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Memorandum

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Date: November 18, 2015

To: Justin Watkins (MPCA)
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Project: Cannon River Watershed HSPF Model Development Project – Phase II

Subject: Technical Memorandum to Document Task 1 - Apply the CRWHSPF model to assess various management scenarios

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Statement of Purpose

This memorandum has been prepared for the Minnesota Pollution Control Agency (MPCA) to document Task 1 of Phase II of the "Cannon River Watershed HSPF Model Development Project" and serves as one of two deliverables, as outlined in Task 1 of the Work Plan, Contract No. 20534. The second deliverable consists of a model package that includes model updates and scenario runs performed in Task 1. The model package will be delivered electronically to MPCA in conjunction with this memorandum.

The subtasks outlined for this phase work include the following:

- Subtask 1-1: Select management scenarios for the Cannon River Watershed Hydrological Simulation Program – FORTRAN (CRWHSPF) model application
- Subtask 1-2: Apply the CRWHSPF model to evaluate the first round of selected management scenarios
- Subtask 1-3: Apply the CRWHSPF model to evaluate the second round of selected management scenarios
- Subtask 1-4: Final Technical Report (this document)
- Subtask 1-5: Prepare Model Package

The objective of Task 1 was to apply the CRWHSPF model to inform the Cannon River Watershed restoration and protection strategies. As part of this effort, a total of ten management scenarios were evaluated. The sections below document the work performed in Task 1 of this project.

Project Background

The MPCA has developed a Watershed Restoration and Protection Strategy (WRAPS) at the HUC8 (8-digit Hydrologic Unit Code) scale. This approach represents an ambitious and comprehensive 10-year statewide effort to assess watershed conditions, develop Total Maximum Daily Loads (TMDLs), and implement watershed protection and restoration strategies for its 81 HUC8 watersheds. The Cannon River HUC8 watershed (Figure 1) includes waters impaired by excessive bacteria (fecal coliform and *E. coli*, nutrients, and turbidity. Lake Byllesby, a highly valued water resource, is also impaired by excessive nutrients. The MPCA has selected the HSPF model to simulate watershed hydrology and water quality. The HSPF model is an important tool in developing an understanding of existing conditions, simulating conditions under various management scenarios, and informing the development of implementation strategies and plans to restore and protect streams and lakes.

In Phase I of this project, the CRWHSPF model was developed to simulate hydrology, sediment and suspended solids (TSS), water temperature, nutrients (phosphorus and nitrogen), biochemical oxygen demand (BOD), dissolved oxygen (DO), phytoplankton and benthic algae. The scale of the watershed model is at the HUC8 watershed level with a subbasin delineation intermediate between the HUC12 and HUC16 scale. The model simulation period is from 1995-2012. The first year (1995) serves as a "warm-up period" to allow the model to equilibrate and not be strongly influenced by the initial conditions. Therefore, model output is often described on the basis of the 1996-2012 period. The model was successfully calibrated and validated for hydrology and water quality based on the datasets and information available at the time the work was conducted.

In Phase II of this project, the CRWHSPF model was applied to evaluate various management scenarios to help provide information on how effective a specific action may be for reducing sediment and nutrient loading in the watershed and for improving water quality. A primary objective of this work is to provide the foundation for the Byllesby Reservoir Phosphorus TMDL.

Cannon River Watershed HSPF Model

In the HSPF model, a watershed is comprised of delineated subbasins (or subwatersheds) that have a single, representative reach segment per subbasin. In the CRWHSPF model, the watershed is divided into 219 subbasins (Figure 2). The average area per subbasin is 4,172 acres and ranges from 45 acres to 28,588 acres. The subbasins and reach segments are connected in the model to represent a watershed drainage area. A subbasin is conceptualized as a group of individual hydrologic response units (HRUs) (also called land segments) that are all routed to a representative reach segment.

The purpose of defining a set of HRUs is to divide a watershed into individual land segments that are assumed to produce homogeneous hydrologic and water quality responses due to similar land use, soils, topography, climate, and land management activities. It is important to note that the individual HRUs are not spatially explicit within a subbasin model. For example, all forest land with a hydrologic soil group (HSG) of A/B in a subbasin would be grouped as a single unit without reference to the varying spatial locations of that HRU type scattered across a subbasin. The geographic (or spatial) location of a subbasin is known and maintains a spatially explicit location in the model.

Complete documentation of the CRWHSPF watershed model, including development, calibration, and validation is provided in the "Cannon River Watershed HSPF Model Development Project" final report (LimnoTech 2015).

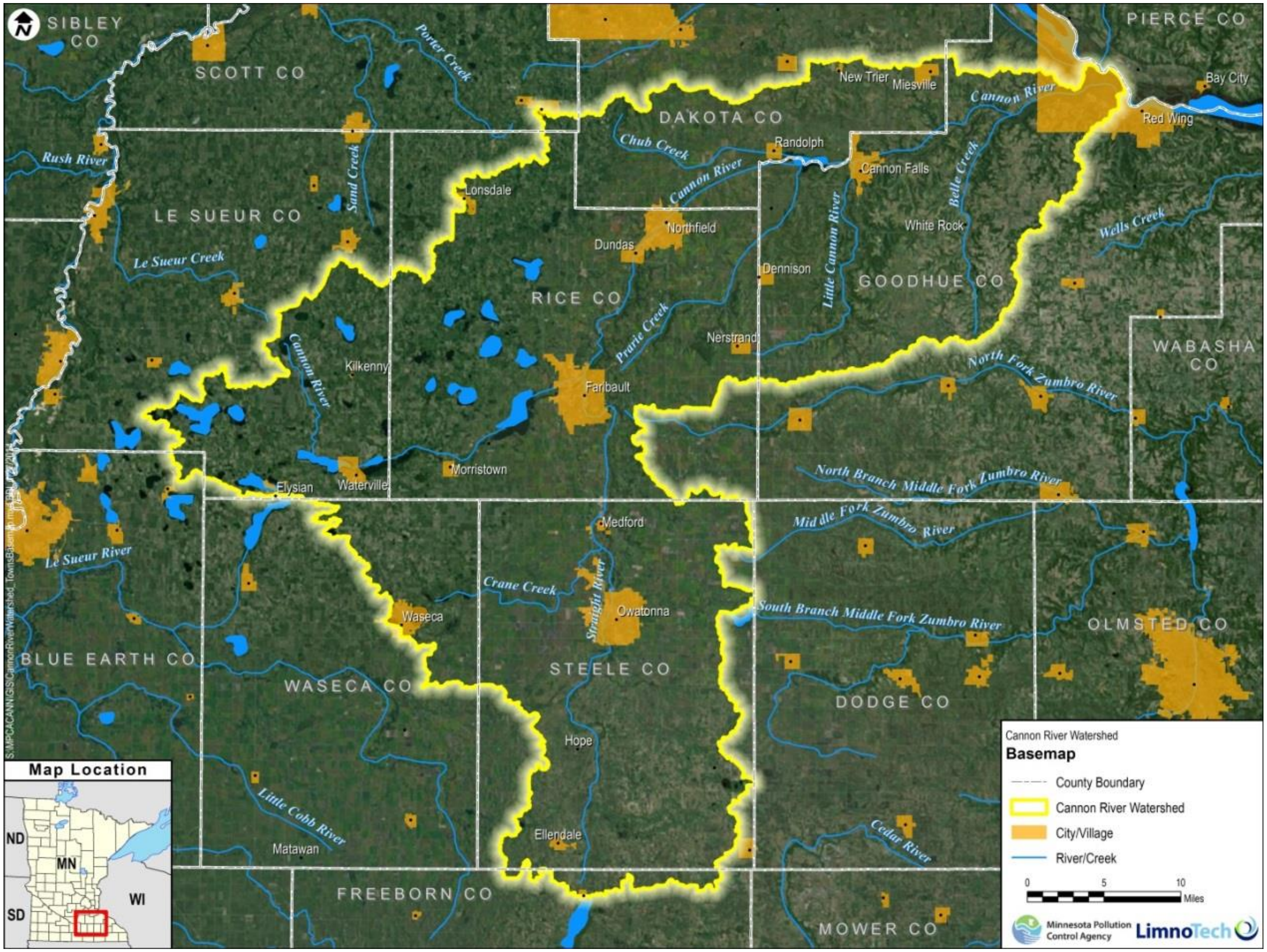

Figure 1. Basemap of the Cannon River watershed, Minnesota

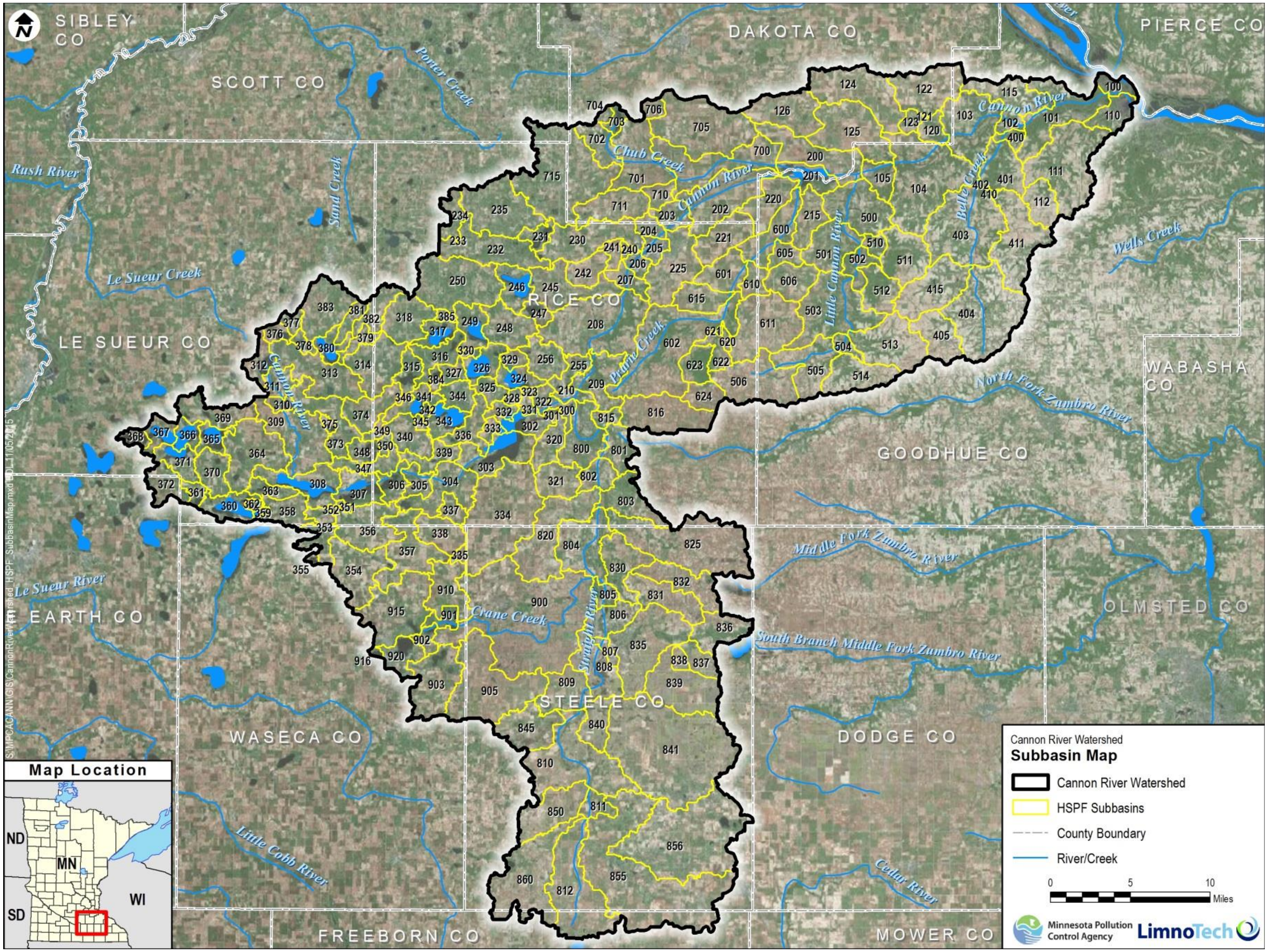

Figure 2. Map of the CRWHSPF model subbasins

Revisions to the CRWHSPF Model Developed in Phase I

Prior to applying the CRWHSPF model to assess the various management scenarios, the following minor revisions and refinements were made to point source inputs and atmospheric deposition inputs:

- The Waseca Wastewater Treatment Plant (WWTP) was removed from the model. Information provided by MPCA in Phase II indicated that the effluent is discharged in the Le Sueur River watershed (Justin Watkins, personal communication).
- The input time-series for the Kilkenny WWTP were modified to represent the facility as an intermittent discharger rather than a continuous discharger. In Phase I, the Kilkenny WWTP was listed as a continuous discharger. However, in Phase II, it was determined that the Kilkenny WWTP uses a stabilization pond and should be represented as an intermittent discharger.
- A revision was made in the external sources (EXT SOURCES) input block related to the wet atmospheric deposition of nitrate and ammonium on the reach and reservoir (RCHRES) water surfaces. A conversion factor is required to properly input wet atmospheric deposition concentrations on model HRUs (i.e., PERLNDs and IMPLNDs). This conversion had also been applied to the model reaches and reservoirs; however, the conversion factor is not necessary to properly input wet atmospheric deposition on a reach or reservoir due to the different method HSPF uses to track concentrations in a reach or reservoir as compared to an HRU. Therefore, the conversion factor was removed from the wet atmospheric deposition inputs to the RCHRES module in the current model.

Application of the CRWHSPF Model to Assess Various Management Scenarios

Following the completion of the model development, calibration, and refinement efforts, the next step of the project was to evaluate the potential load reductions from the implementation of management practices or Best Management Practices (BMPs) in the Cannon River watershed. The sections below describe the application of the CRWHSPF model to the Cannon River watershed to evaluate management scenarios.

Management Scenario Selection Process

LimnoTech and MPCA worked together to define two rounds of management scenarios. During each round an initial list of management scenarios was proposed. MPCA communicated with watershed stakeholders via both email and in-person meetings to solicit feedback on the proposed scenarios. Once the scenarios were finalized, the scenarios were run with the CRWHSPF model. Preliminary results from the first round of management scenarios (scenarios A through E) were presented to stakeholders to inform selection of scenarios for the second round (scenarios F - J). LimnoTech provided guidance on the feasibility of implementing various management scenarios in HSPF and requested information to finalize the scenarios, which was provided by MPCA.

Management Scenario Descriptions

A total of 10 scenarios were simulated to estimate the effect of potential management practices on sediment and nutrient transport and delivery throughout the watershed (Table 1). Each scenario involved a variation of the “baseline” simulation that is based on the historical conditions for the 1996-2012 time period.

Table 1. List of management scenarios simulated with the CRWHSPF model

Scenario ID	Round	Scenario Description	Category
A	1	Major Point Sources at Current Conditions	Point Source
B		Point Sources at Permitted Limits	Point Source
C		Point Sources at RES and 70% AWWDF	Point Source
D		Pre-Settlement Vegetation	Nonpoint Source
E		Conservation Tillage and Green Infrastructure in Waseca	Nonpoint Source
F	2	Cover Crops	Nonpoint Source
G		Perennials and Green Infrastructure in MS4 Areas	Nonpoint Source
H		Wetland Restorations and Sedimentation Ponds	Nonpoint Source
I		Combined Management Scenario #1	Point Source + Nonpoint Source
J		Combined Management Scenario #2	Point Source + Nonpoint Source

Major point sources at current conditions (A)

The first scenario was constructed to serve as an “adjusted baseline” simulation. The purpose of this scenario was to represent the current condition of Faribault, Northfield, and Owatonna WWTP effluent total phosphorus (TP) loads for the entire 1996-2012 simulation period. Historically and as represented in the baseline CRWHSPF model, these major WWTPs discharged effluent TP concentrations above 1.0 mg TP/L during part (Northfield) or most (Faribault and Owatonna) of the 1996-2012 period. After significant upgrades were completed, the facilities began discharging lower effluent TP loads (approximately in 2003 for Northfield and 2012 for Faribault and Owatonna). By representing the major point source TP loads as “current conditions” for the entire simulation period under this scenario, model-predicted results from the other management scenarios could be compared against this “adjusted baseline” to better inform how future management decisions may impact the watershed relative to its present state. Therefore, daily average TP loads were computed for the Faribault and Owatonna WWTPs from observed data during the 1/1/2012–5/31/2015 time period and applied in CRWHSPF as a constant daily load for the entire 1996-2012 simulation period under this scenario. Daily average TP loads were computed for the Northfield WWTP from observed data during the 1/1/2008-12/31/2012 time period and applied in CRWHSPF as a constant daily load for the 1996-2003 time period. Historical TP loads were used for Northfield for the 2004-2012 time period. Figure 3 shows average monthly TP loads for the Northfield WWTP as simulated under this scenario and the baseline CRWHSPF simulation.

Point sources at permitted limits (B)

A scenario was constructed to evaluate the impact on instream water quality from all point sources discharging at maximum permitted limits of flow rate, minimum DO concentration, TSS load, TP load, ammonia load, and/or BOD load. This scenario provided an upper bound on of the impacts of point sources on instream water quality in the watershed. There were several instances where a facility did not have a permit limit for a given constituent. For example, only three facilities in the Cannon River watershed had ammonia limits and zero facilities had nitrate limits. In these cases, the loading time series from the baseline model was used. Figure 3 shows average monthly TP loads for the Northfield WWTP as simulated under this scenario.

Point sources at RES and 70% AWWDF (C)

A second point source scenario was constructed to serve as a lower bound to complement the point sources at permitted limits scenario. This scenario evaluated the impact on instream water quality of point sources discharging at a flow rate equal to 70% of the average wet weather design flow (AWWDF) and TP concentrations at proposed river eutrophication standards (RES). The effluent TP concentrations simulated under the RES ranged from 0.10 to 0.15 mg TP/L (varies with River Nutrient Region), and were applied from June 1 to September 30. For the remainder of the year (October 1 to May 31), the effluent TP concentration was set to the permitted limit, most often 1.0 mg TP/L. For facilities without a permit limit for TP, the loading time series from the baseline model were applied from October 1 to May 31. For facilities that use stabilization ponds, discharge was assumed to occur during June 1-15 and September 15-30. Figure 3 shows average monthly TP loads for the Northfield WWTP as simulated under this scenario.

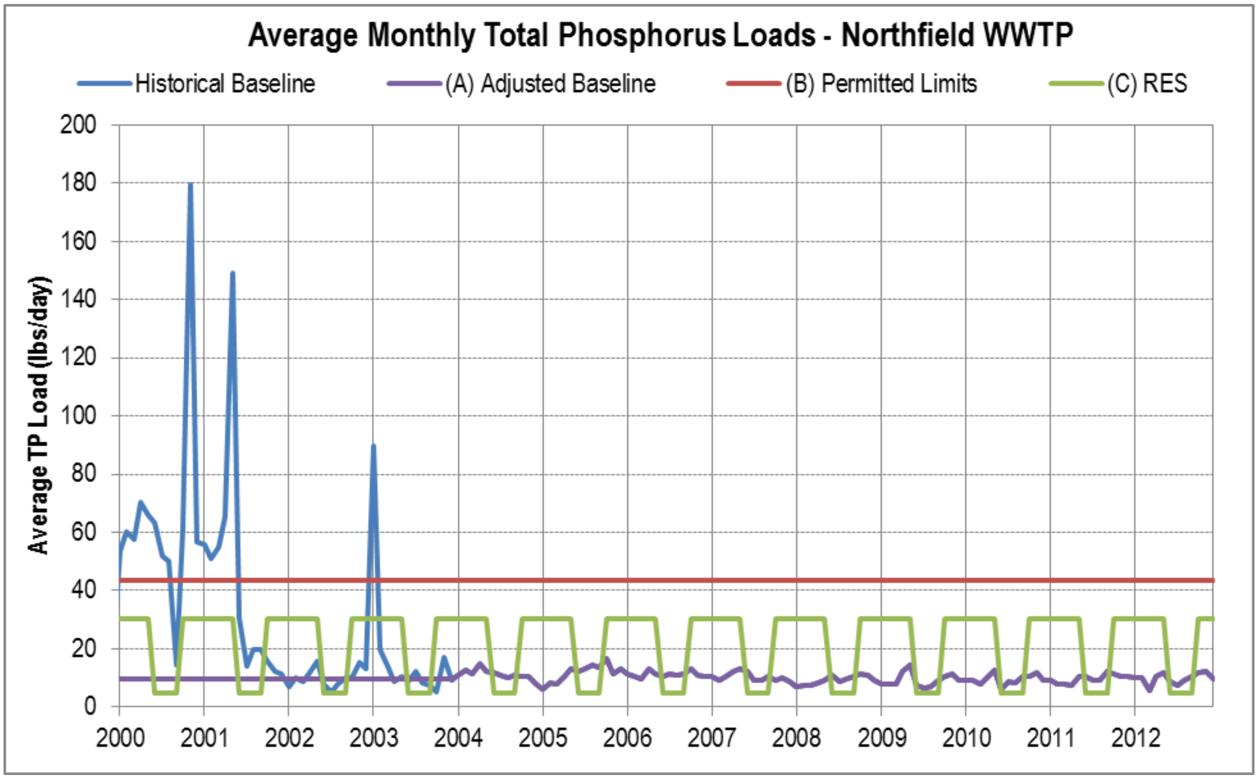

Figure 3. Average monthly total phosphorus (TP) loads discharged from the Northfield WWTP for the 2000-2012 time period as simulated under the baseline CRWHSPF model, the current conditions/adjusted baseline scenario, the permitted limits scenario, and the River Eutrophication Standard (RES) scenario

Pre-settlement vegetation (D)

A scenario was constructed to provide insight on sediment and nutrient loadings under pre-settlement conditions compared to current day conditions. The Minnesota Department of Natural Resources (MNDNR) maintains a digital version of a state map, originally created by Francis J. Marschner, which maps Minnesota's vegetation at the time of European settlement. The assumptions in this scenario included pre-settlement vegetation, no point sources, and pre-settlement rates of atmospheric nitrogen deposition. In this scenario, because it is a pre-settlement condition, agricultural or developed land does not exist. A pre-settlement atmospheric nitrogen deposition rate of approximately 0.50 kg-N/ha/year was applied in this scenario assuming the same proportions of dry/wet ammonia/nitrate as represented in the baseline model. The 0.50 kg-N/ha/year rate originates from a joint National Park Service (NPS) and U.S.

Fish and Wildlife Service (USFWS) effort to develop deposition analysis thresholds (FLAG 2002). This pre-settlement atmospheric nitrogen deposition rate represents over a 95% reduction from the rate in the baseline model (approximately 20 kg-N/ha/year). The reservoirs remained unchanged from the baseline in the model to represent more realistic, present-day hydrologic conditions.

Conservation tillage and green infrastructure in City of Waseca MS4 areas (E)

A scenario was constructed to reflect conservation tillage management practices applied to 30% of the cropland acres with the highest sediment yields in the Cannon River watershed. The selection of the highest sediment yielding cropland land segments for conservation tillage implementation was based on the CRWHSPF model baseline landscape predictions.

The effects of changing from more intensive tillage operations (i.e., conventional, reduced, etc.) where residue cover ranges from 0 to <30% to conservation tillage operations where residue cover ranges from >30% were simulated in the model by modifying several hydrology and sediment related parameters that best translated to the real-world physical representation of managing soil residue and soil organic matter. The parameter adjustments included increasing the nominal upper zone soil moisture storage capacity (UZSN); monthly values of interception storage (MON-INTERCEP) and monthly values of the soil cover factor (MON-COVER); and decreasing the coefficients in the equations that simulate soil washoff (KSER) and gully erosion (KGER). The degree of adjustment for these parameters was determined by the following criteria:

(1) Parameters were adjusted only by an amount that was reasonable relative to values for other land uses (e.g., the soil cover factor was increased but no higher than values for forest or grassland)
(2) Parameters were adjusted until the edge-of-field runoff, sediment and TP reductions relative to the baseline scenario were generally in agreement with values reported in literature or guidance manuals for BMPs.

The Agricultural BMP Handbook for Minnesota provided the primary source of information with reported reduction efficiencies of 50 – 96% for sediment and 55 – 91% for TP (Miller et al. 2012). It is important to note that the reported reduction efficiencies represent load reduction from the land and not the load delivered to a stream.

This scenario also simulated the effects of implementing a range of green infrastructure practices on all developed MS4 areas in the City of Waseca draining to Clear Lake. Although different practices were not explicitly modeled, this scenario implicitly represented green roofs, porous pavement, bioretention, filtration-type, infiltration-type, swales, detention basins, and retention basins/stormwater wetlands by considering the range of sediment and nutrient removals accomplished by various practices (Simpson and Weammert 2009). An overall removal efficiency for sediment, nitrogen, and phosphorus was then determined by weighting the individual removal efficiencies based on the assumed area of implementation (Table 2). The green infrastructure practices were represented in the model using the BMPRAC module. This module simulates the effects of BMPs by applying removal fractions to runoff and pollutant loading time series from pervious and impervious land segments before routing to the receiving reach segments. Constant removal fractions were used for flow and all modeled constituents. Major WWTP TP loads were represented as “current conditions” under this scenario (see scenario A).

Table 2. Green infrastructure removal efficiencies and assumed implementation for individual green infrastructure types used to compute an overall, weighted efficiency for each constituent.

Green Infrastructure Type	Removal Efficiency (%)			Assumed Implementation (%)
	TN	TP	TSS	
Green Roof	43	45	31	5
Porous Pavement	47	50	70	5
Bioretention	58	68	75	20
Filtration Type	40	60	80	10
Infiltration Type	80	85	95	10
Bioswale	10	10	50	10
Retention Pond	20	45	60	20
Detention Basin	20	20	60	20
OVERALL	**37**	**47**	**67**	**100**

Cover crops (F)

A scenario was constructed that applied cover crops to a portion of the cropland acres for every simulation year. This scenario assumed a cereal rye cover crop planted in the fall when crops are typically harvested. Cover crops were implemented on 100% of the cropland acres in the Little Cannon and Belle Creek subbasins in the simulation. These subbasins were chosen because they have high phosphorus yielding cropland land segments, are located in sensitive groundwater areas, and provided the opportunity to compare CRWHSPF results to a Little Cannon SWAT model scenario of 100% cover crop implementation (Justin Watkins personal communication)(LimnoTech 2014). Cover crops were implemented on approximately 12.4% of cropland acres in the remaining parts of the watershed, which represents 10% of the corn/soybean acres and 80% of the early harvested crops. Selection of cover crop implementation in the remaining parts of the watershed was based on CRWHSPF model landscape predictions of the highest sediment and phosphorus yielding cropland land segments.

The effects of cover crops were represented in the model by modifying several hydrology, sediment, and nitrogen related parameters that best translated to the real-world physical representation of adding a vegetative cover to formerly bare soil during winter and spring months. Parameter adjustments included increasing monthly values of interception storage (MON-INTERCEP), nominal upper zone soil moisture storage capacity (MON-UZSN), the index to lower zone evapotranspiration (MON-LZETPARM), and the soil cover factor (MON-COVER). The monthly nitrate concentrations in interflow (MON-IFLW-CONC) and groundwater (MON-GRND-CONC), and the coefficients in the equations that simulate soil washoff (KSER) and gully erosion (KGER) were decreased as part of this scenario to represent cover crops scavenging soil nitrogen and reducing soil erosion processes, respectively.

Parameters were adjusted until the edge-of-field sediment reductions relative to the baseline scenario were generally in agreement with values reported in literature or guidance manuals for BMPs. The Agricultural BMP Handbook for Minnesota provided the primary source of information with reported reduction efficiencies of <1 - 70% for sediment, <1 – 67% for TP, and 16 – 66% for TN (Miller et al. 2012). It is important to note that the reported reduction efficiencies represent load reduction from the land and not the load delivered to a stream. The reduction efficiency values that served as general targets were also consistent with HSPF cover crop scenario applications in other Minnesota watersheds (RESPEC 2014). However, it should be noted that Miller et al. (2012) acknowledge that while sediment erosion and phosphorus reductions commonly occur with the implementation of cover crops, there is a lack of research data in Minnesota and the upper Midwest to quantify this reduction. Major WWTP TP loads were represented as "current conditions" under this scenario (see scenario A).

Perennials and green infrastructure in MS4 areas (G)

A scenario was constructed to simulate the effects of three management actions: (1) conversion of marginal cropland to perennial vegetation, (2) conversion of cropland within a 50 ft buffer of public waters to a perennial vegetated filter strip, and (3) implementation of green infrastructure to treat approximately 25% of the developed MS4 areas in the Cannon River watershed.

For the purposes of this scenario, "marginal cropland" refers to marginally productive row crop agricultural land. Marginal cropland in the Cannon River watershed was determined by intersecting the CRWHSPF model segments defined as cropland, with Crop Productivity Index (CPI) values less than 60 according to the United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) Soil Survey Geographic Database (SSURGO) (USDA NRCS 2012). This methodology was described by MPCA personnel (David Wall, personal communication) and is consistent with the definition of marginal lands in the MPCA Nitrogen in Minnesota Surface Waters study (MPCA 2013). This scenario assumed 100% of marginal cropland in the watershed would be converted to perennial vegetation, which amounted to approximately 10.8% of cropland acres in the watershed.

A Minnesota buffer initiative was signed into law in 2015 requiring perennial vegetation buffers of up to 50 ft on public waters and public drainage systems (MNDNR 2015). This scenario assumed 100% of cropland acres in the watershed falling within a 50 ft buffer of public waters, as defined by the MNDNR Hydrography Dataset "rivers and streams" layer (Minnesota Geospatial Commons 2015), would be converted to perennial vegetation. This amounted to 2.0% of cropland acres in the watershed, a fraction of which was also defined as marginal cropland.

In addition to the land cover change from cropland to perennial vegetation (represented as the grassland land segment category in CRWHSPF), the 50 ft buffers were also assumed to have some additional water quality benefit due to the ability to reduce contaminants in surface runoff from adjacent cropland. The edge-of-field removal efficiencies of the buffers were assumed to be 80% for sediment, 60% for phosphorus, and 40% for nitrogen. The primary source of information used to determine these values was the Agricultural BMP Handbook for Minnesota, with reported reduction efficiencies of 56 – 86% for sediment, 39 – 78% for phosphorus, and 27 – 66% for nitrogen (Miller et al. 2012). For a given subbasin, it was assumed that 25% of the cropland surface runoff would be treated by these new perennial vegetated filter strips. The other 75% was assumed to be untreated because of concentrated flow across the buffers, gully formation, and short-circuiting. Because all cropland in a given subbasin is modeled as one unit, the following "effective" removal efficiencies were computed and used via adjustments to scale factors in the MASS-LINK block: 20% for sediment, 15% for phosphorus, and 10% for nitrogen. These effective removal efficiencies account for both (1) the buffer removal efficiencies for the 25% of cropland assumed to be treated and (2) the 75% of cropland assumed to be untreated [example for sediment: 25% treated*80% removal + 75% untreated*0% removal = effective 20% removal].

This scenario also simulated the effects of applying a range of green infrastructure practices to 25% of all developed MS4 areas in the Cannon River watershed. The top sediment yielding land segments were targeted for green infrastructure implementation based on CRWHSPF model baseline landscape predictions. The same overall removal efficiencies applied in the City of Waseca green infrastructure scenario (see scenario E) were used in this scenario, assuming the same proportion of various green infrastructure practices would be scaled up to treat the larger area (Table 2).

Major WWTP TP loads were represented as “current conditions” under this scenario (see scenario A). Figure 4 shows land defined as “marginal” and 50 ft buffers on streams and rivers in the Cannon River watershed.

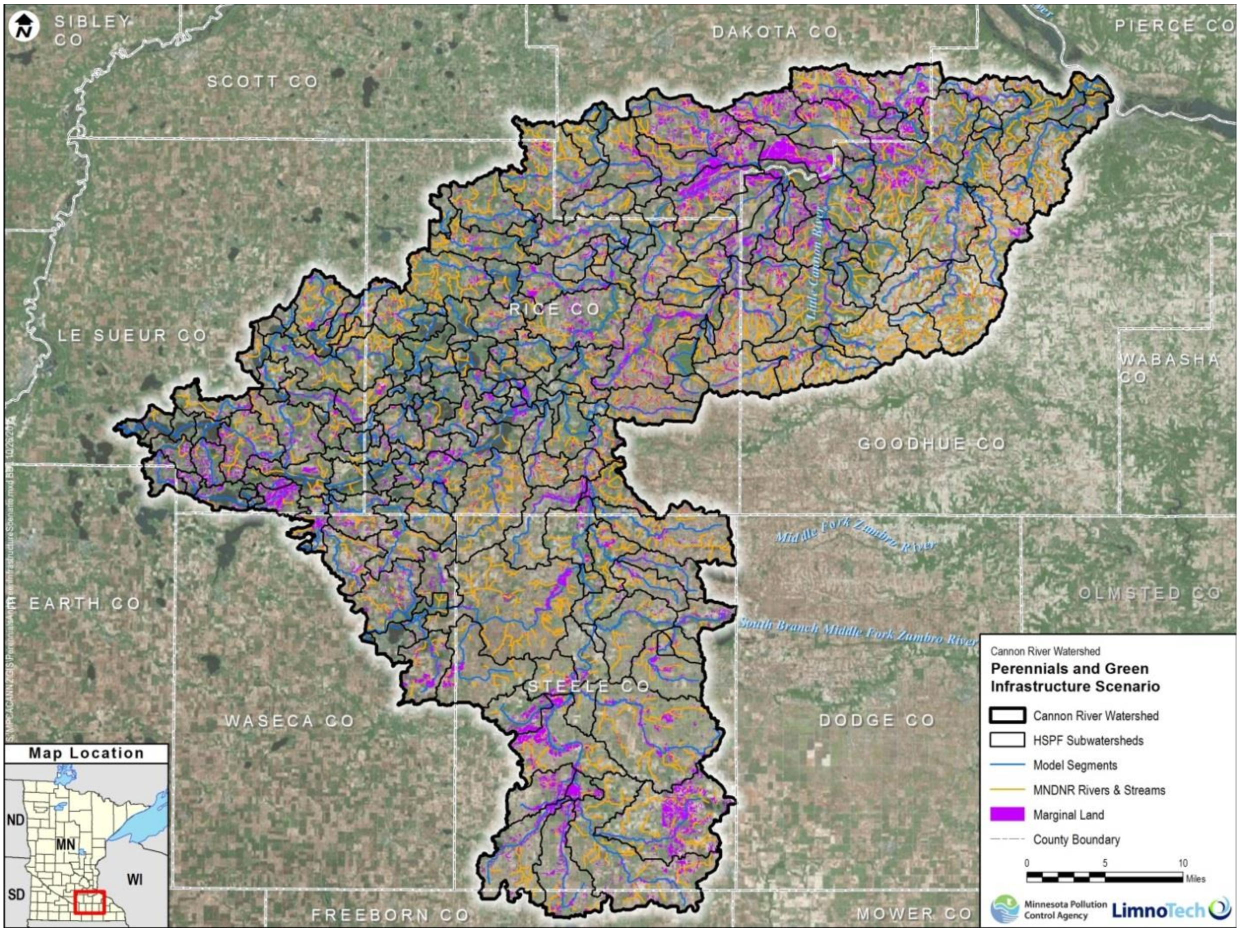

Figure 4. Areas in the Cannon River watershed defined as “marginal” according to the crop productivity index and 50 ft buffers on streams and rivers

Wetland restoration and sedimentation ponds (H)

A scenario was constructed to simulate the effects of two management actions: wetland restoration and sedimentation ponds. The areas suitable for wetland restoration were focused on the Upper Cannon, Middle Cannon, and Straight River lobes. Areas suitable for wetland restoration were identified by a Restorable Wetlands Inventory GIS layer provided to LimnoTech by MPCA personnel (Ashley Ignatius, personal communication).

Areas suitable for sedimentation ponds, hereafter referred to as ponds, focused on the Lower Cannon lobe and Maple Creek subbasins within the Straight River lobe. The ponds reduce peaks flows thereby reducing sediment and nutrient loading (primarily phosphorus). An existing inventory of Goodhue County pond structures and their respective drainage areas was used in selecting locations for the new ponds in the Lower Cannon lobe (i.e., new ponds were not added to locations where a pond already exists and is treating X acres of land). New ponds were placed in the model subbasins with the highest cropland sediment yields, and they collectively capture runoff from approximately 30% of all cropland acres in the Lower Cannon lobe. For representation in the Maple Creek subbasins, maps developed by MNDNR and provided by Cannon River Watershed Partnership personnel were used in selecting cropland drainage areas for implementing new ponds (Beth Kallestad personal communication).

Based on the typical characteristics of the ponds in the watershed, some general assumptions were needed for this scenario. The ponds were represented in the model to be consistent with the edge-of-field ponds currently designed for implementation in the watershed by the Soil and Water Conservation Districts (SWCDs). The ponds were represented as “dry ponds” and designed to capture the approximate 10-year, 24-hour rain event (Beau Kennedy, personal communication). A “dry pond” for this scenario is defined as a pond that is not designed to hold water for more than 24 hours.

Ponds were represented in the model by adding new reach segments (RCHRES). The reach geometry, which is defined with an FTABLE, was constructed to mimic the water storage and peak flow reduction that results from the implementation of a new pond. As noted above, the ponds were represented as “dry ponds” or detention basins, which remain dry except during or shortly after a rain or snowmelt event. The FTABLEs were constructed to approximately capture the runoff from a 10-year, 24-hour rain event (4.37 inches). Flow from land segments was routed to the new RCHRES in the SCHEMATIC block of the model before being routed to the receiving reach segment from the baseline scenario.

Major WWTP TP loads were represented as “current conditions” under this scenario (see scenario A). Figure 5 shows areas identified as suitable for wetland restoration and parcels in the Maple Creek subbasins assumed to drain to ponds under this scenario.

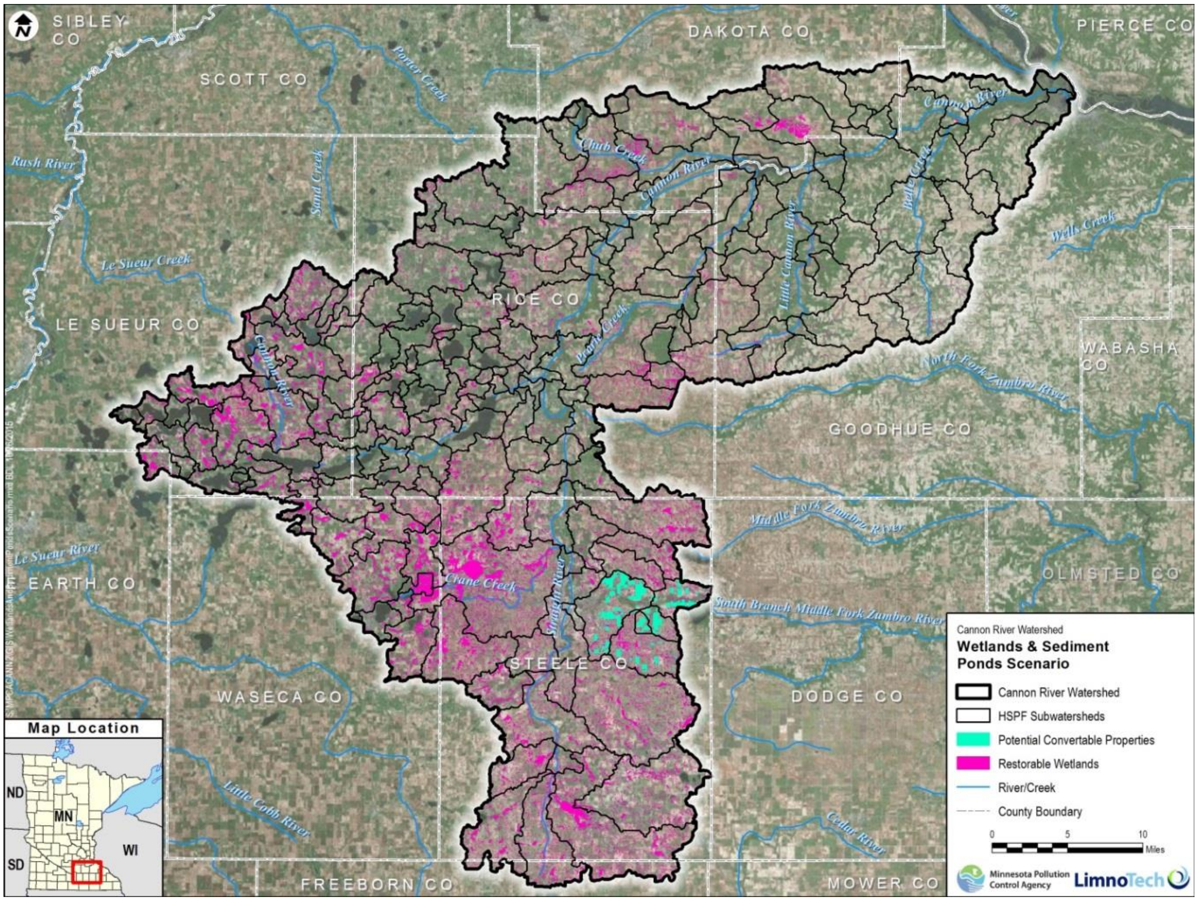

Figure 5. Areas in the Cannon River watershed suitable for wetland restoration and areas in the Maple Creek subbasins assumed to drain to ponds under this scenario

Combined management scenario #1 (I)

To understand the benefits of implementing multiple BMPs, a scenario was constructed that combined the following actions represented in scenarios A, F and G:

- Major point source effluent TP loads set to current conditions (see scenario A);
- Cover crops applied to 100% of cropland acres in the Little Cannon and Belle Creek subbasins, and to approximately 12.4% of cropland acres with the highest sediment yields in the remainder of the watershed (see scenario F); and
- Conversion of all cropland acres classified as "marginal lands" and all cropland acres falling within a 50 ft buffer of rivers/streams to perennial vegetation (see scenario G);

Assumptions were the same in this combined scenario as described above for the individual scenarios.

This scenario also simulated a reduction in the low flow TP concentrations in the Straight River upstream of the Owatonna WWTP, and elsewhere in the Straight River lobe, to approximately 0.10 mg-P/L. In order to simulate a reduction in phosphorus loads under low flow conditions in the Straight River lobe independent of the major point source TP load contributions (Faribault and Owatonna), benthic phosphate release rates were reduced by 75% for river segments in the Straight River lobe under this scenario. The baseline CRWHSPF model contained a benthic release of phosphate (BRPO4) during May 1 – September 30 for both lake and river segments and is described in more detail in the CRWHSPF model development report (LimnoTech 2015). The 75% reduction was chosen because it resulted in a June-September low flow average TP concentration of approximately less than or equal to 0.10 mg-P/L in river segments not influenced by the major WWTPs (e.g. Crane Creek, Maple Creek, Turtle Creek, and Straight River upstream of Owatonna). The 0.10 mg-P/L target was suggested by MPCA personnel (Justin Watkins personal communication).

Combined management scenario #2 (J)

The final management scenario involved a slight modification of the first combined management scenario, described above. For the October 1 – May 31 period, major point sources were assumed to discharge at permitted limits of flow rate and TP load. For the June 1 – September 30 period, the major point sources were assumed to discharge effluent TP loads set to current conditions. All other modifications remained the same as the first combined management scenario (cover crop implementation, conversion of cropland to perennial vegetation, and reduction in benthic phosphate release rates).

Management Scenario Results

The CRWHSPF model is a tool that can be used to help determine the most effective land management practices at target locations to maximize sediment and nutrient load reduction and conservation benefits in the Cannon River watershed. Location within the watershed, land and soil properties, and existing land uses and practices all factor into prioritizing management practices that will maximize water quality and ecosystem benefits.

The quantification of sediment and nutrient load reductions for a given management practice is accomplished by comparing a "baseline" run with a "scenario" run and assessing the relative change(s) between the simulations. The two types of CRWHSPF model runs are described below:

- The "**baseline**" run represents conditions in the watershed for the 1996 through 2012 time period. The run includes historical climate and hydrology conditions and sediment and nutrient sources (atmospheric deposition, point sources, nonpoint sources), and it accounts for the best available estimates of land uses and activities in the watershed.

- A “**scenario**” run represents the implementation of specific BMPs and/or management practices under historical climate and hydrology conditions for the 1996 through 2012 time period.

The analysis of the scenario results consists of the following steps:

1. Define an accurate and appropriate baseline condition for the watershed;
2. Simulate the baseline condition;
3. Define the scenarios;
4. Make changes to model inputs, parameters, and/or configuration to represent a given scenario;
5. Simulate the scenario conditions; and
6. Compare the model results from the baseline and scenario simulations to quantify the difference in local sediment and nutrient local yields (in terms of UALs) and loads delivered to the outlet (in terms of mass per year).

As described in the previous section, the first management scenario was constructed to serve as an “adjusted baseline” (see scenario A). This scenario was different than the true baseline or “historical baseline” in that it did not represent conditions in the watershed for the 1996 through 2012 time period, but rather it represented the major point source TP loads as “current conditions”. To better inform how future management decisions may impact the Cannon River watershed relative to its present state, relative load changes for the remaining scenarios were computed using the “adjusted baseline” loads rather than the “historical baseline” loads.

The management scenario results are summarized in the sections below. For the evaluation of the scenarios relative to one another, it is important to consider the “level of implementation” for each scenario in regard to the estimated load reduction reported for each scenario. The specified level of implementation is not the same across the scenarios and varies from 5% to 30% of specific targeted land areas (e.g., developed or agricultural). Given the different levels of implementation, the comparison of the scenarios is not absolute but instead provides a relative comparison. Therefore, the level of implementation for each scenario must be taken into consideration when using the information for making management decisions. For reference, Table 3 summarizes the management actions considered for each scenario along with the prescribed “level of implementation”.

Table 3. Description of management actions simulated under each scenario including the proportion of cropland or developed land segments undergoing treatment or land conversion and the overall watershed-wide level of implementation.

Scenario ID	Scenario Abbreviation	Description of Scenario Changes	Proportion of Land Segment Type Undergoing Treatment		Proportion of Land Segment Type Undergoing Land Conversion		Proportion of Watershed Undergoing Treatment / Conversion
			Cropland	Developed	Cropland	Developed	
A	"Adjusted" Baseline	Major WWTPs at Current TP Loads	-	-	-	-	-
B	Point Source Limits	All Point Sources at Permitted Limits	-	-	-	-	-
C	Point Sources RES	All Point Sources at RES & 70% AWWDF (Jun-Sep), Permitted TP Limits & 70% AWWDF (Oct-May)	-	-	-	-	-
D	Pre-Settlement Vegetation	Pre-Settlement Vegetation	-	-	100%	100%	84.0%
E	Consv. Tillage & Waseca G.I.	Conservation Tillage, Green Infrastructure in City of Waseca MS4 Areas, Major WWTPs at Current TP Loads	31.1%	1.2%	-	-	19.4%
F	Cover Crops	Cover Crops, Major WWTPs at Current TP Loads	23.4%	-	-	-	14.5%
G	Perennials & 25% G.I.	Conversion of Marginal Cropland & 50 ft Buffers to Perennial Vegetation, Green Infrastructure in 25% of MS4 Areas, Major WWTPs at Current TP Loads	25.0%	6.6%	12.3%	-	21.8%
H	Wetlands & Ponds	Wetland Restoration, Sedimentation Ponds, Major WWTPs at Current TP Loads	6.9%	-	8.5%	-	9.2%
I	Combined 1	Cover Crops, Conversion of Marginal Cropland & 50 ft Buffers to Perennial Vegetation, Low Flow Phosphorus Load Reduction, Major WWTPs at Current TP Loads	43.1%	-	12.3%	-	31.1%
J	Combined 2	Cover Crops, Conversion of Marginal Cropland & 50 ft Buffers to Perennial Vegetation, Low Flow Phosphorus Load Reduction, Major WWTPs at Current TP Loads (Jun-Sep), Major WWTPs at Permitted Flow & TP Limits (Oct-May),	43.1%	-	12.3%	-	31.1%

Sediment

A comparison of sediment yields and loading for the historical baseline run, the adjusted baseline run, and the various management scenarios on an average annual basis over the simulation period (1996-2012) is provided in Tables 4-5 and Figures 6-7 below. Sediment yield refers to sediment loading on a mass per area basis (in tons/acre/yr) from the landscape. Sediment loading refers to the amount of sediment that is delivered to the watershed outlet and Lake Byllesby (in tons/yr). The relative load change is calculated as the scenario load minus the "adjusted" baseline load, divided by the "adjusted" baseline load at the watershed outlet and Lake Byllesby.

For the "historical" baseline run, the model calculated an average sediment load of 149,170 tons/yr at the watershed outlet and 80,179 tons/yr to Lake Byllesby. The overall sediment yield calculated for the baseline run was 0.135 tons/acre/yr. Subbasins in the Driftless Area ecoregion had relatively higher simulated sediment yields than other subbasins in the watershed. This, coupled with relatively higher simulated instream erosion rates in Driftless Area reach segments, resulted in the model predicting relatively higher sediment loading from areas of the watershed downstream of Lake Byllesby.

The point source sediment load is the same between the two baseline scenarios; therefore, the average sediment load is the same as well. The model-estimated sediment loading to the watershed outlet and Lake Byllesby for the point source scenarios (B and C) were slightly greater (≤1%) than the adjusted baseline run. The increase in sediment load for the point source scenario at the permitted limits (B) is attributed to permitted effluent flows and/or sediment concentrations that were higher than the adjusted baseline. The slight increase (≤0.1%) in sediment load for the point source scenarios where the effluent flow is set at 70% AWWDF (C) can be attributed to the 70% AWWDF flows that were higher than the adjusted baseline effluent flows.

The pre-settlement vegetation scenario (D) results serve as an indicator of the extent to which historical land use changes have affected sediment erosion in the Cannon River watershed. The results of the pre-settlement vegetation scenario suggest a sediment yield of 0.051 tons/acre/yr under the pre-settlement conditions, which is nearly three-fold lower than the adjusted baseline yield of 0.135 tons/acre/yr. The results of this scenario indicate that the conversion of natural landscape to agriculture and developed land uses in the watershed has significantly increased sediment loading in the Cannon River watershed.

Conservation tillage practices tend to reduce sediment load because of the increased residue cover that protects soil from erosion. The application of conservation tillage (scenario E) to 30% of the highest sediment yielding cropland acres in the model resulted in an estimated annual sediment load reduction of 15% at the watershed outlet and 9% to Lake Byllesby compared to the adjusted baseline run. The green infrastructure implementation to City of Waseca MS4 areas draining to Clear Lake (scenario E) resulted in a minimal reduction of annual sediment loading to the watershed outlet and Lake Byllesby, but resulted in a 36% reduction of sediment loading to Clear Lake.

The use of cover crops serves to reduce soil erosion by increasing both the canopy cover and the amount of residue left on the soil surface at post-harvest. The application of cover crops (scenario F) resulted in an estimated sediment load reduction of 14% at the watershed outlet and 4% at Lake Byllesby compared to the adjusted baseline run. As described earlier, the majority of cover crop implementation occurred in the Little Cannon River and Belle Creek watersheds, both of which discharge to the Cannon River downstream of Lake Byllesby, hence the relatively low reduction in sediment loads delivered to the lake. The locations of cover crop implementation were similar to the locations of conservation tillage implementation with some overlap; however, not all locations were the same between the two scenarios. At the outlet of the Little Cannon River watershed, the CRWHSPF cover crop scenario estimated a 22% sediment load reduction. This agrees relatively well with the 26% reduction predicted by a scenario simulated using the Little Cannon SWAT model that also assumed 100% implementation of cover crops on cropland acres (LimnoTech 2014).

The combined effects of converting marginal cropland and cropland within 50 ft buffers of streams to perennial vegetation and implementing green infrastructure on 25% of developed MS4 areas (scenario G) resulted in an estimated sediment load reduction of 12% at the watershed outlet and 14% at Lake Byllesby compared to the adjusted baseline run. Given the relatively small area of developed land across the watershed, it is not expected that the green infrastructure implementation alone would result in a substantial sediment load reduction. Therefore, the majority of the sediment load reductions at the watershed outlet and Lake Byllesby are likely attributable to the cropland BMPs simulated under this scenario. However, at the more local, tributary scale where developed land cover dominates, reductions in sediment load that result from green infrastructure will likely have a greater water quality benefit.

The results of the wetland restoration and sedimentation pond scenario (H) indicated a reduction in sediment loading of 7% relative to the adjusted baseline at the watershed outlet. The estimated sediment load reduction at Lake Byllesby was 5% relative to the adjusted baseline. The reduction in peak flows, the detention of surface runoff, and subsequent settling of solids in the ponds resulted in lower sediment loading for this scenario compared to the adjusted baseline. The levels of implementation of this scenario were the lowest of any nonpoint source scenario, with only 6.9% of cropland converted to wetlands and 8.5% of cropland routed to sedimentation ponds for an overall implementation to 15.4% of cropland acres (9.2% of the watershed).

The combined management scenarios (I and J) involved the application of cover crops and converting marginal cropland and cropland within 50 ft buffers of streams to perennial vegetation. Because the only difference between the two combined management scenarios was an increase in major point source flows and TP loads during the October-May period, there is nearly no difference in sediment loading between the two simulations. While model results indicate that there is an additional benefit to applying multiple management practices, the effects are not simply the sum of the reductions of each individual practice implemented as a stand-alone practice. Rather, the added benefit of multiple practices is somewhat less. In general, the highest level of pollutant reduction occurs with the implementation of the first BMP, with each successive BMP becoming less effective (MPCA 2015). Typically, each successive BMP (e.g., the second, third, fourth, etc.) in a treatment train or successive management practice is receiving runoff that has considerably less volume and concentration of pollutants (MPCA 2015). This means there is less load that can be reduced and a point may be reached where flow volume or concentration cannot be reduced further by a given BMP or management practice (MPCA 2015). The sediment load reduction estimated is 22% at the watershed outlet and 15% at Lake Byllesby. The model results indicate that the combined management scenarios provide the greatest overall sediment load reduction with the exception of the pre-settlement vegetation scenario.

Sediment landscape yield scenario maps are provided in Appendix A.

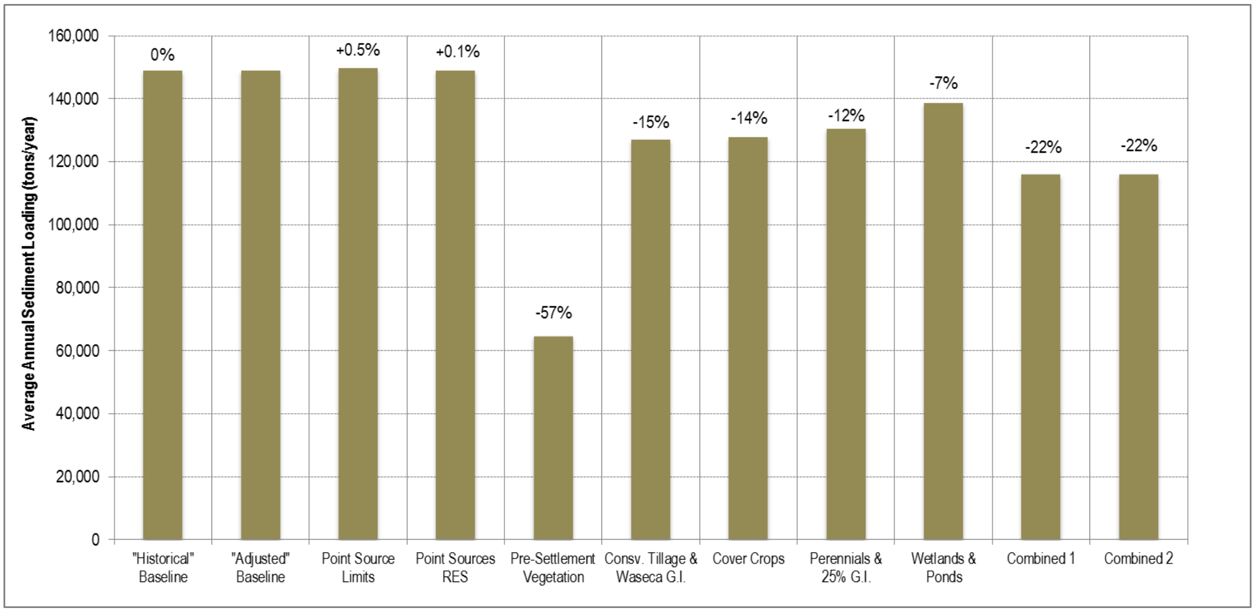

Figure 6. Simulated total sediment loading at the Cannon River watershed outlet for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996 – 2012).

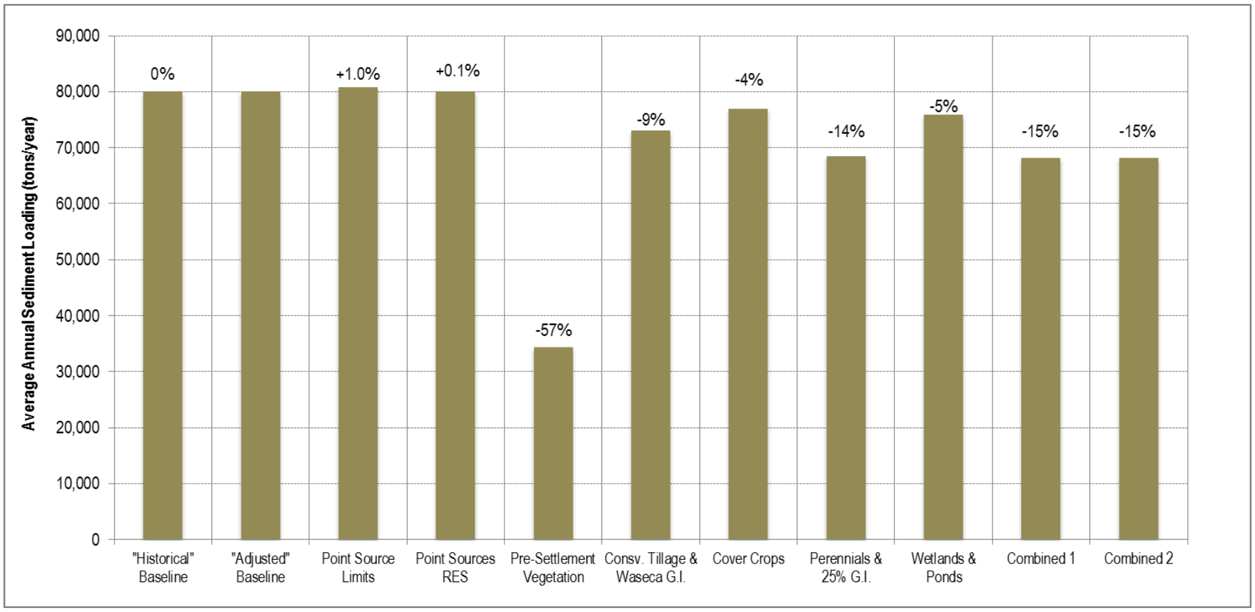

Figure 7. Simulated total sediment loading to Lake Byllesby for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996 – 2012).

Table 4. Summary of simulated sediment yields and loading at the Cannon River watershed outlet for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996-2012).

Scenario ID	Scenario Abbreviation	Sediment Yield (tons/acre/yr)[a]	Sediment Loading (tons/yr)[a]	Sediment Loading Change (relative to adjusted baseline)
-	"Historical" Baseline	0.135	149,170	0%
A	"Adjusted" Baseline	0.135[b]	149,170	-
B	Point Source Limits	0.135[b]	149,884	+0.5%
C	Point Sources RES	0.135[b]	149,276	+0.1%
D	Pre-Settlement Vegetation	0.051	64,733	-57%
E	Consv. Tillage & Waseca G.I.	0.112	127,270	-15%
F	Cover Crops	0.115	128,084	-14%
G	Perennials & 25% G.I.	0.110	130,705	-12%
H	Wetlands & Ponds	0.112	138,934	-7%
I	Combined 1	0.097	116,088	-22%
J	Combined 2	0.097	116,169	-22%

[a] *Tons are in English tons. The yield represents a watershed-wide weighted average yield.*

[b] *Sediment yields represent the landside or landscape sediment loading; therefore, the sediment yield for the point source scenarios are the same as the baseline.*

Table 5. Summary of simulated sediment yields and loading to Lake Byllesby for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996-2012).

Scenario ID	Scenario Abbreviation	Sediment Loading (tons/yr)[a]	Sediment Loading Change (relative to adjusted baseline)
-	"Historical" Baseline	80,179	0%
A	"Adjusted" Baseline	80,179	-
B	Point Source Limits	80,981	+1.0%
C	Point Sources RES	80,256	+0.1%
D	Pre-Settlement Vegetation	34,359	-57%
E	Consv. Tillage & Waseca G.I.	73,168	-9%
F	Cover Crops	77,104	-4%
G	Perennials & 25% G.I.	68,653	-14%
H	Wetlands & Ponds	76,040	-5%
I	Combined 1	68,266	-15%
J	Combined 2	68,319	-15%

[a] *Tons are in English tons*

Phosphorus

A comparison of phosphorus yields and loading (TP and orthophosphate (PO4)) for the historical baseline run, the adjusted baseline run, and the various management scenarios on an average annual basis over the simulation period (1996-2012) is provided in Tables 6-7 and Figures 8-9 below. Phosphorus yield refers to phosphorus loading on a mass per area basis (in lbs/acre/yr) from the landscape. Phosphorus loading refers to the amount of phosphorus that is delivered to the watershed outlet and to Lake Byllesby (in lbs/yr). The relative load change is calculated as the scenario load minus the adjusted baseline load, divided by the adjusted baseline load at the watershed outlet and Lake Byllesby. Table 7 also shows the June-September flow-weighted mean TP concentration and the mean TP concentration at the June-September 80th percentile flow for the Cannon River at the Lake Byllesby inlet.

For the historical baseline scenario, the model calculated average TP loads of 675,835 lbs/yr at the watershed outlet and 420,743 lbs/yr to Lake Byllesby. The TP yield calculated for the baseline run was 0.453 lbs/acre/yr. These loads were greater than the loads predicted under the adjusted baseline scenario (A) due to the higher “historical” effluent TP loads from the Faribault, Northfield, and Owatonna WWTPs. For the point source scenario set at permitted effluent flow and constituent limits (B), the model-estimated annual TP loading to the watershed outlet and to Lake Byllesby was 5% and 11% greater, respectively, than the adjusted baseline run. The increase in the TP load is attributed to higher effluent flows and/or TP concentrations specified in the permitted limits scenario. For the point source scenario where the effluent flow was set at 70% AWWDF and TP concentrations were at the RES during June-September (scenario C), TP loads increased by 1% at the watershed outlet and 2% to Lake Byllesby. The slight increase in TP loads can be attributed to setting TP concentrations to the permitted limit during October-May coupled with setting effluent flow to 70% AWWDF, which was higher than the adjusted baseline. The mean TP concentration at the June-September 80th percentile flow for the Cannon River at the Lake Byllesby inlet was lower under scenario C (0.148 mg-P/L) compared to those predicted by the adjusted baseline run (0.172 mg-P/L). This demonstrates that reducing point source TP loads during June-September relative to the adjusted baseline decreased low-flow TP concentrations entering Lake Byllesby during these summer months despite the overall increase in annual point source TP loads.

Although the landscape TP yields were reduced substantially (90% lower TP yields relative to the adjusted baseline) for the pre-settlement vegetation scenario (D), model predictions of low-flow TP concentrations and TP and PO4 loading at the watershed outlet were higher than anticipated. An investigation into model results revealed phosphorus concentrations accumulating in the various lakes in the watershed, most of which are in the Upper Cannon lobe. Benthic phosphate release rates from lake sediments were not modified under this scenario. Atmospheric and nonpoint source nitrogen loads to the lakes were also significantly reduced in this scenario, which appears to have substantially decreased phytoplankton growth due to nitrogen limitation and contributed to in-lake phosphorus accumulation in the model. HSPF does not automatically simulate a reduction in benthic phosphate release rates as the phosphorus concentration in the overlying water column increases. Instead, the reductions in the benthic phosphate release requires manual input. This limitation was discussed in the “Summary and Recommendations” section of the CRWHSPF model development report (LimnoTech 2015). Because of this limitation and the reduction in phytoplankton phosphorus uptake under this scenario, the simulated in-lake phosphorus concentrations were often five to ten times higher than the adjusted baseline scenario. Increased phosphorus loading from lake sediments simulated in the pre-settlement vegetation scenario therefore partially offset the phosphorus load reductions that were achieved through point source removal and landside nonpoint source reduction. Consequently, CRWHSPF predicted higher than anticipated TP concentrations during very low to mid-range flow regimes. Because of the uncertainty in model predictions of instream phosphorus concentrations and loads under the pre-settlement vegetation (D) due to the limitations of the HSPF model framework at simulating nutrient cycling and eutrophication processes in lakes, these estimates are not included in this report. Note that TP yield is not influenced by the limitations described above.

The conservation scenario (E) was estimated to provide approximately 12% TP load reduction at the watershed outlet and the perennials scenario (G) resulted in roughly 11% TP load reduction to Lake Byllesby. The green infrastructure implementation to City of Waseca MS4 areas draining to Clear Lake (scenario E) provided minimal reduction of TP loading to the watershed outlet and Lake Byllesby, but resulted in a 22% reduction of TP loading to Clear Lake. The wetland restoration and sedimentation pond scenario (H) resulted in the lowest mean TP concentration (0.161 mg-P/L) at the June-September 80th percentile flow for the Cannon River at the Lake Byllesby inlet compared to scenarios E through G. The CRWHSPF cover crop scenario (F) estimated a 25% TP load reduction at the outlet of the Little Cannon River watershed. This estimate agrees relatively well with the 19% TP load reduction predicted by the Little Cannon SWAT model that also assumed 100% implementation of cover crops on cropland acres (LimnoTech 2014).

As with sediment, the combined management scenarios were estimated to provide the greatest overall TP load reduction with the exception of the pre-settlement vegetation scenario. The TP load reductions estimated at the watershed outlet were 20% (scenario I) and 17% (scenario J). The TP load reductions to Lake Byllesby were estimated at 15% (scenario I) and 9% (scenario J). Although the increase in major point source flows and TP loads during the October-May period under scenario J resulted in the different TP load reductions between the two combined management scenarios, the mean TP concentration at the June-September 80th percentile flow for the Cannon River at the Lake Byllesby inlet was the same between the scenarios (0.123 mg-P/L) and the lowest of all management scenarios considered.

Phosphorus landscape yield scenario maps are provided in Appendix B. TP load duration curves for the Cannon River at the Lake Byllesby inlet are provided in Appendix C.

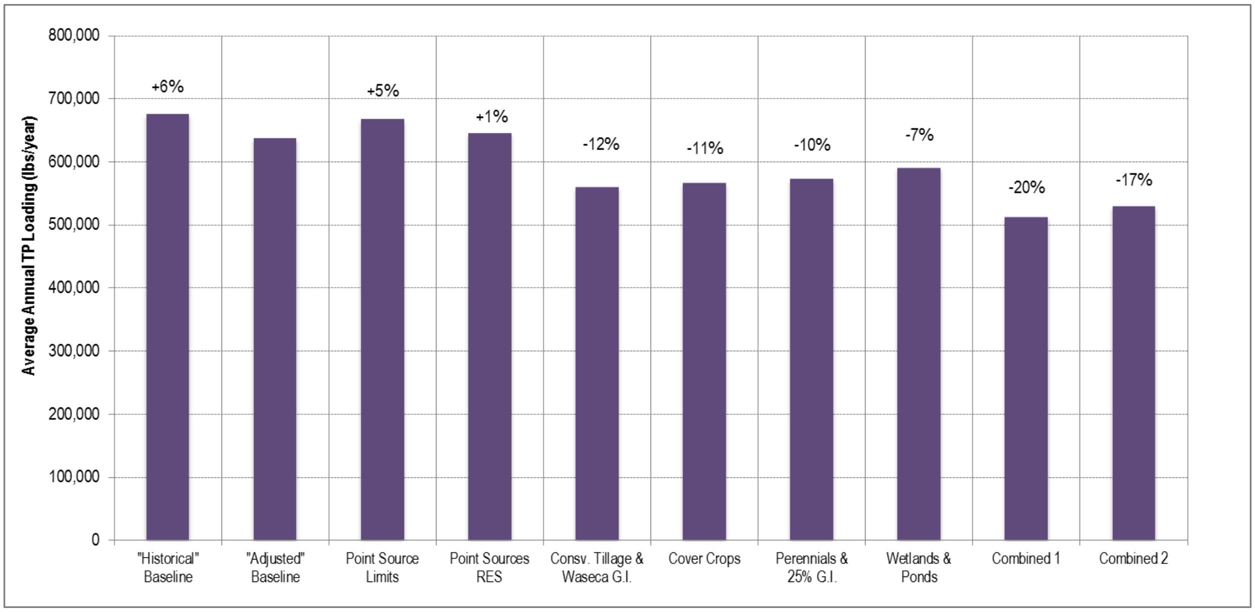

Figure 8. Simulated total phosphorus loading at the Cannon River watershed outlet for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996 – 2012).

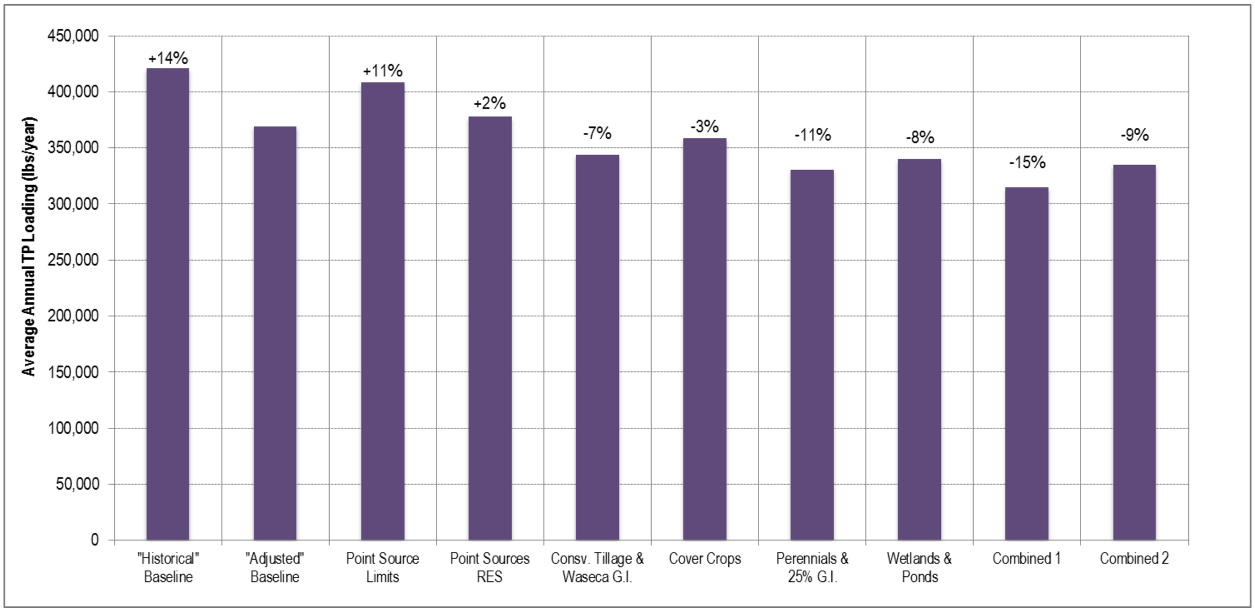

Figure 9. Simulated total phosphorus loading to Lake Byllesby for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996 – 2012).

Table 6. Summary of simulated phosphorus yields and loading at the Cannon River watershed outlet for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996-2012).

Scenario ID	Scenario Abbreviation	TP Yield[a] (lbs/acre/yr)	TP Loading (lbs/yr)	TP Loading Change (relative to adjusted baseline)	PO4 Yield[a] (lbs/acre/yr)	PO4 Loading (lbs/yr)	PO4 Loading Change (relative to adjusted baseline)
-	"Historical" Baseline	0.453	675,835	+6%	0.395	376,295	+6%
A	"Adjusted" Baseline	0.453[b]	637,211	-	0.395[b]	353,724	-
B	Point Source Limits	0.453[b]	667,308	+5%	0.395[b]	370,633	+5%
C	Point Sources RES	0.453[b]	645,722	+1%	0.395[b]	361,242	+2%
D	Pre-Settlement Vegetation [c]	0.044	-	-	-	-	-
E	Consv. Tillage & Waseca G.I.	0.381	559,827	-12%	0.328	318,473	-10%
F	Cover Crops	0.390	566,746	-11%	0.336	322,058	-9%
G	Perennials & 25% G.I.	0.372	572,345	-10%	0.320	329,813	-7%
H	Wetlands & Ponds	0.373	590,537	-7%	0.300	333,096	-6%
I	Combined 1	0.325	512,632	-20%	0.276	301,880	-15%
J	Combined 2	0.325	529,741	-17%	0.276	314,467	-11%

[a] *The yield represents a watershed-wide weighted average yield.*

[b] *Phosphorus yields represent the landside or landscape phosphorus loading; therefore, the phosphorus yield for the point source scenarios are the same as the baseline.*

[c] *Model predictions of instream phosphorus loads under the pre-settlement vegetation scenario were omitted due to limitations of the HSPF model framework at simulating phosphorus dynamics in multiple lakes in this scenario.*

Table 7. Summary of simulated phosphorus loading to Lake Byllesby and TP concentrations at the Cannon River inlet to Lake Byllesby for the “historical” baseline run, “adjusted” baseline run, and management scenarios (1996-2012).

Scenario ID	Scenario Abbreviation	TP Loading (lbs/yr)	TP Loading Change (relative to adjusted baseline)	PO4 Loading (lbs/yr)	PO4 Loading Change (relative to adjusted baseline)	Cannon River Jun-Sep Flow-Weighted Mean TP Conc. (mg/L)	Cannon River Jun-Sep Mean TP Conc. (mg/L) at 80th Percentile Flow
-	“Historical” Baseline	420,743	+14%	242,170	+16%	0.399	0.259
A	"Adjusted" Baseline	369,268	-	208,287	-	0.361	0.172
B	Point Source Limits	408,426	+11%	230,254	+11%	0.379	0.235
C	Point Sources RES	377,645	+2%	215,522	+3%	0.350	0.148
D	Pre-Settlement Vegetation[a]	-	-	-	-	-	-
E	Consv. Tillage & Waseca G.I.	343,900	-7%	196,511	-6%	0.342	0.170
F	Cover Crops	358,692	-3%	203,288	-2%	0.359	0.172
G	Perennials & 25% G.I.	330,421	-11%	193,012	-7%	0.323	0.164
H	Wetlands & Ponds	339,873	-8%	190,570	-9%	0.347	0.161
I	Combined 1	314,838	-15%	185,286	-11%	0.304	0.123
J	Combined 2	335,071	-9%	199,998	-4%	0.304	0.123

[a] *Model predictions of instream phosphorus loads under the pre-settlement vegetation scenario were omitted due to limitations of the HSPF model framework at simulating phosphorus dynamics in multiple lakes in this scenario.*

Nitrogen

A comparison of nitrogen yields and loading for the historical baseline run, the adjusted baseline run, and the various management scenarios on an average annual basis over the simulation period (1996-2012) is provided in Tables 8-9 and Figures 10-11 below. Nitrogen yield refers to nitrogen loading on a mass per area basis (in lbs/acre/yr) from the landscape. Nitrogen loading refers to the amount of nitrogen that reaches or is delivered to the watershed outlet and to Lake Byllesby (in lbs/yr). The relative load change is calculated as the scenario load minus the adjusted baseline load, divided by the adjusted baseline load. The scenario results described below focus on TN; however, the relative changes in loads between the baseline run and the scenarios for nitrate are consistent with the TN results. This is expected because for the Cannon River watershed, a large majority of the model simulated TN (over 85%) is in the form of nitrate.

For the "historical" baseline scenario, the model calculated an average TN load of 11,769,796 lbs/yr at the watershed outlet and 9,082,614 lbs/yr to Lake Byllesby. The TN yield calculated for the baseline run was 14.3 lbs/acre/yr. These loads were slightly less (<1%) than the loads predicted under the adjusted baseline run (scenario A). For the point source scenario set at the permitted effluent flow and constituent limits (B), the model-estimated TN loading to the watershed outlet and to Lake Byllesby was 6% and 9% greater, respectively, than the adjusted baseline run. The TN load for the point source scenario where the effluent flow was set at 70% AWWDF (C) was 1% greater at the watershed outlet and Lake Byllesby relative to the adjusted baseline. The increase in the TN loads for these two point source scenarios is attributed to higher effluent flows and/or TN concentrations compared to the effluent flows and TN concentrations in the adjusted baseline run.

The pre-settlement vegetation scenario (D) provides a pre-settlement reference for the nitrogen loading rates in the Cannon River watershed. The pre-settlement vegetation scenario loading rates of TN is 1.0 lb/acre/yr are approximately fourteen-fold lower than the baseline run of 14.3 lbs/acre/yr. For pre-settlement conditions, the model-estimated TN loading was 95% lower at the watershed outlet and 94% lower at Lake Byllesby when compared to the adjusted baseline run. The results of this scenario indicate the conversion of natural landscape to agriculture and developed land uses in the watershed as well as the increase in atmospheric nitrogen deposition have significantly increased the nitrogen input to and export from the Cannon River watershed.

Of the remaining scenarios, the first combined management scenario (I) was estimated to provide the greatest overall TN load reduction relative to the adjusted baseline (18% at the watershed outlet). The second combined management scenario (J) had slightly higher TN loading at the watershed outlet due to the increase in major point source flows and TN loads during the October-May period.

Nitrogen landscape yield scenario maps are in Appendix D.

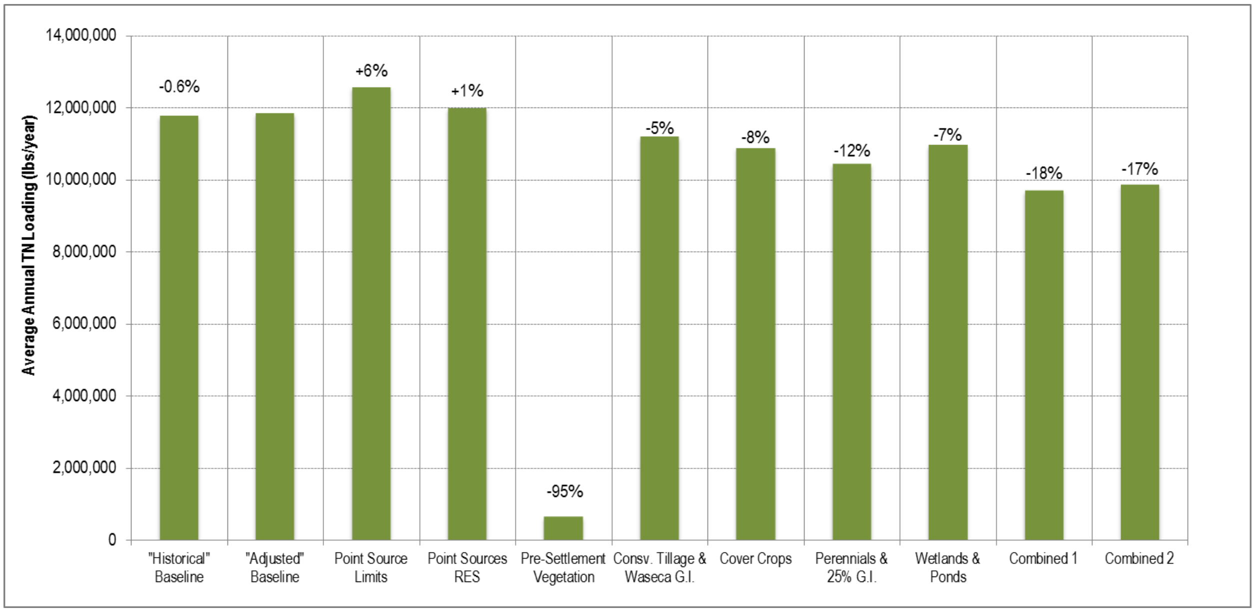

Figure 10. Simulated total nitrogen loading at the Cannon River watershed outlet for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996 – 2012).

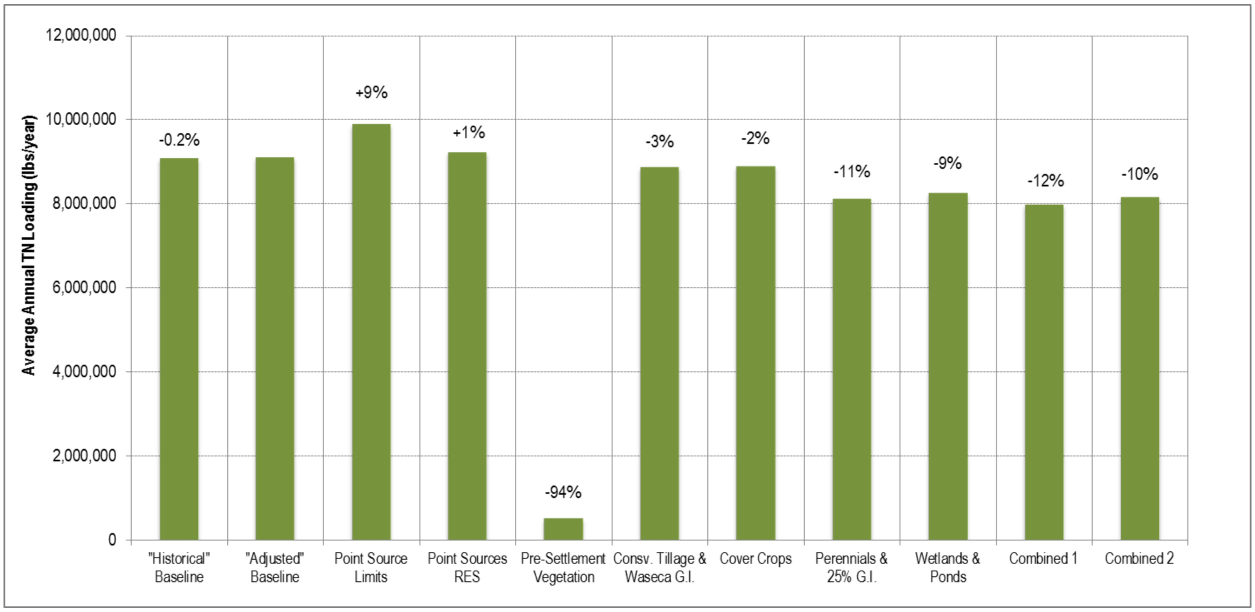

Figure 11. Simulated total nitrogen loading to Lake Byllesby for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996 – 2012).

Table 8. Summary of simulated nitrogen yields and loading at the Cannon River watershed outlet for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996-2012).

Scenario ID	Scenario Abbreviation	TN Yield[a] (lbs/acre/yr)	TN Loading (lbs/yr)	TN Loading Change (relative to adjusted baseline)	NO3 Yield[a] (lbs/acre/yr)	NO3 Loading (lbs/yr)	NO3 Loading Change (relative to adjusted baseline)
-	"Historical" Baseline	14.3	11,769,796	-0.6%	12.8	10,318,619	-1%
A	"Adjusted" Baseline	14.3[b]	11,843,034	-	12.8[b]	10,450,764	-
B	Point Source Limits	14.3[b]	12,577,590	+6%	12.8[b]	10,916,787	+4%
C	Point Sources RES	14.3[b]	11,995,439	+1%	12.8[b]	10,597,790	+1%
D	Pre-Settlement Vegetation	1.0	631,329	-95%	0.8	350,825	-97%
E	Consv. Tillage & Waseca G.I.	13.5	11,198,180	-5%	12.1	9,891,174	-5%
F	Cover Crops	13.1	10,890,479	-8%	11.7	9,574,722	-8%
G	Perennials & 25% G.I.	12.6	10,446,459	-12%	11.2	9,142,793	-13%
H	Wetlands & Ponds	12.5	10,965,783	-7%	11.1	9,653,617	-8%
I	Combined 1	11.6	9,702,496	-18%	10.3	8,483,896	-19%
J	Combined 2	11.6	9,858,862	-17%	10.3	8,627,956	-17%

[a] *The yield represents a watershed-wide weighted average yield.*

[b] *Nitrogen yields represent the landside or landscape nitrogen loading; therefore, the nitrogen yield for the point source scenarios are the same as the baseline.*

Table 9. Summary of simulated nitrogen yields and loading to Lake Byllesby for the "historical" baseline run, "adjusted" baseline run, and management scenarios (1996-2012).

Scenario ID	Scenario Abbreviation	TN Loading (lbs/yr)	TN Loading Change (relative to adjusted baseline)	NO3 Loading (lbs/yr)	NO3 Loading Change (relative to adjusted baseline)
-	"Historical" Baseline	9,082,614	-0.2%	8,017,206	-0.7%
A	"Adjusted" Baseline	9,101,039	-	8,072,573	-
B	Point Source Limits	9,891,932	+9%	8,372,373	+4%
C	Point Sources RES	9,231,637	+1%	8,198,614	+2%
D	Pre-Settlement Vegetation	505,607	-94%	294,169	-96%
E	Consv. Tillage & Waseca G.I.	8,862,557	-3%	7,863,812	-3%
F	Cover Crops	8,892,421	-2%	7,880,130	-2%
G	Perennials & 25% G.I.	8,115,668	-11%	7,148,013	-11%
H	Wetlands & Ponds	8,250,280	-9%	7,281,954	-10%
I	Combined 1	7,982,965	-12%	7,054,312	-13%
J	Combined 2	8,149,806	-10%	7,214,295	-11%

Management Scenario Summary

A suite of potential management actions were evaluated with the CRWHSPF model to estimate the potential benefits of these practices with respect to reducing present-day sediment and nutrient loads. When assessing the scenarios relative to one another, it is important to consider the "level of implementation" in regard to the estimated load reduction reported for each scenario. The specified level of implementation was not the same across the scenarios and varied from 9.2% to 31.1% of the entire watershed area (excluding the pre-settlement vegetation scenario). The location of management practice or BMP implementation also differed across the scenarios and should be taken into consideration when using scenario results to help inform management decisions. Management scenario results have been generally expressed as the "percent change relative to the adjusted baseline". This approach was taken because the relative differences between the "baseline" and the individual scenarios are more certain than the absolute differences (e.g., in sediment loading).

Based on the model scenario results, the following list summarizes the management practices that are indicated as likely to be the most effective in reducing sediment and nutrient loading and improving water quality:

- Sediment: combined management (I and J), conservation tillage & green infrastructure (E), cover crops (F) and perennials & green infrastructure (G);
- Total Phosphorus (TP) and Orthophosphate (PO4): combined management (I and J), conservation tillage & green infrastructure (E), cover crops (F) and perennials & green infrastructure (G);
- Total Nitrogen (TN) and Nitrate (NO3): combined management (I and J) and perennials & green infrastructure (G).

It should be noted that the pre-settlement vegetation condition is not listed as an effective practice for reducing sediment and nutrient loading and improving water quality. This scenario does not represent a feasible management practice (i.e., the watershed will never be returned to a pre-settlement vegetation condition). The purpose of this scenario was to estimate the increased sediment and nutrient loading in the watershed resulting from the conversion of the natural landscape to agriculture and developed land uses.

Project Outcomes

The outcomes of this project include the following:

1. Model applications that assess various management scenarios were successfully developed, and the results can be used by decision-makers, including agency staff and stakeholders, to educate and inform the development of implementation strategies to restore and protect waters.
2. MPCA staff, local partners and citizen volunteers will be able to integrate the results of the modeling into strategies for the Watershed Restoration and Protection Plan report and implementation plan for improving water bodies on the Minnesota 303(d) List of Impaired Waters.
3. Model applications inform and support the development of the allowable total maximum daily loads of pollutants into impaired lakes and stream segments.

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Appendix A - Sediment

LANDSCAPE UNIT AREA LOADING MAPS

The annual average load generated per acre is mapped for each model subbasin. The maps only represent landscape yields and do not account for changes in point source discharge; therefore, maps are not available for the point source scenarios. Please note that the shading of a subbasin is based on a relative scale to differentiate unit area loading rates. The color of the shading is not intended to indicate whether the load generated is bad or good in terms of water quality.

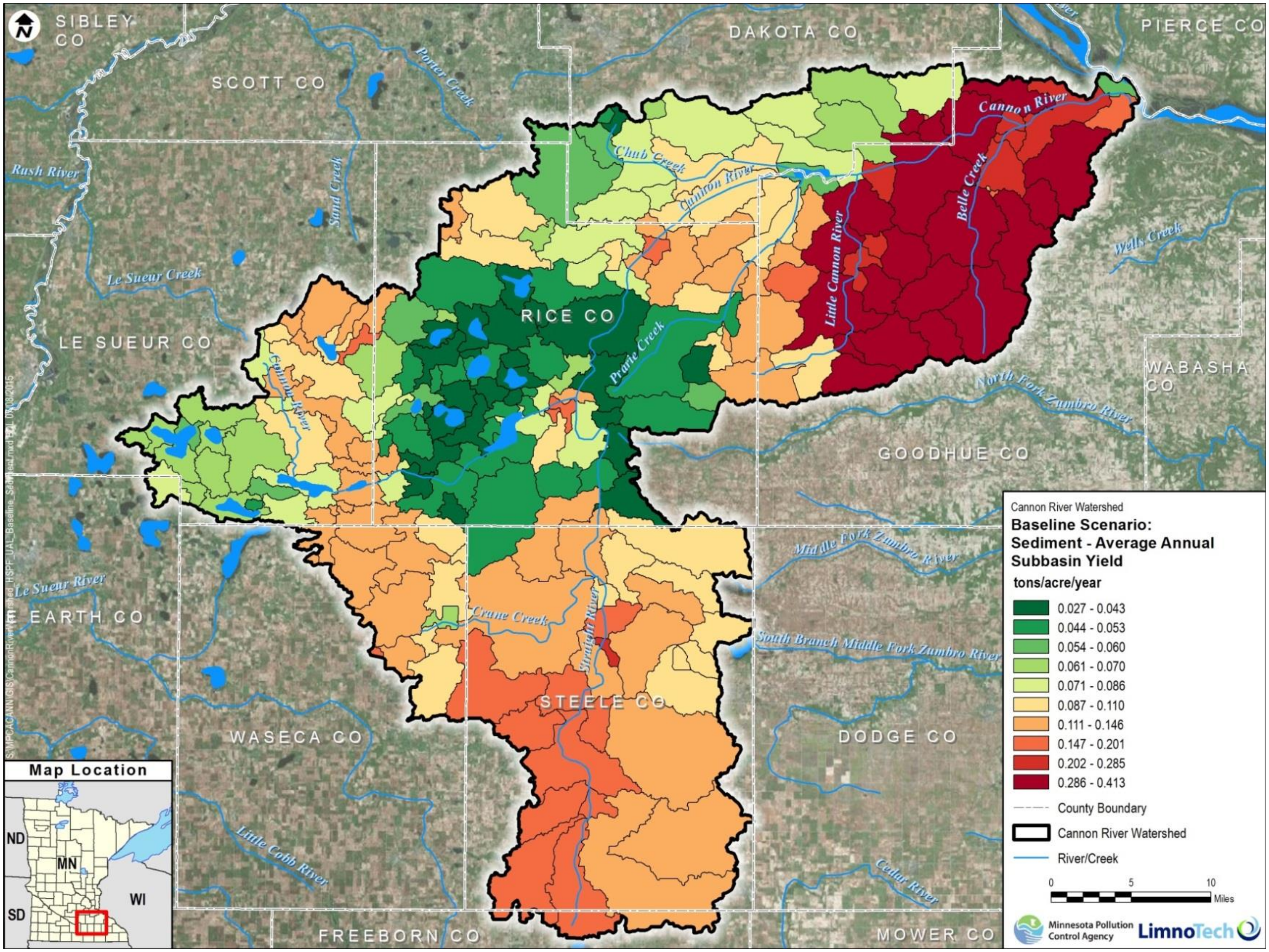

Figure A-1. Average annual sediment subbasin yield for the baseline simulation. Note that landscape yields are the same for both the "historical" and "adjusted" baseline scenarios.

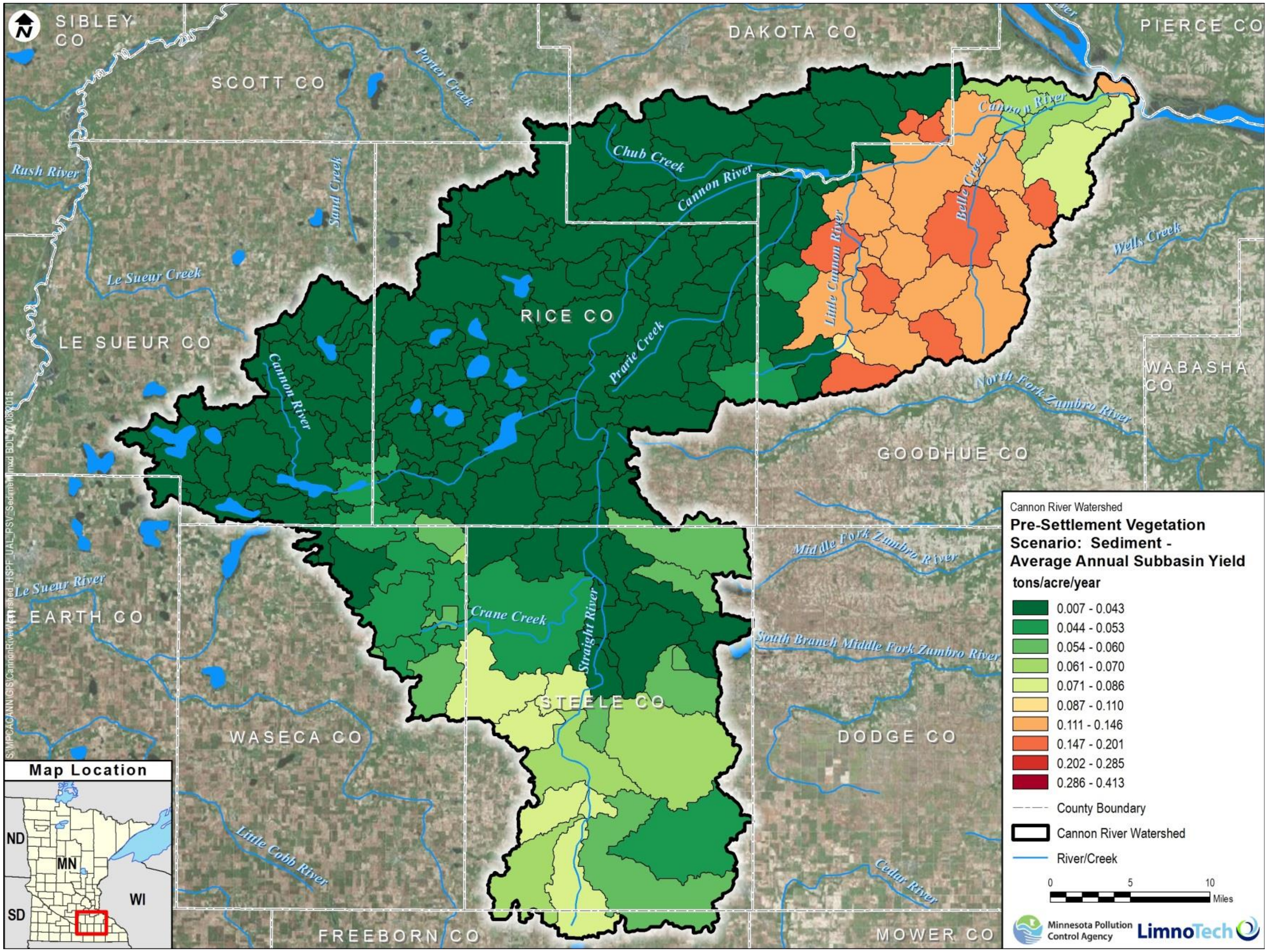

Figure A-2. Average annual sediment subbasin yield for the pre-settlement vegetation scenario (D).

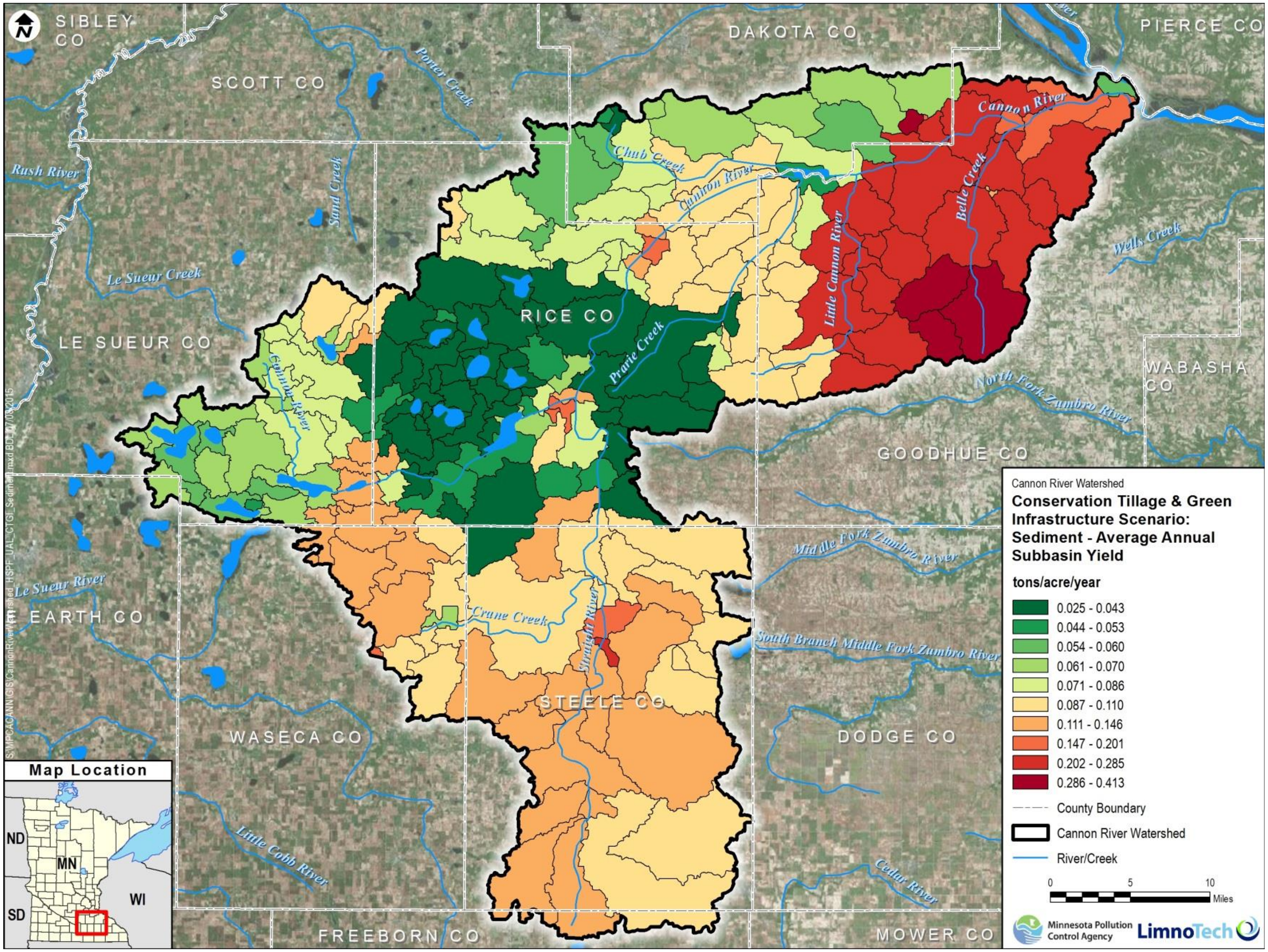

Figure A-3. Average annual sediment subbasin yield for the conservation tillage and Waseca green infrastructure scenario (E).

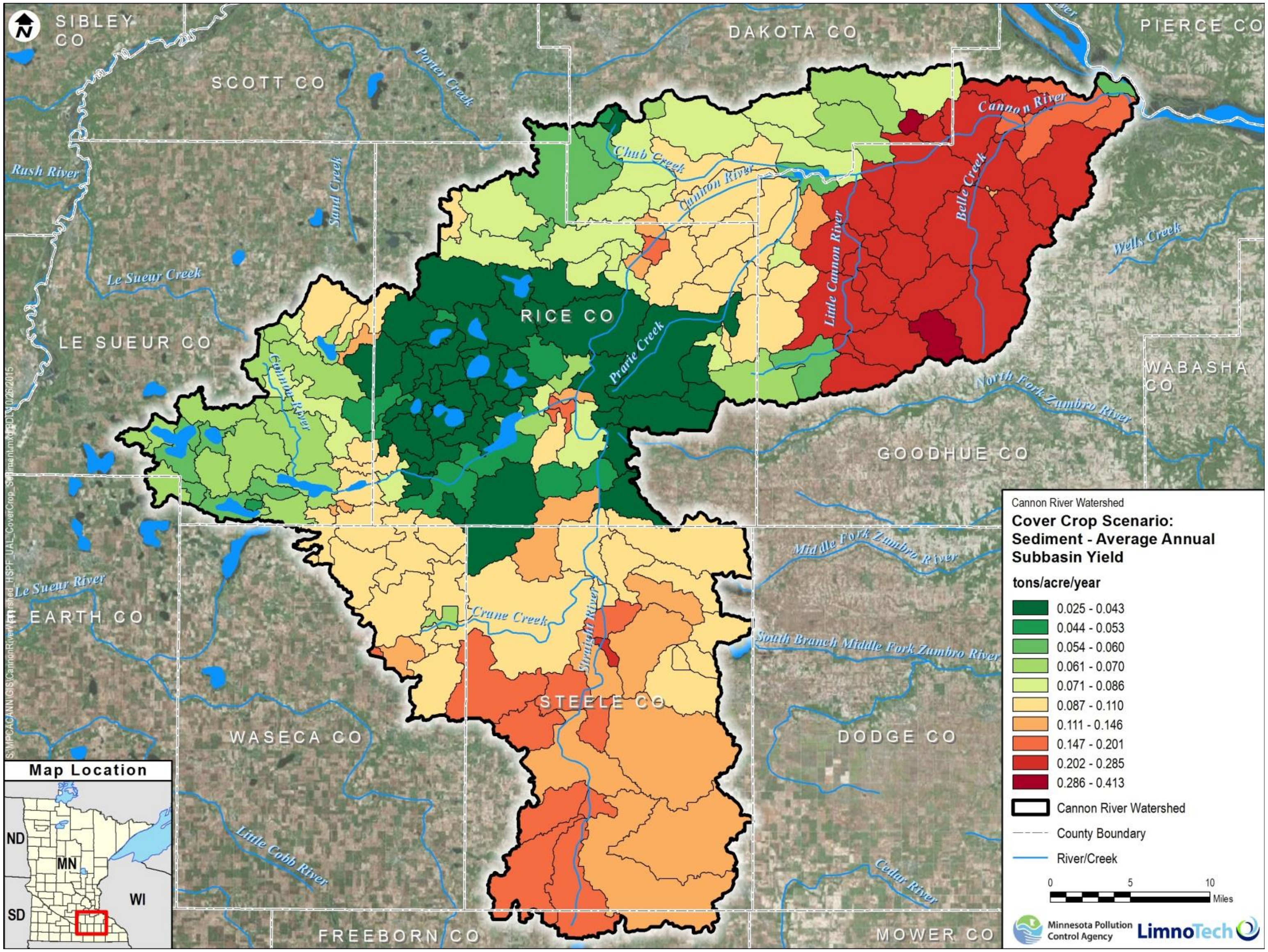

Figure A-4. Average annual sediment subbasin yield for the cover crop scenario (F).

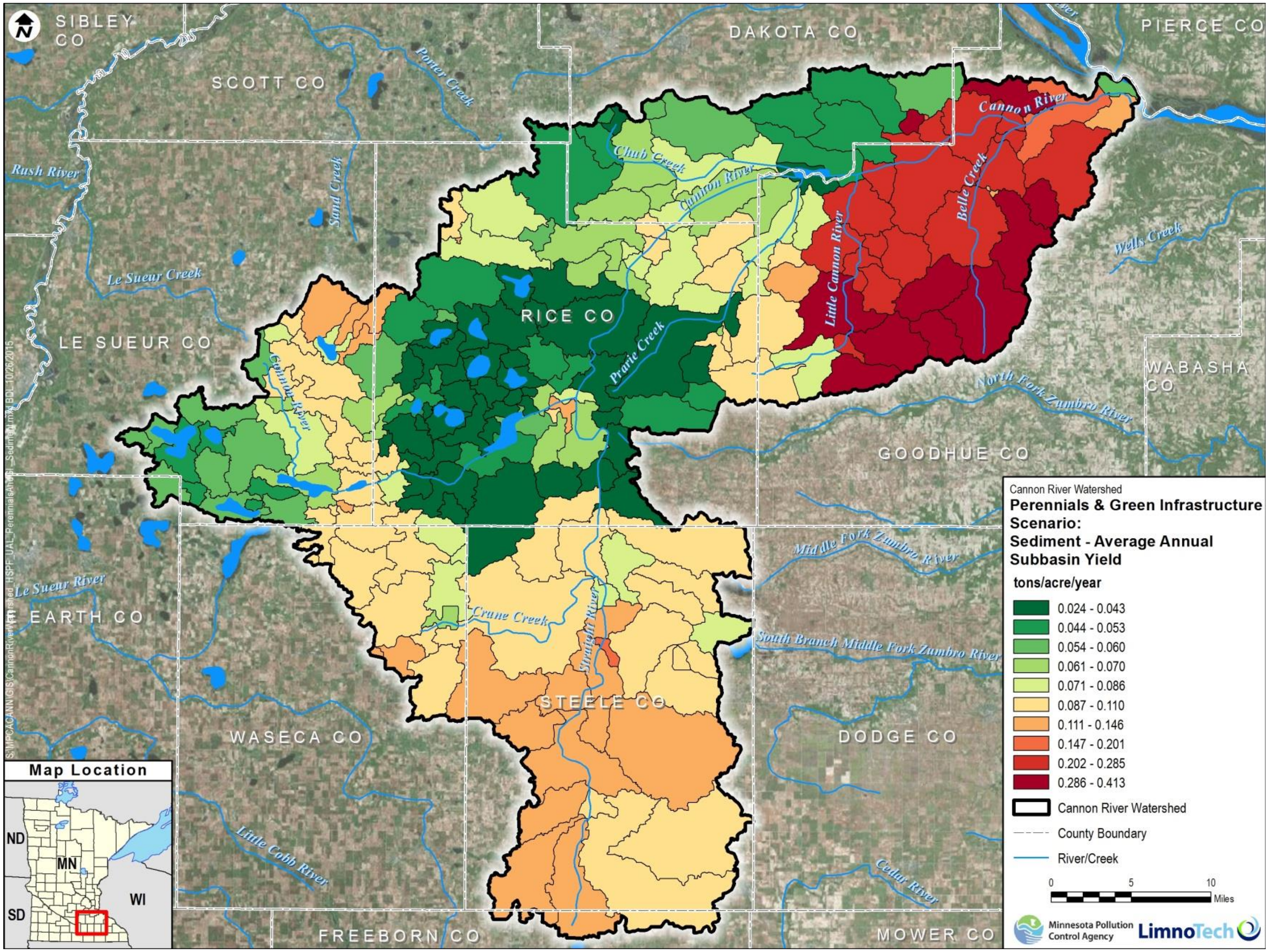

Figure A-5. Average annual sediment subbasin yield for the perennial vegetation and green infrastructure scenario (G).

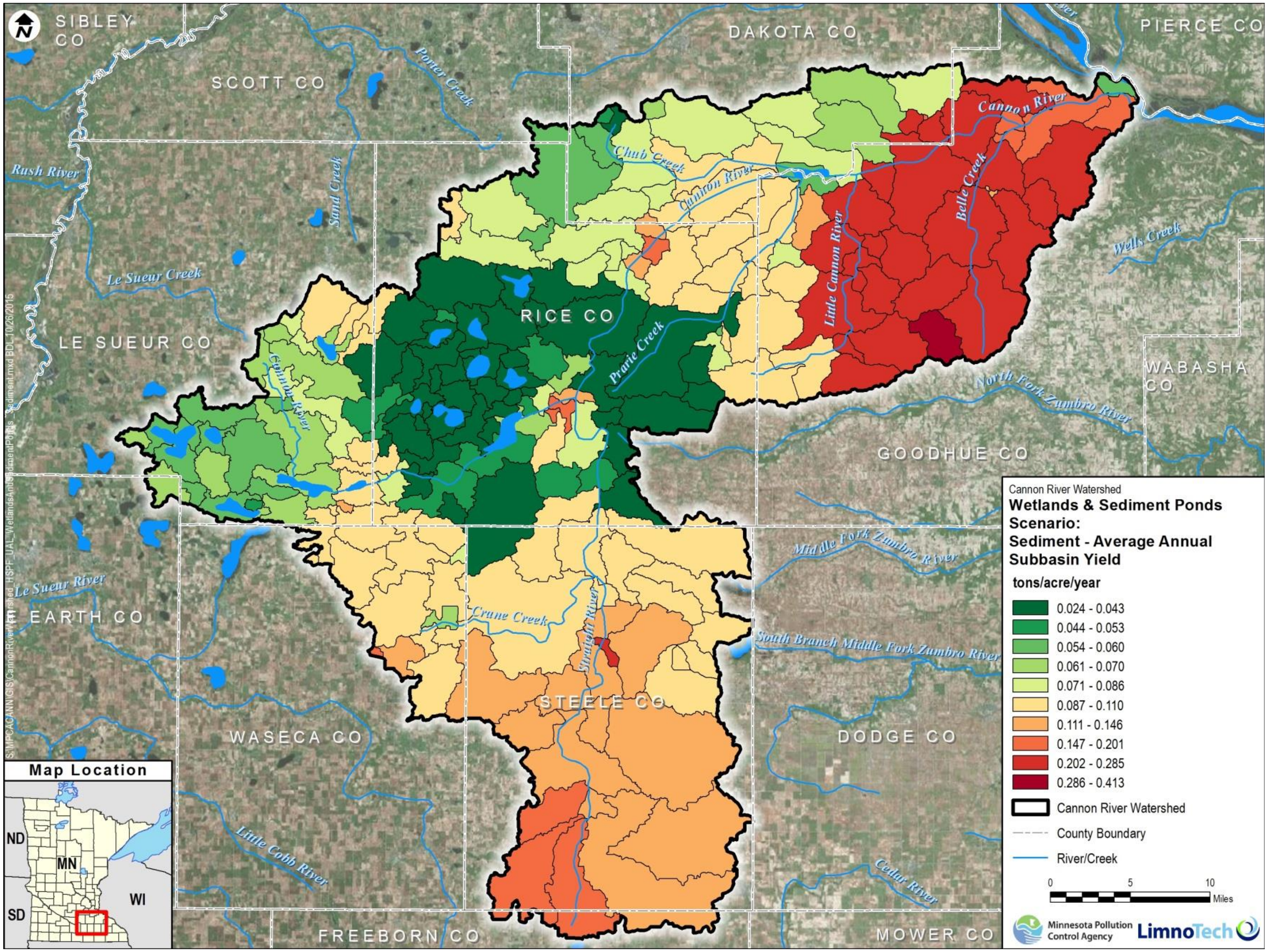

Figure A-6. Average annual sediment subbasin yield for the wetland restoration and sedimentation ponds scenario (H).

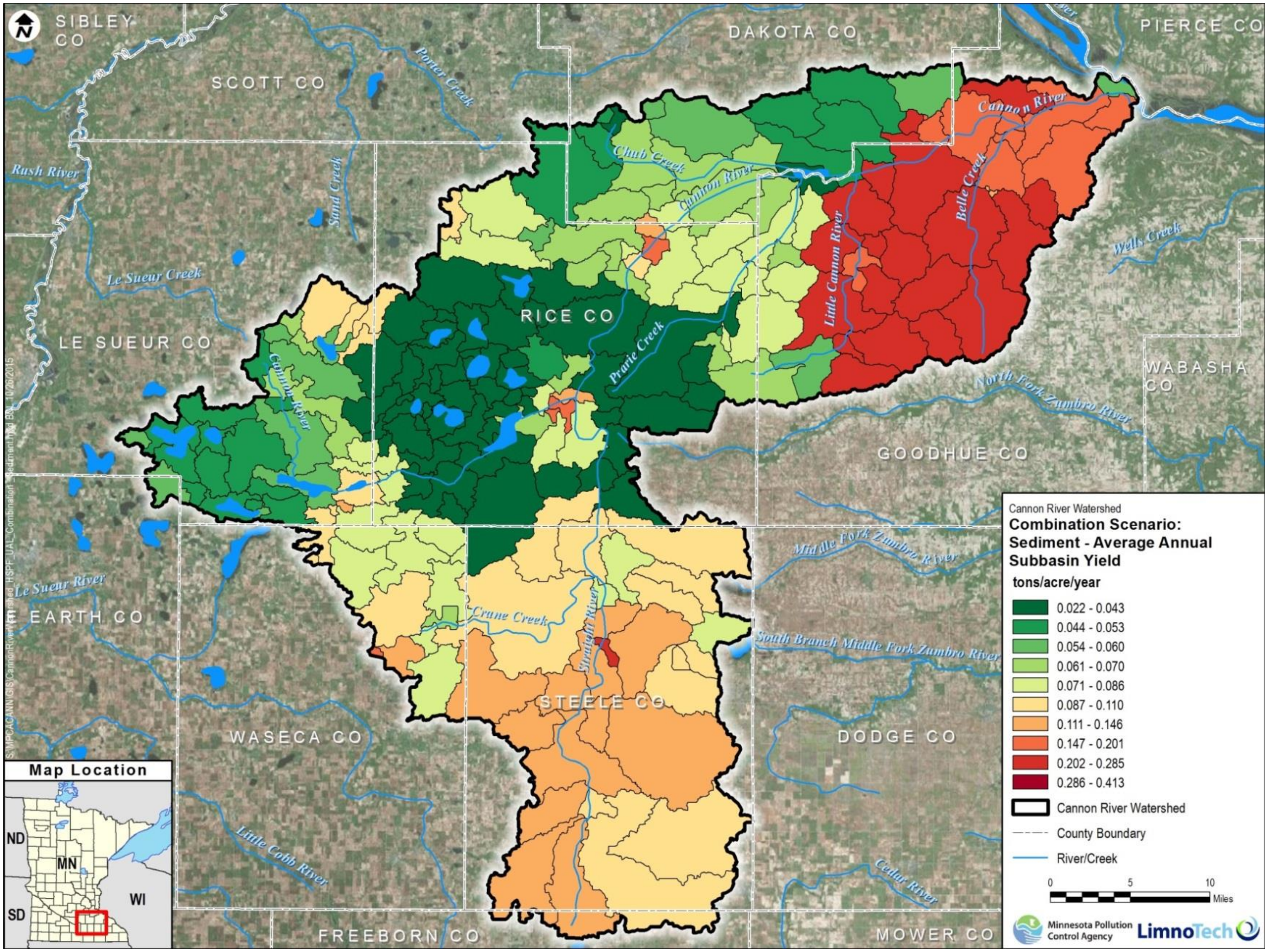

Figure A-7. Average annual sediment subbasin yield for the combination scenarios (I and J). Note that the maps only represent landscape yields and do not account for changes in point source discharges, which was the only difference between scenarios I and J.

Appendix B - Phosphorus

LANDSCAPE UNIT AREA LOADING MAPS

The annual average load generated per acre is mapped for each model subbasin. The maps only represent landscape yields and do not account for changes in point source discharge; therefore, maps are not available for the point source scenarios. The scales change between constituents. Please note that the shading of a subbasin is based on a relative scale to differentiate unit area loading rates. The color of the shading is not intended to indicate whether the load generated is bad or good in terms of water quality.

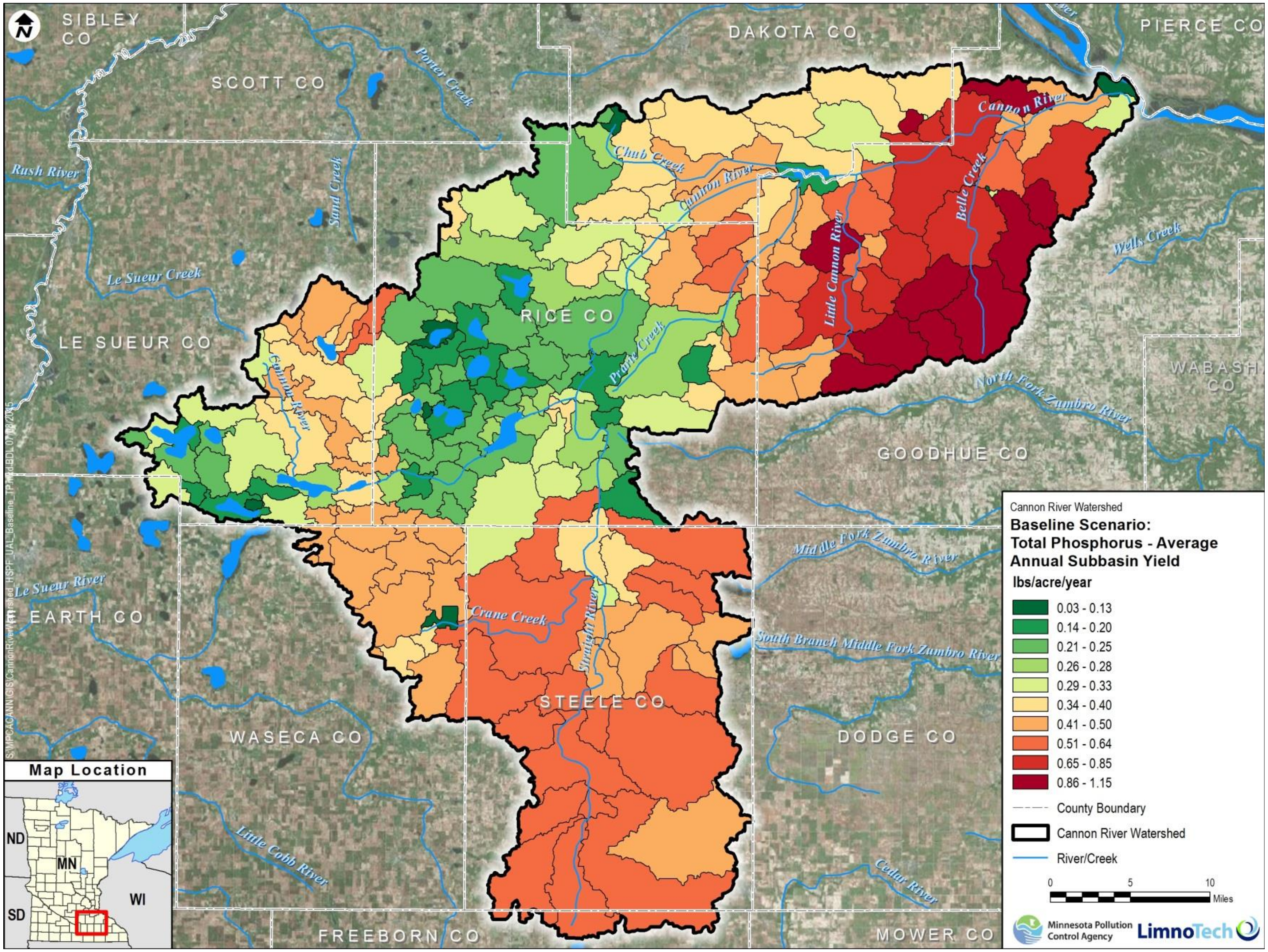

Figure B-1. Average annual total phosphorus subbasin yield for the baseline simulation. Note that landscape yields are the same for both the "historical" and "adjusted" baseline scenarios.

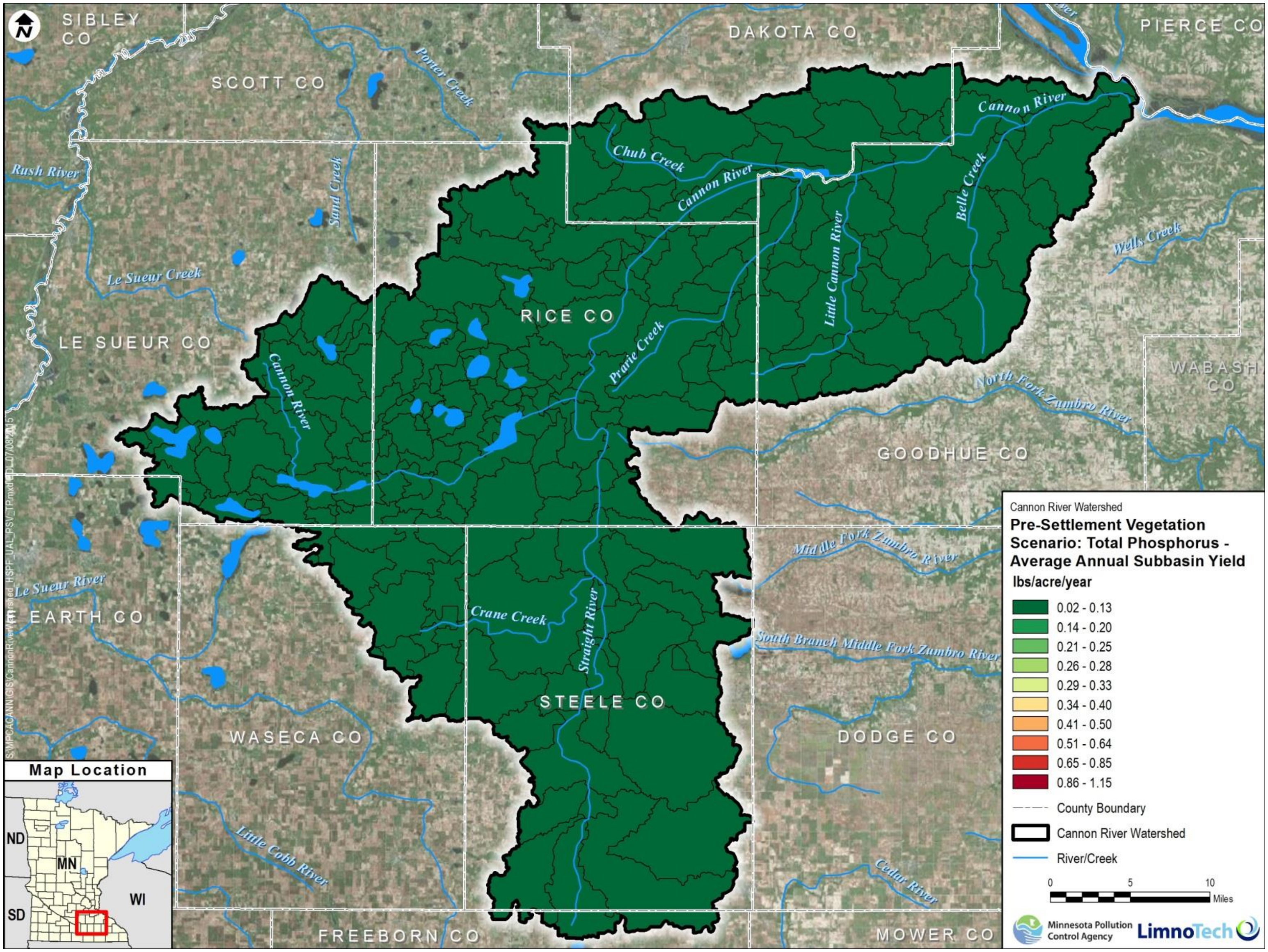

Figure B-2. Average annual total phosphorus subbasin yield for the pre-settlement vegetation scenario (D).

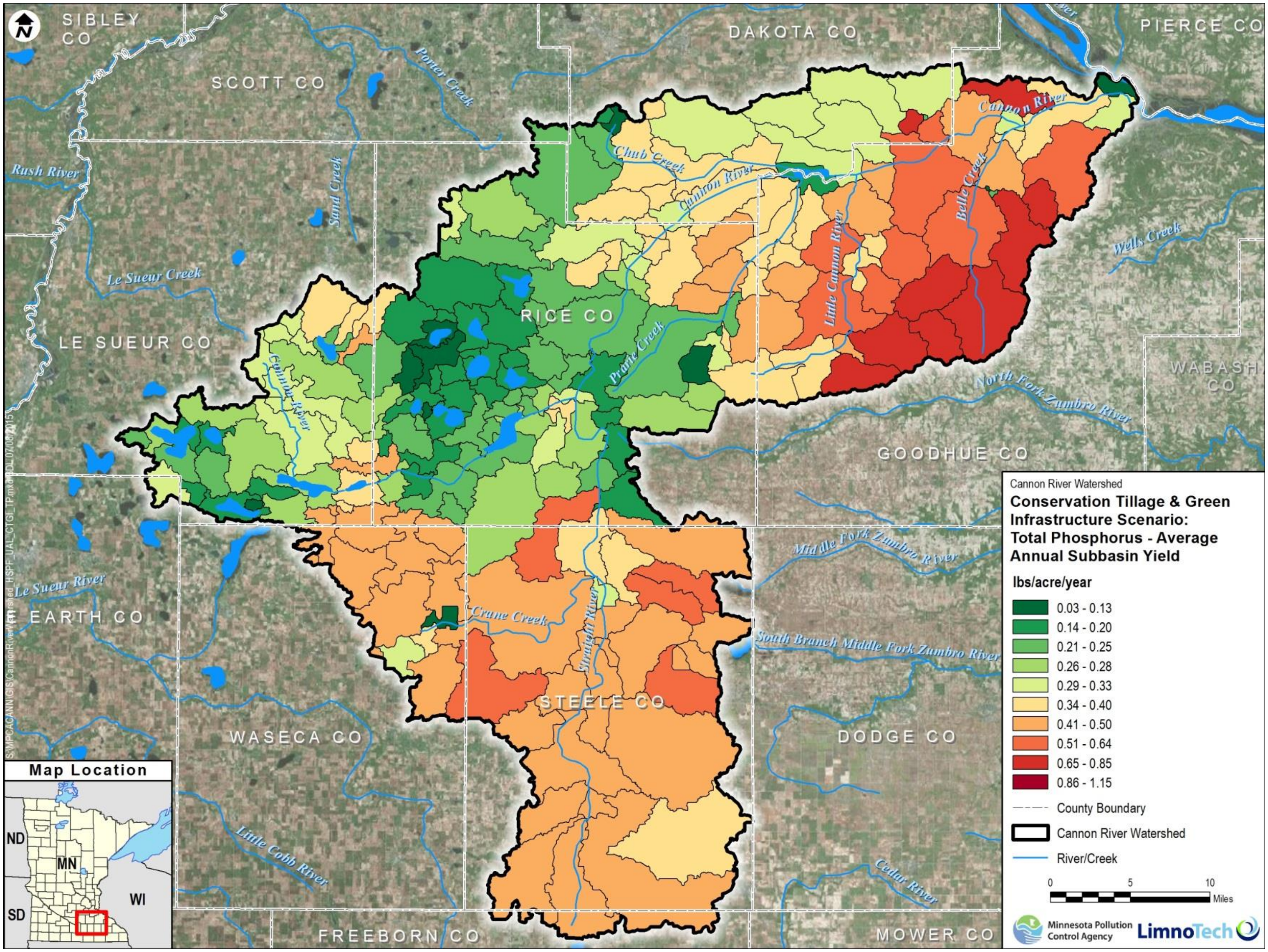

Figure B-3. Average annual total phosphorus subbasin yield for the conservation tillage and Waseca green infrastructure scenario (E).

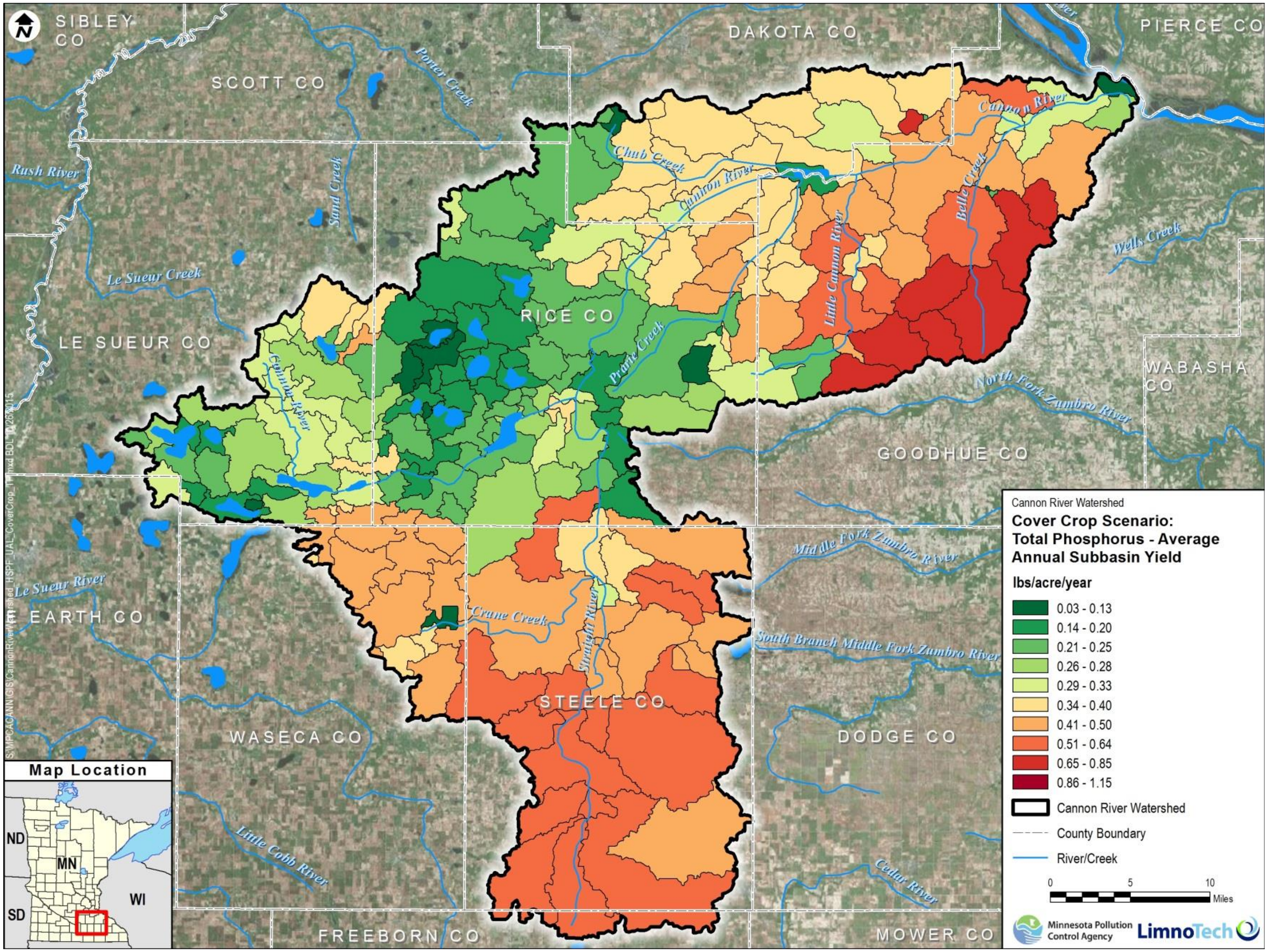

Figure B-4. Average annual total phosphorus subbasin yield for the cover crop scenario (F).

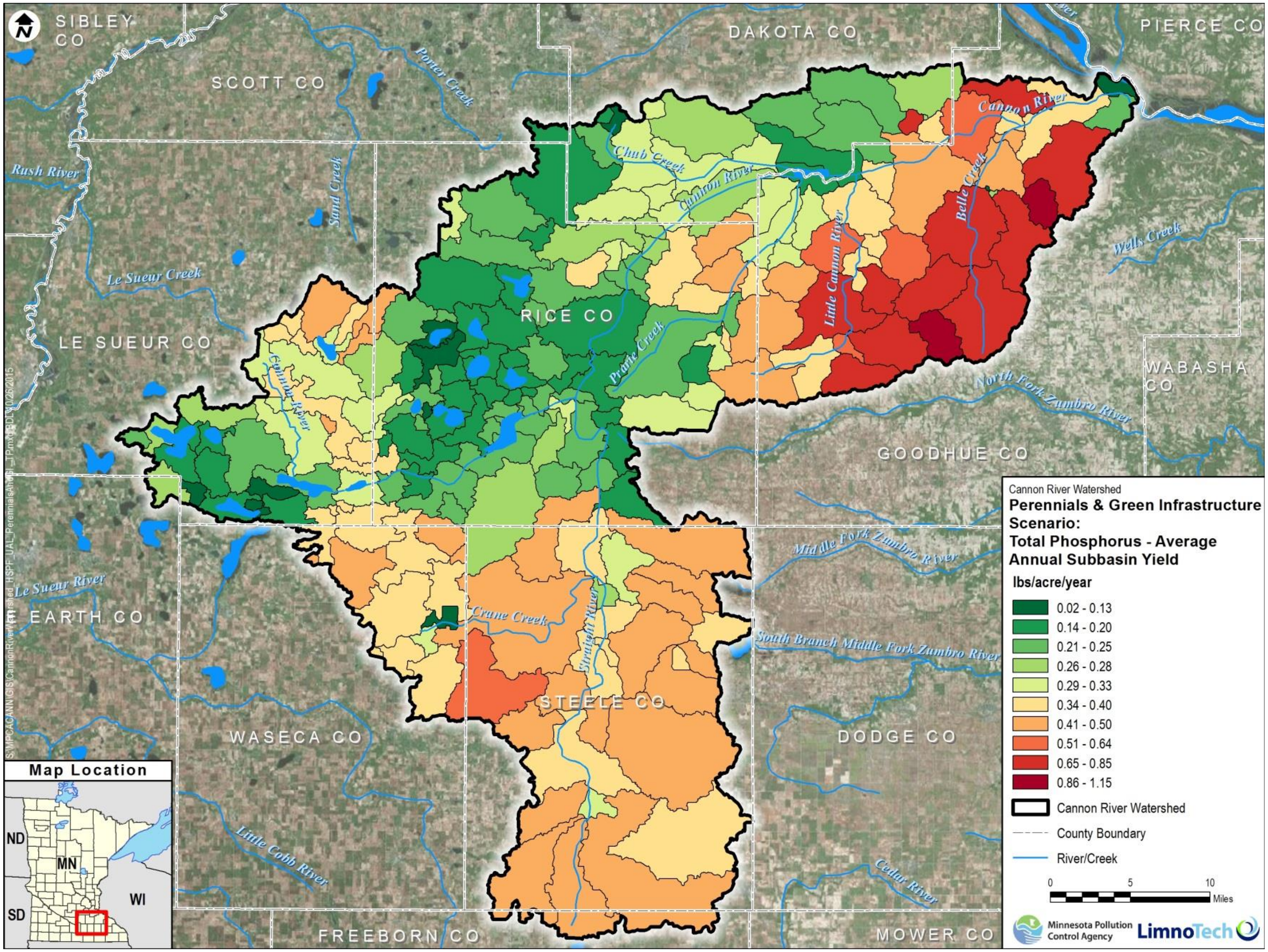

Figure B-5. Average annual total phosphorus subbasin yield for the perennial vegetation and green infrastructure scenario (G).

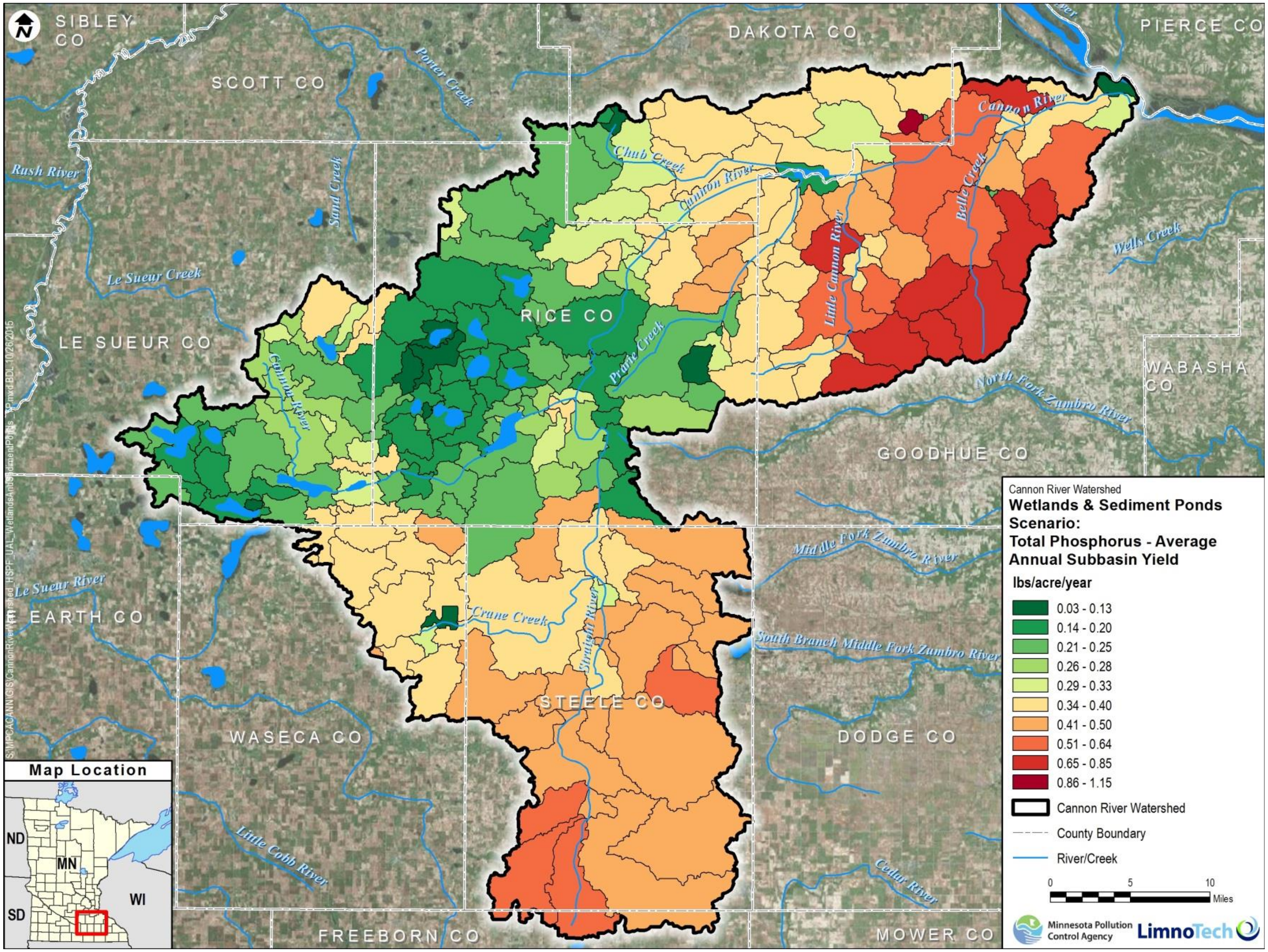

Figure B-6. Average annual total phosphorus subbasin yield for the wetland restoration and sedimentation ponds scenario (H).

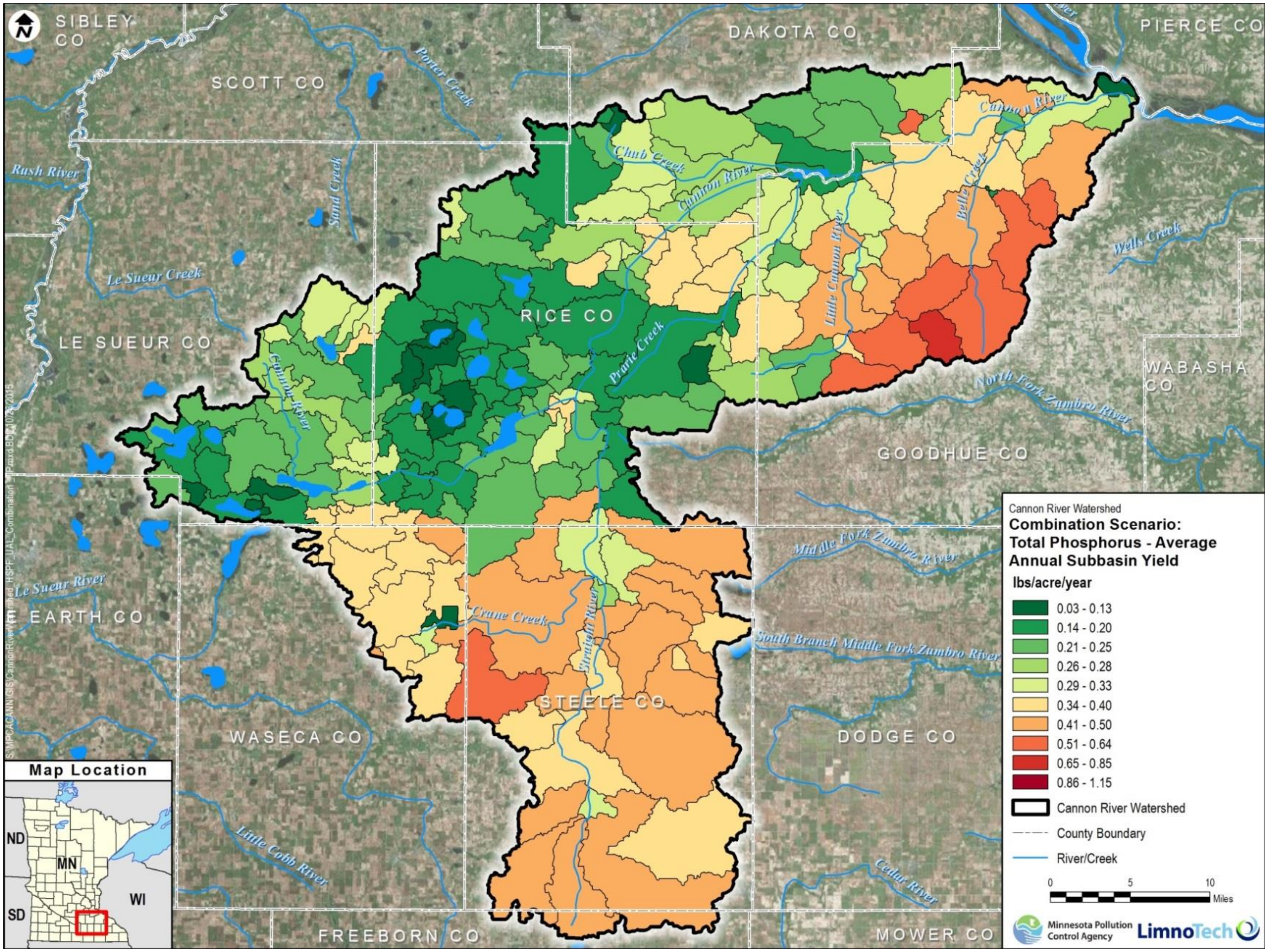

Figure B-7. Average annual total phosphorus subbasin yield for the combination scenarios (I and J). Note that the maps only represent landscape yields and do not account for changes in point source discharges, which was the only difference between scenarios I and J.

Appendix C - Phosphorus

TOTAL PHOSPHORUS LOAD DURATION CURVES

A TP load duration curve for the Cannon River at the Lake Byllesby inlet was constructed for each scenario. Using model predicted results for the 1996-2012 period (June-September only), flow duration intervals were computed from daily flow rates and plotted on the x-axis and the corresponding daily TP loads were plotted on the y-axis. The TP loads corresponding to the proposed RES of 0.15 mg-P/L were computed for each flow duration interval and plotted as a reference line.

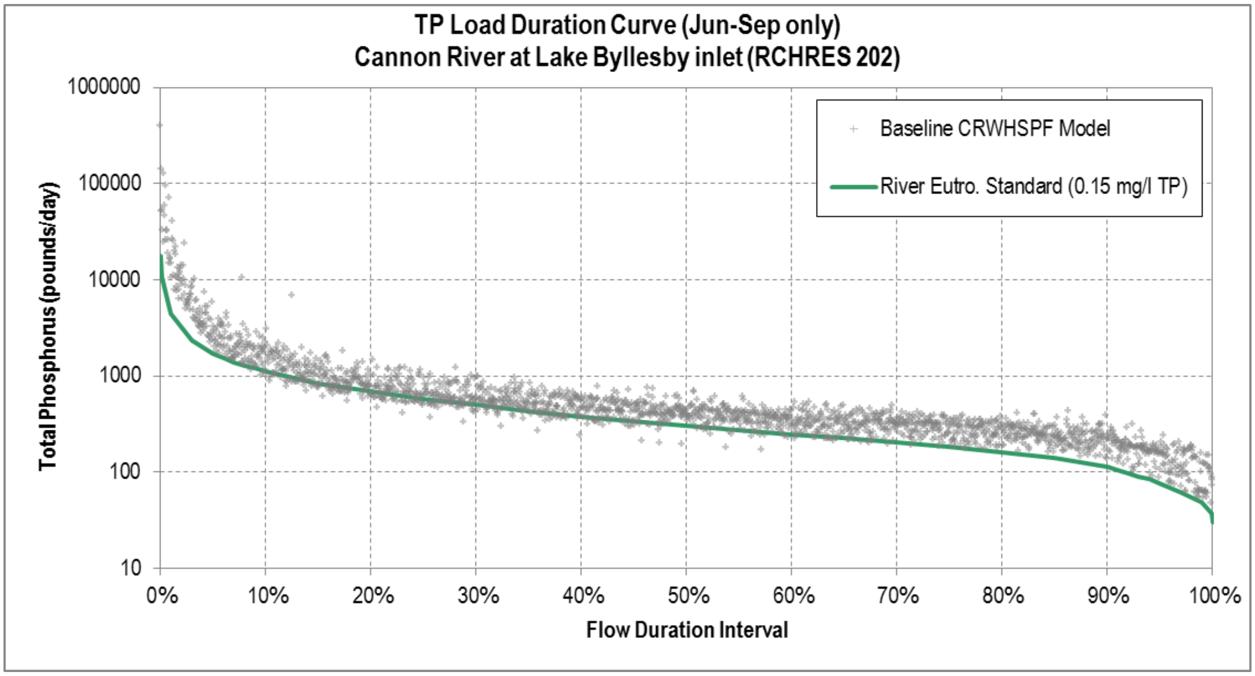

Figure C-1. TP load duration curve for the historical baseline simulation.

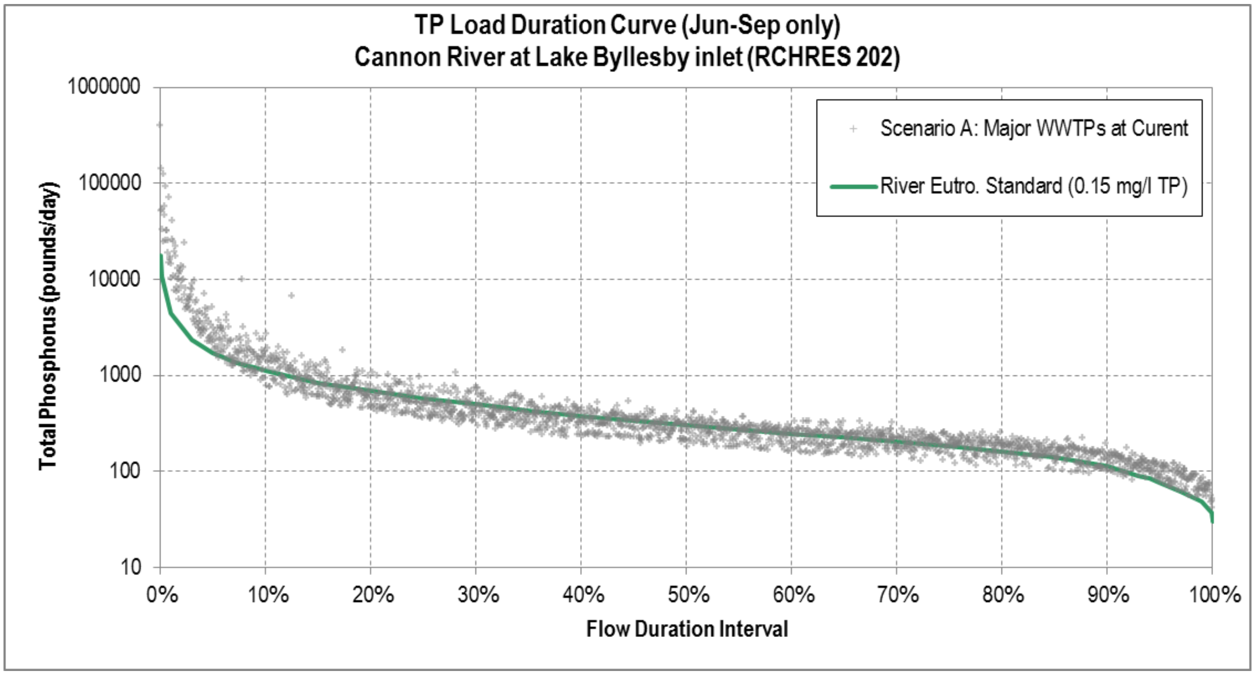

Figure C-2. TP load duration curve for adjusted baseline simulation (A).

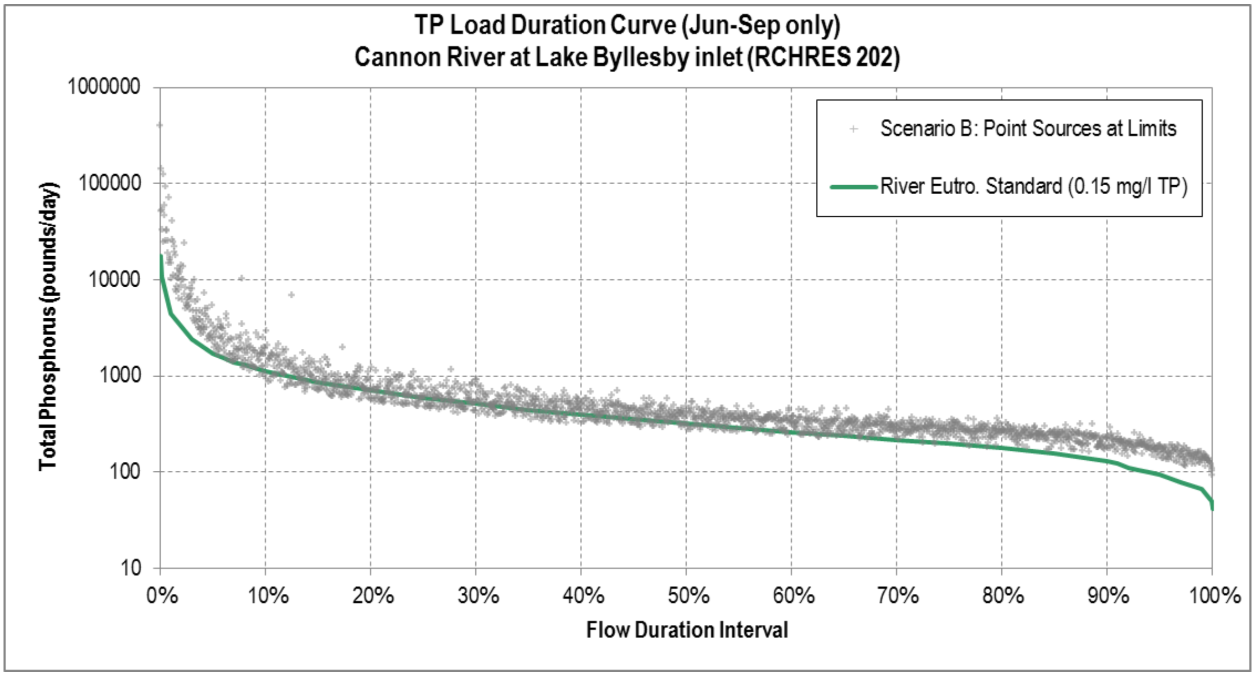

Figure C-3. TP load duration curve for the point sources at permitted limits scenario (B).

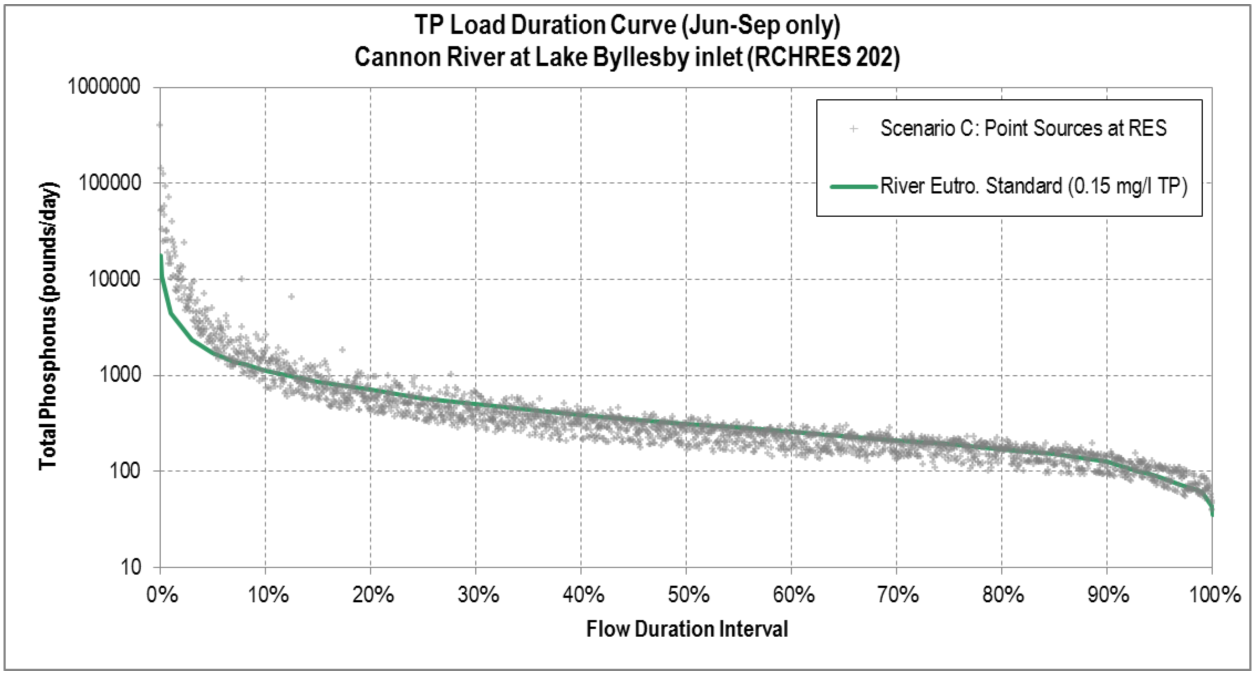

Figure C-4. TP load duration curve for the point sources at RES scenario (C).

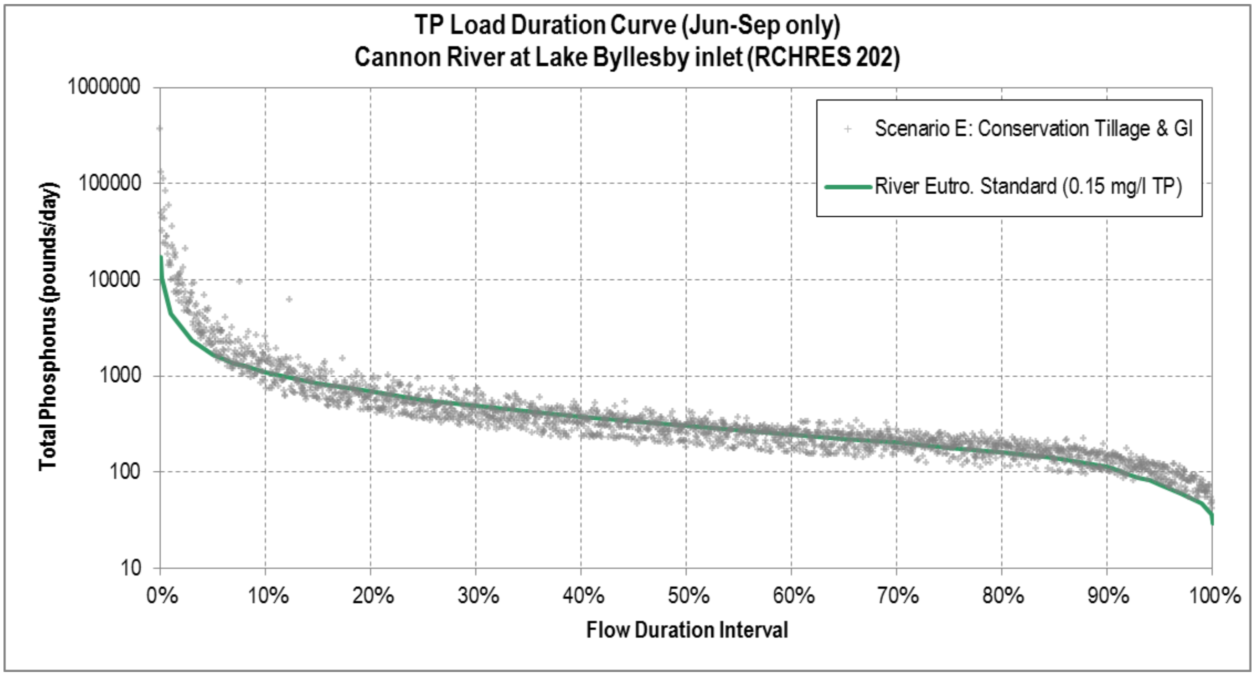

Figure C-5. TP load duration curve for the conservation tillage and Waseca green infrastructure scenario (E).

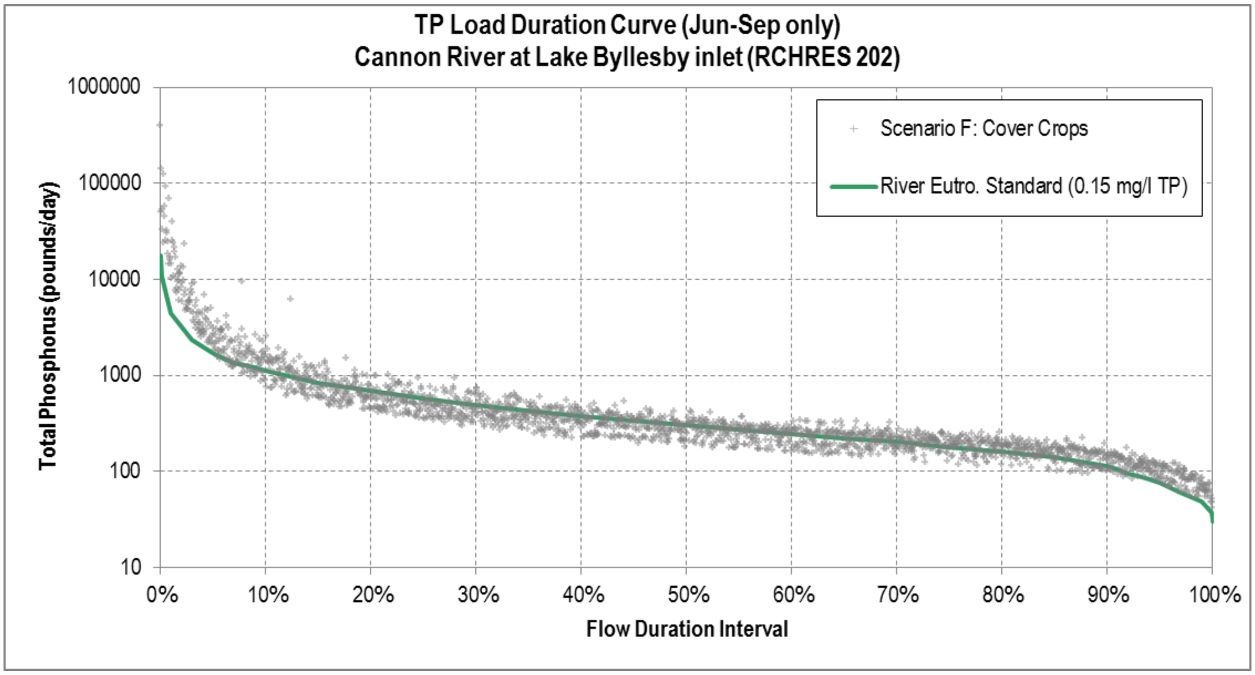

Figure C-6. TP load duration curve for the cover crop scenario (F).

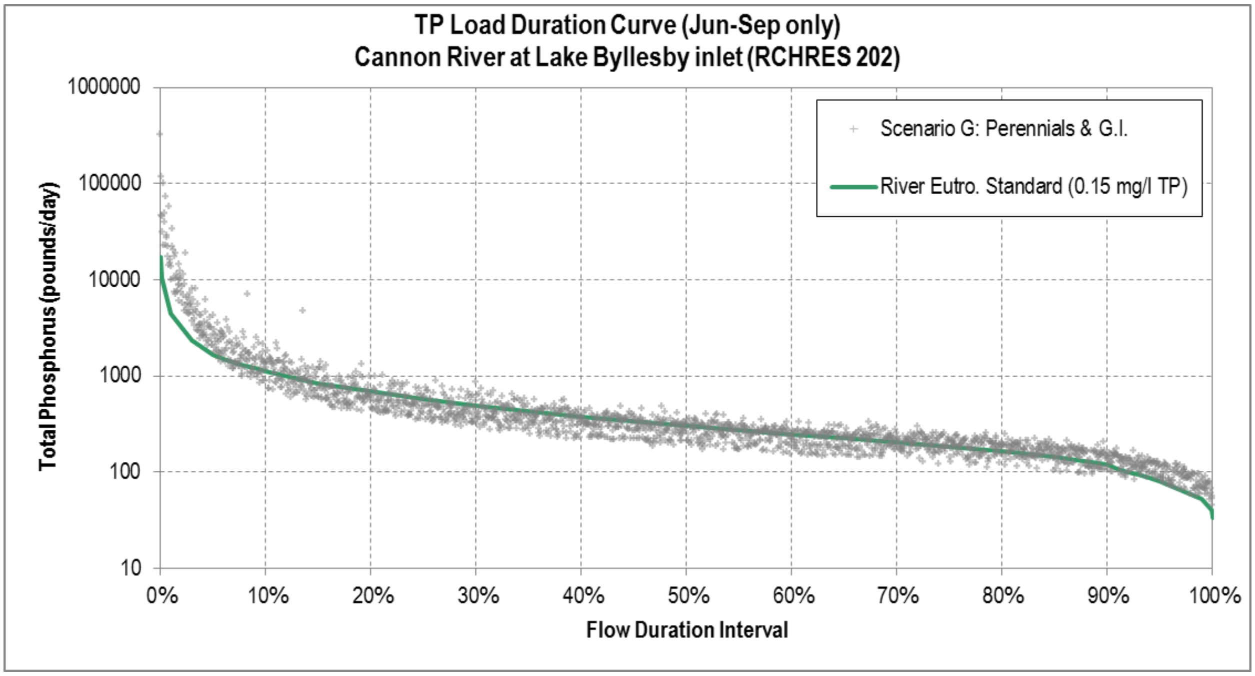

Figure C-7. TP load duration curve for the perennial vegetation and green infrastructure scenario (G).

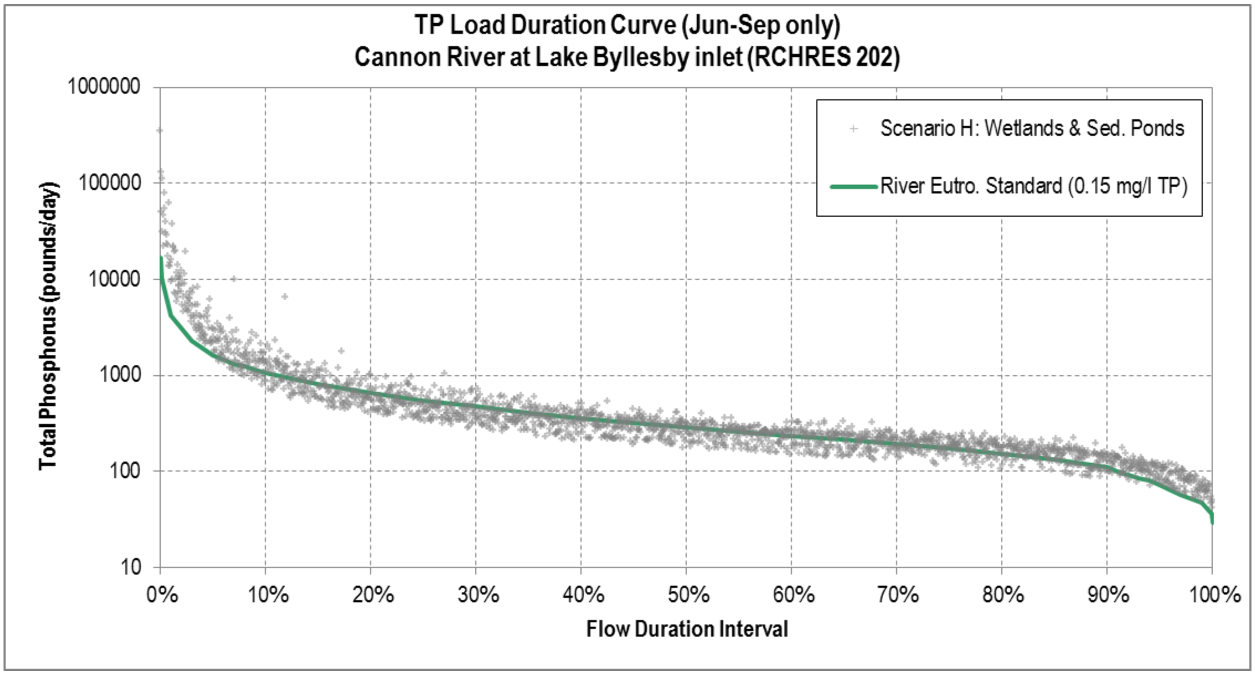

Figure C-8. TP load duration curve for the wetland restoration and sedimentation ponds scenario (H).

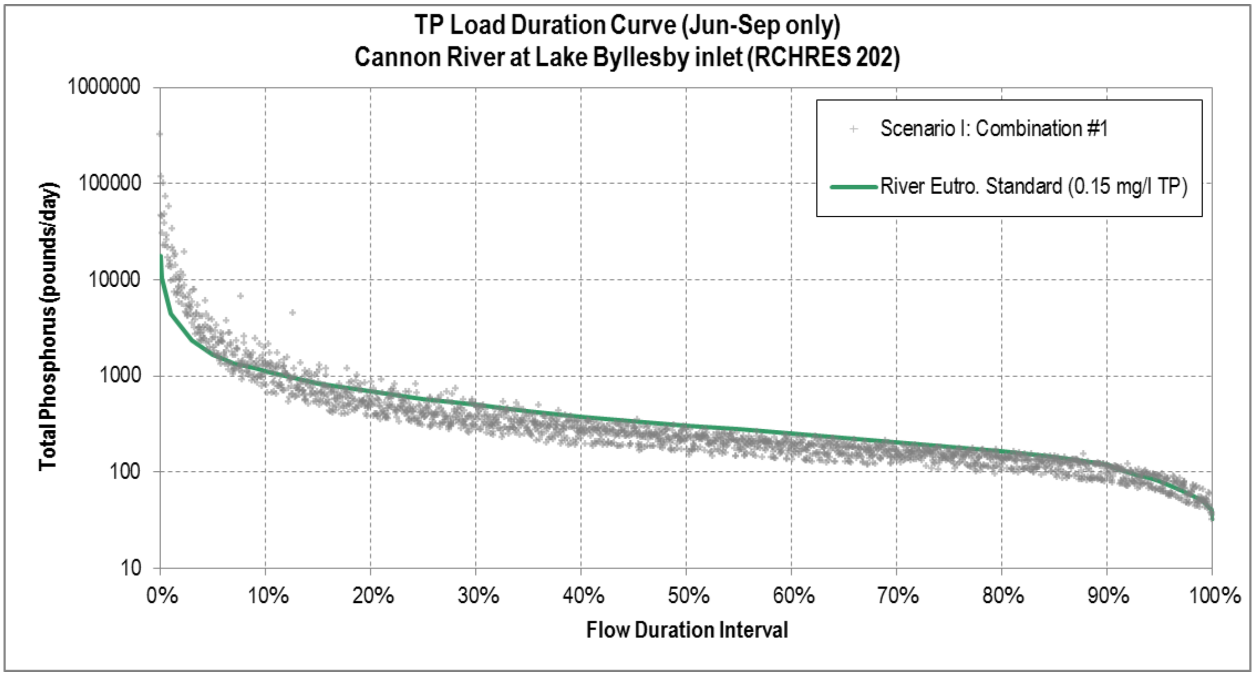

Figure C-9. TP load duration curve for the first combination management scenario (I).

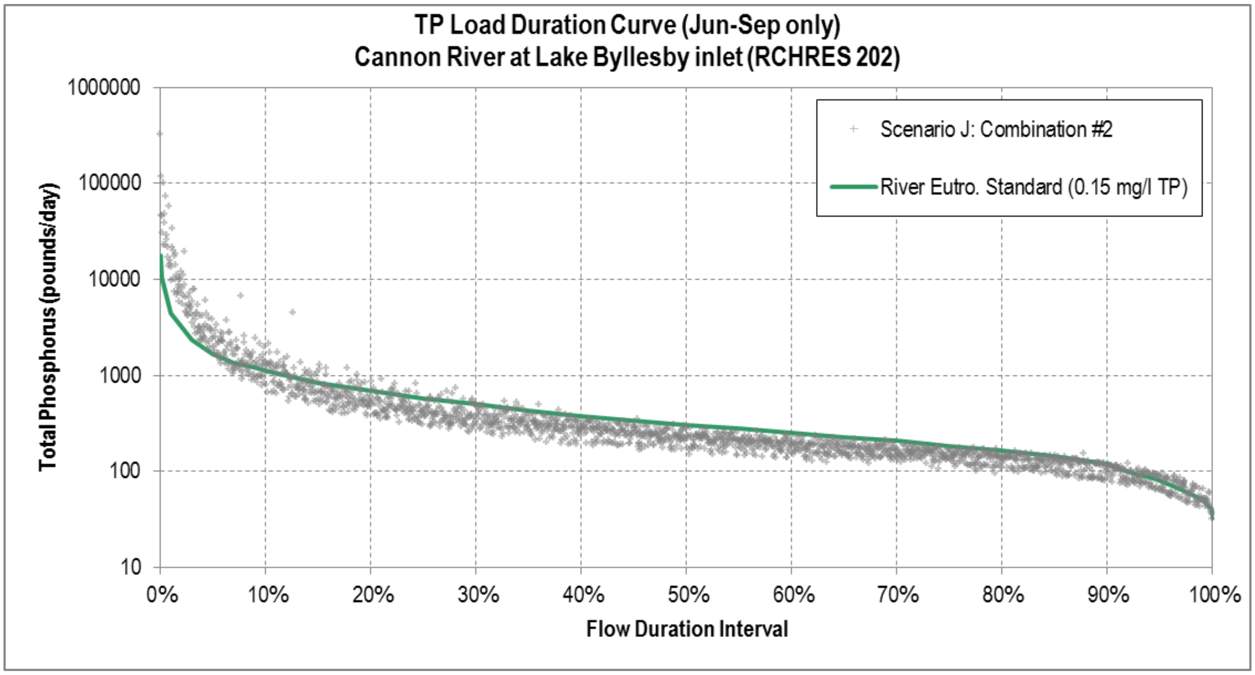

Figure C-10. TP load duration curve for the second combination management scenario (J).

Appendix D - Nitrogen

LANDSCAPE UNIT AREA LOADING MAPS

The annual average load generated per acre is mapped for each model subbasin. The maps only represent landscape yields and do not account for changes in point source discharge; therefore, maps are not available for the point source scenarios. Please note that the shading of a subbasin is based on a relative scale to differentiate unit area loading rates. The color of the shading is not intended to indicate whether the load generated is bad or good in terms of water quality.

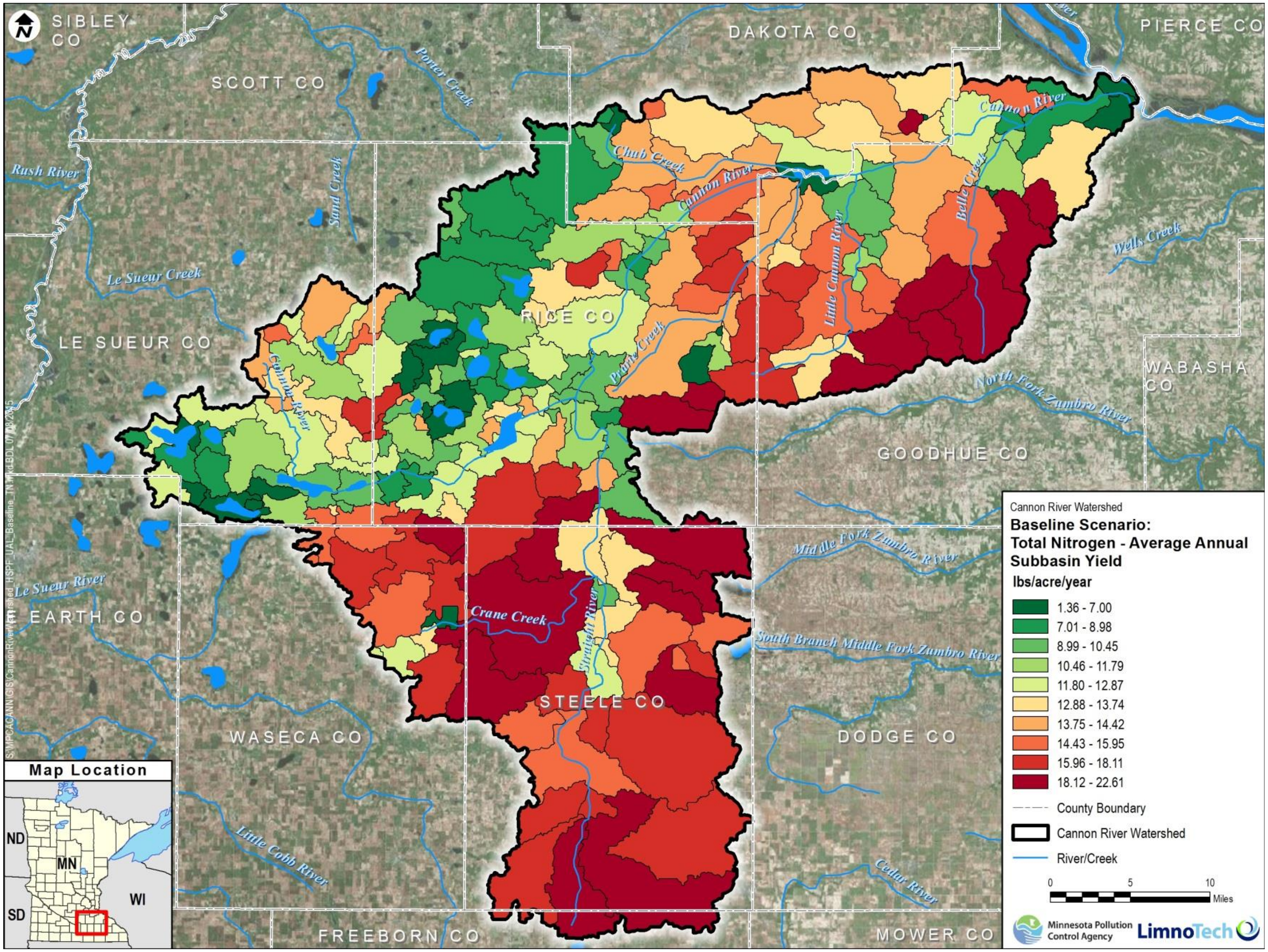

Figure D-1. Average annual total nitrogen subbasin yield for the baseline simulation. Note that landscape yields are the same for both the "historical" and "adjusted" baseline scenarios.

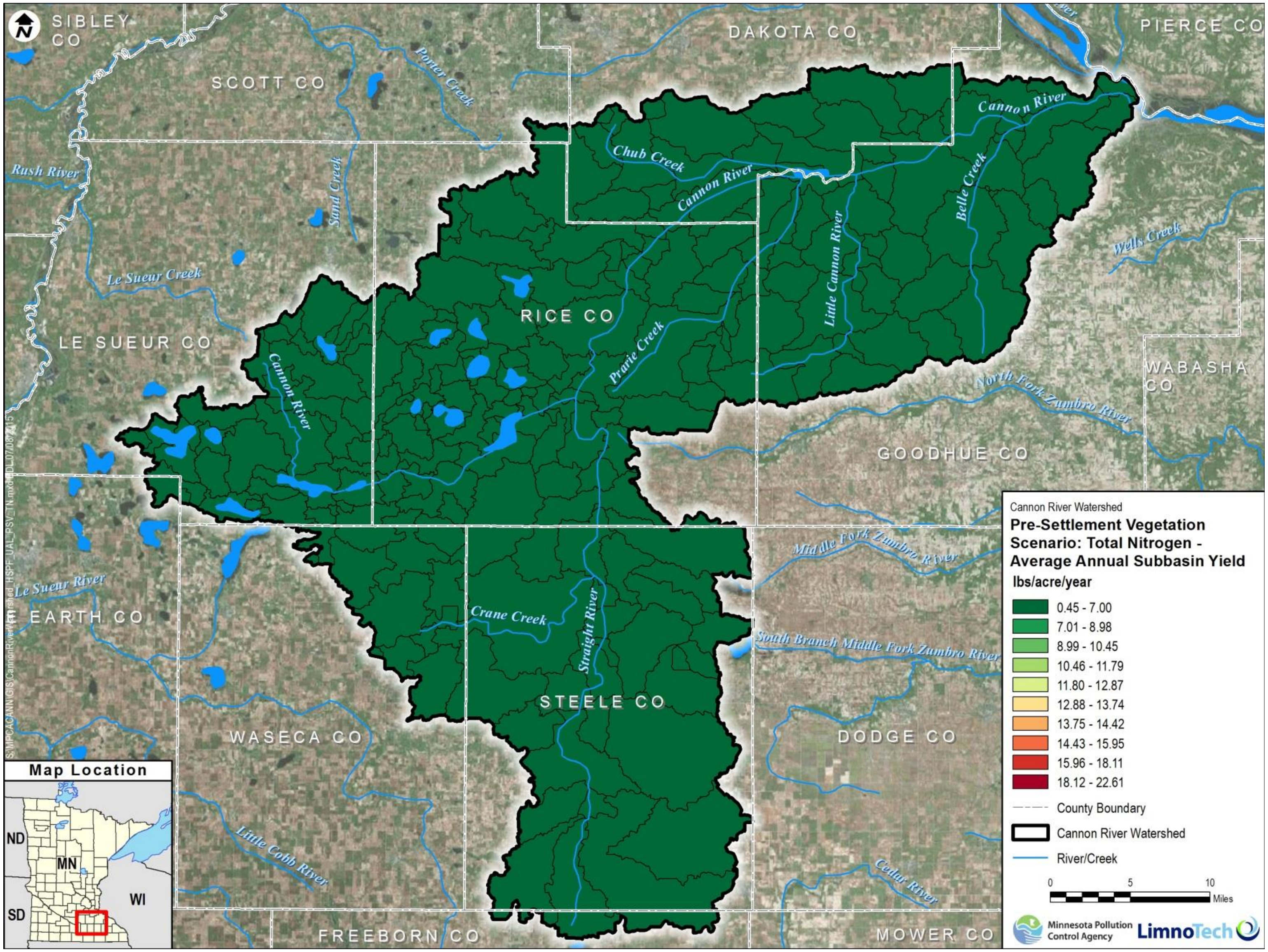

Figure D-2. Average annual total nitrogen subbasin yield for the pre-settlement vegetation scenario (D).

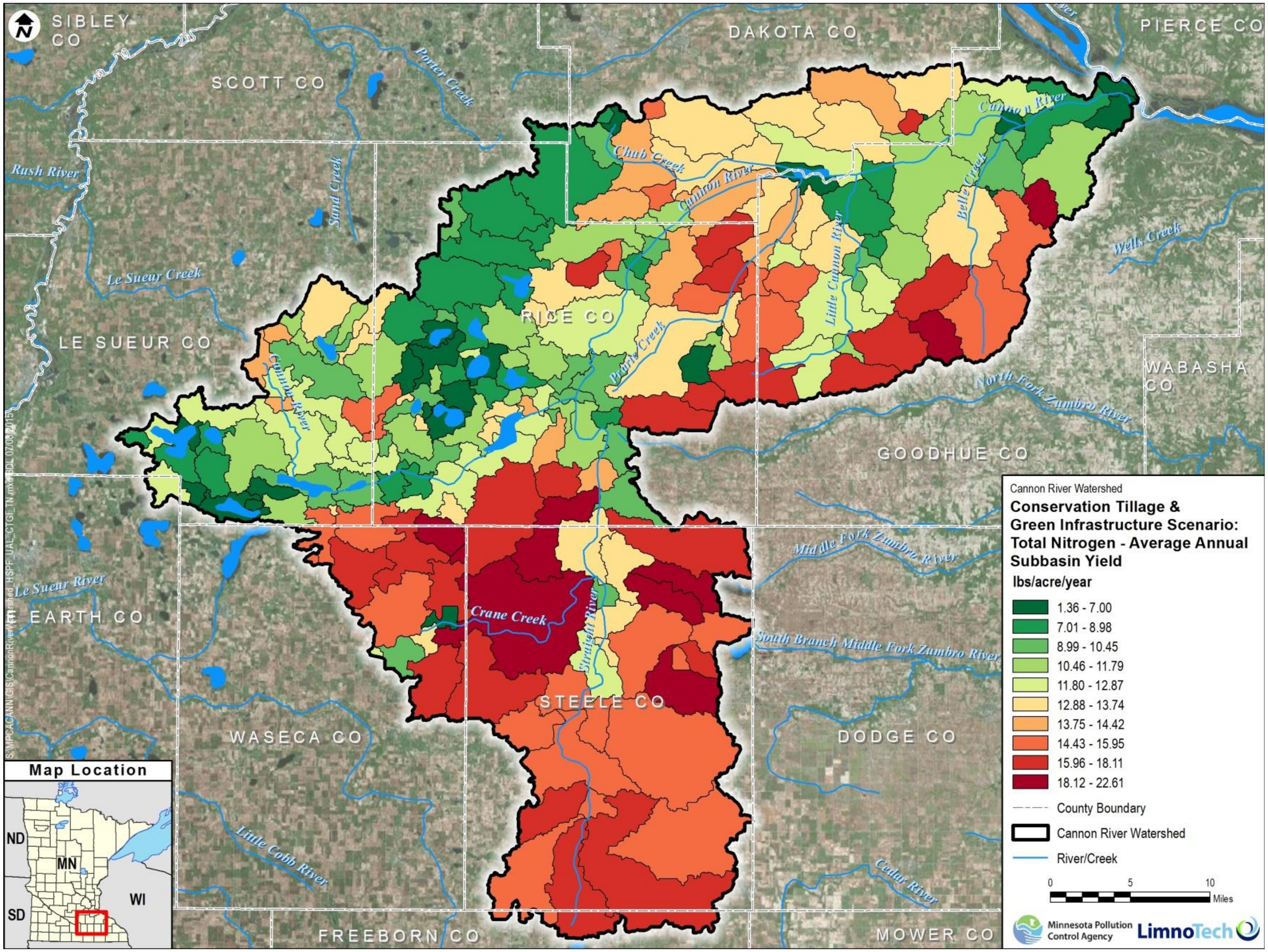

Figure D-3. Average annual total nitrogen subbasin yield for the conservation tillage and Waseca green infrastructure scenario (E).

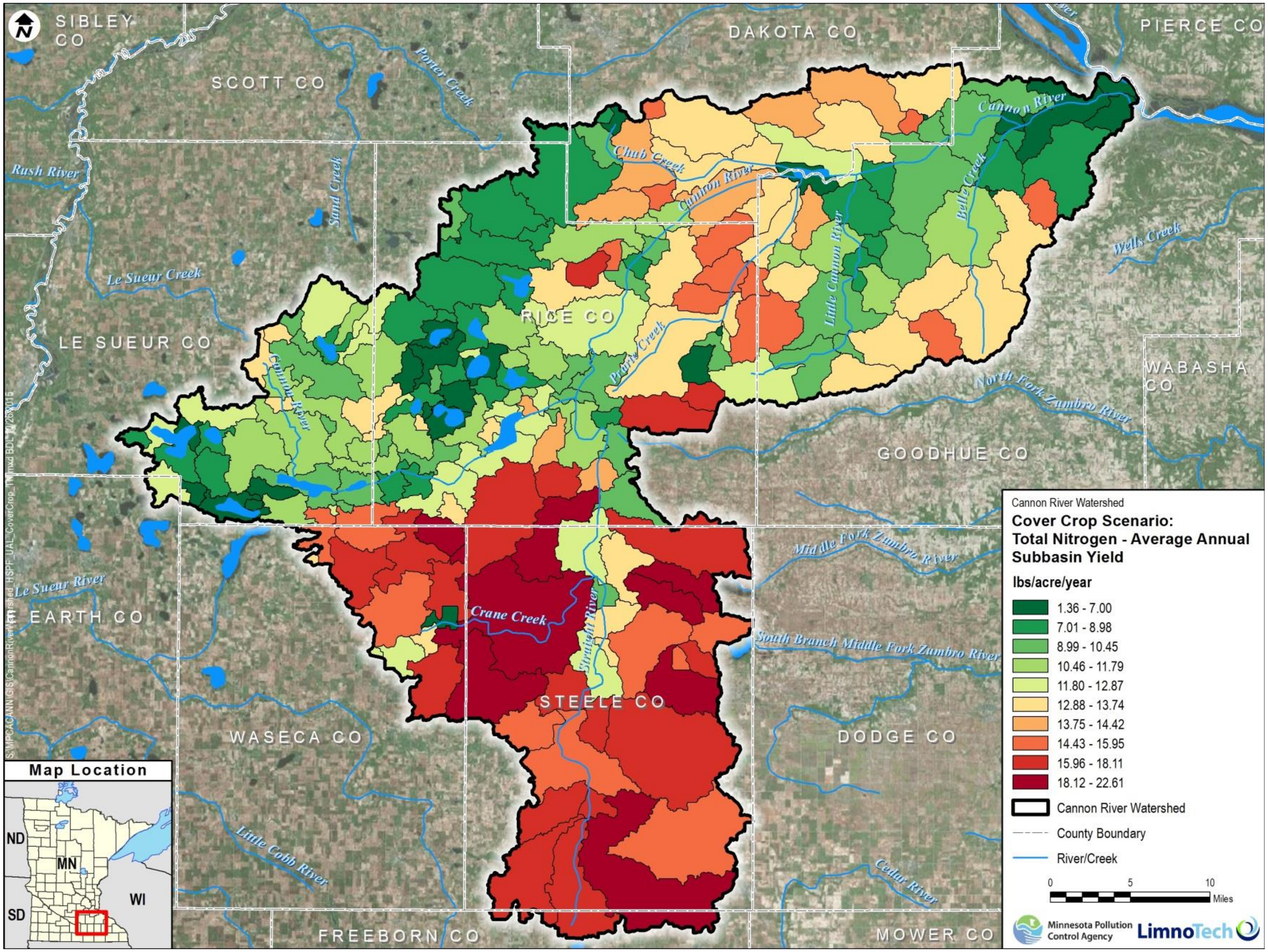

Figure D-4. Average annual total nitrogen subbasin yield for the cover crop scenario (F).

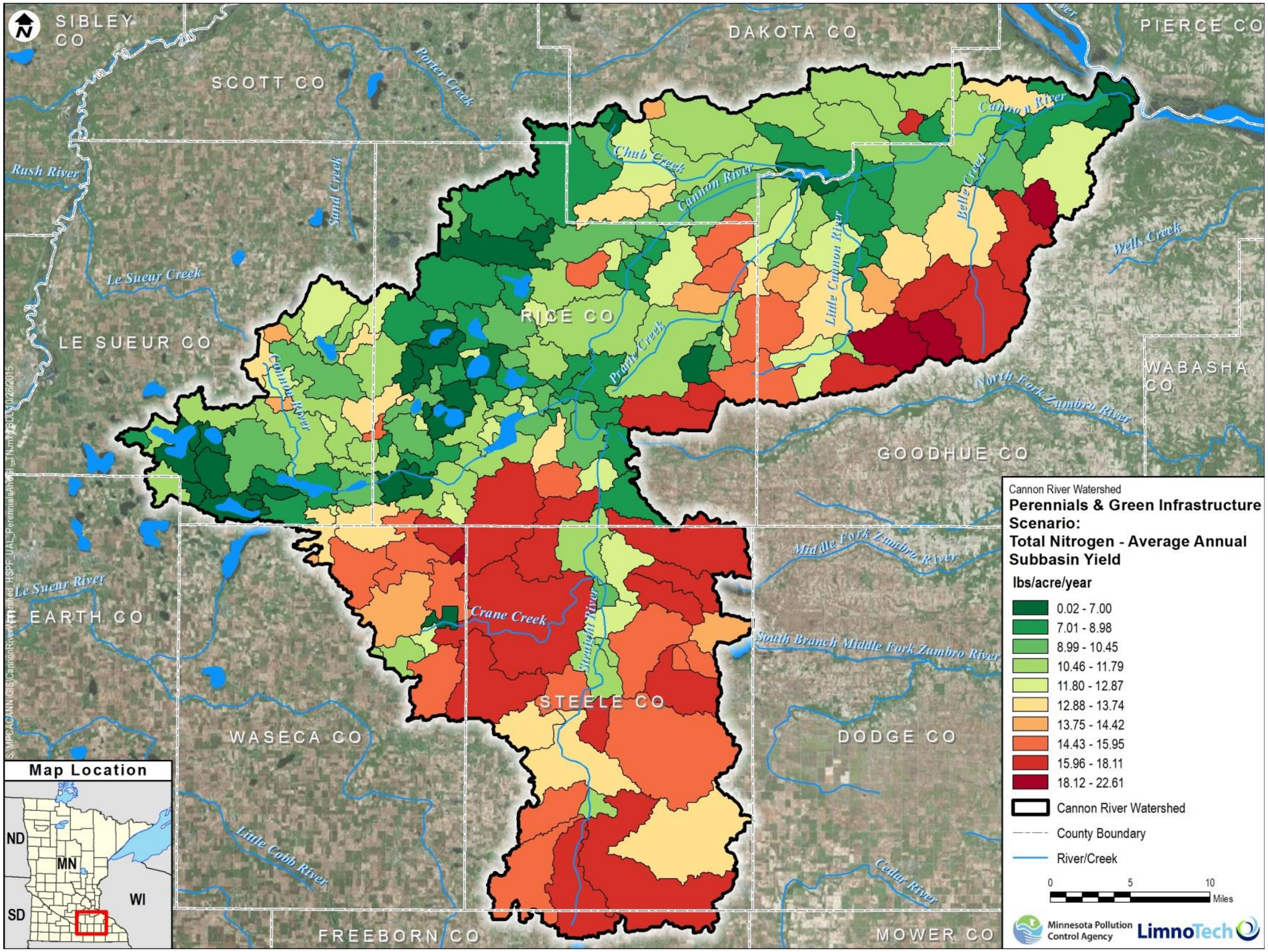

Figure D-5. Average annual total nitrogen subbasin yield for the perennial vegetation and green infrastructure scenario (G).

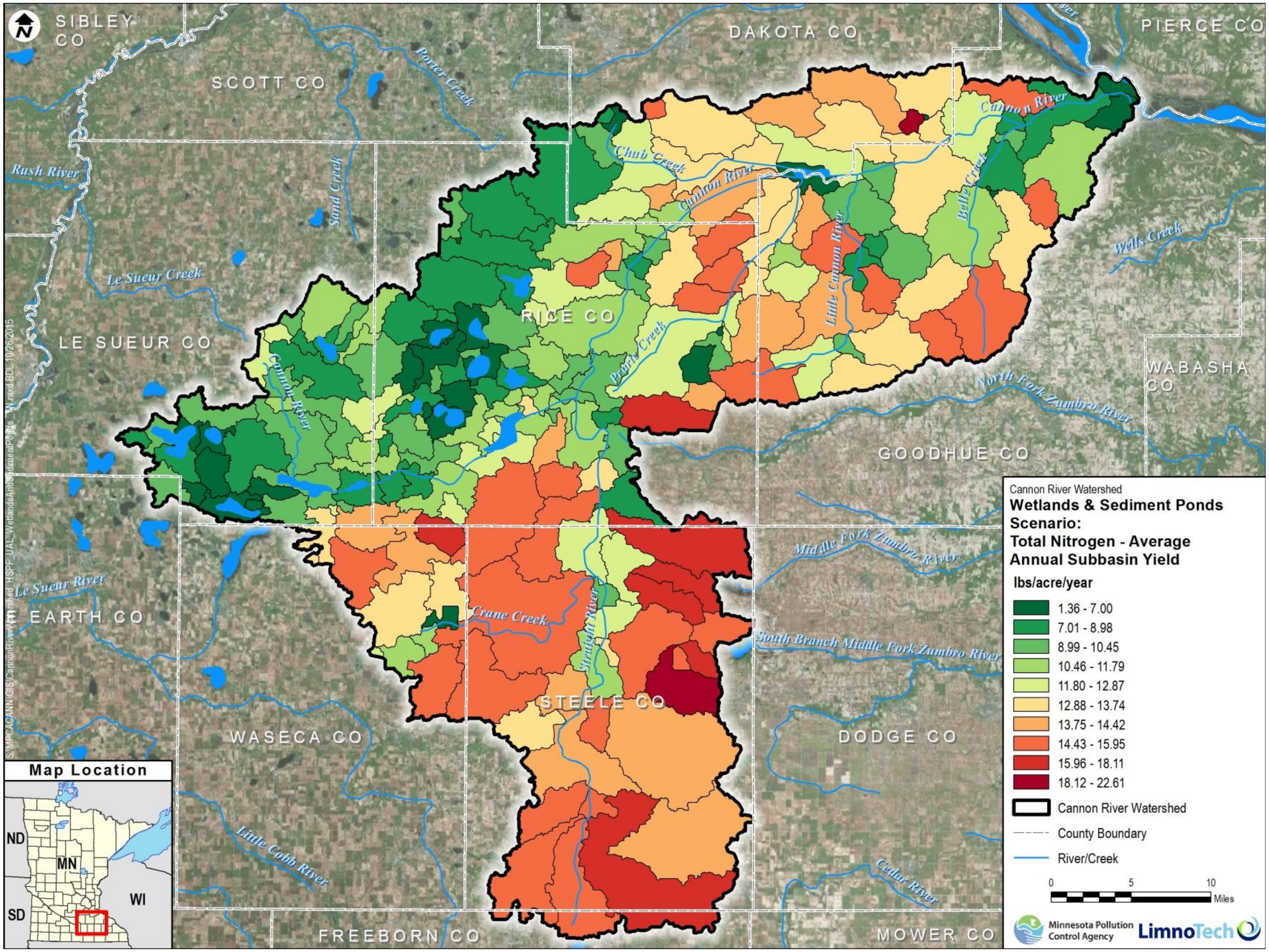

Figure D-6. Average annual total nitrogen subbasin yield for the wetland restoration and sedimentation ponds scenario (H).

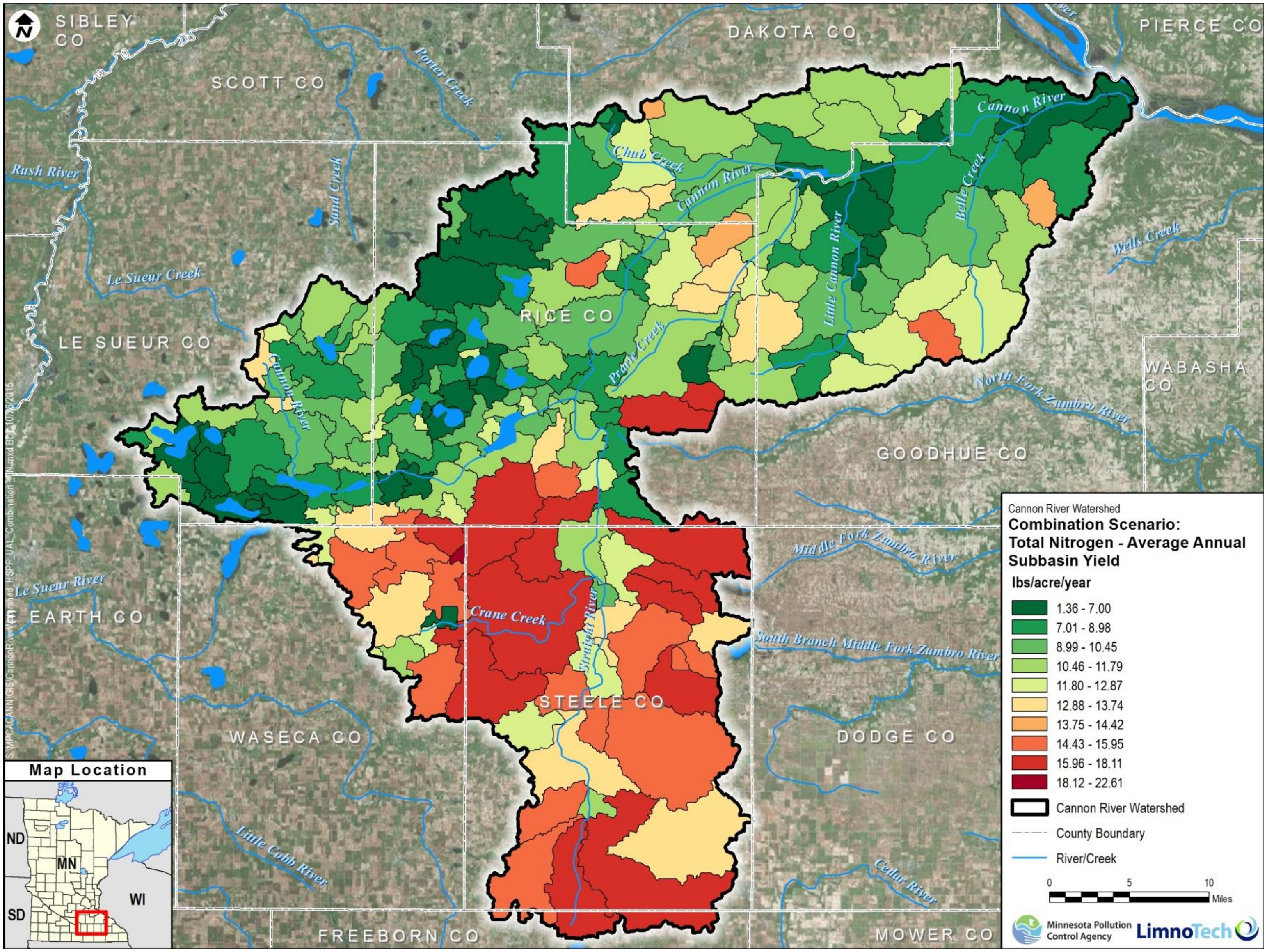

Figure D-7. Average annual total nitrogen subbasin yield for the combination scenarios (I and J). Note that the maps only represent landscape yields and do not account for changes in point source discharges, which was the only difference between scenarios I and J.