restore wetlands 1.6%

reduce N rate 14%,spring preplant N 2.1%,restore wetlands 1.6%,controlled drainage 1.3%

reduce N rate 14%,spring preplant N 2.1%,restore wetlands 1.6%,saturated buffers 1.3%

reduce N rate 14%,spring preplant N 2.1%,restore wetlands 1.6%,saturated buffers 1.3%,riparian buffer 0.6%

reduce N rate 14%,spring preplant N 2.1%,restore wetlands 1.6%,corn&soybean cover crops 2.9%

reduce N rate 14%,spring preplant N 2.1%,restore wetlands 1.6%,saturated buffers 1.3%,corn&soybean cover crops 2.9%

reduce N rate 14%,spring preplant N 2.1%,restore wetlands 1.6%,saturated buffers 1.3%,riparian buffer 0.6%,corn&soybean cover crops 2.9%

reduce N rate 14%,N inhibitor 0.0%,spring preplant N 2.1%,sidedress N 2.1%,restore wetlands 1.6%,controlled drainage 1.3%,saturated buffers 1.3%,riparian buffer 0.6%,corn&soybean cover crops 2.9%,perennial crops 3.0%

Figure 6. Costs or Cost Savings for Different Suites of Practices That Would Provide A Range of Reductions in N Loading at Minimum Cost, with the Overall State Results Shown.

Figure 6 shows 20 of the 198 suites or combinations of BMPs that are compared in the spreadsheet. The suites shown are those that would provide a range of N loading reductions more cost-effectively than any other suites that provide the same or less reduction. The suites that appear in this graph are those referred to here as an “efficient frontier”. That means that as we move right on the graph to suites that cost more, we have weeded out any suites that don’t reduce the N load by more than the cheaper suites on the left. The green bar shows that reducing the rate on 14% of suitable acres by around 12%. Adding saturated buffers to the N rate reduction would reduce loading a bit more. Replacing the saturated buffers with a shift to spring preplant N on 2.1% along with the reduced rate would reduce the N load by over 13%. The legend below the graph shows the order at which other BMPs would enter the mix. The additional BMPs cost money, but the fertilizer rate reduction saves enough money to offset the additional cost until around a 17% load reduction.

With the adoption rates entered in the main screen, the far right bar shows that the greatest attainable load reduction is 22.3%. This is attained with the rate reduction, shifting to spring preplant N, installing riparian buffers, restoring the wetlands, implementing controlled drainage, and planting cover crops on the corn, soybeans, and the short season crops.

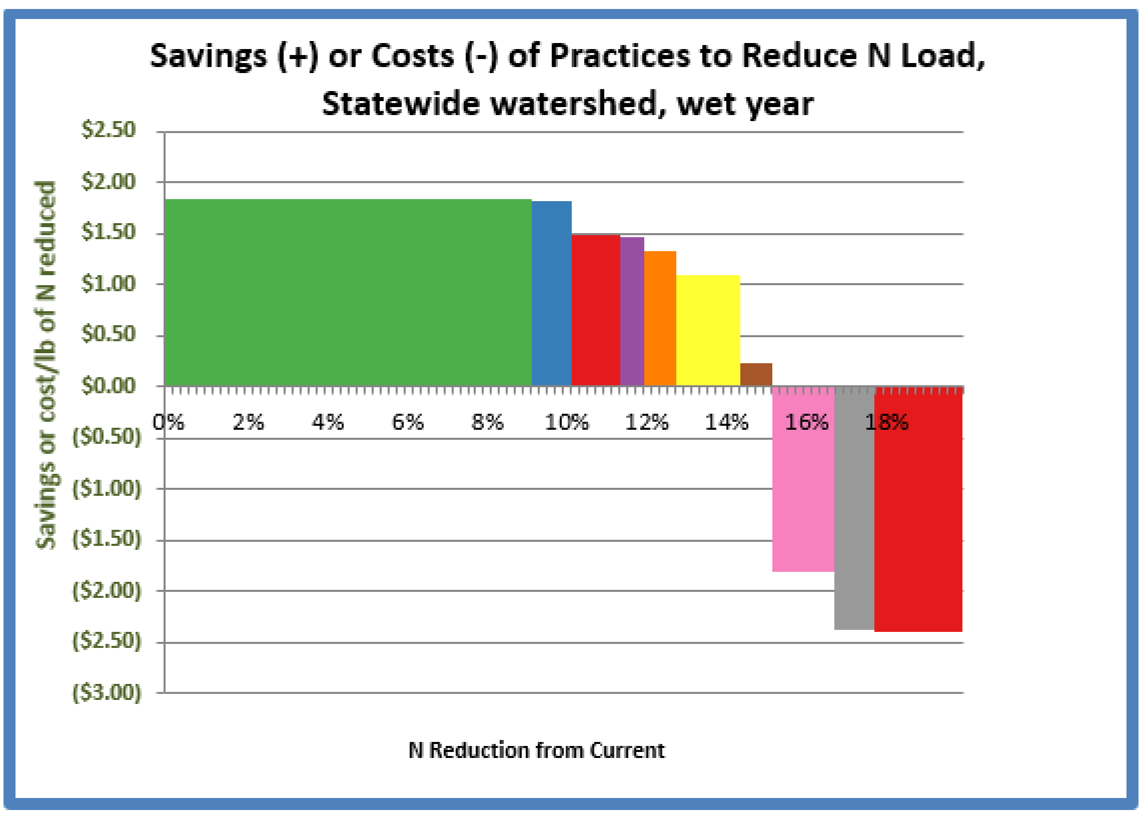
It is interesting that five other BMPs are not included in the maximum-load-reduction BMP suite: N inhibitor, the split spring preplant/sidedressed N application, saturated buffers, tile line bioreactors, and replacing corn and soybeans on marginal cropland with perennial crops.

The N inhibitor BMP is a recent addition to the model. The N inhibitor suitable acres are corn acres that are fall-applied. It enters the calculations in two ways: first, N rate!D23 can be used to indicate how much of the fall-applied corn is not already receiving inhibitor, and so is available to receive it as a BMP. This is 0 % of the fall-applied corn by default. The N inhibitor adoption rate in Main_calcs!D8 can then be used to apply inhibitor to a percentage of the remaining fall-applied corn. That N inhibitor adoption rate is set at zero by default, however, because applying inhibitor has the counterintuitive effect of actually decreasing the overall N load reduction rather than increasing it. The N load reduction decreases because fall-applied corn receiving inhibitor is assumed to NOT be available for shifting to spring preplant or sidedressed application, and those two BMPs are assumed to be implemented along with an N rate reduction to the target rate while the inhibitor acres stay at the current, non-target N rate. N rate!D25 shows how much of the INCREASED inhibitor-treated corn acres would also receive the target N rate. This is in contrast with the CURRENT inhibitor-treated corn acres, which are assumed to get the current N rate. By default, D25 is set equal to the percentage of non-inhibitor corn acres that receive the target N rate, which is 90%, in Main_calcs C134. The cost of increasing inhibitor use goes up considerably if NOT accompanied by the N rate reduction to the target rate, because that reduction provides a fertilizer cost savings that offsets most of the inhibitor cost. You can demonstrate this effect by setting D25 to zero rather than the default formula “='Main calcs'!C134”.

The suites of BMPs are mutually exclusive, so that the interpretation of any individual bar is that that suite would be used in the entire watershed, replacing the suites illustrated by the bars to the left of that bar. The vertical axis in Figure 6 shows the cost or cost savings per pound of N load reduced. The cost/acre for the different suites can also be displayed by clicking a button. Also, if the user desires to focus only on the suites that provide the greatest reductions, a minimum percentage for inclusion can be entered in D67.

These results assume an average weather year. The N fertilizer rate reduction BMP tends to look financially attractive in the average year scenario, which is considered to be the baseline scenario. However, agricultural interests tend to raise concerns about high N fertilizer losses from the crop root region in a wet year, which would reduce yield. They also raise concerns about the possibility of not getting the fertilizer applied at all in the spring preplant or sidedressing time windows in a wet year. Also, the reduction in N load resulting from the various BMPs will vary due to different water volumes in dry and wet years.

The loading can also be calculated by the model for an unusually wet year or a dry year. The box at A19 can be used to select either of these weather scenarios. If the “wet year” scenario is selected, cell C20 will be highlighted. This cell allows the user to specify a percentage of the fertilizer that is lost to the crop. The adjustment is then made in the yield response functions in the BMP sheet. Figure 7 shows that reducing the N rate is still the cheapest BMP to implement and reduces the N load by about 9 percent, but now yield reduction means that the same BMP combination costs more than it does in an average year. If much more than 30 percent of the N is lost in a wet year, that BMP would no longer be the first one that enters the efficient frontier.



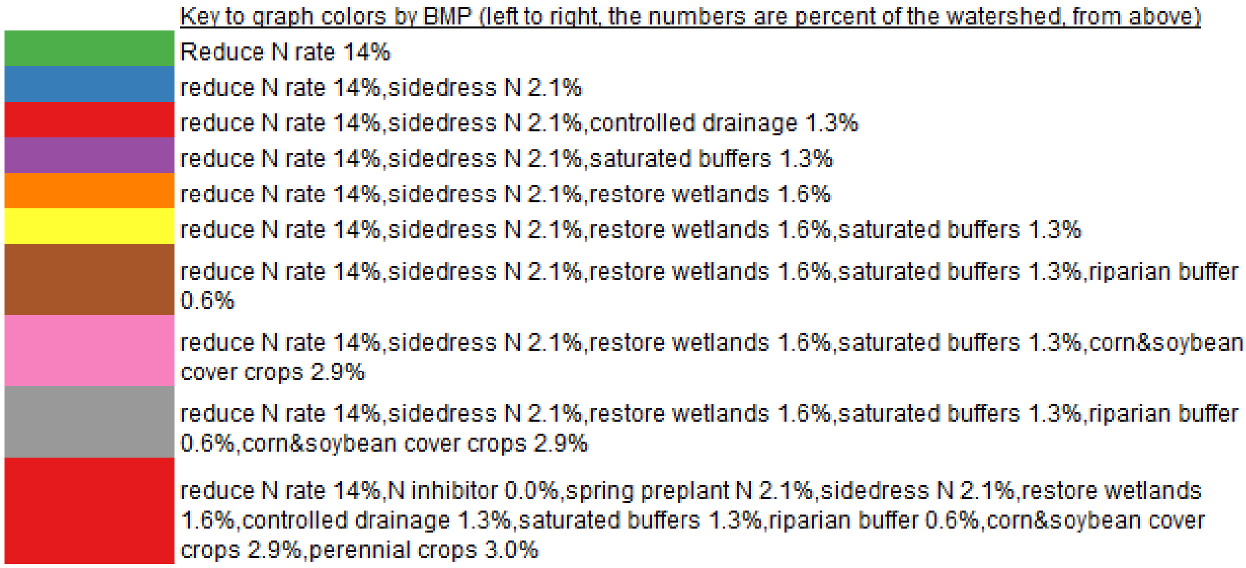
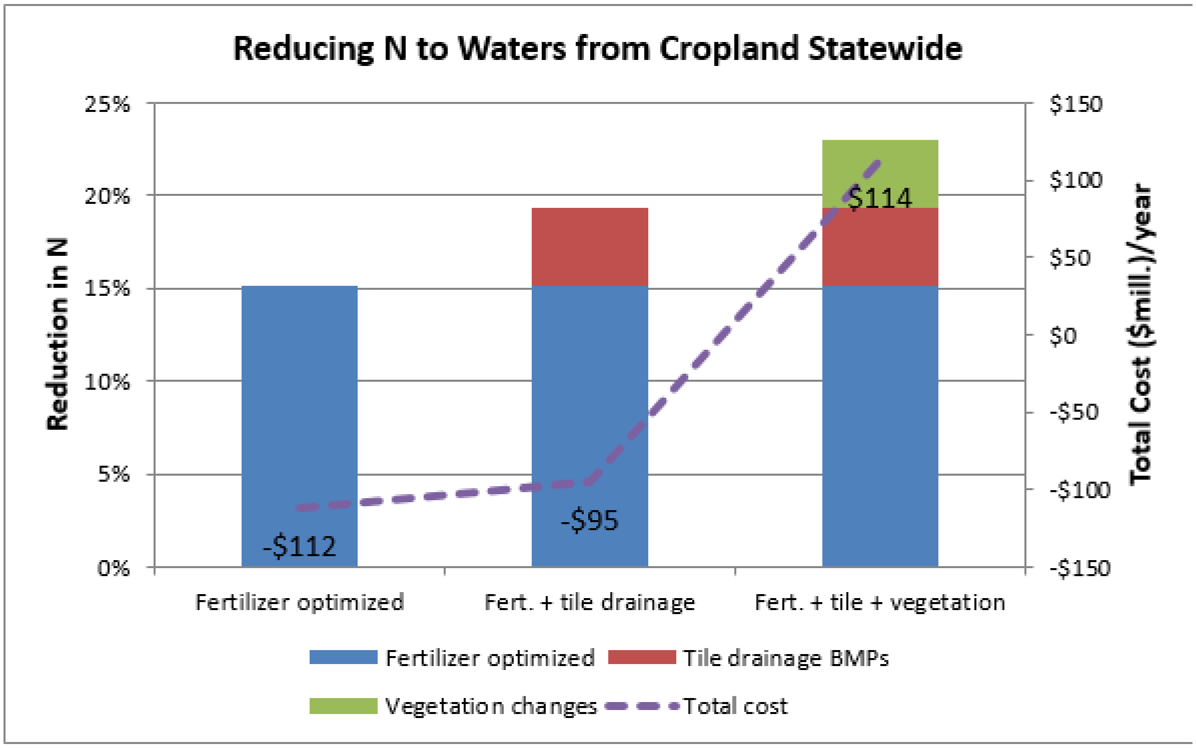


Figure 7. Suites of Practices That Would Provide Different Reductions in N Loading in a Wet Year Where 30 Percent of the Fertilizer is Lost.

Scenarios

Figure 8 below shows the cumulative load reductions and the statewide annual costs for the three groups of BMPs listed in Table 3 if adopted at the rates shown in Figure 2. The first blue bar shows the results from only optimizing the fertilizer rates and timing. The middle bar shows the combined impact of adding the tile drainage-related BMPs. The right bar shows what happens when the vegetation-related BMPs are added. This graph is contained in the Scenarios sheet, at F22. It requires the model to be recalculated three different times to arrive at the three different bars, so click the button at F20 to update this graph. The adoption rates for this graph are entered in the cells starting at B3 in the Scenarios sheet, NOT the adoption rates entered in the main screen in the Main Calcs sheet.



Adoption rates: Apply N at recommended rate on 90% of corn; shift 0% of N inhibitors and 45% of fall-applied N to preplant and 45% to split preplant/sidedressed; plant riparian buffers on 70% and restore wetlands on 50% of suitable acres; install bioreactors on 20% and install controlled drainage on 50% of tiled land of 1% or less slope; install saturated buffers on 50% and plant rye cover crops on 10% of corn and soybean acres; plant perennial crops on 10% of marginal land

Figure 8. Comparison of the load reductions and total statewide annual costs for the three groups of BMP suites with reductions achieved in three watersheds when a 12 or 25 percent target N reduction is chosen, in an average weather year.

Sensitivity analysis

Many of the default parameters in the model are highly uncertain and will likely vary widely from one watershed and situation to another – hence the need for a planning tool in the first place. In order to gauge the relative impact of different parameters on the results, several graphs similar to the one shown below in Figure 9 are included in the "Sensitivity" sheet. Each vertical bar illustrates the impact of varying that parameter +/- 50% from the default value. Figure 9 shows the graph for the N rate reduction BMP. The variables that have the greatest impact are the target rate (whether the exact U of MN recommendation, or more or less than that rate), the reduction in the N rate with spring application vs. the target rate (shown as a percent of the 30 lb. rate difference assumed for spring vs. fall application), the percentage of the N that is fall-applied in the watershed, and the percentage reduction in tile line N with spring application vs. fall application.

Log of saved scenarios

The area of Main Calcs sheet starting at A50 contains a place to enter a scenario name and a button to run a macro that will save the 100 or so parameters to a column of the Log sheet. The names of the saved scenarios will then appear in the dropdown box below A55. You can reload the parameters for any of the saved scenarios by selecting the scenario name in that box. Loading a saved scenario will erase the values previously entered. A warning will be displayed before actually erasing the old values and replacing them with the saved one.

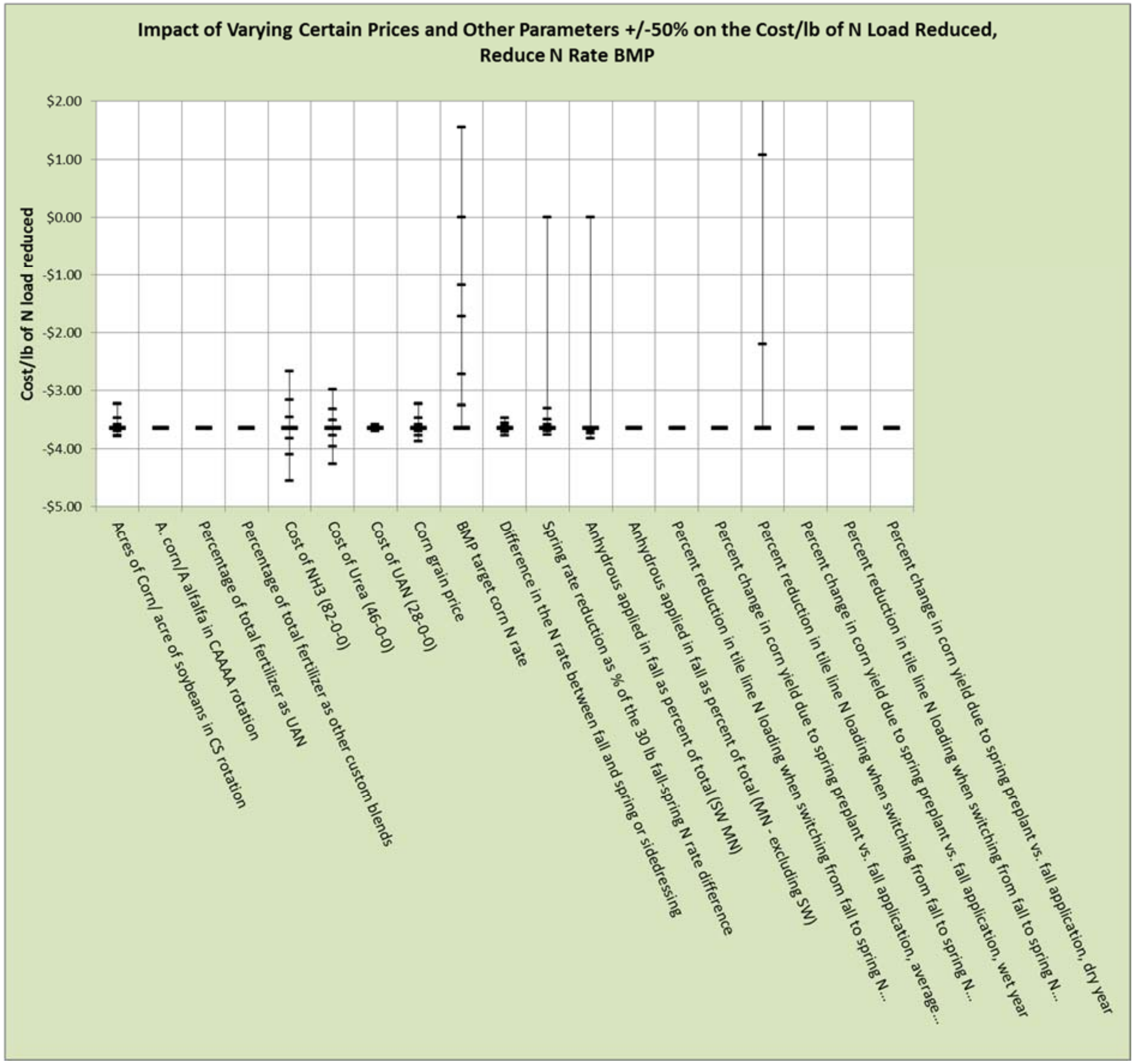


Figure 9. Sensitivity Analysis of the Impacts of Varying Individual Parameters +/- 50% on the Cost/lb of N Load Reduced, for the Rate Reduction BMP

Spreadsheet Organization

Descriptions of the sheets currently in the spreadsheet are as follows:

Sheet name	Description
Watersheds	Acres of each agroecoregion in each pilot watershed and in the entire state, with percentages of the state total acres of each region in each watershed. Contains a combo box to select a watershed for inclusion in the current vs. BMP scenario comparisons. Includes data on acreage suitable for each practice in each region.
Main_calcs	A data table displays various measures of effectiveness and cost for each individual practice and combination of interest. The practices are then sorted, and a subset of the practices is identified that provide the greatest "bang for the buck" as they achieve greater reductions in the N load. Graphs display that subset of practices sorted by effectiveness. This sheet also contains the corn fertilizer target rates and the parameters of several equations used in the region-by region N loss calculations in the other sheets.
Scenarios	Tables of the impacts three types of BMP scenarios, namely, fertilizer optimization, drainage-related, and vegetation change BMPs. Also contains results calculated for all 68 HUC8 watersheds, the ten major basins in the state, the overall Mississippi River Basin, and the overall state (80 total watershed scenarios).
Log	Log of saved scenarios, with roughly 100 different parameters for each.
Sensitivity	This contains a table and two graphs with a sensitivity analysis of the most important prices and a couple other parameters, and their impact on the cost/lb of N reduced. The table numbers are static values that are updated via a macro that runs when the button at the top is clicked.
Current	Baseline scenario data representing the current situation without implementation of any BMPs. The percentages in row 2 display the acres in the watershed selected in Watersheds. Fertilizer and manure application information and N loss calculation.
BMP	This sheet calculates the N load for any combination of 1) corn N application rates, 2) corn and soybean land converted to a perennial crop, and 3) cropland restored to wetland.
N rate	The calculations of the target corn N fertilizer rates for the rate reduction BMP, fertilizer rate differences due to timing, and tile line loading.
Fert timing	Inputs and calculations related to shifting fall-applied corn acres to a) spring preplant or b) a split preplant and sidedressing application. (The actual calculations of fertilizer application costs and yield penalties from late planting take place in a separate Ferttiming.xlsm spreadsheet, with only the summary costs/acre transferred over to this sheet. See below for more details.)

Wetlands	Wetland restoration cost, acreage, and effectiveness calculations.
Sheet name	Description
Controlled drainage	Controlled drainage cost, acreage, and effectiveness calculations. The costs are from Christianson et al. (Christianson et al. 2012). Includes the list of regions and a place to indicate the percentage of each region that would be suitable for bioreactors, in the fifteen high-N-load HUC8 watersheds, the two pilot watersheds, and statewide.
Tile Line Bioreactor	Bioreactor cost, acreage, and effectiveness calculations.
Saturated Buffers	Saturated buffer cost, acreage and effectiveness calculations.
Covercrop	The cover crop cost and effectiveness calculations. Includes columns for corn grain, soybeans, sugarbeets and short-season crops.
Returns_per_A	The budget_import sheet data re-organized as needed for the Current and BMP sheets. The regions are across the top and the crops run down the rows. The perennial crop (switchgrass assumed, for now) costs and yields are entered manually in this sheet, and are the same for all regions.
Cropcost_ Benchmarks	Crop gross value and net return to land/acre numbers for comparison against the BMP costs, see Main_calcs!C173:C174.
Optimize	This sheet allows the user to enter a maximum and minimum acceptable adoption rate for each BMP, along with a minimum desired N reduction percentage constraint and a maximum annual cost constraint.
Sources	List of sources for default prices and costs used in the calculations
SuitA_Desc	Descriptions of the rows in the “Watersheds” sheet
Budget_import	List of agronomic crop yields and returns to land used to calculate the economic impacts of shifting cropland to perennial crops or wetlands, by region, as imported from the separate budget spreadsheet.

Discussion of How the Different BMPs Are Integrated Into the BMP Sheet Calculations:

The data entry cells for the practices are the yellow cells in the Main_calcs sheet starting in D7, but those cells are not linked directly to BMP. Rather, those cells link to the data table that starts around cell A133. All of the practice combinations are listed in rows 134:145. The combo box in A130 allows the user to select any practice or combination scenario. The data for the selected scenario are then transferred to cells C134:C145, which serve as the origins for any calculations that require those parameters.

To view the data relevant to any given practice in the BMP sheet and the other sheets, the user needs to first select that practice in the combo box in A130 of Main Calcs, or else enter a scenario number 1 – 198 in C147. There are buttons in some of the sheets that will select the relevant practice when you click the button. The BMP sheet does not have such a button, however, since it is used with all of the practices.

The Individual BMP Models Behind The Scenes

The calculations behind each BMP are each the result of a literature search (Fabrizzi and Mulla 2012) and of a separate project to estimate cropland nitrogen losses to streams through tile drainage, leaching to groundwater, and surface runoff (Mulla et al. 2012). The calculations are contained in the other sheets in the file, and differ quite a bit because of the different natures of the BMPs themselves.

The "Current" sheet is fairly similar to the sheet that David Mulla and his staff used to model the N loads by region in that part of the project, with row 2 added at the top. That row contains the percent of each region that is contained in the watershed selected by the user. For example, 22.4% of the "steep stream banks" region is contained in the Le Sueur River watershed. David's spreadsheet contained crop acreages but did not contain estimates of how much of the corn followed soybeans, corn, or alfalfa, which is important information for arriving at the corn fertilizer rates. So, we imputed acres by previous crop by, first, assuming that there is one acre of corn following soybeans, for every soybean acre. That then assumes a rotation of one year corn and one year soybeans. We imputed acres of corn following alfalfa by assuming there is one year of corn following alfalfa for every four acres of alfalfa. That would imply a rotation of one year corn with a four-year alfalfa stand. The rest of the "current" sheet includes a detailed accounting of the N sources and destinations developed and described by Mulla et al. (2012).

The BMP sheet contains a copy of much of the region-by-region information from the "current" sheet but then makes the changes in corn fertilizer N rates, N loading calculations, crop acres, and corn yields that would happen with 1) the fertilizer rate reduction BMP, 2) the BMPs of shifting from fall to spring preplant or a split of sidedressing and spring preplant N application with N inhibitor or not, 3) seeding a cereal rye cover crop to the corn, soybean and short-season crop acres, or 4) shifting part of the corn and soybean acres to riparian buffers, wetlands, or perennial crops. Refer to the Appendix or to the comments in the spreadsheet itself for more information.

The N rate sheet contains the fertilizer response function, the fertilizer and corn prices, and other information needed to arrive at the N target application rate. By default, the target N rate is the U of MN extension recommended rate, but that can be reduced further or increased by the user. The U of M recommendations give a range in rates around the profit-maximizing optimum. We have assumed that a rate near the high end of that range would be applied in the fall, while the low end of the range would be used for spring preplant or sidedressing. We have a 30 lb difference built in, but that can be changed.

The Watersheds sheet contains acres of cultivated ag land, forests, and urban area by region. It has acres of each of the ten crops by region, and also the suitable acres of the different BMPs. Another thing in the Watersheds sheet, up at the top, is an area that the user can use to zero out any of the BMPs on any given individual BMP that the user wants to exclude from the analysis.

The Wetlands, Controlled Drainage, Tile Line Bioreactor, Saturated Buffers and Cover crop sheets include the percent reduction in N load that the BMP is expected to achieve, along with some fairly simple calculations of installation cost, annual capital cost, and maintenance cost. Refer to the detailed model documentation for more information on these models.

Corn grain and silage acres receiving the target N rate

The corn target N rate calculations are complicated by the different legume credits for the part of the corn acres that follow soybeans or alfalfa, by the rate differences related to the N fertilizer product prices, the rate differences between fall and spring application, the impact of using N inhibitors, and the N contributed by manure. The default soybean credit of 30 lb/acre is based Table 20, on page 16 of the 2011 release of (Kaiser et al. 2011). The 100 lb default alfalfa credit is based on Table 21, assuming 2-3 plants/ft2. The rate reduction adoption rate in Main Calcs Cell C134 links to Watersheds row 5, which shows the reduced rate acres by region. That adoption rate also enters directly into the inhibitor calculations in BMP rows 178 and 179, but the rest of the linkages to the BMP calculations are via row 5 of Watersheds. The weighted average target N rate is capped at the current rate.

The corn silage N rate is assumed to be the same as the corn grain N rate. The corn silage is also valued at the grain yield and price.

The (assumed current existing rates) and the (optimal target rate) for a given area are plugged into equations to represent N losses to tile drainage, ground water and surface runoff. Then the difference between the losses to waters with current rates and losses to waters with optimal rates are calculated to determine the net potential benefit.

The target fertilizer N rate is a percentage of approximately the U of M recommended N rate, derived from the quadratic corn yield response function discussed above:

$$Y = 135.08 + 0.5595\ N - 0.002\ N^2$$

which is assumed to plateau at the maximum-yield N rate of 140 lb for corn following soybeans. The U of M recommended rate maximizes the (economic) return rate, and is derived by maximizing the function (also see Figure 9):

$$\text{Profit} = P\ Y - w\ N - \lambda\ (\ Y - (135.08 + 0.5595\ N - 0.002\ N^2)$$

where P is the price of corn, Y is the yield of corn, w is the N price, and N is the N rate.

The latest recommendations for corn after soybeans and corn after corn are in the web calculator http://extension.agron.iastate.edu/soilfertility/nrate.aspx. For 55-cent N and $5.00 corn, that calculator shows a maximum profit rate of 111 lb, with a range of 102-122. Using the quadratic yield response regression formula discussed above, I calculate a maximum return rate of:

$$140 - 250 * (\text{N price/lb / corn price/bushel})$$

or 117 lb at an N price of 55 cents and a corn price of $5.00, so that seems reasonably close to calculator's 1111 lb. That maximum-profit rate can be varied up or down by a percentage (the default is 100%). I label that rate the (potentially-adjusted) "BMP target rate" rather than the recommended rate, as we decided to label it in one of the meetings.

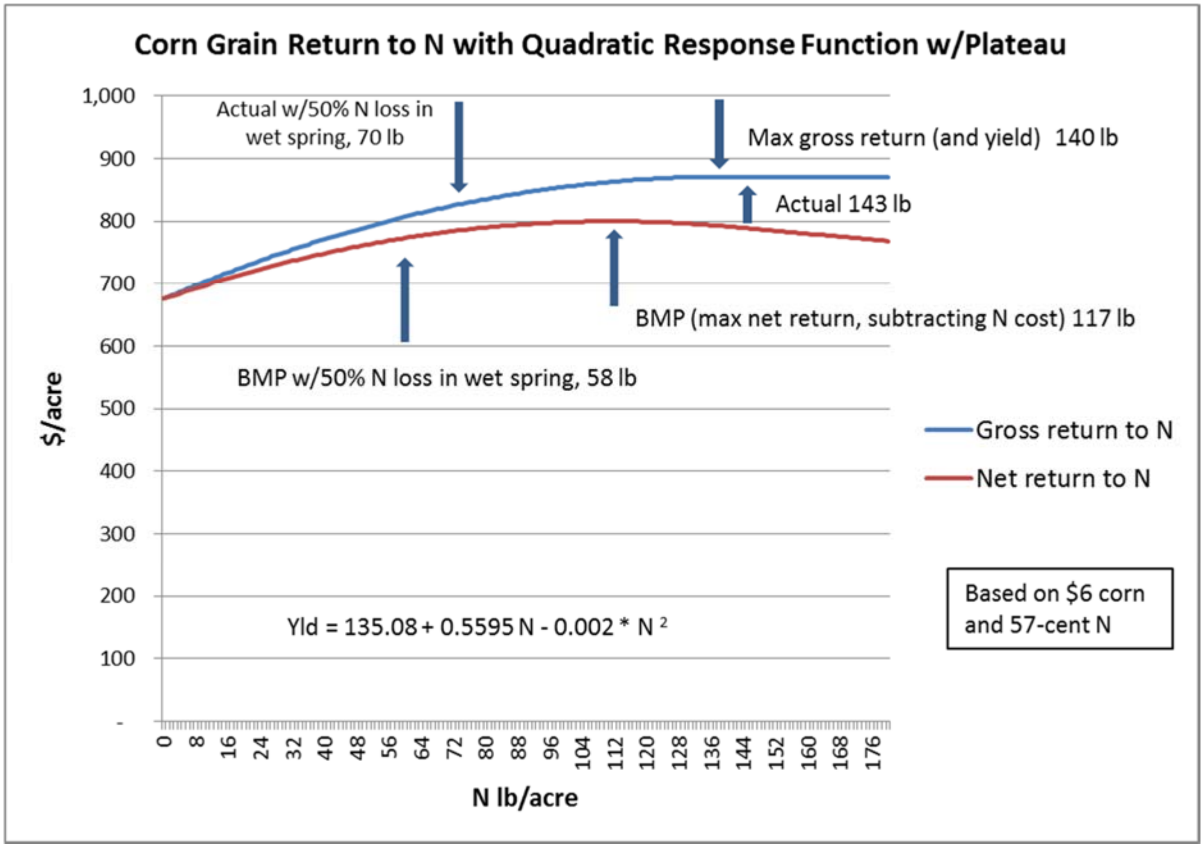


Figure 9. Illustration of The Corn Grain Nitrogen Fertilizer Response Function Built into the N Rate Sheet

A possible enhancement that could be made to the spreadsheet in the future would be to have the target N rate vary depending on the N source assumed in a particular scenario. For example, suppose we have a current scenario where the N is fall-applied NH_3 costing only $0.49/lb, and we change that to a split spring preplant and sidedressed application where the sidedressed portion is liquid costing $0.71/lb. That means the ratio goes from 6.00/0.49 or 12.24, to 6.00/0.71 or 8.45. The current scenario target rate at the 12.24 ratio should really be 119 lb, while the sidedressing scenario at the 8.45 ratio should be 110 lb. That 9 lb. rate reduction would reduce the corn yield by 0.9 bushel.

The target N rate considers the previous crop, because the U of M recommendations and the quadratic yield function both require the previous crop to be specified. The following example for the "wetter clays and silts" agroecoregion illustrates how the survey average nitrogen rate was used to impute rates that varied depending on the previous crop. There are 14,000 acres of this agroecoregion in each of the Elm Creek and Rush River watersheds.

One acre of corn after soybeans is assumed to be grown for every soybean acre, with one acre of corn after alfalfa for every four alfalfa acres (consistent with a four-year alfalfa stand rotated with one year of corn). For example, acres of these crops in the wetter clays and silts region are:

corn grain	7,601	acres
corn silage	12	
total corn	7,613	
soybeans	5,958	
alfalfa	226	

Applying the assumed ratios to the above soybean and alfalfa acreages, implies that there are 5,958 acres of corn after soybeans and 226/4 or 56 acres of corn after alfalfa. The rest of the corn is assumed to be corn after corn, and calculates to (7,601 + 12 – 5,958 – 56) or 1,599 acres.

In a few regions, the sum of corn after soybeans and corn after alfalfa exceeds total corn acres, so the acres of corn after soybeans and corn after alfalfa are reduced proportionately so that their sum equals total corn. That implies that there is no corn in those regions.

The survey N rate in this region is 150 lb. The U of M recs are for a soybean N credit of 34 lb and an alfalfa credit of 70 lb with assumptions about the alfalfa stand that are listed in the spreadsheet.

Applying some algebra to the 150 lb survey rate with the above credits results in N rates of:

corn after corn – 178 lb/acre

corn after soy - 144 lb/acre

corn after alfalfa - 108 lb/acre

as the existing situation. Multiplying those rates times the imputed acreages of 1,599 for corn after corn, 5,958 of corn after soy, and 56 of corn after alfalfa, and dividing by the total corn acreage of 7,613. That should give an overall average equal to the 150 lb survey rate, aside from a bit of rounding.

The assumed existing N rate is based on the 2009-10 survey of counties, and then translated into agroecoregion averages by Professor Mulla's staff. One thing we discussed once was how cover crop effectiveness might vary with weather – i.e. in a wet year, the probability of a successful stand might be greater than the 20% assumed here, and that the reduction in drainage losses given a successful stand might be greater than 50%. Currently, those factors do not vary with weather, in the absence of data on how to vary them. However, the absolute amounts of N in the drainage water are much larger in a wet year than in an average or dry year, so in absolute terms a cover crop reduces N drainage losses by a greater amount in a wet year.

The target N rate, which is the same for all regions, can be varied by changing a percentage from the 100% of the U of M recommended rate that is the default. The assumed existing rate varies by region and is varied more deeply in the spreadsheet. We don't envision the existing rates being changed by the casual user.

N Fertilizer product mix and application timing by agroecoregion

The U of M survey report lists application timing by N source on p. 6. According to that report, NH3 was applied 61% of the time in the fall and 28% in the spring, while urea was 77% in the spring and only 10% in the fall. Project staff used unpublished data from that survey to estimate quantities of NH3 and urea N by agroecoregion. However, those calculations did not break out how much of each of those two products was applied in the fall versus in the spring by region. The 15 HUC8 watersheds contained in the model are mainly comprised of 15 agroecoregions that are in south-central and southwestern Minnesota and have mainly heavy soils. Under the rationale that NH3 application works well in the fall on heavy soils but not in the spring due to problems getting the soil slot to close after knifing so that the NH3 gas doesn't escape, it was assumed that all of the NH3 applied in those 15 regions (and thus in the 15 HUC8 watersheds) was applied in the fall, and that no urea was fall-applied in those 15 regions. Adding up that NH3, it was less than the total statewide fall-applied N as indicated in the survey and referred to in the previous paragraph here. The remaining NH3 is accounted for if 25% of the NH3 applied in the rest of the state was fall-applied and the other 75% of NH3 was spring-applied, and if no urea was fall-applied in the fall anywhere in the state.

These assumptions thus deviate slightly from the survey in that the 10% of urea that was applied in the fall is ignored. Perhaps that discrepancy could be reconciled in the model in the future, but time constraints have not allowed it to be addressed to date.

Given those assumptions, the NH3 price of $0.49/lb is used to value all fall-applied N. The liquid price of $0.72/lb is used for any sidedressed N. The urea price is used for the spring-applied N in the SC and SW regions since all NH3 was fall-applied there. In the rest of the state, the spring-applied N price is a weighted average of the NH3 price and the urea price, since some NH3 is assumed to be spring-applied there.

Moving on down the columns of the BMP sheet, are the following:

Percent of N fall-applied (row 163) and ***extra fall-applied corn fertilizer N (row 166)***

Extra fall-applied corn fertilizer lb N/ac is the 30 lb/A from the Fert timing sheet multiplied by percent fall-applied, but capped by the (current – BMP) average N rate from row 165. In other words, the current N rate is assumed to include an extra fall-applied amount. Two sources that discuss corn yield differences at different rates of fall- and spring-applied fertilizer are (Randall and Mulla 2001; Sawyer et al. 2006). Table 3 on page 14 of Sawyer et al. shows that a 120 lb spring application gave a 175 bushel yield, while a 160 lb fall application gave 169 bushels. In Randall and Mulla, the fall-spring difference in losses in Table 8 is 9 kg/ha for both years, or about 8 lb/acre if I did the conversion accurately, and the four-year total difference between fall and spring in Table 9 is 22 kg/ha/year or 19 lb/acre/year. The ratio of tile line loss to total loss in NBMP shows that leaching losses are around 150% of tile line losses, so if you scale up the 8-19 lb/acre tile line losses from this article to the total of tile line plus leaching and runoff losses, it would put you in the neighborhood of 30 lb.

Total fall-applied corn fertilizer, lb N, Total spring preplant corn fertilizer, lb N, Sidedressed corn fertilizer, lb N, Total corn fertilizer, lb N, and Total fertilizer, , , , , , lb N – These are all fairly straightforward calculations. The split is important because the fall fertilizer is priced as NH3, the sidedressed fertilizer as liquid, and the spring preplant as a weighted average of the remaining fertilizer. The weighting calculations are in the Watersheds sheet.

Row 134 brings over the current N rate on corn after soybeans, for use as a cap on the BMP rate used in the yield response function. The next row shows the current corn yield.

Next is the economically-optimal N rate based on corn-after-soybeans. This rate is for acres receiving the reduced rate, if less than all corn acres. The predicted corn yield below it is an average of the predicted yield on reduced-N acres and the current yield on corn acres not receiving reduced N.

Planting a cover crop is assumed to reduce the corn yield in a wet year, but not an average or dry year. The default reduction is 6%. That reduction is multiplied times the probability of a successful cover crop stand (20%), so it should not have much of an impact in a wet year, and none at all in an average or dry year. That reduction can be modified in rows 43:45 of the Covercrop sheet.

The target N rates plus any extra fall-applied N in the BMP sheet are assumed to be no more than the current N rates shown in the Current sheet. The comparison calculations are shown in the screen shot in Figure 8 below. The current N rates are shown in row 137. These rates are assumed to be averaged over all previous crops.

The target BMP rates, also averaged over previous crop, are shown in row 138-140. Those rates are for corn acres receiving the target rate.

The manure N/acre is shown next, in row 151. This manure N is added to the fertilizer N to calculate the N loads. The user can select a percentage of this manure N to credit against the target rate, so row 150 shows the percentage of the manure N to be so credited.

The percent of the N that is fall-applied in the current scenario, and in the BMP scenario after any shift to spring that the user selects, are shown in rows 162 and 163. The rates of fall-applied, spring preplant, and sidedressed N are multiplied by acres of each to arrive at total corn N and total watershed fertilizer N in rows 198 and 201.

The manure is assumed to be applied to the corn grain and silage acres only, not the other crops. The calculation is to bring over the watershed total pounds of manure N from the Animal sheet (via the Current sheet), and then to divide by acres of corn grain and silage acres from the Current sheet to arrive at the manure N lb/A in row 151. The perennial crop, wetland, and riparian buffer scenarios take land away from corn and soybeans. So, the model reduces the manure N in proportion to the reduction in corn acres. If, say, perennial crops are set to replace 100% of the corn and soybeans (such a high percentage is admittedly unrealistic, but there would be some impact at lower percentages as well), then pounds of manure N/acre of corn approaches infinity. That seemed unrealistic. If corn were really eliminated from the watershed, this version of the model assumes that livestock production and manure generation would soon be eliminated as well.

	A	B	AH	AI	AJ	AK	AL	AM
1	Select a BMP combination / Combine All BMPs / Statewide / Hide Zones Not in Selected Watershed / Show All Regions		**Swelling Clay Lake Sediments**	**Undulating Plains**	**Very Poorly Drained Lake Sedi**	**Wetter BE Till**	**Wetter Clays & Silts**	Totals
162	Percent of N fall-applied, current		4.3%	11.7%	4.6%	65.6%	68.6%	
163	Percent of N fall-applied, BMP		1.7%	4.9%	1.8%	29.8%	29.5%	17.3%
164	Percent reduced rate including timing minimum		90.0%	90.0%	90.0%	90.0%	90.0%	
165	N rate on Corn, before wet spring losses, averaged over previous crop, not including manure (lb N/ac),		73.4	61.2	75.6	45.4	59.0	
166	before wet spring losses, averaged over previous crop, after any manure credits, with extra fall N, capped at current (lb N/ac),		73.4	61.2	75.6	45.4	59.0	
167	Total corn grain & silage acres		42,879	263,849	109,256	412,703	492,869	7,538,303
168	Acres originally spring applied, total		41,014	233,028	104,231	141,919	154,792	4,557,358
169	Acres originally spring applied, adopting rate reduction		36,912	209,725	93,807	127,727	139,313	4,101,622
170	Acres originally spring applied, NOT adopting rate reduct		4,101	23,303	10,423	14,192	15,479	455,736
171	Acres originally fall applied, total		1,865	30,821	5,025	270,784	338,077	2,980,945
172	Acres currently fall-applied with N inhibitor		466	7,705	1,256	67,696	84,519	745,236
173	Acres currently fall-applied wo N inhibitor, avail for inhib or time shift		1,399	23,116	3,769	203,088	253,558	
174	Acres fall-applied shifted to N inhibitor, current rate		0	0	0	0	0	0
175	Acres fall-applied with N inhibitor & target rate		0	0	0	0	0	0
176	Acres shifted from fall to spring preplant		629	10,402	1,696	91,390	114,101	1,006,069
177	Acres shifted from fall to split spring/sidedress		629	10,396	1,695	91,339	114,037	1,005,510
178	Acres fall-applied w/o inhib, adopting rate reduction only		0	6	1	51	63	559
179	Acres fall-applied with inhib, adopting rate reduction		420	6,935	1,131	60,926	76,067	670,713
180	Acres fall-applied, NOT adopting rate reduction		186	3,082	503	27,078	33,808	298,094
181	Check - total corn grain & silage acres		42,879	263,849	109,256	412,703	492,869	7,538,303
182	Acres fall-applied		606	10,023	1,634	88,056	109,938	969,366
183	Acres originally spring applied		41,014	233,028	104,231	141,919	154,792	4,557,358
184	Acres shifted from fall to spring preplant or sidedress		1,258	20,798	3,391	182,729	228,138	2,011,579
185								
186	Fall-applied corn fertilizer, lb N, rate reduction on acres currently getting inhibitor		33,355	460,917	92,376	2,996,904	4,737,066	42,556,080
187	Fall-applied corn fertilizer, lb N, inhibitor bmp but current rate		-	-	-	-	-	0
188	Fall-applied corn fertilizer, lb N, rate & inhibitor bmp		33	472	91	3,270	4,912	43,971
189	Fall-applied corn fertilizer, lb N, non-adopting		21,377	334,551	58,638	2,570,046	3,836,305	31,885,992
190	**Total fall-applied corn fertilizer, lb N**		**54,765**	**795,940**	**151,105**	**5,570,220**	**8,578,283**	**74,486,043**
191	Original spring preplant corn fertilizer, bmp, lb N		2,535,444	11,672,499	6,650,127	4,902,071	7,169,756	205,158,857
192	Original spring preplant corn fertilizer, non-adopting, lb N		470,166	2,529,463	1,216,251	1,346,971	1,756,496	45,973,429
193	Spring preplant corn fertilizer shifted from fall, lb N		43,230	578,934	120,230	3,507,466	5,872,209	52,958,879
194	Preplant portion of split preplant/sidedress, lb N		12,962	173,584	36,049	1,051,655	1,760,684	15,878,836

Figure 10. Screen shot of part of the BMP sheet, current as of 08/07/14

Fall N applications switched to spring or split spring/sidedressing, percent of fall-applied acres

These percentages enter the calculations in rows 164 and 176 of BMP. By default, corn acreage shifted from fall to spring or sidedress N is also assumed to get the target N rate, based on B25 of the Fert_timing sheet. BMP row 164 is where the rate reduction adoption rate is set to no less than the sum of the spring and sidedress adoption rates times the percentage of the N that is fall-applied. Row 176 is where the acres shifted to spring preplant is calculated. This adoption rate also enters into the tile drainage loss factor in N Rate!E94.

Weather scenarios and fertilizer N lost in a wet year

The N loading calculations in the Current and BMP sheets are done for three weather scenarios: dry year (10th percentile), wet year (90th percentile) and average year (50^{th} percentile) see "Cropland N Losses in Runoff" section of (Mulla et al. 2012). The N fertilizer rate reduction BMP tends to look financially attractive in the average year scenario, which is considered to be the baseline scenario. However, agricultural interests tend to raise concerns about high N fertilizer losses from the crop root region in a wet year, which would reduce yield. They also raise concerns about the possibility of not getting the fertilizer applied at all in the spring preplant or sidedressing time windows in a wet year.

Also, the reduction in N load resulting from the various BMPs will vary due to different water volumes in dry and wet years.

The combo box in Main Calcs!A19 allows the user to specify one of the three weather scenarios, which dictates which of the rows in Current and BMP are used in the results. If the “wet year” scenario is selected, cell C21 will be highlighted. This cell allows the user to specify a percentage of the fertilizer that is lost to the crop. The adjustment is then made in the yield response functions in row 258 of the BMP sheet.

The N load reductions resulting from a fertilizer rate reduction vary depending on the weather scenario selected.

If the N rate reduction is the only BMP selected and the weather scenario is switched between an average year, a wet year, and a dry year, one that is noticeable is that the percent N load reduction is higher in a dry year than in an average or wet year. This difference is due to the fact that the tile line reduction is calculated as a constant term plus a slope times the rainfall. (see rows 258-261 in the Current sheet). Thus, when rainfall varies, the N load does not change proportionally.

Interactions between acres of riparian buffers, perennial crops, and wetlands

These interact because all three (perennial crop acres, riparian buffer acres, and wetland pool and buffer acres) compete for current corn (grain plus silage) plus soybean acres. The suitable acres for each of these BMPs is different, however. The Watersheds sheet contains total acres for each of them and overlapping acres between each pair of the three, and acres that overlap among all three. For the overlapping acres, if the total of the three adoption percentages exceeds 100% of the corn and soybean acres, the acres are allocated based on the priority order shown at the bottom of the main screen. The user can enter any priority order desired there, but it is recommended that the BMP with the lowest cost/lb of N removed be selected first.

Further complicating the calculations, for wetlands two different acreages must be calculated – 1) acres of the wetland pool and buffer themselves, which enters into the installation and maintenance costs as well as the opportunity cost of lost crop production, and 2) acres of cropland treated (N load reduced) by the function of the wetland. The calculations in the Wetlands sheet provide the ratio of pool plus buffer acres to treated acres.

Maximum suitable acres of riparian buffers (labeled “buff_acres” of the Watersheds sheet) put constraints on acreage of buffers. The riparian buffer suitable acres are also separated into marginal and nonmarginal land. The marginal land is allocated to buffers first, up to the adoption rate entered by the user. Once all marginal land has been allocated to buffers, remaining buffer acres are allocated from the nonmarginal suitable buffer acres. Maximum suitable acres of wetlands are labeled “potwetrest” and are shown in row 70 of Watersheds).

The wetland percentage is also multiplied by corn and soybean acres to arrive at the wetland (treated + pool + buffer) acres. Treated acres is multiplied by the percentage in Wetlands B8 to arrive at pool plus buffer acres, which is multiplied by B20 to calculate the wetland installation and maintenance costs. Before calculating those costs, pool plus buffer acres are first adjusted to be no more than the “potwetrest” maximum suitable wetland acres. That acreage is also deducted from corn and soybean acres to arrive at remaining corn and soybean acres in BMP rows 15:17. Treated acres (the difference) is multiplied by the N load reduction percent in Wetlands B22 to calculate the N load reduction. The treated acres remain in corn and soybean production.

If the total of the wetlands and perennial crop adoption percentages is more than 100%, the **cost/lb of N removed** is compared for these two BMPs, using the numbers in Main calcs!K194 and L194. Around A248: C254, the costs of these three BMPs are compared. If the wetland has the lowest cost and perennial crops have the second lowest, the available corn and soybean acres are then allocated to wetlands up to the user-specified percentage, and any remaining corn and soybean acres are then allocated to perennial crops, and then the rest, if any, to the riparian buffers which are the most expensive.

The adoption rates for these BMPs are transferred from Main_Calcs!C138:139 and 145 to Watersheds rows 18:49. These BMPs compete for some of the same suitable acres, so when the treated acres for the three exceed the suitable acres, the acres are allocated among them based on the priority order entered in Main_calcs!B40:B42. C40:C42 shows how they compared in cost/lb of N reduced in the previous recalculation, as a guide to the user. The potentially suitable buffer acres are in the Watersheds sheet, and are brought over to row 27 of BMP. That number is current corn and soybean acres. Buffer acres (along with perennial and wetland pool and buffer acres) are subtracted from current corn and soybean acres to arrive at BMP corn and soybean acres in rows 15-17. Buffer acres are multiplied by switchgrass costs/acre for the costs that enter into crop returns in row 271.

The switchgrass costs are from row 218 of the Returns_per_A sheet. For these buffer cost calculations, the switchgrass is assumed to not be harvested regardless of the switchgrass price/ton. This is a difference from the perennial acre calculations, where the switchgrass revenue is added in if a switchgrass price is entered that provides revenues that exceed the harvesting costs. I assume that the buffers will be too narrow or small to justify harvesting biomass from them.

This percentage is multiplied by the current corn and soybean acres and transferred to rows 27 and 30 of BMP. The perennial crop is assumed to have zero N load, so the corn and soybean N loads are reduced in direct proportion to the reduction in their acreage.

Watersheds!row 102 shows the N loading from the bottom of the BMP sheet. Row 103 reduces those numbers achieved by the controlled drainage and/or bioreactors and/or saturated buffers. Row 104 reduces that N load by the percent of region acres in the watershed that are suitable, and multiplies by the removal percentage.

If these calculations are zeroed out when you view the Watershed sheet, click the button at the top of the sheet to select this BMP from the list in the Main_calcs sheet.

Cereal rye cover crops seeded to corn grain, soybean and short-season crop acres

These calculations are the same for all regions, so the calculations are much more straightforward. A 20% default probability of a successful stand is based on aerial seeding into standing corn and soybeans, 90% into sugarbeets and short-season crops in September, based on U of MN Department of Agronomy and Plant Genetics grad student Elizabeth Wilson's work(Wilson 2012). The N reduction percentages are intended to be generally in line with results in (Strock et al. 2004). The seeding rate is from the regional cover crop website. The rye seed prices are from Elizabeth Wilson. The machinery and chemical costs are from U of MN machinery costs and crop enterprise budgets.

Mark Zumwinkle at the Minnesota Department of Agriculture contributed to the cover crop analysis with information from a farmer in SE MN who aerially seeded winter rye into soybeans in the fall of 2011 and then was able to harvest approximately three tons/acre of rye hay in spring 2012(personal communication 5/31/12). The rye hay was valued by the farmer at $90/ton as feed for a beef herd.

The default rye seeding rate in the spreadsheet differs from that farmer's practice because the default number is the midpoint of the range suggested on the web-based cover crop decision tool (Midwest Cover Crops Council undated). That range was 96-175 lb/acre, so the midpoint is 135 lb. The farmer reportedly seeded only 75 lb/acre. The default rye seed price is $0.22/lb or $12.50/bushel (56 lb), from Melissa Wilson.

Mr. Zumwinkle argues that aerial seeding date is very important, with 9/1 the ideal date for seeding into soybeans because the soybean leaves drop at that point and provide a mulching effect that helps the rye seed become established. Soybean leaf drop is based on shortening day length, so is very dependable. He also thought that one of the keys to the farm's success is that he was planting soybeans back into land in soybeans last year, so he could delay the soybean planting until the forage was harvested. Seeding into standing corn is trickier and should be delayed until 9/20-25 when the corn is browning and dropping leaves, because when seeding earlier, much of the rye seed can get caught in the whorls of the corn plants and be lost, and the dropping corn leaves can help mulch the seed just like the soybean leaves do. It is difficult to get the helicopter operators to do the seeding on the proper dates, however.

He also commented that a sustainable rotation with perennial forages may improve soil conditions at the surface and make it easier to establish a cover crop than on corn-soybean land. He also recommended not attempting to seed a cover crop when conditions are too dry. He felt that under those conditions, a success rate of 30-60% might be possible rather than the 20% I am assuming.

Down the road, he thought that seed coatings for rye may improve the success rate by preventing the seeds from sprouting in moisture conditions that are too dry for success. He thought that 0.25-0.5" of rain is necessary.

Covercrop

The cover crop calculations for corn grain and soybeans are separate from those for the short season crops of corn silage, peas, sweet corn, potatoes, dry edible beans, sugar beans, wheat, barley, and oats, so that the adoption rates and stand establishment success rates can be different. By default the corn grain and soybean cover crops are planted by helicopter in September, before harvest, while the other crops are planted using ground equipment after harvest. The ground equipment is assumed to achieve a 90% stand establishment success rate compared to 20% for helicopter seeding, and also costs less per acre. However, the N load reduction percentages for the short season crops is reduced by an arbitrary 10% to account for years when the cover crops get planted on time but are followed by an early winter that prevents satisfactory growth. Sugar beet acres are assumed to be planted to a cover crop in early spring rather than in the fall, so the N load reduction percentages are assumed to be only half that of the other short season crops.

Earlier versions of the spreadsheet assumed that the cover crops are planted on both the corn and soybean acres. Barley and oats are not fertilized as heavily as wheat and corn. By default, barley and oats acres are not planted to cover crops. D6:E9 can be used to vary which individual short season crops are planted to cover crops.

Data entry cells have been added to the cover crop sheet for a harvested cover crop forage yield, value/ton, and harvesting cost/ton, for situations where that is considered. The default values for the forage value are zero by default under the rationale that a typical corn-soybean cash grain farm operator may not have a market for the forage, or may not want to delay corn or soybean planting in order to harvest the forage.

Controlled Drainage

The calculations for controlled drainage and tile line bioreactors are organized using similar logic to the Wetlands sheet. Main_calcs cell C37 lets the user select the maximum slope for the controlled drainage acreage calculations, which draw from columns in the Watershed sheet. A GIS analysis was performed to estimate the total area of installed subsurface tile drainage systems within each agroecoregion. This was accomplished by overlaying several data layers: poorly and very poorly drainage soils data from the SSURGO database; slopes of less than 3 percent from SSURGO; and corn, soybean, wheat, and sugarbeet fields from CDL. To identify the subset of artificially drained areas that are appropriate for controlled drainage systems, a further GIS analysis employed the use of a 30-meter DEM to identify drained areas with slopes less than 0.5, 1, and 2 percent. This results in three classes of areas suitable for controlled drainage at the corresponding slopes of 0.5, 1, and 2 percent. In general, controlled drainage becomes more cost-effective at lower slopes, as more acres of drained land can be controlled with a single control structure. The user can choose the maximum slope to be considered for controlled drainage in the spreadsheet tool with the combo box in cell C37 of the Main calcs sheet. It is important to note that although limiting controlled drainage to slopes of 0.5 percent or less will increase the effectiveness of nitrogen removal (lower cost per pound of nitrogen removed), it will greatly reduce the number of acres within a given watershed that the practice can be applied on.

Note that the total areas within each agroecoregion that are suitable for controlled drainage may not be contiguous. For example, if one considers several fields in a small area, there may be small sections of each of those fields that are flat enough for controlled drainage, but each section could be sufficiently small so as to prohibit cost-effective implementation of controlled drainage. When viewed on a larger scale, those many small flat areas are lumped together to produce an aggregate area that would be suitable for controlled drainage. However, as noted, these areas may not actually be near each other at all. This results in a potential overestimation of the areas suitable for controlled drainage. It is recommended to limit the adoption rate of controlled drainage to no more than 50 percent to reduce these effects.

The Controlled Drainage sheet contains the inputs for characterizing the costs and nitrogen removal capacity of controlled drainage systems. Columns C, D, and E contain the inputs for slopes of 0.5, 1, and 2 percent, respectively. Row 4 contains the input for nitrogen removal efficiency; the default value is estimated based on several published studies. Thorp, Jaynes, and Malone (2008) reported long-term average annual nitrogen load reductions of 40.5, 40.7, and 46.3 percent for Minneapolis, Rochester, and Saint Cloud, MN, based on a modeling simulation of controlled drainage. Additionally, the authors reported a reduction of 45.5 percent for Fargo, ND.

Row 5 contains the inputs for installation costs. The 0.5-1.0% installation cost is from Christianson et al. The default installation values for 0-0.5% and 1.0-2.5% are assumed to be inversely proportional to the number of acres treated (i.e. the installation cost at 1% is double that of 0.5% because the acreage is halved), but there is no empirical data at this point to support that assumption. Christianson et al. do not state a slope that their numbers relate to. Row 8 contains the annualized installation cost, which is calculated for the interest rate (row 6) and project life (row 7) entered. Replacement intervals and costs for the control structure and gates are entered in rows 10 – 13. Annual maintenance for gate adjustment is included in row 14, and the annualized maintenance and replacement costs are calculated in row 15. The annualized total cost per acre is given in row 16.

Tile Line Bioreactor

This sheet contains the inputs for characterizing tile line woodchip bioreactors (bioreactors). The contributing subsurface drainage area (drainage area, hereafter) is entered. Although the sizes of individual bioreactors vary greatly, for this project it was necessary to determine a standard bioreactor drainage area that can be used to determine cost and N removal on a per acre basis. The average drainage area of seven bioreactors in Illinois was 29.6 acres (with minimum and maximum values of 5 and 70 acres) (Verma et al. 2010). Christianson, Tyndall, and Helmers reported a typical drainage area of 20.2 ha (50 acres) for bioreactors in Iowa (Christianson et al. 2012). Christianson and Helmers reported drainage areas of 30 to 80 acres in Iowa (Christianson and Helmers 2011). Drainage areas for bioreactors installed in Rice and Mower Counties in Minnesota were 7 acres and 30 acres, respectively (Moncrief 2011; Anonymous undated). An additional bioreactor installed in southwestern Minnesota treats drainage water from 80 acres. A default value of 40 acres was chosen for the drainage area in this decision tool, but the user can change this value (cell C3).

Another important component in assessing the viability of bioreactors is determining N removal efficiency. Verma et al. published an N removal efficacy curve that relates bioreactor nitrogen load reduction to loading density (treatment area in acres per 100 square feet of bioreactor) (Verma et al. 2010). Few other removal efficiencies have been published. A bioreactor treating approximately 80 acres in southwestern Minnesota has an estimated N removal of 20%. A brief analysis of typical drainage areas and bioreactor dimensions using the efficacy curve from Verma et al. (2010) showed that a loading density of 8.5 acres treated per 100 square feet of bioreactor (footprint) corresponded to the economically optimal bioreactor dimension. This is the dimension at which the average expected cost of N removal (cost per unit of N removed) is minimized. Lower loading densities can be achieved in two ways: 1) by decreasing the number of acres treated by the bioreactor and keeping the dimensions constant (from a typical average dimension), or 2) by increasing the bioreactor footprint and holding the treatment area constant. In case 1, overall N load entering the bioreactor is reduced, while the fraction of N removed by the bioreactor actually increases. However, the increase in N removal is less significant than the decrease in N entering the bioreactor and overall N load reduction is decreased. With no change in dimensions, the costs remain the same, and there is actually an increase in N removal cost ($ per pound removed). In case 2, the increase in N removal gained by adding additional volume (or area) to the bioreactor is not large enough to offset the cost of the additional woodchips that are necessary, and again the N removal cost increases.

It is important to note that the efficacy curve developed by Verma et al. (2010) is valid only for loading densities from 1.25 to 8.5 acres per 100 square feet. As more information becomes available, a better understanding of bioreactors and their treatment characteristics may show that other situations (i.e. different design geometry, higher loading density) are more desirable.

The optimal loading density is included in the spreadsheet tool as the loading density desired (cell C4). Woodchip depth is entered in C5. A desired bioreactor area (footprint) is then calculated (C6) based on the drainage area and desired loading density. The user then has the option to enter a different value for the actual bioreactor footprint in C7. Because the desired loading density corresponds to the maximum loading density at which the bioreactor efficacy curve is valid, the user will receive an error message if the actual area installed is smaller (corresponding to a larger loading density) than the desired area in C6. Conversely, entering a bioreactor area that is too large will result in a similar error as the loading density may not be less than 1.25 acres per 100 square feet.

After entering the actual installed footprint of the bioreactor, the installed loading density is computed (C8). The N removal rate is calculated for *both the desired (C9) and actual installed (C10) footprints.* The user is further able to enter a value to override either of the calculated N removal rates (C11).

We are interpreting the N load reduction percentages discussed above as percent of flow passing through the bioreactor. However, not all of the tile drainage system flow typically passes through a bioreactor. Typical is 50-70% passing through it. Cell C12 can be used to enter the expected percentage passing through it. The final nitrogen removal efficiency value used in the model as a percent of the tile drainage system flow is in C13. If a value is entered in C11, C13 is set equal to C11; if no value is entered in C11 to override the calculated values, C13 is set equal to C10. If the user wishes to simulate the desired condition, the actual installed footprint should be set to the desired footprint, and the user should ensure that no value is entered in C11 to override the calculated N removal rate.

Installed woodchip volume is calculated based on the depth of woodchips and the installed bioreactor footprint. The user can also enter a value for the width of the bioreactor, which then calculates a value for the required length of the bioreactor. The width and length of the bioreactor are not used in the model.

Economic inputs include the woodchip cost, number of control structures required, control box cost, labor cost, interest rate, bioreactor life, as well as various maintenance costs. Woodchip cost per cubic yard is entered in C20, and total woodchip cost is calculated in C21. The default cost of woodchips is given as $22 per cubic yard, which is based on information from a University of Minnesota Extension document detailing the construction costs of a bioreactor in Mower County, Minnesota. A depth of woodchips of 4 feet was assumed to attain the actual volume of woodchips installed at that site. The number of control structures required per bioreactor is entered in C22 (this value is assumed to be two). The cost of each control structure is entered in C23, and the total control structure cost is calculated in C24. The total cost of materials is computed in C24. The costs of the two control boxes necessary to operate a bioreactor are also entered by the user. A value of $750 per control structure is the default value in the model, based on an assumed cost of $1500 for two control structures (Sonia Jacobsen, personal communication, 11/4/11).

Labor necessary for bioreactor installation is entered in C27. Total labor and material costs are summed for the total initial investment (C29).

Annualized capital cost (C33) is calculated based on amortizing the initial investment over an assumed useful life (C32) and discounted at the rate entered (C30). Further economic inputs include the annual maintenance cost, as well as the replacement intervals and costs for both woodchips and the gates used in the control structures. There is little guidance available for the replacement interval of the woodchip media; a default value of 10 years is used here, although Christianson and Helmers (2012) suggest intervals of 20 and 8 years for woodchip and gate replacement, respectively, in Iowa bioreactors.

Finally, total annualized cost is computed on a per acre basis (C43). A portion of the tile line nitrogen entering the bioreactor is reduced by the percentage entered by the user (or the default value at the constructed dimensions). The nitrogen removed within the bioreactor is combined with the annualized cost to estimate the nitrogen removal cost on a per pound basis. It is important to note that when the bioreactor is used with certain practices (lower fertilizer N inputs, for example), the amount of nitrogen entering the bioreactor may be reduced, which will similarly reduce the amount of nitrogen load reduction achieved within the bioreactor. Reducing the N load entering the bioreactor, and as a result, the nitrogen removed within the bioreactor, will increase the per pound nitrogen removal cost for the bioreactor.

Saturated Buffers

This sheet follows the same structure of the Tile Line Bioreactor, characterizing the inputs for saturated buffer and their cost information. The basic parameters are from Jaynes and Isenhart (2014). Their research site locates in a 48 ha (118.6 acres) field of Iowa with a treated drainage area 24.96 acres. In their study, saturated buffer is supposed to be implemented together with riparian buffer. The length and width of the riparian buffer are entered in C4 and C5. Flow rate infiltrating to the riparian buffer is calculated in C11, given the water level set in a control box, values of which are input in C9 and C10. With values in C13 and C14, actual percentage of diverting flow into the buffer is calculated in C15. Tile line N load reduction of total tile flow used in the BMP comparison is given in C19, using the values of actual tile flow volume and N concentration in tile flow.

The major cost is the installation cost of the control box and materials and labor for installing extra tile lines. Given the presumed annual interest rate, annualized NPV of installation cost is in C28 with a per-acre cost plus maintenance cost in D32.

Wetlands

The assumptions in this sheet are based mainly on Iovanna et al.'s 2008 JSWC article, plus a phone conversation with Sue Galatowitsch. The reduction percentage is rounded off from the mean of several studies cited by Fabrizzi (Fabrizzi and Mulla 2012). The main data required here is the wetland pool area as a percentage of the watershed draining into the pool; the area of a grassed buffer around the pool; and the effectiveness in terms of the percentage of N removed. Dr. Galatowitsch commented that a wetland is fairly cheap to establish by breaking tile lines. I have entered investment amounts of $500/acre for that and $250/acre to establish the grassed buffer, but those costs need to be refined. The investment is converted to an annualized capital cost via an amortization formula based on an assumed life of the wetland and a discount rate.

The wetlands calculations in rows 80-87 of the Watersheds sheet are a bit tricky in that the adoption percentage from Main_calcs is applied to the total region acres in row 80, unless the potential pool and buffer acres in row 57 times the ratio of (treated + pool + buffer)/(pool + buffer) in Wetlands row 7 is less than total region acres. For combinations of wetlands along with perennials and/or riparian buffers, all three of these BMPs compete for the corn and soybean acres, so the wetland acres is reduced if total corn and soybean acres is less than needed for all three of those BMPs. In that case, row 84 will show the reduced pool plus buffer acres, and the N reductions in row 87 is reduced proportionally.

Additional information on the content of the individual sheets

(The sheet names are listed as subheadings below)

Main_calcs

This sheet contains the main inputs and summary graphs. The combo box at A6 allows the user to select one of the watersheds or the entire state to view in the graphs. Cells are provided for the user to vary the following parameters:

Corn grain & silage acres receiving the target N rate
Fall N target rate acres receiving N inhibitor
Fall N applications switched to spring, % of fall-app. acres
Fall N applications switched to sidedressing, % of corn acres
Riparian buffers % of suitable acres
Restored wetlands % of suitable acres
Controlled drainage % of suitable acres
Saturated buffers % of suitable acres
Tile line bioreactors % of suitable acres
% corn grain & soybean acres planted w/cover crop rye
% short season crops planted to a cereal rye cover crop

Perennial crop % of corn & soybean area

Other parameters that can be changed in the Main_calcs sheet include:

Percent of manure N credited in target N rate
Controlled drainage max slope, %
Switchgrass market price, $/ton dry matter (default zero)
Weather scenario (average year, wet year (average of 20% wettest) or dry year (20% driest)
Percentage of applied fertilizer and manure N lost before the growing season in the event of a wet year (default 50%)

Cost ranking for riparian buffers, restoring wetlands, and perennial crops.

The BMP default acreage percentages can be changed here, and the individual region percentages can also be reduced below this watershed limit in the "Watersheds sheet."

The current acreages, fertilizer and manure N rates and cost, and the current N load are summarized starting in A114, followed by a breakdown of the load by land use type. The manure is assumed to be applied to the corn grain and silage.

Below that is a large database of scenarios extending across the columns. The first few columns of this database are shown in the screenshot below (Figure 11). Scenarios include every individual BMP and all combinations of BMPs considered in the model. The values for the main inputs for each BMP are shown in the rows below the scenario descriptions.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
133	Insert data table / Delete data table / View main screen / View filter		14%,N inhibitor 0.0%,spring preplant N 2.1%,sidedress N	Reduce N rate 14%	N inhibitor 0.0%	Spring preplant N 2.1%	Sidedress N 2.1%	Wetlands 1.6%	Bioreactors 0.5%	Controlled drainage 1.3%	Saturated buffers 1.3%	Riparian buffers 0.6%	Corn&Soybean cover crops 2.9%	Short-season cover crops 3.0%	Perennial crops 0.3%
134	% of corn receiving target N rate		90%	90%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
135	% of current fall-applied corn receiving N inhibitor		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
136	Fall N applications switched to spring, % of fall-app acres		45%	0%	0%	45%	0%	0%	0%	0%	0%	0%	0%	0%	0%
137	Fall N applications switched to sidedressing, % of fall-app acres		45%	0%	0%	0%	45%	0%	0%	0%	0%	0%	0%	0%	0%
138	Restored wetlands % of applicable regions		50%	0%	0%	0%	0%	50%	0%	0%	0%	0%	0%	0%	0%
139	Tile line bioreactors % of suitable acres		0%	0%	0%	0%	0%	0%	20%	0%	0%	0%	0%	0%	0%
140	Controlled drainage % of suitable acres		50%	0%	0%	0%	0%	0%	0%	50%	0%	0%	0%	0%	0%
141	Saturated buffers		50%	0%	0%	0%	0%	0%	0%	0%	50%	0%	0%	0%	0%
142	Riparian buffers % of suitable acres		70%	0%	0%	0%	0%	0%	0%	0%	0%	70%	0%	0%	0%
143	% corn grain&soybean A planted w/cover crop rye		10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%	0%
144	% short season planted to a cereal rye cover crop		50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%	0%
145	Perennial crop % of total cropland area		10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%
146	Acres treated by BMP (million)		-	7.0093	-	1.0323	1.0317	0.7929	-	0.671	0.6712	0.2758	1.4217	1.5209	0.1274
147	Scenario number	198	198	1	2	3	4	5	6	7	8	9	10	11	12
148	Reduction in N loading, watershed (million)	lb	50.68181	27.13	0.00	8.64	8.80	5.82	0.33	2.52	3.49	2.63	2.28	3.89	1.27
149	***Cost/lb of N load reduced, including the change in fert cost, crop return, cover crop cost, and annualized wetland restoration and bioreactor installation costs due to the policy that reduces N loss by 1 lb***		2.24	-4.62	0.00	-3.05	-0.79	1.00	14.83	2.42	1.26	16.27	36.67	20.74	1.48
150	Acres treated by BMP (million)	acres	0.0000	7.01	0.00	1.03	1.03	0.79	0.27	0.67	0.67	0.28	1.47	1.53	0.1313
151	BMP corn N fert & manure/acre	lb	99.930	107.20	146.17	134.50	134.33	146.16	146.17	146.17	146.17	146.13	146.17	146.17	146.21
152	BMP corn N fert cost/acre		$34.16	33.70	58.79	53.38	55.75	58.79	58.79	58.79	58.79	58.79	58.79	58.79	58.80
153	N total fert & manure difference in watershed	lb	-385.599	-304.25	0.00	-89.47	-90.73	-6.17	0.00	0.00	0.00	-22.14	0.00	0.00	-9.54
154	Difference in N loading/acre, watershed	lb	1.01	0.54	0.00	0.17	0.17	0.12	0.01	0.05	0.07	0.05	0.05	0.08	0.03
155	Percent of N fertilizer applied		4.5%	2%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%
156	Percent of current N loading		23.0%	12%	0%	4%	4%	3%	0%	1%	2%	1%	1%	2%	1%
157	Difference in N fert/acre corn	lb	(46.20)	-38.96	0.00	-11.67	-11.84	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.05
158	Difference in corn grain yld/acre	bu	(2.47)	-2.17	0.00	-0.49	-0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
159	Crop net returns/acre, current (with corn revenue)		$115.09	115.09	115.09	115.09	115.09	115.09	115.09	115.09	115.09	115.09	115.09	115.09	115.09
160	Crop net returns/acre, BMP (with corn revenue)		$108.24	111.51	115.09	114.29	114.24	115.05	115.09	115.09	115.09	112.46	115.09	115.09	114.80
161	Difference with BMP		-$6.85	-3.58	0.00	-0.80	-0.85	-0.04	0.00	0.00	0.00	-2.62	0.00	0.00	-0.29
162	Percent difference		-6.0%	-3%	0%	-1%	-1%	0%	0%	0%	0%	-2%	0%	0%	0%
163	Other BMPs cost ($ million)		-$179.37	0.00	0.00	0.00	0.00	-7.49	-4.94	-6.10	-4.38	0.00	-83.58	-80.78	0.00
164	Actual wetlands % of applicable regions		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
165	**N fert cost (-) or savings (+) on corn gr & sil ($ million)**		$199.79	$195.40	$0.00	$42.10	$23.65	$2.45	$0.00	$0.00	$0.00	$8.65	$0.00	$0.00	$3.77
166	**Market value of the corn yield difference**		-$79.74	-$70.16	$0.00	-$15.70	-$16.69	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Figure 11. The Big Data Table in the Main_Calcs Sheet

Below the database of input data is an Excel data table that calculates various key results in rows 148-170 for the various scenarios, with differences compared to the current situation summarized below row 114. The way an Excel combo box works is that Excel takes the scenario numbers in row 147 and plugs them one at a time into cell C147. For any given scenario number, the index functions in C134:C146 extract the inputs for that scenario and display them in C134:C146. C148:C170 then displays the key results for the scenario number in C147. The command button in C130 allows the user to select any given BMP or combination to display in C148:C170. The data table function then copies those key results over to the column below that particular BMP's inputs, and repeats the process for the other BMPs each time Excel recalculates.

Excel does not allow the user to insert or delete rows or columns within the overall data table area. The data table body must first be deleted before making such changes, and then re-entered. The header row 147 and the header column C needs to remain when the data table body is deleted. Macros attached to the buttons in cell A133 will delete and re-enter the data table when changes need to be made to it. Two graphs of the N load reduction effectiveness versus cost of the individual BMPs are shown in rows 2 through 30. One graph is on a per-watershed-acre basis, and the other is per treated acre. Acres treated are different from one BMP to another. The same information is shown in the table below the graphs. The BMPs can be sorted eight different ways by changing the selection in the combo box in cell H35.

The bottom graph of N load reduction versus cost for frontier BMP combinations in rows 55:78 draws on data from the data table that is manipulated by macros. The macros are stored in the Excel VBA editor, and can be viewed by selecting Developer, Visual Basic. When Excel is first installed on a computer, by default the Developer tab is not shown in the top-level menu. To show the Developer tab, select File, Options, Customize Ribbon, and check the box next to Developer under Main Tabs.

When the macros run, they copy the data from rows in the data table labeled: "Scenario number", "Reduction in N losses, watershed (million)", and "Cost/lb of N load reduced …". Those rows of data are transposed and pasted into the columns starting at A7 in the "Workspace" sheet. Those three columns are then sorted in ascending order by the cost/lb in column C in the same sheet. The "View Details" button runs a macro that will scroll to cell A7.

The scenario descriptions are then shown. Total cost by practice (column E) is calculated by multiplying the cost/lb of N reduced times the N reductions, and is expressed in millions of dollars.

The idea behind the column labeled "Frontier scenarios" (Column E) is that since the "Cost/lb" column is sorted from low to high, we only consider BMPs and combinations that give greater N reductions as the cost increases down the column (Figure 12). After sorting, the cheaper BMPs appear higher in the column. So, formulas in column F display the column B reductions for the BMPs on that "efficient frontier" but display blank values for the BMPs that don't provide increasingly greater reductions. Cell D67 also allows the user to weed out suites of BMPs that provide only small reductions, so that the graph shows only those BMPs that are most effective.

	A	B	C	D	E	F	G
7	Scenario	N Reductions	Cost/lb of N reduced	BMP Suite	Total cost by practice ($ million)	Total N Reductions, frontier scen	Percent of max reduction
8	1	32.9910	-$1.84	Reduce N rate 14%	-$60.80	32.99	50
9	13	32.9910	-$1.84	reduce N rate 14%,N inhibitor 0.0%	-$60.80	-	-
10	15	36.6127	-$1.82	reduce N rate 14%,sidedress N 2.1%	-$66.80	36.61	55
11	58	38.9224	-$1.67	reduce N rate 14%,sidedress N 2.1%,saturated buffers 0.5%,,	-$65.05	38.92	59
12	19	35.3476	-$1.67	reduce N rate 14%,saturated buffers 0.5%	-$59.05	-	-
13	48	35.3476	-$1.67	reduce N rate 14%,N inhibitor 0.0%,saturated buffers 0.5%,,	-$59.05	-	-
14	57	40.7777	-$1.49	reduce N rate 14%,sidedress N 2.1%,controlled drainage 1.3%,,	-$60.70	40.78	62
15	18	37.2406	-$1.47	reduce N rate 14%,controlled drainage 1.3%	-$54.70	-	-
16	47	37.2406	-$1.47	reduce N rate 14%,N inhibitor 0.0%,controlled drainage 1.3%,,	-$54.70	-	-
17	56	45.5403	-$1.33	reduce N rate 14%,sidedress N 2.1%,restore wetlands 1.6%,,	-$60.41	45.54	69
18	17	42.0667	-$1.30	reduce N rate 14%,restore wetlands 1.6%	-$54.52	-	-
19	46	42.0667	-$1.30	reduce N rate 14%,N inhibitor 0.0%,restore wetlands 1.6%,,	-$54.52	-	-
20	14	36.6797	-$1.29	reduce N rate 14%,spring preplant N 2.1%	-$47.14	-	-
21	126	47.7396	-$1.23	reduce N rate 14%,sidedress N 2.1%,restore wetlands 1.6%,saturated buffers 0.5	-$58.66	47.74	72
22	65	44.3105	-$1.19	reduce N rate 14%,restore wetlands 1.6%,saturated buffers 0.5%,,	-$52.77	-	-
23	108	44.3105	-$1.19	reduce N rate 14%,N inhibitor 0.0%,restore wetlands 1.6%,saturated buffers 0.5%,	-$52.77	-	-
24	53	38.9915	-$1.16	reduce N rate 14%,spring preplant N 2.1%,saturated buffers 0.5%,,	-$45.39	-	-
25	125	49.5062	-$1.10	reduce N rate 14%,sidedress N 2.1%,restore wetlands 1.6%,controlled drainage 1.	-$54.31	49.51	75
26	64	46.1129	-$1.05	reduce N rate 14%,restore wetlands 1.6%,controlled drainage 1.3%,,	-$48.42	-	-
27	107	46.1129	-$1.05	reduce N rate 14%,N inhibitor 0.0%,restore wetlands 1.6%,controlled drainage 1.3	-$48.42	-	-
28	121	47.0318	-$1.04	reduce N rate 14%,sidedress N 2.1%,riparian buffers 0.7%,restore wetlands 1.6%,	-$48.70	-	-
29	52	40.8484	-$1.00	reduce N rate 14%,spring preplant N 2.1%,controlled drainage 1.3%,,	-$41.04	-	-
30	55	40.8164	-$0.99	reduce N rate 14%,sidedress N 2.1%,riparian buffers 0.7%,,	-$40.45	-	-
31	60	43.5730	-$0.98	reduce N rate 14%,riparian buffers 0.7%,restore wetlands 1.6%,,	-$42.88	-	-
32	103	43.5730	-$0.98	reduce N rate 14%,N inhibitor 0.0%,riparian buffers 0.7%,restore wetlands 1.6%,,	-$42.88	-	-
33	175	49.2278	-$0.95	reduce N rate 14%,sidedress N 2.1%,riparian buffers 0.7%,restore wetlands 1.6%,	-$46.95	-	-
34	16	37.2640	-$0.93	reduce N rate 14%,riparian buffers 0.7%	-$34.77	-	-
35	45	37.2640	-$0.93	reduce N rate 14%,N inhibitor 0.0%,riparian buffers 0.7%,,	-$34.77	-	-
36	123	43.0893	-$0.90	reduce N rate 14%,sidedress N 2.1%,riparian buffers 0.7%,saturated buffers 0.5%,	-$38.70	-	-
37	131	45.8135	-$0.90	reduce N rate 14%,riparian buffers 0.7%,restore wetlands 1.6%,saturated buffers 0	-$41.13	-	-
38	161	45.8135	-$0.90	reduce N rate 14%,N inhibitor 0.0%,riparian buffers 0.7%,restore wetlands 1.6%,sa	-$41.13	-	-
39	51	45.6052	-$0.90	reduce N rate 14%,spring preplant N 2.1%,restore wetlands 1.6%,,	-$40.84	-	-
40	174	50.9918	-$0.84	reduce N rate 14%,sidedress N 2.1%,riparian buffers 0.7%,restore wetlands 1.6%,	-$42.60	50.99	77
41	62	39.5829	-$0.83	reduce N rate 14%,riparian buffers 0.7%,saturated buffers 0.5%,,	-$33.02	-	-
42	105	39.5829	-$0.83	reduce N rate 14%,N inhibitor 0.0%,riparian buffers 0.7%,saturated buffers 0.5%,,	-$33.02	-	-

Figure 12. Intermediate Calculations in Workspace Sheet that Serve as the Basis for the Frontier Scenarios Graph

It is important to note that the BMPs and combinations in a given row here are assumed to be mutually exclusive. We are ignoring the possibility of partially implementing BMPs from more than one row. Also, the nitrogen reductions in column B are the total reduction in the watershed resulting from implementing that BMP or combination of BMPs at the specified adoption rates (as defined in cells D7 to D18 in the main calcs sheet).

Cell F5 shows the maximum nitrogen load reductions attainable by any of the BMPs or combinations in the list. Column G divides the column F reductions by the maximum to arrive at percentages that will appear in the horizontal axes of the graphs.

For the graph to show a linear cost change across the width of the segment for any given BMP, the cost difference from the previous frontier BMP is divided by the N load difference to calculate the incremental change per one-percent load change. That data is pasted into the table starting in I8. For each row, that increment is then added to the cost shown in the previous load.

The other thing the macro does as it is writing out each row of rows 8-225, is to write out the BMP or combination label from row 238.

A key feature of the bottom graph is that the width of each horizontal line segment represents the reduction in N load achieved by each frontier BMP scenario. The way that feature is achieved is by having the macro write out data to 100 rows, with each row representing one percent of the maximum reduction achieved by the most effective frontier BMP. The macro does this by reading in the percentages shown in the range G8:G226 into an array, then scanning down through the array. For each non-zero element of that array, the macro writes one row for each percentage point in that array. The macro writes out the average cost/lb and the total cost for the watershed.

The weather scenarios and the percentage of the N lost is discussed below in the "Discussion of how the different practices are integrated into the BMP sheet calculations" section below.

Scenarios

This sheet contains two types of scenario comparisons. The first is to compare the three aggregate groups of BMPs, as discussed on page 20 above. The second comparison, which starts around Q46, uses a macro to recalculate the results for the adoption rates entered in the main screen, for all of the 68 HUC8 watersheds, the 10 major basins, the overall state, and the overall Mississippi River basin area in Minnesota. The results are displayed in rows 54:92, sorted alphabetically by watershed. A second macro can be used to make a copy of those results to rows 93:126. It then sorts the copied watershed results by cost/lb of N reduced, when the button in Q93 is clicked.

Log

When the user enters a scenario name and clicks the "Click to Save the Current Scenario Under the Name Entered Below" button in the Main Calcs sheet, a macro will locate the next blank column in this sheet and save a copy of roughly 100 different parameters to that column, along with a scenario name at the top of the column. Selecting a scenario name in the dropdown box will then reload those values in the different sheets they came from, erasing previously-stored values. A popup box will warn you before erasing those values.

Sensitivity

This sheet contains a similar list of the model parameters. When the user clicks the button near cell I97, a macro will scan through the list of parameters. It will vary each parameter up and down to 11 different levels +/- 50%, and will record the cost/N load reduction calculated for each level. The user can choose to run the macro for all 100 parameters at one time, or only one or a few at a time. The macro will take awhile to run through the entire list, since it recalculates the full model 11 different times for each parameter. The macro needs further modification to deal with a few situations where parameters are discrete values that are not reasonable to vary by the percentages specified, or where the stated percentages result in unreasonable values.

Watersheds

Most of the data in the model is organized in 36 agroecoregions (referred to simply as "regions" below)[6]. Watershed-level results are calculated as weighted averages of the region-level results for the regions contained in a given watershed. This sheet contains the list of regions and cultivated agriculture area of each in the state and in each of the watersheds. This sheet also contains a list of the regions with a place to indicate which regions are suitable for each of the various BMPs based on factors such as slope and existing tile drains. The suitable regions can be indicated by entering a percentage of the region acreage that is suitable.

Row 4 shows the acres of each region that is in the currently-selected watershed, and is a lookup to rows 171-250, discussed below.

The area starting in row 78 has the data on the split of N fertilizer between NH3 and urea, and the fall-spring split. Those numbers go into the calculation of the average cost of spring preplant N based on the assumption of whether NH3 can or cannot be applied in the spring in a particular region.

Below that in row 153 is the region total cultivated agricultural land acres in the state. Rows 154-166 are the region acres in each watershed. Row 255 shows how much of the currently-selected watershed is made up of that column's particular region, and sums to 100% across the row. Row 256 shows how much of that region is contained in the currently-selected watershed.

Current

This sheet is named "Current" because it contains the information for the current situation or status quo without implementing the BMPs. It begins with a row of percentages of each region included in the selected watershed, followed by the crop acreages. Most of the data in this sheet is from Professor Mulla's calculations, as discussed in (Mulla et al. 2012), except that we multiply his agroecoregion acreages times the percentage of each region that is contained in the watershed selected by the user. The University of Minnesota's corn fertilizer recommendations vary with previous crop, so the corn acres are allocated to three previous crop categories, as follows: Acres of corn (grain and silage) after soybeans is set tentatively equal to soybean acres, based on a corn-soybeans rotation. Corn after alfalfa is set equal to 25% of alfalfa acres, based on a rotation of one year corn and a four-year alfalfa stand. If the total of corn after soybeans plus corn after alfalfa is greater than the total corn acres, corn after soybeans and corn after alfalfa are reduced proportionately to equal corn acres. On the other hand, if the total of corn after soybeans plus corn after alfalfa is less than total corn acres, the difference is assumed to be corn after corn.

The crop fertilizer and manure nutrient calculations follow in the next area of the spreadsheet (see screenshot below, which shows the regions in the Statewide). Rows 120:124 have the estimates of manure applications. The corn fertilizer calculations begin estimated rates per acre from a fertilizer use survey by the U of MN Department of Soil, Water, which covered non-manured land. To convert those

[6] Three of his original regions were deleted to reduce the file size because they were mainly forested and contained little or no cultivated agricultural land – 11, Forested Lake Sediments; 17 Mesabi Range; and 19 Northshore Moraine.

numbers to estimates for an average of manured and non-manured corn land, producers with manured land were assumed to credit some of the manure applications against the non-manured land rates, based on the assumed manure N credit percentages in C120:C124, which were also used in (Mulla et al. 2012). Those adjustments result in the corn fertilizer rates in row 132.

1	Show All Regions		Alluvium & Outwash	Anoka Sand Plains	Blufflands	Central Till	Coteau	Drift & Bedrock Complex	Drumlins
119	Manure lbs from Mulla's spreadsheet, sheet Animal!columnsDM-DR	Expected available N from U of MN recommendations likely to be credited against fertilizer N by producers with manured land							
120	Beef	70%	5,827,326	119,481	5,820,191	2,750,391	7,365,984	-	3,593,047
121	Dairy	75%	5,928,866	187,830	7,231,424	7,882,797	1,857,645	-	9,225,878
122	Hog	90%	5,187,554	54,898	1,637,404	1,260,080	10,573,638	-	1,344,443
123	Chicken	70%	237,798	227	2,237	209,567	7,931	-	578,304
124	Turkey	70%	2,491,503	62,792	217,598	818,527	50,475	-	901,025
125	Manure lbs from Animal!column DR (state total)		19,673,047	425,228	14,908,855	12,921,363	19,855,674	-	15,642,697
126	Manure lbs from Animal!column DR (state total) assumed credited in the current scenario		15,105,087	318,031	11,125,250	9,691,110	16,106,582	-	11,680,071
127	Percent credited		77%	75%	75%	75%	81%	#DIV/0!	75%
128	Manure lbs from Animal!column DR (watershed)		19,673,047	425,228	14,908,855	12,921,363	19,855,674	-	15,642,697
129	Manure lbs from Animal!column DR (watershed) credited against fertilizer under current scenario (reduction in fert N rate)		15,105,087	318,031	11,125,250	9,691,110	16,106,582	-	11,680,071
130	Manure credited/acre		29.8	10.3	55.4	44.9	29.3	0.0	59.5
131	Fertilizer rate, Corn,, (lb N/ac), non-manured		127.6	125.2	138.2	126.9	130.0	117.0	117.0
132	Fertilizer rate, Corn, (lb N/ac), manured & non		97.8	115.0	82.8	82.0	100.7	117.0	57.5
133	**, Corn Silage, , , , , (lb N/ac),**		97.8	115.0	82.8	82.0	100.7	117.0	57.5
134	Manure N rate on corn, lbs/ac		38.8	13.7	74.2	59.8	36.1	0.0	79.7
135	Fertilizer & manure rate, Corn, (lb N/ac), manured & non		136.7	128.7	157.0	141.8	136.8	117.0	137.2
136	Fertilizer & manure rate, Corn, (lb N/ac), manured & non, adj for wet spring		136.7	128.7	157.0	141.8	136.8	117.0	137.2
137	Fert & man rate, Corn after soy, (lb N/ac), manured & non		125.8	127.3	139.4	129.8	132.7	119.0	116.0
138	Fert & man rate, Corn after alf, (lb N/ac), manured & non		89.8	91.3	103.4	93.8	96.7	83.0	80.0
139	Fert & man rate, Corn after corn, (lb N/ac), manured & non		159.8	161.3	173.4	163.8	166.7	153.0	150.0
140	**, Soybeans, , , , , (lb N/ac),**		3	3	3	3	3	3	3
141	Fertilizer rate, Spring Wheat, , , , , (lb N/ac),		107	107	107	107	107	107	107
142	, Barley, , , , , (lb N/ac),		66	66	66	66	66	66	66
143	, Oats, , , , , (lb N/ac),		48	48	48	48	48	48	48
144	, Sugarbeet, , , , , (lb N/ac),		83	83	83	83	83	83	83
145	, Potatoes, , , , , (lb N/ac),		195	195	195	195	195	195	195
146	, Alfalfa, , , , , (lb N/ac),		10	10	10	10	10	10	10
147	, Other hay, , , , , (lb N/ac),		10	10	10	10	10	10	10
148	Sweet corn, peas & dry edible beans....(lb N/ac)		75.5	103.4	74.1	81.5	82.9	0.0	71.3
149	Total corn fertilizer, lb N		49,556,225	3,565,430	16,642,582	17,707,069	55,422,103	91	11,298,347
150	Fertilizer on soybeans&hay, lb N		3,277,208	403,752	1,133,968	1,941,665	1,795,753	207,672	2,066,737
151	Fertilizer on wheat...soybeans, lb N		7,765,202	620,030	851,668	2,616,450	2,295,230	78,874	2,999,827
152	Fertilizer on Sweet corn, peas & dry edible beans, lb N		3,433,585	34,981	199,327	62,161	27,506	-	100,917

Figure 13. Screen Shot of Part of the Current Sheet

Row 139 contains a formula derived from solving the equation:

$$N_{bar} = [C_c\, N_c + C_s\, (N_c + S) + C_a\, N_c\, (N_c + A)] \,/\, (C_c + C_s + C_a)$$

for the fertilizer rate on corn after corn N_c, where N_{bar} is the surveyed current N fertilizer rate on all corn, C_c, C_s, and C_a are acres of corn after corn, after soybeans, and after alfalfa; N_s, and N_a are imputed N fertilizer rates on corn after soybeans and corn after alfalfa; and S and A are soybean and alfalfa N credits of 34 and 70 lb/acre from the University of Minnesota recommendations (Rehm et al. 2006). That publication has an N credit of 100 lb for alfalfa with 2-3 plants/ft2, and 40 lb for 1 plant/ft2, so I averaged those two numbers.

The surveyed current N fertilizer rates and the corn yields were originally available by county and then later were weighted to agroecoregions. For the BMP calculations, predicted corn yields are calculated based on a "target" N rate. The default for the target N rate is the U of M recommended N rate, but it can also be adjusted up or down by a percentage if the user is interested in evaluating the impact of a higher or lower rate.

The corn N response function was provided by Professor Mulla as:

$$\text{Corn bushels/acre} = 135.08 + 0.5595\ N - 0.002\ N^2$$

where N is lb of fertilizer N/acre, and is derived from data for corn following soybeans. The yield response function results in a maximum yield at 140 lb of N, and is assumed to plateau at that rate rather than declining at higher N rates. The corn yield at this rate is 174.2 bushels. The maximum profit N rate at a corn price of $5.00/bushel and an N price of $0.05484/lb is 117 lb, with a yield of 173.2 bushels.

Since the yield function is based on a corn-after-soybeans N rate, the 34 lb soybean N credit is subtracted from the imputed corn-after-corn rate N_c for use in the yield response functions in rows 257:261. The N rates used in the response functions are capped at the yield-maximizing rate in N-rate!C66 even if the actual rate in row 252 is higher, assuming the quadratic yield function levels off at that point. This function may not be accurate outside southern Minnesota, and could vary from place to place.

Manure N is added to the fertilizer N in the yield function, implicitly assuming that manure N and fertilizer N provide equivalent yield boosts. The economic impacts of shifting cropland to a perennial crop, buffer, or wetland are calculated based on per-acre returns to land (revenues minus costs other than a land cost) shown in crop enterprise budgets contained in the "Returns_per_A" sheet. The land cost is omitted because it is constant because the total amount of land in the watershed remains constant. The crop returns to land used to calculate the economic impact of acreage shifts are based on actual yields, not yields predicted by the nitrogen response function.

The BMP sheet discussed next includes the same yield response function but uses the target N rate for corn after soybeans rather than being based on the adjusted current rate, unless the adjusted current rate is less than the target rate in which case the current rate is used.

Row 196 here in the Current sheet shows the difference between the corn yield predicted by the N response function and the actual yields in that data. The differences vary by region. The model compares the yield response function's ***predicted yields*** here at the imputed corn-after-soy N rate (which is based on the surveyed N rate on overall corn), to the ***predicted yields at the target N rate*** in the BMP scenario in the BMP sheet.

The remainder of the sheet calculates the N load by crop in three categories: leaching, drainage, and runoff, and under three precipitation regimes: dry, wet, and average.

To allow users to consider the effect of a ***wet spring*** where a percentage of the corn fertilizer and manure N is lost before the corn plants need it, when "Spring weather" in the main screen is set to "wet", the percentage from the Main_calcs sheet (default arbitrarily set at 30%) is subtracted from the amount calculated above to arrive at the rate for the corn yield response function.

BMP

This sheet is similar to the Current sheet except for the modifications required to calculate the results for the BMP scenario rather than the current situation.

The first row (2) after the region names shows the percent of each region that is located in the selected watershed. Below that (B3: B13) is a set of percentages of each practice's suitable acres. These will all be at 100% unless the user reduces the acreage of a given practice. Reductions would be entered in the

The next area at the top of the sheet has the agronomic crop acreages as before, but the corn and soybean acres are adjusted for any area shifted to the perennial crop or to restored wetlands, based on the percentages of total cultivated agricultural area entered by the user in the Main_calcs sheet. The acreage required for those two shifts is shown, and then if that requirement is greater than total corn and soybean acres, the shift is reduced to equal that total.

The target N fertilizer rates are in row 138-142, averaged over previous crop (soybeans, corn or alfalfa) based on the acreages in rows 33-35 and the target rates in the N rate sheet, and divided by the conditions of fertilizing timing (including application of N inhibitors). If the target rate is greater than the current rate for any region (in the Current sheet, and also shown in row 137 for reference), the target rate is set equal to the current rate –The corn yields predicted by the N response function are shown in row 262. The economic impact of the N fertilizer rate BMP is based on the difference in the predicted yields here versus the yields predicted at the adjusted current rates from row 196 of Current. The economic impact of shifting corn and soybeans to a perennial crop or wetland is based on the actual yields, however, as in Current.

The N load reductions resulting from the cover crop practice affect row 340 for the leaching for all the crops , row 381 for crop drainage

N rate

The percentages used to allocate the corn acres by previous crop (soybeans, alfalfa, or corn) are in rows 4-5. Rows 8-17 calculate average N fertilizer costs based on the prices of the three main fertilizer products, with different prices for use in the spring preplant, sidedressing and N inhibitor BMP costs. The corn grain price is entered here as well. The return to land for the corn silage acres is currently based on the corn grain yields and price, rather than using corn silage yields, since corn silage prices are difficult to determine.

In rows 22-25, N inhibitor cost and current adoption conditions are identified explicitly.

The U of MN corn N fertilizer recommended rates and legume credits are shown next, followed by the calculation of the target rates used in the model. Cell D20 contains a percentage of the recommended rate to assume for the corn acres in the BMP sheet when not reducing the N fertilizer rate. For a scenario where the N rate is not reduced, we would want the fertilizer costs, yields, and N losses to match in the current and BMP calculations. For that to happen, since the surveyed current corn N rates in the Current sheet vary by region, this percentage needs to be set at a level to give an N rate averaged over the previous crops that is at least as high as the highest current rate of any region. The 130% here seems to give that result.

Cells C30:F30 contain the extra N assumed with fall application (default 5 lb/A) and the reduction for spring and sidedress application (default -15 lb/A). C92: C94 has the reduction in tile line N assumed when switching from fall to spring preplant or sidedressing,

Fert Timing

This sheet contains cells to enter data on the N products applied to corn when applying in the fall or before planting in the spring. By default, fall-applied N is assumed to be NH3 while spring preplant applications are urea. Sidedressing applications are assumed to be liquid, and that is not set up to be changed by the user.

A separate Ferttiming.xlsm spreadsheet is available to calculate the additional investment required for fertilizer application equipment and fertilizer storage space that would be required to apply the N fertilizer in the more limited time window before planting in the spring or as a sidedressed application rather than in the fall, and the equipment changes required to shift from NH3 to urea or liquid. These investment amounts are then annualized to annual ownership costs, and the operating costs for fuel, labor, and repairs are added. Corn yield losses are calculated for years with wet springs when working days are limited, based on 36 years of historical data from the University of Minnesota's Southwestern Research and Outreach Center at Lamberton. These calculations are summarized to a single per-acre cost or cost savings for each of the spring preplant and the split application scenario, for the three weather scenarios modeled in the main spreadsheet – an average year, a wet year (20% wettest), and a 20% driest year. Click the button at cell G1 to run a macro that lets you select the ferttiming.xlsm file and then copies these six values from that spreadsheet over to this sheet. See below for more details on the calculations in Ferttiming.xlsm.

Two other data items are entered in this sheet: tile line N recovery for sidedressed N relative to preplant-applied N (default 100%), and a corn yield difference due to the split preplant/sidedressed BMP relative to the preplant-only BMP. This latter item is currently nonfunctional because those yields are assumed to be the same, but this space is included in case the decision is made later to vary the yields between those scenarios.

Returns_per_A

This sheet contains enterprise budgets for corn grain, corn silage, and soybeans. It also contains summary information from another spreadsheet for the other crops, which is currently not used. The imported data here is from the budget_import sheet data, re-organized as needed for the Current and BMP sheets. The regions are across the top and the crops run down the rows. The perennial crop (switchgrass assumed, for now) costs and yields are entered manually in this sheet, and are the same for all regions. The corn data is complicated by the need to separate out the nitrogen fertilizer and yield data so it can be varied in the BMP calculations.

The perennial crop costs are entered two ways: 1) with harvest costs, and 2) without harvest costs. The user enters a yield/acre and market value/ton. If the crop value is sufficient to cover the harvest cost, the crop is assumed to be harvested and the net value is transferred to the BMP sheet. Otherwise, the cost without harvest is transferred.

Budget_import

This sheet contains a list of agronomic crop yields and returns to land used to calculate the economic impacts of shifting cropland to perennial crops or wetlands, by region. It is imported (copied and pasted) from the separate budget spreadsheet. Depending on how often we plan to update these numbers, I could add a macro that I have used elsewhere that prompts the user to select the file name of the budget name and then imports the data automatically from that file.

Cost Implications of Changing Corn Fertilizer Timing

The concept underlying these calculations is that if all of the corn fertilizer is shifted to spring before planting or sidedressed after planting rather than applied in the fall, more applicators will be required to complete the operation. In Minnesota, it is not usually possible to begin fieldwork until around April 1. Corn planting gets underway in late April and needs to be completed in early May to avoid yield reductions, so there is somewhat less than one month to get the preplant fertilizer applied before the start of planting, and a bit more than one month if fertilizer application can be done while planting is underway. April can be rainy, so there is a concern that there will not be enough working days available to finish the fertilizer application in an unusually wet year even though there is plenty of time in an average or dry year.

If preplant application is the only alternative to fall that is considered, then if the number of applicators is not sufficient to complete preplant fertilizer application, planting could be delayed if that is judged to be better than planting it without fertilizer. A delay in planting past some target end date reduces the corn yield (default 1.5 bushel/day of delay). So, a macro in the spreadsheet solves for the number of fertilizer applicators such that their annual cost is just equal to the lost corn revenue due to the delay in planting past the target end date. It solves that problem for both the current fall application scenario and the spring preplant scenario, and calculates the increase in application plus yield reduction cost that results from limiting fertilizer application to spring only.

The increased cost for fertilizer application equipment for the spring should be at least partially offset by reductions in cost for the equipment previously used for fall and spring application. How much the cost reduction will be is unclear, however. The fall-applied N is assumed to be NH_3. Reports are that the NH_3 equipment currently in use is quite old, dating back as far as the 1960s. Some of the industry is reported to be switching to urea rather than replacing that old NH_3 equipment (Coulter 2012). The reasons are unclear, but NH_3 is highly toxic if leaked. NH_3 must also be knifed in, which is slower and more costly than broadcasting urea. At any rate, if the NH_3 equipment continues to be maintained and replaced as needed under our BMP scenario, perhaps in order to have the option of going back to applying part of the N in the fall to avoid spring weather risk, then the only savings from eliminating the fall application would be the operating cost for fuel, labor, and repairs. On the other hand, if the switch to spring means that replacing the old NH_3 equipment, then the savings would include both the operating and the capital ownership cost. Equipment replacement is assumed here, so both operating and capital ownership costs are included.

For the BMP of a split preplant and sidedressed fertilization, in an average or dry year part of the fertilizer is applied preplant and the rest sidedressed after planting. That practice obviously requires two types of applicators rather than one, requiring additional investment. It is assumed, however, that a side benefit of the split application is that the preplant component is less risky because in a wet year the entire rate can be sidedressed if the working days in April are not sufficient to complete the preplant component.

Since 1973 the staff at the University of Minnesota's Southwestern Research and Outreach Center has been recording whether each day of the growing season is suitable for fieldwork. That database of 37 years of daily data is incorporated into ferttiming.xlsm. Specially-developed Excel VBA functions draw on each individual year's data to calculate the number of working days between any two user-entered dates. For fall or spring preplant application, they use a starting date for fertilizer application (default November 1 for fall and April 1 for spring) and the target end date for corn planting (assumed to be the same as the end date for preplant fertilization, default May 3). For sidedressing, the start date is assumed to be the planting target end date, and the ending date is when the corn is too tall to drive through with the sidedressing applicator (default June 20). The number of acres fertilized per day are calculated from the assumed number of applicators along with performance data provided by Kirwan (Kirwan 2012). Investment per applicator for the applicators themselves, related equipment, and additional fertilizer storage capacity to store the fertilizer over the winter is from O'Rourke (O'Rourke and Winter 2010).

Ferttiming.xlsm – A Separate Spreadsheet for Analyzing the Cost Implications of Changing Corn Fertilizer Timing

Including the fertilizer timing calculations in the main NBMP.xlsm spreadsheet caused recalculation to slow down to an unacceptable level, so these calculations were moved over to a separate spreadsheet file named ferttiming.xlsm. More specifics are described below for each of the two sheets in that spreadsheet.

Timing sheet

The first items in this sheet are a default watershed name, corn acres, and the N fertilizer rate. The Le Sueur River watershed with its 274,344 corn acres and a 117 lb/acre rate are the defaults. The choice of watershed should not really matter as long as the corn acres are large enough so that the number of applicators is in the double digits so that rounding does not become an issue. O'Rourke and Winter point out that going to spring application would mean that the fertilizer would need to be stored over the winter months. The only reason for including the N rate here is to calculate the volume of that storage.

The next area of the sheet shows that by default, the fall-applied N is NH_3 while the spring preplant N is urea. That data is just for information in this version. Formulas must be entered manually further down to reference the performance and cost data for the appropriate equipment for each product. A toolbar, tractor, and pickup truck are required to apply NH3. A self-propelled floater and a tender are used to apply urea, while a sidedress applicator and tractor are used for sidedressing. Performance information (acres covered per day), investment/unit, annual ownership costs, and operating costs per acre are calculated.

Input data for calculating the working days required to apply fertilizer and plant corn are shown next. Inputs common to fall, spring preplant, and sidedressing are listed in rows 68-85. Rows 87-175 have the inputs and calculations for comparing spring preplant (labeled BMP) versus the current fall-applied scenario. Results are shown for the average of the 10% wettest years, the 10% driest years, and the average of all years.

A macro attempts to find an approximately cost-minimizing number of applicators is optimized separately for the current and BMP scenarios when you click the "Recalculate" button. The criterion that is minimized is the sum of the application equipment annual ownership and operating costs, the fertilizer storage cost, and the yield penalty due to delayed planting, if any. The optimization procedure begins with the initial guess of acres/applicator in cells B104 and B119. That value for acres/applicator is divided into total corn acres to arrive at the number of applicators needed, which is rounded off and shown in B106 and B121, and comes to 49 applicators for the current scenario and 87 for the BMP scenario. Two data tables in rows 158-175 calculate the cost sum for other numbers of applicators up to 60% less than and greater than those initial numbers. If increasing or decreasing the number of applicators reduces the cost, that change is made by adjusting the acreages in B104 and B119. Recalculating once or twice usually seems to solve for a stable number of applicators.

The area below row 178 contains the calculations for the split preplant/sidedressing BMP scenario. These calculations do not include yield penalties because the time window for preplant and sidedressing combined, appears to be long enough to complete fertilizer applications without delaying planting in any year, although there are a number of years when there is not enough time to complete the preplant application and all of the N would need to be applied in sidedressing. Row 195 contains cells for the user to enter a probability of not completing the preplant application that is tolerable for that user. The number of preplant applicators (floaters for urea) is adjusted based on the probabilities entered.

While there is no yield penalty for the split application, there is the additional investment and annual costs for the two different types of applicators.

The bottom of that sheet contains summary costs per acre for the two BMPs and the three weather scenarios. These values need to be copied over to the "Fert_timing" sheet of the NBMP.xlsm spreadsheet. That can be done manually, or a macro in the "Fert_timing" sheet will do it for you. Note that the reduced revenue from any delay-related corn yield reductions is combined with the application costs in these six numbers. After transfer to nbmp.xlsm, those values will enter into the cost side of the calculations there. Corn yields are handled separately from costs in nbmp.xlsm, so technically the yield reductions here should be kept separate from the costs and then factored into the yield calculations there. But, that is more work and would not affect the bottom line costs in the main calculations, so for expediency they are handled this way at least for now.

Days_by_yr sheet

This sheet contains the daily working day data for the 36 years, with each year shown in a separate column. The data is arranged with August at the top so that the fall fertilizer application period is shown in the same column as the following spring data.

Below that daily data are rows containing the total working days between the target start and end dates, the calculated actual completion dates in each year, and the bushels of yield reduction (penalty) based on the actual completion dates. The default yield reduction is 1.5 bushels/day past the target end date. The yield reductions are calculated only on the unfertilized acreages on each date (assumed to be equal to the unplanted acres), NOT on total acres. One of the years when there is a yield penalty under the preplant BMP scenario is 1979 (labeled as 1978-79), when fertilization and planting would not have been completed until May 13 and the yield reduction was 6.9 bushels/acre. The yield penalty calculations in the VBA function have been replicated starting in cell C275 to demonstrate the methodology incorporated into the function.

Below and to the right of the daily data, starting in cell AW274, are the calculations of the average completion dates and yield penalties for the 10% wettest years, the 10% driest years, and all years. The summary numbers from this table are transferred back to the Timing sheet.

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