Appendix 4: Water Quality Modeling Results

Modeling Overview

Summary

One of the primary goals of the Working Lands Watershed Restoration Program (WLWRP) is to improve water quality through economically viable changes in land use and/or agricultural practices. To provide an estimate of the potential water quality benefits of this program, the Minnesota Pollution Control Agency (MPCA) employed a sophisticated water quality model (*Hydrologic Simulation Program – Fortran* or HSPF) to predict changes in pollutant loads that can be directly attributed to on-the-ground restoration strategies identified in this report. Two different restoration scenarios, as well as a baseline scenario, were modeled in each of six study watersheds. Each scenario was run for a period of 13 years using historical meteorological and land cover data as inputs to the models (except for Whiskey Creek which was modeled for a period of 11 years). Each modeled scenario produced continuous daily estimates of pollutant loads and concentrations for all reaches and lakes in the target watersheds. An annual average of the daily model output data was calculated and used to estimate the annual pollutant load reductions that would occur following implementation of each restoration strategy (see Long-term and Mid-term Scenario spreadsheets below).

Restoration Practices

The water quality modeling efforts focused on two particular restoration practices that were identified as being economically feasible. The first restoration practice is the conversion of marginal row crop acres, defined as acres with a Land Capability Class (LCC) of 4 through 8 as well as acres with a LCC value of 3 that also have steep slopes, to perennial grasses. In order to model the water quality benefits of this type of conversion, the physical and biological characteristics of land covered with perennial grass need to be understood and parameterized in the HSPF model as a unique land category. For each watershed model, we used an existing set of parameters that that had been calibrated to match the characteristics of perennial grassland in that particular watershed. Conversion rates of marginal row crop acres to perennial grasses were 30% in the Mid-term scenario and 100% in the Long-term scenario.

The second restoration practice modeled in this study is the adoption of cover crops on existing row crop acres. In order to model the impact of cover crop adoption on water quality, a new land category was developed and incorporated into the HSPF models. The new land category (i.e. row crop with cover crop) retains many of the physical, hydrological and biological characteristics of conventional row crop acres but differs in how the land responds to rain events in late spring and fall when cover crops are the dominant vegetative cover (more detail on cover crop representation is given below). Modeling the adoption of cover crops on existing row crop acres did not take into account successful establishment rates but rather assumed successful cover crop adoption over a given percent of row crop acres depending on the modeled scenario.

Restoration Scenarios

Using different combinations of these two restoration practices, two distinct restoration scenarios were modeled. The first restoration scenario, referred to as the Mid-term scenario in this report, assumed 30% of all marginal row crop acres would be converted to perennial grass. This conversion rate is based on the percent of survey respondents who indicated a willingness to convert some of their marginal row crop acres to perennial grasses. This conversion was combined with a 40% cover crop adoption rate on all remaining row crop acres. This adoption rate is based on the percent of survey respondents who indicated willingness to incorporate cover crops into their farming practices. As stated earlier, we assumed that all farms choosing to incorporate cover crops were immediately successful in establishing an effective cover crop. Improvements to water quality from implementation of the Mid-Term scenario are presented in the main body of this report in the form of a pollutant load reduction within a targeted channel reach or lake relative to the pollutant load in the baseline scenario.

The second restoration scenario, referred to as the Long-term scenario in this appendix, assumed a conversion rate of 100% from marginal row crop acres to perennial grass —in other words, conversion of all marginal acres. This conversion was combined with a 50% cover crop adoption rate on all remaining row crop acres. The Long-Term model scenario is clearly optimistic when compared with the results of the farmer survey. But it provides an upper-bound on the magnitude of water quality improvements that might be possible through implementation of this program in pilot watersheds.

An alternative application of the Mid-term scenario, in which high-loading acres are specifically targeted, was modeled in a single watershed (the LeSueur River watershed). The objective of this targeting methodology was to focus implementation efforts on areas with higher pollutant loading rates. Sediment and nitrogen loads were calculated on a 30x30 meter grid within the target watersheds. Sediment loads were estimated using the RUSLE equations (Revised Universal Soil Loss Equations) and nitrogen loads were estimated using regression equations developed by Dr. William Lazarus based on the University of Minnesota's NBMP tool. Phosphorus loads were estimated as a function of the sediment and nitrogen loads. The loading rates were grouped into three categories representing Low, Moderate, and High loading areas. The load distributions between groups were used to estimate alternative pollutant reduction factors that might be expected due to targeting areas with higher loading rates.

Methodology

Prior to modeling the WLWRP restoration scenarios, the MPCA modeled the existing, or baseline, conditions to generate daily load and concentration data within the six selected watersheds. Daily baseline data was generated for the following water quality constituents: 1) sediment; 2) phosphorus and 3) nitrogen. The baseline model scenarios used the most current HSPF models available for each of the six watersheds. The baseline and restoration scenarios were modeled for the same time period and used the same meteorological and land cover data as inputs to the model. The purpose of the baseline model scenarios is to provide an estimate of existing water quality conditions and to provide a benchmark from which to calculate the reductions in load and concentration that result from implementation of the restoration scenarios.

All of the baseline HSPF models were originally built and calibrated at the HUC-8 scale. Land categories for each model, and the spatial distribution of land categories throughout the HUC-8 watershed, were determined using the National Land Cover Database or NLCD (a product of the *Multi-Resolution Land Characteristics Consortium* located at https://www.mrlc.gov). Among the many different land categories included in the baseline models, all of the models contained some land that was parameterized to represent the physical and biological characteristics of land covered with perennial grasses. The parameters for perennial grass have been well calibrated to represent the processes that characterize perennial grassland in each specific watershed. Some of the key parameters include infiltration rate and capacity, vegetative cover and surface roughness, all of which affect surface overland flow. In the restoration scenarios, these original perennial grassland categories were used to represent those acres that were converted from marginal row crop acres to perennial grassland as part of the restoration strategy.

The existence of a perennial grass category in all of the original baseline models made modeling of the marginal-to-perennial restoration strategy a relatively straightforward exercise. However, none of the original baseline models included a land category that accurately represented the physical and biological characteristics of row crop acres with cover crops. Therefore, the MPCA modeling team determined that a new land category for row crop with cover crop was needed. This conversion approach was preferred over an empirically-based pollutant reduction ratio because it ensured the conservation of mass for water and pollutants leaving row crop acres and entering the channel network. The row crop with cover crop land category developed for each of the six watersheds retained many of the physical and biological characteristics associated with row crop land but differed in several key parameters: the infiltration rate and capacity were increased as well as vegetative cover and surface roughness. Most of these changes were made on a seasonal basis such that during the prime growing season, the new cover crop land category behaved just like the original row crop category. The primary differences occurred during spring and fall when the benefits of cover crops are thought to be greatest.

With the addition of this new land category, both conservation practices described above (i.e. conversion of marginal row crop acres and cover crop adoption) were modeled as a relatively straightforward trade of acres between land categories. In order to model the conversion of marginal row crop acres to perennial grasses for the two restoration scenarios, the percent of total row crop acres that are marginal within each target watershed had to be determined. This was done by the University of Minnesota, Department of Applied Economics, using raster datasets from the SSURGO spatial database (produced and maintained by NRCS). These datasets contained information on LCC values and surface slope for all of the target watersheds. MPCA modelers were then able to represent the conversion from marginal row crop acres to perennial grasses by implementing an acre-for-acre trade between the row crop land category and the perennial grassland category.

As an example, consider a target watershed with baseline acreages of 10,000 in row crops and 100 in perennial grass, in which 1,000 of the total row crop acres are marginal. Following implementation of the Long-Term scenario, the target watershed would have acreages of 9,000 in row crops and 1,100 in perennial grass – that is, all 1,000 of the marginal row crop acres were converted to perennial grass.

In some of the original HSPF watershed models, row crop acres are split into different types, such as those using conventional tillage practices versus those using conservation tillage practices. In these cases, marginal acres were subtracted from each row crop type proportionally based on the relative abundance of each type in the baseline scenario.

A similar methodology was used to model the adoption of cover crops. Following the conversion of marginal row crop acres to perennial grass, a prescribed percent of all remaining row crop acres were modeled as if cover crops had been successfully incorporated into management practices. MPCA modelers were able to represent cover crop adoption by implementing an acre-for-acre trade between the remaining row crop land category and the new cover crop land category. Continuing with the Long-Term scenario example described above, with a prescribed cover crop adoption rate of 50%, the restoration scenario would now have acreages of 4,500, 1,100 and 4,500 for original row crop, perennial grass and row crop with cover crops respectively.

Implementation Acres in Targeted Watersheds by Scenario:

- Long-term Scenario
- Mid-term Scenario

Modeled Outcomes in Targeted Watersheds

Buffalo River – Whiskey Creek

Of the six targeted watersheds modeled for the WLWRP, Whiskey Creek in the Buffalo River watershed shows the greatest overall improvement in water quality following implementation of the restoration strategies. On average, TSS, TP and TN loads all decreased about 20% following implementation of the Mid-term Scenario. As with most of the other targeted watersheds in the study, load reductions of TSS, TP and TN are greatest in the upstream portion of the Whiskey Creek watershed and decrease downstream toward the confluence with the South Fork of the Buffalo. This spatial trend, both in Whiskey Creek and in most of the other watersheds, is driven primarily by a greater percentage of marginal row crop acres located in upstream reaches (see linked spreadsheet *ImplementationAcres_MidTermScenario.xlsx* for details on the distribution of acres throughout all the targeted areas). More marginal row crop acres allows for greater conversion to perennial grassland and thus higher reductions in nutrient and sediment loads.

Compared to other targeted watersheds, Whiskey Creek has an unusually high percentage of marginal row crop acres. In the baseline model, roughly 40% of row crop acres are considered marginal, compared to 20% in most of the other modeled watersheds. Implementation of the Mid-term scenario resulted in 13% of all row crop acres being converted to perennial grass. This high conversion percentage is largely responsible for the large load reductions modeled in Whiskey Creek. Roughly 35%

of all row crop acres in the targeted reaches received cover crops under the Mid-term scenario, similar to implementation percentages in other targeted watersheds.

Buffalo River-Whiskey Creek linked documents

Long-term Scenario – Spreadsheet

Water Quality Maps:

- Total Suspended Sediment (TSS) Load Reduction
- Total Phosphorus (TP) Load Reduction
- Total Nitrogen (TN) Load Reduction

Mid-term Scenario – Spreadsheet

Water Quality Maps:

- TSS Load Reduction
- TP Load Reduction
- TN Load Reduction

Reach Location Map

Chippewa River – Shakopee Creek

The targeted area in Upper Shakopee Creek is unique among the targeted watersheds in that three out of the six modeled reaches are modeled as lake reaches (only one reach among all the other watersheds is modeled as a lake reach). The physical and biogeochemical processes that affect nutrient uptake and transport within these lake reaches are notably different than the processes at work in open channel reaches. Lakes can serve as a biological or physical trap for nutrients and sediment running off from surrounding acres. Thus, the loads and concentrations leaving a lake reach may not reflect the loads and concentrations being delivered to the lake from the surrounding acres. The effect of these lake reaches on the water-quality response of Upper Shakopee Creek to the Mid-term scenario is evident in the lower TP and TN load reductions modeled in this watershed.

Norway Lake, the largest of the three modeled lakes, is the outlet of the upstream-most targeted reach. Norway Lake (reach 156, see location map below for reference) receives runoff from nearly 40% of the row crop acres within the targeted area. Despite the relatively large contribution of row crop acres to this lake reach, the baseline model scenario shows relatively low nutrient and sediment loads leaving this reach (see linked spreadsheet '*ShakopeeWLWRP_MidTermScenario.xlsx*' with baseline and restoration scenario loads). Model results from the Mid-term scenario show a minimal reduction in TN load from Norway Lake (3.9%) as well as from the two smaller lake reaches (1.8% in reach 155 and 3.2% in reach 157). The reduction in TP load from Norway Lake is similar to the TP load reductions in the channel reaches, indicating that Norway Lake is a more effective nitrogen sink than a phosphorus sink.

Unlike the other targeted watersheds, the greatest reduction in pollutant loads within the targeted reaches of Upper Shakopee Creek occurs in the downstream-most reach (reach 153). This spatial pattern is due in part to the relatively low nutrient load reductions of the upstream lake reaches as well as the distribution of row crop acres among the targeted reach segments. Reach 153 receives runoff from nearly 40% of all row crop acres in the targeted area (see linked spreadsheet '*ImplementationAcres_MidTermScenario.xlsx*' for details on the distribution of acres throughout the targeted area). While the ratio of implementation acres to row crop acres is similar among all targeted reaches, the ratio of implementation acres to *total* acres is highest in the downstream reach. The high percent of total implementation acres (or treated acres) in the downstream reach may help explain why the greatest reduction in pollutant loads occurs at the downstream end of the targeted reaches.

Chippewa River – Upper Shakopee Creek linked documents

Long-term Scenario - Spreadsheet

Water Quality Maps:

- TSS Load Reduction
- TP Load Reduction
- TN Load Reduction

Mid-term Scenario - Spreadsheet

Water Quality Maps:

- TSS Load Reduction
- TP Load Reduction
- TN Load Reduction

Reach Location Map

Le Sueur River – Freeborn Lake/Cobb River/Cobb Creek

Similar to the targeted area in the Chippewa, an upstream targeted reach in the Le Sueur watershed is modeled as a lake reach. However, unlike the Chippewa where the greatest load reductions were in the downstream reach, the greatest reductions in load in the Upper Cobb River occur in the two headwater reaches (reach 712 and 715, see location map below for reference). The percent of row crop acres converted to perennial grass in these two headwater reaches (11% in reach 712; 7% in reach 715) is similar to the conversion percent in other targeted watershed reaches, while the percentage of conversion in the three downstream reaches is minimal (1-3%). This difference in the percent of row crop acres converted to perennial grass drives most of the spatial variability in load reductions in this watershed.

Model results from the Mid-term scenario in the Upper Cobb River watershed show the lowest annual average reduction in TP load among all the targeted watersheds and the second lowest annual average reduction in TN load. The lower reductions in TN and TP loads may reflect the use of tile drains on much of the targeted acres. Quicker evacuation of water from the subsurface via tile drains likely reduces nitrogen uptake and, to a lesser extent, phosphorus uptake, by cover crops. The average annual reduction in TSS load in the targeted area is similar to reductions shown in other targeted watersheds.

Le Sueur River – Freeborn Lake/Cobb Creek linked documents

Long-term Scenario – Spreadsheet

Water Quality Maps

- TSS Load Reduction
- TP Load Reduction
- TN Load Reduction

Mid-term Scenario – Spreadsheet

Water Quality Maps

- TSS Load Reduction
- TP Load Reduction
- TN Load Reduction

Reach Location Map

Sauk River – Getchell Creek Area

Model results from the Mid-term scenario in the Getchell Creek and County Ditch No. 9 target basins show a relatively uniform average annual reduction in load of about 15% for all of the water quality constituents (TSS, TP and TN). As with most of the other targeted watersheds, the greatest reduction in load, regardless of constituent, occurred in the upstream target reach. In Getchell Creek, the upstream reach (reach 157, see location map below for reference) had reductions of 19.5%, 19.4% and 17.9% for TSS, TP and TN loads respectively. The downstream reach (reach 245) had the smallest reductions in load, with reductions of 11.8%, 12.6% and 12.9% for TSS, TP and TN respectively. Unlike the other targeted watersheds, the downstream reach in Getchell Creek receives TSS, TP and TN loads from an upstream tributary that was not targeted in the WLWRP and thus contributes 'untreated' constituent loads to the downstream reach. Contributions from this untreated tributary almost certainly reduce the effectiveness of the land use changes in the downstream reach.

Under the Mid-term scenario, roughly 14% of total row crop acres in reach 157 are converted to perennial grass. This is at least two times greater than the conversion rate in the other target reaches and helps explain why reach 157 has the greatest load reductions. In County Ditch No. 9 (reach 221) the vast majority of change is in the form of cover crop adoption, with only 4% of all row crop acres (or less than 1% of total acres) being converted to perennial grass. The limited acreage of marginal row crop land within this particular reach helps explain why load reductions are less than in other reaches.

Sauk River – Getchell Creek and County Ditch 9 linked documents

Long-term Scenario – Spreadsheet

Water Quality Maps

- TSS Load Reduction
- TP Load Reduction
- TN Load Reduction

Mid-term Scenario -- Spreadsheet

Water Quality Maps

- TSS Load Reduction
- TP Load Reduction
- TN Load Reduction

Reach Location Map

Minnesota River, Mankato – Rogers Creek and St. Peter Area

There are very few marginal row crop acres within the Rogers Creek watershed (see linked spreadsheet *ImplementationAcres_MidTermScenario.xlsx* for details on the distribution of acres throughout the targeted area). Thus, implementation of the restoration scenarios is predominantly through cover crop adoption. Model results from the Mid-term scenario show that nutrient load reductions in Rogers Creek are some of the largest reductions in any of the targeted watersheds, with both TP and TN loads being reduced by more than 20%. The downstream-most reach of Rogers Creek (reach 613, see location map below for reference) is only 428 total acres in size, compared to 16,791 total acres within the upstream reach (reach 611). Because the much larger reach (reach 611) flows into the much smaller reach (reach 613), the changes in water quality are very similar between the two reaches. Implementation of the Mid-term scenario results in a reduction in TSS load in Rogers Creek of roughly 15%. This is less than the reduction in nutrient loads but is still comparable to TSS load reductions in other targeted watersheds.

Reductions in nutrient and sediment loads are negligible in the Minnesota River main-stem reach (reach 610). Implementation rates for cover crops and the conversion of marginal acres are similar for the local contributing area. However, unlike the other WLWRP target reaches, this is not a headwater reach. Instead, this main-stem reach receives nutrient and sediment loads from ten major (HUC-8 scale) watersheds upstream. Thus, the volume of water and the mass of nutrient and sediment loads within this reach are far too great for the overall water quality in this reach to be affected by local restoration practices implemented on less than 2% of the total contributing acres.

Minnesota River-Mankato – Rogers Creek and St. Peter Area linked documents

Long-term Scenario -- Spreadsheet

Water Quality Maps

- TSS Load Reduction
- TP Load Reduction
- TN Load Reduction

Mid-term Scenario -- Spreadsheet

Water Quality Maps

- TSS Load Reduction
- TP Load Reduction
- TN Load Reduction

Reach Location Map

Root River – Watson Creek

The most striking model result from the Mid-term scenario in the Watson Creek watershed is the very limited reduction in TSS load. The modeled TSS load was reduced by just 2.5% despite a relatively high row-crop to perennial-grass conversion percentage (16% of all row crop acres were converted to perennial grass). The limited reduction in TSS load from the field-based BMP practices used in this study indicates that channel scour and/or near-channel sources of sediment are a significant contributor to the total TSS load in Watson Creek. The channel network in Watson Creek is relatively steep compared to other WLWRP watersheds, increasing the potential for in-channel and near-channel sediment contributions and limiting the effectiveness of field-based practices on TSS load.

In contrast to the small TSS load reduction, model results within Watson Creek show a relatively large reduction in TN load compared to other targeted watersheds. Watson Creek is unique among the WLWRP watersheds in the extent to which manure is incorporated into agricultural practices. Model input data indicates that 58% of all row crop acres in the Watson Creek watershed receive some form of manure. This compares to manure incorporation rates of 7-18% on row crop acres in other targeted watersheds. In the Watson Creek model, row crop acres that incorporate manure have higher nitrogen loading rates than non-manured row crop acres. Conversion of these high nitrogen loading acres to perennial grasses at relatively high rates (a 16% conversion rate as noted above) is the primary driver behind the large TN load reductions in Watson Creek.

Root River – Watson Creek linked documents

Long-term Scenario -- Spreadsheet

Water Quality Maps

- TSS Load Reduction
- TP Load Reduction
- TN Load Reduction

Mid-term Scenario -- Spreadsheet

Water Quality Maps

- TSS Load Reduction
- TP Load Reduction

- TN Load Reduction

Reach Location Map