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# Memorandum

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**To:** Justin Watkins (MPCA)
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**CC:**

**Project: Zumbro River Watershed HSPF Model Development Project – Phase II**

**Subject:** Task 3: Technical Memorandum to Document Tasks 1 and 2 - Refinement of the ZRWHSPF Watershed Model and Application to Management Scenarios

## Statement of Purpose

This memorandum has been prepared for the Minnesota Pollution Control Agency (MPCA) to document Phase II of the "Zumbro River Watershed HSPF Model Development Project" and serves as one of two deliverables, as outlined in Task 3 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 and Task 2. The model package will be delivered electronically to MPCA in conjunction with this memorandum.

The tasks outlined for this phase work include the following:

- Task 1: Refine the Zumbro River Watershed Hydrological Simulation Program - FORTRAN (ZRWHSPF) model developed in Phase I
- Task 2: Apply the ZRWHSPF model to assess various management scenarios
- Task 3: Reporting and model package

The objective of Task 1 was to refine point source inputs based on updated MPCA datasets; refine the sediment calibration, as needed, based on new data and information; and evaluate the model calibration/validation following the model refinements to ensure the model performs as good or better than the Phase 1 version. The objective of Task 2 was to apply the ZRWHSPF model to explore the potential hydrologic and water quality changes in response to implementing management practices in the Zumbro River watershed. As part of this effort, a total of ten (10) management scenarios were evaluated. The sections below document the work performed in Tasks 1 and 2 of this project.

## Project Background

The MPCA is undertaking a watershed restoration and protection (WRAP) approach at the HUC8 (8-digit Hydrologic Unit Code) scale. This 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 Zumbro River HUC8 watershed (Figure 1) includes waters impaired by excessive fecal coliforms, mercury, PCBs, and turbidity. Lake Zumbro, 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 1 of this project, the ZRWHSPF 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 1995-2009. 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 ZRWHSPF model was refined based on new data and information. The model was then 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 Lake Zumbro Phosphorus Total Maximum Daily Load (TMDL).

# Zumbro 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 ZRWHSPF model, the watershed is divided into 109 subbasins (Figure 2). The average area per subbasin is 678 acres and ranges from 17 acres to 37,565 acres. The subbasins and reach segments are networked (or connected) together 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 (or stream) 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. The model contains a total of 1,740 HRUs. The average area per HRU is 518 acres and ranges from <1 acre to 15,888 acres. 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 lumped or 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 ZRWHSPF watershed model, including development, calibration, and validation is provided in the "Zumbro River Watershed HSPF Model Development Project" final report (LimnoTech 2014).

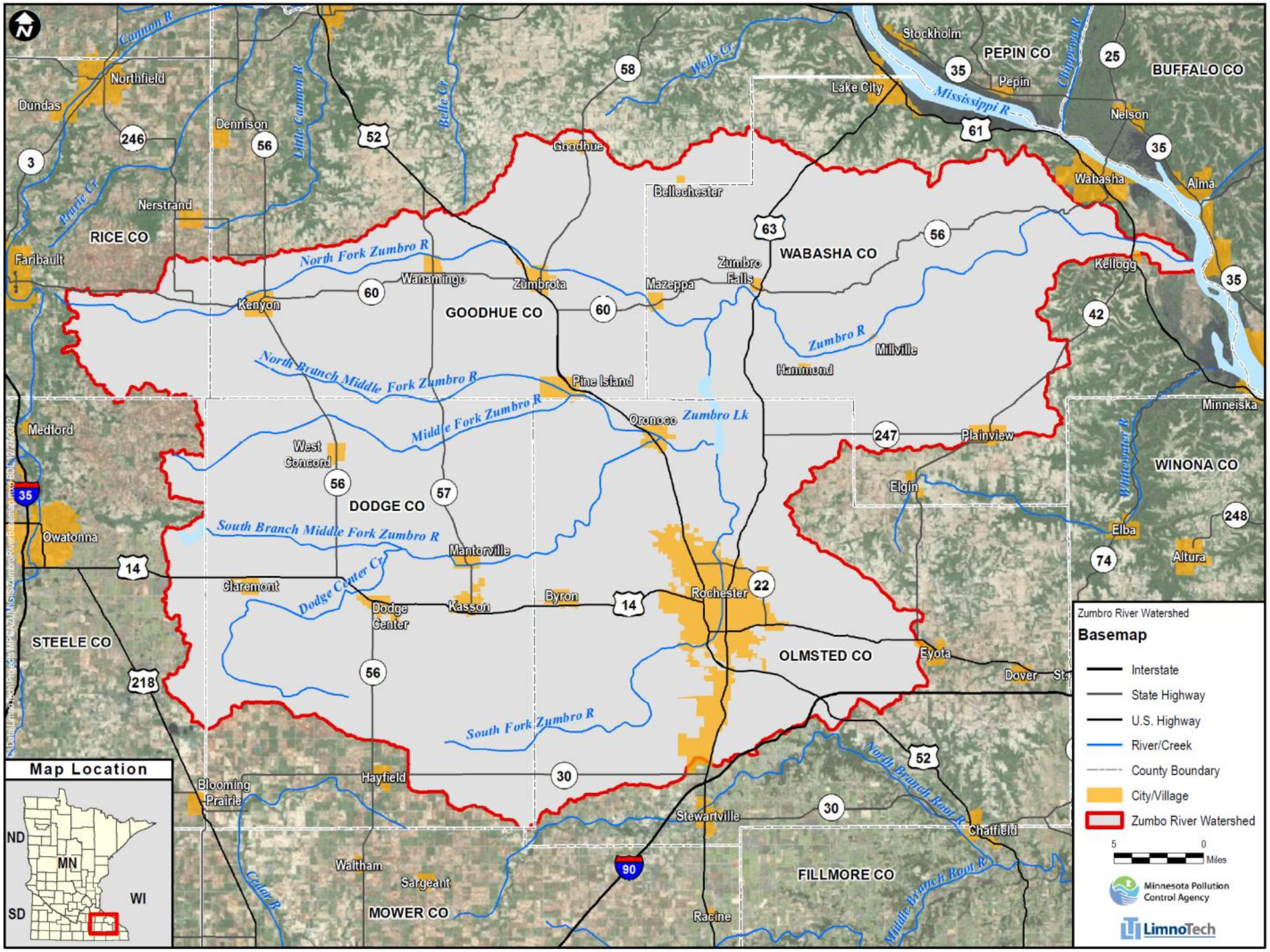


**Figure 1. Basemap of the Zumbro River watershed, Minnesota**

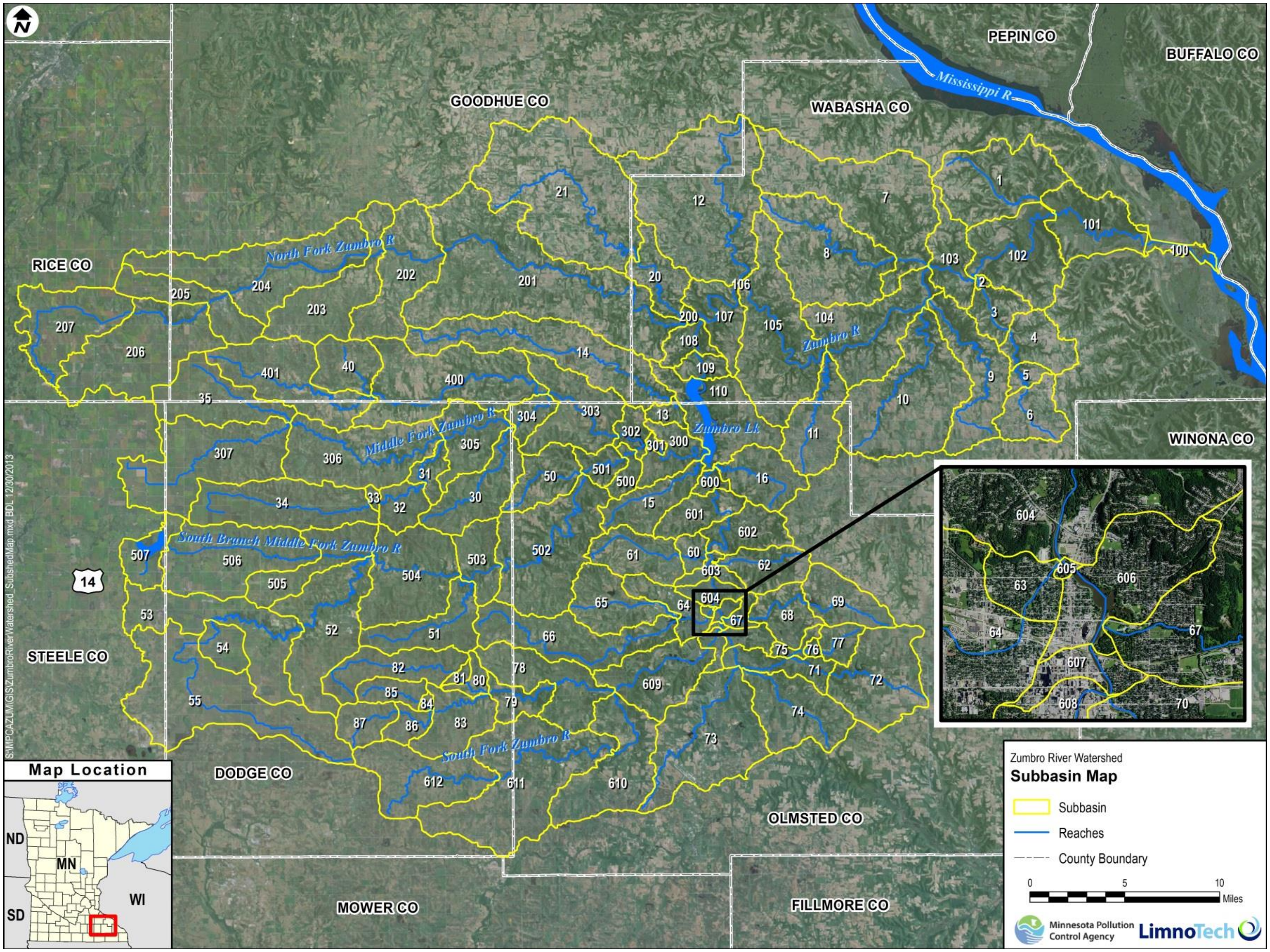


**Figure 2. Map of the ZRWHSPF model subbasins**

# Task 1: Refine the ZRWHSPF Model Developed in Phase 1

The purpose of Task 1 was to revise point source inputs and refine the sediment calibration, as needed, based on new and more accurate datasets and information. Additional revisions and refinements were made to atmospheric deposition inputs, model reach hydraulic function tables, and the nutrient and algae calibration to improve the model representation of the watershed. A description of the model revisions and refinements is provided in the sections below.

## Point Sources

Point source inputs were revised based on improved and more accurate datasets. Revisions were made to both major and minor point source inputs and included the following:

- Rochester Wastewater Treatment Plant (WWTP)/Water Reclamation Plant: Revised or corrected total phosphorus (TP) input concentrations based on new information provided by MPCA. The changes were primarily made to data points in 2004 and 2005.

- Zumbrota WWTP: Revised the flow, carbonaceous biochemical oxygen demand (CBOD), TSS, and DO input concentrations for 2002 based on monthly discharge monitoring report (DMR) summary data provided by MPCA. Because data were still not available for pH, TP, and ammonium plus ammonia (NH4+NH3), the input values for these parameters were not revised. These input values are based on an overall monthly average calculated from all years with available data (LimnoTech 2014).

- For the minor point sources with limited data, a few adjustments were made to the previously assumed concentrations based on further review of the available data and literature sources of typical effluent concentrations by facility type. Table 1 outlines the revised minor point source input assumptions.

**Table 1. Minor point source input concentrations.**

| Parameter | Previously Assumed Concentration (mg/L) | New Assumed Concentration for WWTPs | New Assumed Concentration for Industrial/Other |
|---|---|---|---|
| TSS | 1.0 | 5.0 | 1.0 |
| DO | 8.0 | 8.0 | 8.0 |
| BOD5 | 1.0 | 5.0 | 1.0 |
| NO3 | 10.0 | 10.0 | 1.0 |
| NO2 | 0.1 | 0.1 | 0.1 |
| NH3 | 1.0 | 1.0 | 1.0 |
| TP | 0.05 or 0.10 | 1.0 | 0.10 |

A check was performed between the MPCA and HSPF calculated TSS and TP loads for the two major point sources in the watershed, the Rochester WWTP and the Zumbrota WWTP. For the Rochester WWTP, the average relative percent difference between the MPCA and HSPF loads is less than 2% for TSS and TP (Figure 3). For the Zumbrota WWTP, the average relative percent difference between the MPCA and HSPF loads is 4% for TSS and 8% for TP (Figure 4). The small differences in the loads are likely attributable to variations in calculation and data gap filling methods.


**Figure 3. Calculated MPCA and HSPF annual TSS and TP loads for the Rochester WWTP.**

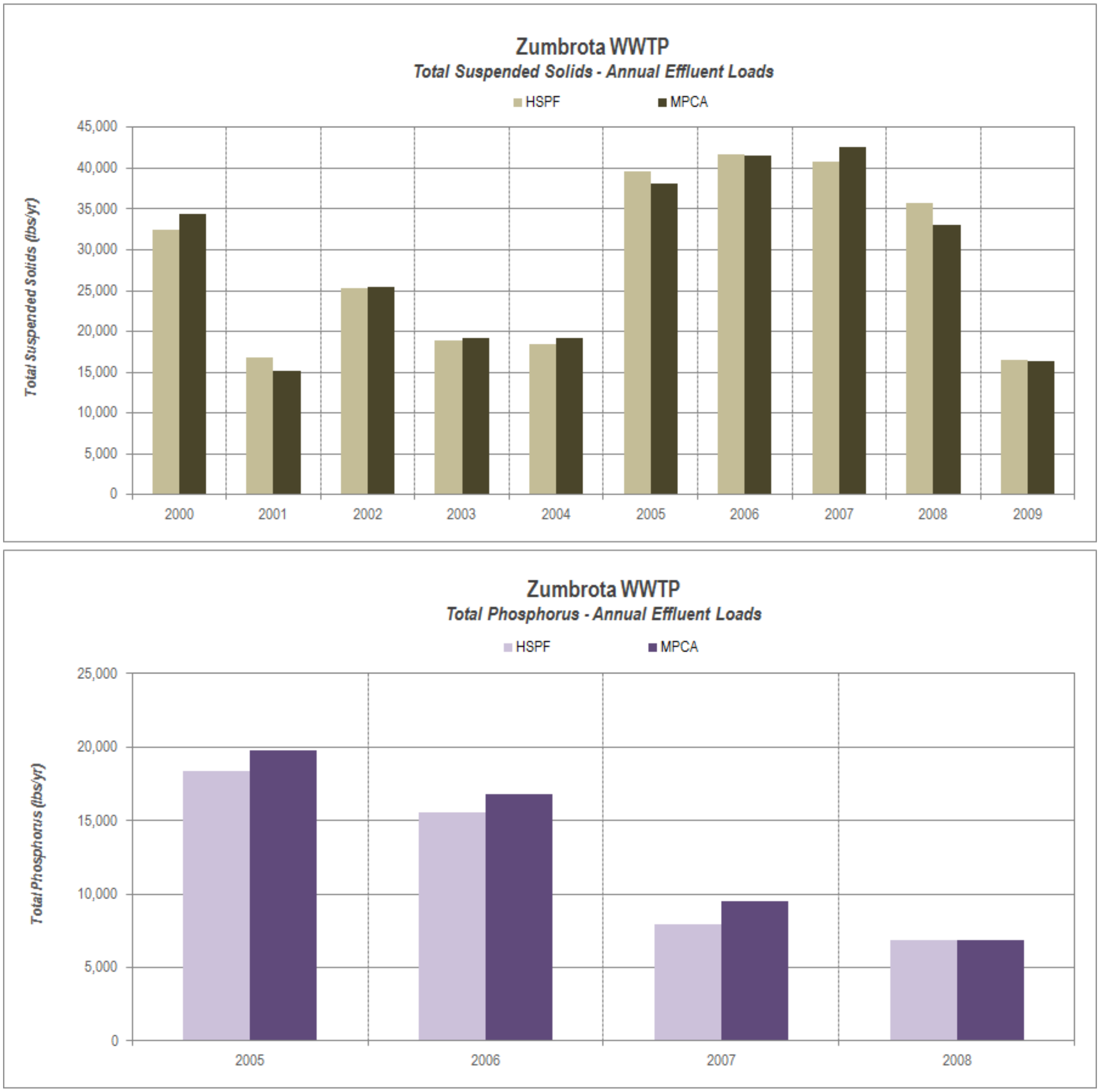


**Figure 4. Calculated MPCA and HSPF annual TSS and TP loads for the Zumbrota WWTP.**

## Atmospheric Deposition

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.

## Hydraulic Function Tables (FTABLES)

The HSPF model uses a hydraulic function table, called an FTABLE, to represent the geometric and hydraulic properties of water bodies, including both stream reaches and fully mixed reservoirs (USEPA 2007). The accuracy of the FTABLE is particularly important for the simulation of flow velocity and sediment transport (USEPA 2007). The FTABLEs for all model reaches were modified to maintain a small depth of flow at extreme low flow conditions. The FTABLES for Lake Zumbro, Rice Lake, and the storage reservoirs were not modified.

The primary purpose of this refinement was to allow for a more reasonable simulation of flow velocities, which in turn affects the simulation of sand movement. A secondary purpose of this refinement was to prevent model instabilities in the water quality simulation attributed to extreme low flow conditions. In the previous calibration, instabilities related to low flow conditions were addressed by adding small amounts of flow volume during the most susceptible time periods to reach segments exhibiting instabilities via the "special actions" module. Because the FTABLE refinement addressed the instabilities, the addition of flow volume via the "special actions" module was removed from the current model. This modification improved the representation of flow velocity at low flow conditions, improved the representation of sand movement, and addressed model instability issues in the water quality simulation that occurred during low flow conditions. The modification did not affect the overall hydrology calibration as the changes only impact extreme low flow conditions.

## Sediment

The purpose of the sediment calibration review and refinement was to ensure that the ZRWHSPF model provides the best representation of sediment processes and loading based on an evaluation of new data and information. The sediment calibration was revisited and modified based on the 2014 United States Geological Survey (USGS) report titled, "Suspended-Sediment Concentrations, Loads, Total Suspended Solids, Turbidity, and Particle-Size Fractions for Selected Rivers in Minnesota, 2007 through 2011" (Ellison et al. 2014), as well as additional data and information provided by USGS and MPCA.

Based on a review of the new data and information, it appeared that the original ZRWHSPF model calibration was underpredicting sediment loading in the Zumbro River watershed. It is likely that the original calibration targets, which were primarily based on estimated TSS concentrations and loads from continuous turbidity measurements, underestimated the sediment loads delivered to the stream network and the watershed outlet. Therefore, the sediment calibration was refined and enhanced to incorporate the new data and information provided in the USGS report (Ellison et al. 2014), as was feasible given the known limitations of the HSPF model.

Complete documentation of the approach used to refine and enhance the sediment calibration is provided in the technical memorandum titled, "Zumbro River Sediment Calibration Evaluation for Potential Refinement: Summary of Approach for Sediment Calibration Refinement and Enhancement" (LimnoTech 2015). Below is a summary of the modifications made to the model and the results of the sediment calibration refinement.

Based on the new data and information available to support the revision of the original sediment calibration, the following refinements and enhancements were identified:

- Adjustments to the upland/landside sediment loading were needed to increase the sediment load transported to the stream network. The revisions would be consistent with the loadings reported in the available literature.
- The sediment trapping efficiency of Lake Zumbro was increased to an annual average target range between ~50-70%. The previous target was 30-40% sediment trapping efficiency. The new

trapping efficiency target range for the model refinement was based on a load estimate analysis (FLUX) performed by MPCA over the 2007-2008 time period where the TSS load estimated at the outflow of the lake was only 35% of the inflow loads.

- The TSS load delivered to the watershed outlet was increased to an annual average target range of 25,149 to 323,038 tons/yr (median 179,000 tons/yr), which was derived based on the USGS report (Ellison et al., 2014). The previous annual target for the original model calibration was 145,500 tons/yr.

To address the modifications listed above, the following revisions were made to the ZRWHSPF model:

- Upland and gully sediment erosion were increased using the KRER (coefficient in soil detachment equation), KSER (coefficient in soil washoff equation), and KGER (coefficient in soil matrix scour equation) parameters.
- Upland and gully sediment erosion parameterization was modified by ecoregion to represent the higher likelihood of erosion in the driftless-blufflands area and the lower likelihood of erosion in the Western Corn Belt Plain (WCBP) area.
- The instream transport of sand particles was enhanced by promoting both erosion and deposition processes with modification to the KSAND and EXPSND parameters (coefficient and exponent, respectively, in the sand load power function equation).
- The fall velocities (W) of silt and clay particles were increased for Lake Zumbro and Rice Lake to promote greater sediment trapping capacity.
- Critical shear stresses for silt and clay scour (TAUCS) and deposition (TAUCD) were modified in all reach segments.

## Nutrients and Algae

Nutrient (phosphorus and nitrogen) loading; phytoplankton growth, death, and decay; and nutrient cycling are highly interdependent. A change in watershed loading and/or instream parameterization for one nutrient species may have a significant impact on another individual nutrient species. Sediment and phosphorus are also linked. The transport of phosphorus can occur in dissolved and particulate forms. The forms of particulate phosphorus include phosphorus sorbed by soil particles and organic matter eroded during runoff, and these forms may comprise a major proportion of phosphorus transported from land. As a result of these interdependencies and linkages, additional modifications were necessary to update the calibration of nitrogen and phosphorus following the sediment calibration enhancement and refinement. The following changes were made to the model to refine the nitrogen and phosphorus calibration:

- The rate of nitrification (KTAM20) was reduced;
- Benthic release rates of phosphate (BRPO4) and ammonia (BRTAM) were introduced for Lake Zumbro and Rice Lake;
- The fraction of algal preference for nitrate (ALNPR) was increased; and
- The following parameters related to phytoplankton growth were modified: the temperature below which phytoplankton growth ceases (TALGRL), the concentration of plankton not subject to advection at very low flow (MXSTAY), the outflow at which the concentration of plankton not subject to advection is midway between the low and high flow “stay” concentrations (OREF), and the chlorophyll *a* concentration above which high algal death rate occurs (CLALDH).

## Model Performance

The overall model performance for sediment in the current model can be summarized as:

- The current model results for the 1996-2009 simulation period compared to observed data are "as good as" or "better than" the results obtained during the original model calibration and validation exercise.
- The prediction of landside sediment unit area loads (UALs) increased relative to the previous model calibration and validation exercise.
- The prediction of annual TSS loads to Lake Zumbro and at the Zumbro River at Kellogg location (near the watershed outlet) increased relative to the previous model calibration and validation exercise.
- The prediction of TSS trapping in Lake Zumbro increased relative to the previous model calibration and validation exercise.

Area-weighted UALs by land use type are shown in Figure 5 for both the original calibration and the current calibration. Although UALs increased from the original calibration to the current calibration to increase the sediment load transported to the stream network, absolute UALs by land use type remained within literature ranges.

A review of the sediment source apportionment revealed little change between the original calibration and the current calibration. For the entire watershed, bed and bank erosion contribution increased from 39% to 44% while gully/ravine and upland erosion decreased by approximately 2% each. A breakdown of the sediment sources is shown in Table 2.

The average annual suspended sediment load simulated at the Zumbro River at Kellogg location was 250,500 tons/year for the entire simulation period (1996-2009), which is within the revised target range and 64% higher than the 153,000 tons/year simulated in the original calibration. A comparison of annual TSS loading between the original calibration and the current calibration is shown in Table 3 for the South Fork Zumbro River and the Zumbro River at Kellogg location.

The long-term Lake Zumbro sediment trapping efficiency was simulated as 52%, which is within the revised target range of 50-70% and increased from the 33% trapping efficiency simulated in the original calibration. The average annual change in bed depth over the entire simulation period is shown for all reaches in Figure 6 for both the original calibration and the current calibration.

Comparisons of simulated daily average TSS concentrations and observed TSS concentrations from MPCA grab samples and continuous turbidity measurements for the Zumbro River at Kellogg location are shown in Figure 7 (2008 only) for both the original calibration and the current calibration and in Figure 8 (2007-2009) for the current calibration only. The time period for the current calibration evaluation is consistent with the time period used in the original calibration.

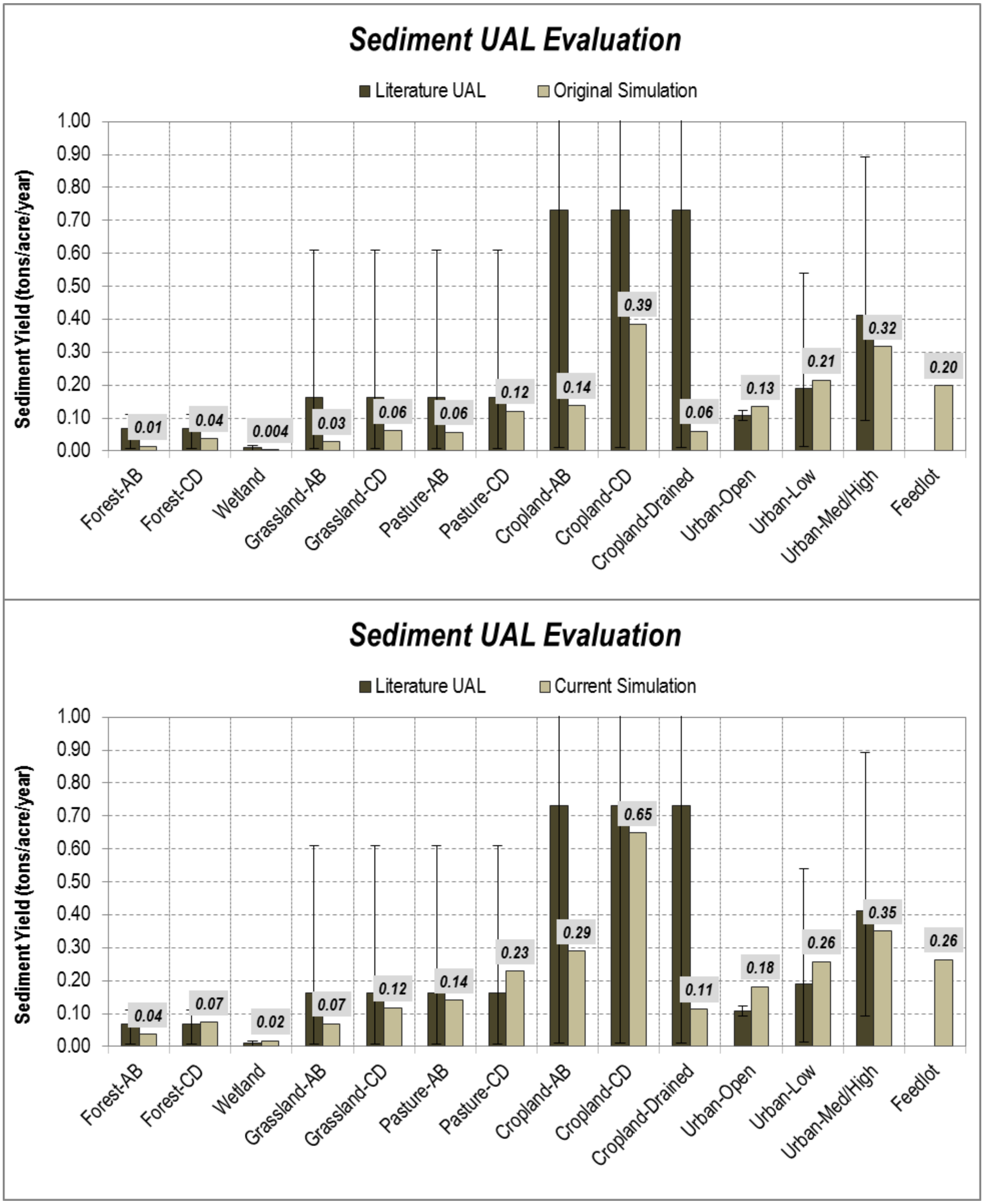


**Figure 5. Area-weighted UALs for the ZRWHSPF model by land use type compared to literature averages (error bars represent minimum and maximum) (1996-2009). The top bar chart represents the original calibration, and the bottom chart represents the current calibration.**

**Table 2. Breakdown of sediment sources by major drainage area and for the entire ZRWHSPF model (1996-2009) for the original calibration and the current calibration.**

| Original Calibration | | | | | |
|---|---|---|---|---|---|
| Drainage Area | Gully/Ravine | Upland | Tile Drains | Point Sources | Bed/Bank Erosion |
| South Fork | 21% | 52% | 0.3% | 0.4% | 27% |
| Middle Fork | 19% | 42% | 0.8% | 0.0% | 38% |
| North Fork | 17% | 50% | 0.2% | 0.1% | 33% |
| Mainstem | 14% | 31% | 0.0% | 0.0% | 55% |
| Entire Watershed | 18% | 42% | 0.4% | 0.1% | 39% |
| Current Calibration | | | | | |
| Drainage Area | Gully/Ravine | Upland | Tile Drains | Point Sources | Bed/Bank Erosion |
| South Fork | 22% | 54% | 0.3% | 0.2% | 24% |
| Middle Fork | 21% | 48% | 1.0% | 0.0% | 30% |
| North Fork | 17% | 62% | 0.3% | 0.1% | 20% |
| Mainstem | 9% | 22% | 0.0% | 0.0% | 69% |
| Entire Watershed | 16% | 40% | 0.4% | 0.1% | 44% |

**Table 3. Comparison of the annual TSS loading (tons/year) between the original calibration and the current calibration.**

| Year | South Fork Zumbro River (Reach 604) | | Zumbro River at Kellogg (Reach 101) | |
|---|---|---|---|---|
| | Original Calibration | Current Calibration | Original Calibration | Current Calibration |
| 1996 | 20,500 | 29,600 | 62,800 | 126,500 |
| 1997 | 22,600 | 26,800 | 126,300 | 215,800 |
| 1998 | 13,200 | 20,200 | 214,600 | 382,000 |
| 1999 | 31,800 | 50,000 | 128,200 | 253,200 |
| 2000 | 94,300 | 158,500 | 109,800 | 174,500 |
| 2001 | 109,500 | 143,300 | 342,200 | 481,800 |
| 2002 | 32,100 | 46,800 | 167,700 | 290,900 |
| 2003 | 4,200 | 5,900 | 21,800 | 48,000 |
| 2004 | 71,500 | 104,500 | 285,400 | 406,400 |
| 2005 | 10,200 | 15,900 | 66,000 | 138,800 |
| 2006 | 12,900 | 21,000 | 45,100 | 94,400 |
| 2007 | 122,400 | 174,500 | 507,200 | 749,500 |
| 2008 | 15,000 | 25,100 | 56,300 | 120,400 |
| 2009 | 3,500 | 4,800 | 8,300 | 25,300 |
| AVERAGE | **40,300** | **59,100** | **153,000** | **250,500** |

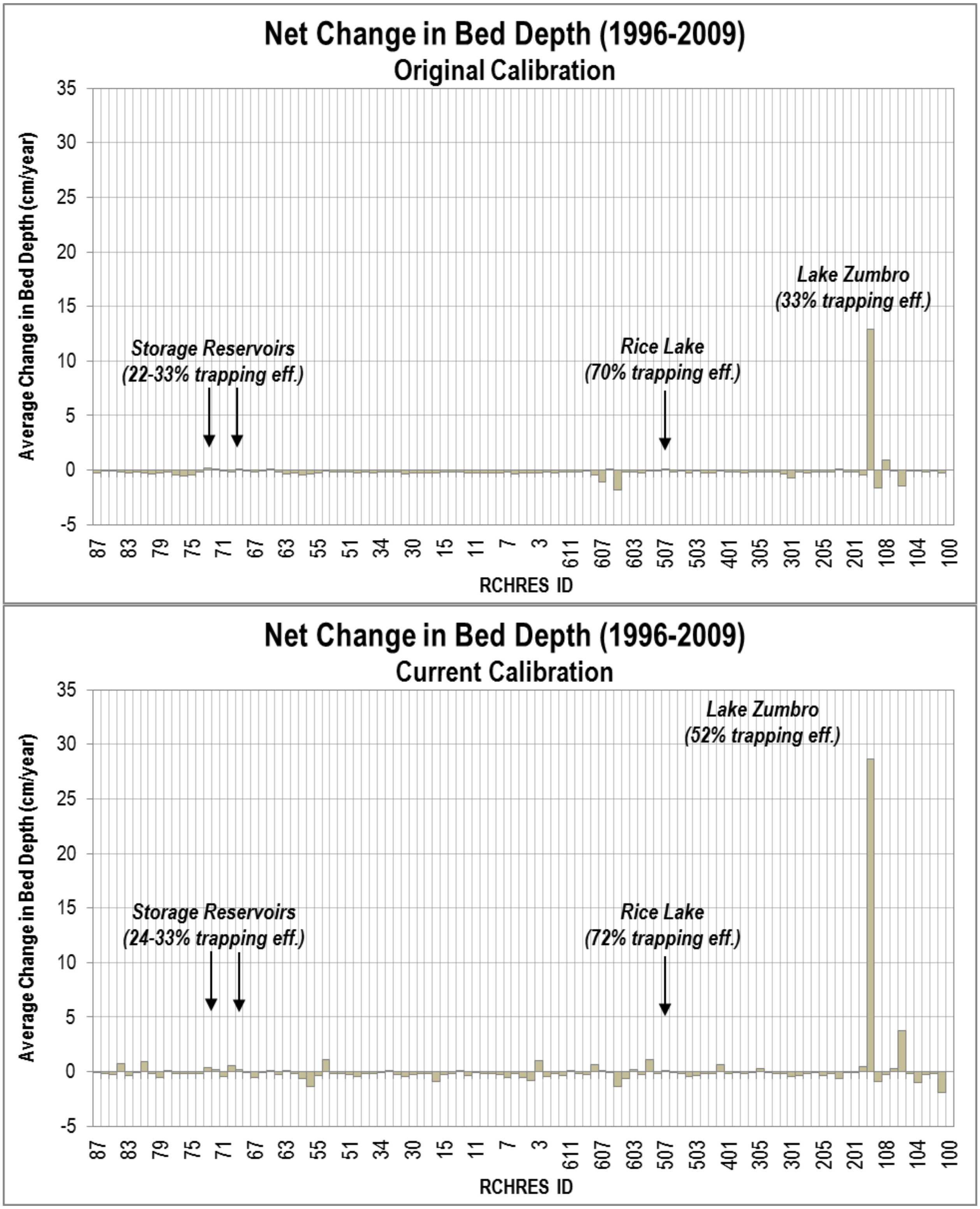


**Figure 6. Average annual change in bed depth for all reaches in the ZRWHSPF model (1996-2009). The top bar chart represents the original calibration, and the bottom chart represents the current calibration.**

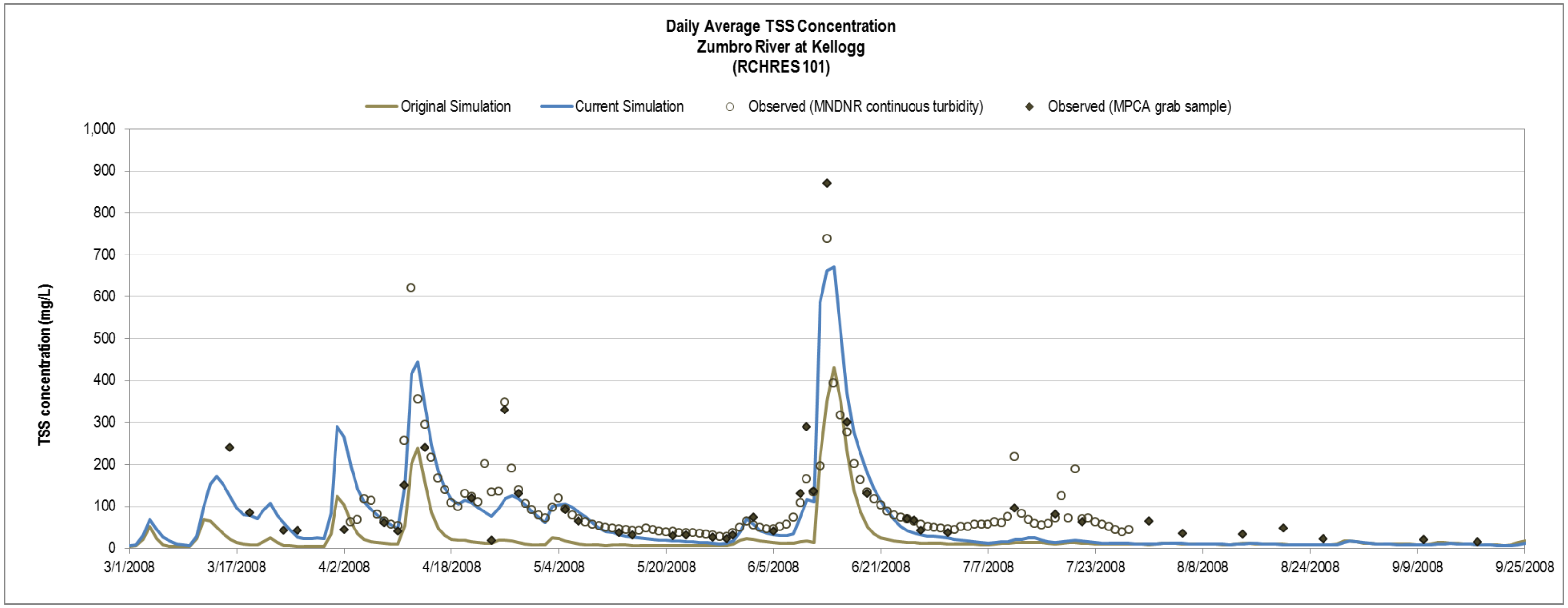


**Figure 7. Comparison of the original and current calibration simulation of daily average total suspended solids concentrations for the Zumbro River at Kellogg for 2008.**

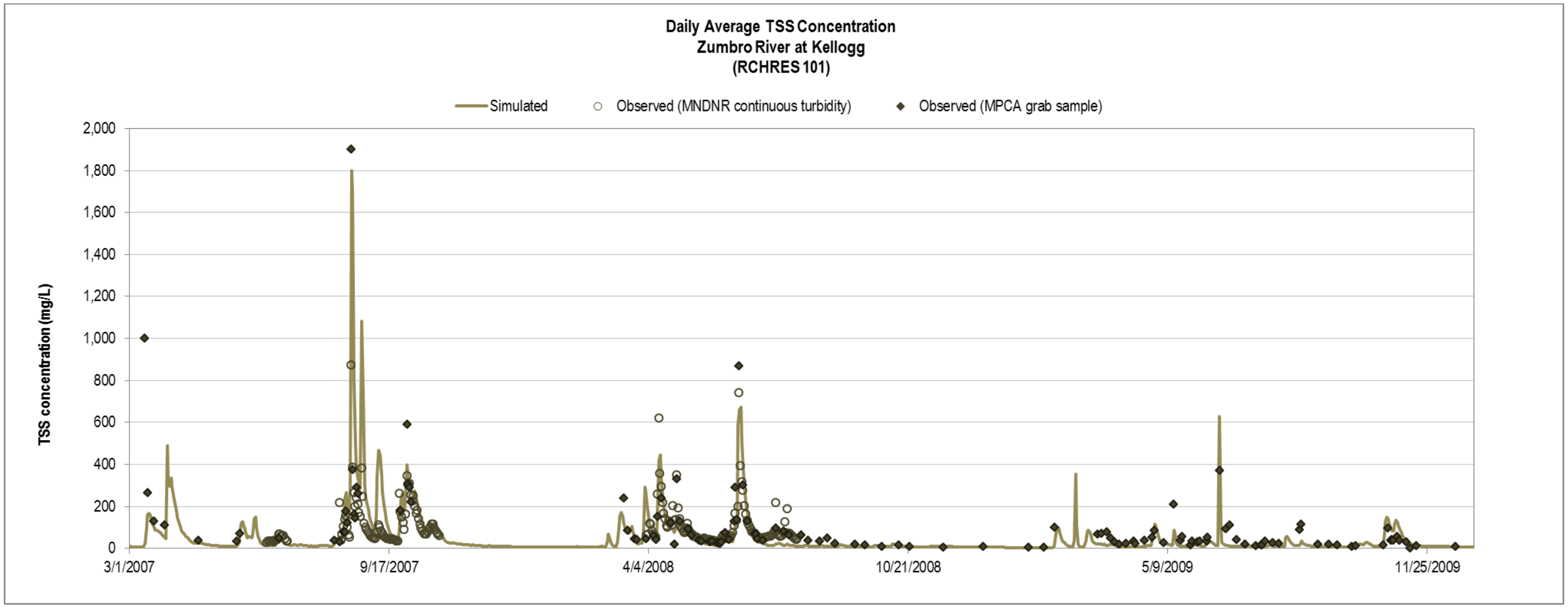


**Figure 8. Current model calibration simulation of daily average total suspended solids concentrations for the Zumbro River at Kellogg (2007-2009).**

### *Phosphorus and Nitrogen*

The overall model performance of the current model for phosphorus and nitrogen can be summarized as:

- The current model results for the 1996-2009 simulation period compared to observed data are "as good as" or "better than" the results obtained during the previous model calibration and validation exercise.
- The prediction of annual TP loads increased relative to the previous model calibration and validation exercise (62% increase for the Zumbro River at Kellogg).
- The predictions of annual total nitrogen (TN) loads were relatively unchanged compared to the previous model calibration and validation exercise (i.e., less than a 1% decrease for the Zumbro River at Kellogg location).

Comparisons of simulated and observed nutrient concentrations for the Zumbro River at Kellogg are shown in Figure 9 (TP) and Figure 10 (TN) for both the original calibration and current calibration.

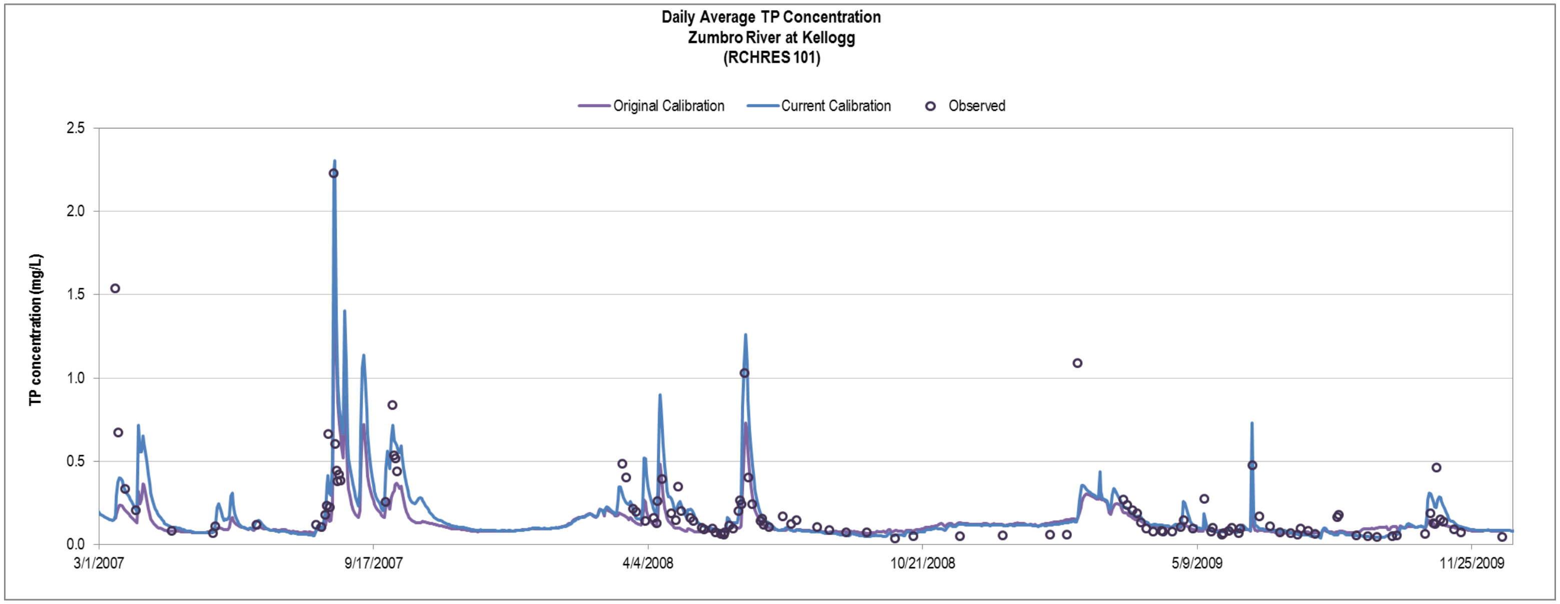


**Figure 9. Comparison of the original and current calibration simulation of daily average total phosphorus concentrations for Zumbro River at Kellogg for 2007-2009.**

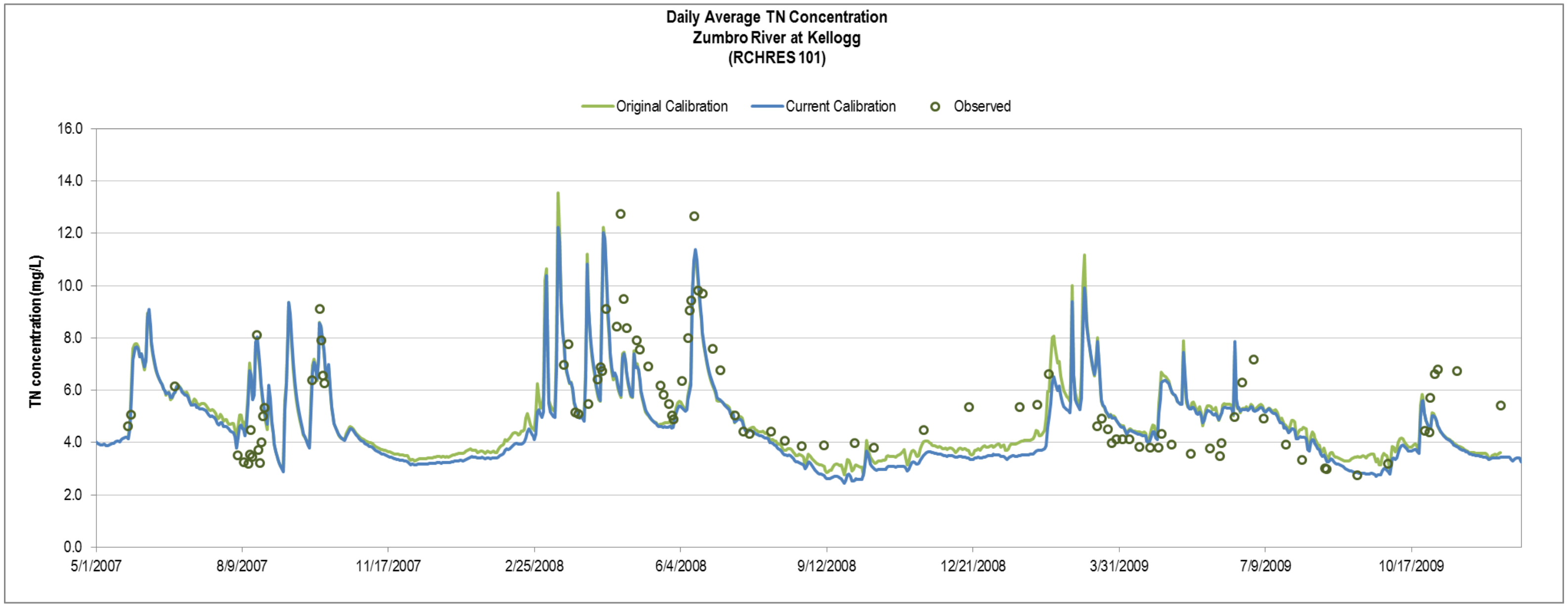


**Figure 10. Comparison of the original and current calibration simulation of daily average total nitrogen concentrations for Zumbro River at Kellogg for 2007-2009.**

# Task 2: Apply the ZRWHSPF 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 Zumbro River watershed. The sections below describe the application of the ZRWHSPF model to the Zumbro River watershed to evaluate management scenarios.

## Management Scenario Descriptions

During the Zumbro Watershed Partnership (ZWP) meeting held on November 20, 2014 in Rochester, Minnesota, watershed stakeholders discussed several potential management or BMP scenarios that could be set-up and run with the ZRWHSPF model. The scope of work for this phase included the simulation of a total of eight (8) scenarios to estimate the effect of potential management practices on sediment and nutrient transport and delivery to local tributaries, Lake Zumbro, and the watershed outlet. A total of 10 scenarios were evaluated. Each scenario was a variation of the "baseline" simulation that is based on the historical conditions for the 1996-2009 time period.

**Table 4. List of management scenarios simulated with the ZRWHSPF model**

| Scenario ID | Scenario Description | Category |
|---|---|---|
| A | Point Sources at Permitted Limits | Point Source |
| B | Point Sources at RES and 70% AWWDF | Point Source |
| C | Point Sources at 0.40 or 0.50 mg P/L and 70% AWWDF | Point Source |
| D | Conservation Tillage | Nonpoint Source |
| E | Green Infrastructure - 5% Implementation | Nonpoint Source |
| F | Green Infrastructure - 25% Implementation | Nonpoint Source |
| G | Pre-Settlement Vegetation | Nonpoint Source |
| H | Cover Crops | Nonpoint Source |
| I | Sedimentation Ponds | Nonpoint Source |
| J | Combined Management Scenario | Point Source + Nonpoint Source |

### *Point sources at permitted limits (A)*

A scenario was constructed to evaluate the impact on instream water quality of all point sources discharging at permitted limits of flow rate, minimum DO concentration, TSS load, TP load, ammonia load, and/or BOD load. This scenario provides 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 four (4) facilities in the Zumbro River watershed had ammonia limits and zero (0) facilities had nitrate limits. In these cases, the loading time series from the baseline model was used.

### *Point sources at RES and 70% AWWDF (B)*

A second point source scenario was constructed to serve as a lower bound to complement the first point source 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 P/L, depending on the receiving stream the point source discharges to, and were applied from June 1 to September 30. The effluent TP concentration for Rochester WWTP was simulated at 0.125 mg P/L. For the remainder of the year (October 1 to May 31), the loading time series from the baseline model were applied. There are four (4) facilities that use stabilization ponds in the Zumbro River watershed. For these facilities, discharge was assumed to occur during June 1-15 and September 15-30.

### *Point sources at 0.40 or 0.50 mg P/L and 70% AWWDF (C)*

Based on the results of point source scenario A and B, the MPCA defined a third point source scenario was constructed to investigate the effects of setting effluent TP concentrations above the proposed RES but below permitted limits for the June 1 to September 30 time period for a select group of point sources. The effluent TP concentrations for the Byron, Dodge Center, Kasson, Mantorville, and Pine Island WWTPs were simulated at 0.50 mg P/L. The effluent TP concentration for Rochester WWTP was simulated at 0.40 mg P/L. For the October 1 to May 31 time period, the loading time series from the baseline model was used for these facilities. The flow rate for these facilities was set to 70% of the AWWDF for the entire year. The flow rate and loading time series from the baseline model simulation were applied for all other facilities.

### *Conservation tillage (D)*

Practices that increase soil organic matter and provide surface cover will tend to increase the volume of water infiltration into the soil, which serves to reduce surface runoff and sediment erosion as well as to improve the health of the soil. On farm fields, the implementation of reduced tillage operations is a potential method of accomplishing an increase in soil organic matter (ZWP 2012). A scenario was constructed to reflect conservation tillage management practices applied to 30% of the cropland acres with the highest sediment yields. The selection of the highest sediment yielding cropland land segments for conservation tillage implementation was based on the ZRWHSPF 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 two criteria: (1) parameters were only adjusted by an amount that was reasonable relative to values for other land uses – for example, the soil cover factor was increased but no higher than values for forest or grassland, and (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.

### *Green infrastructure – 5% Implementation (E)*

The first of two (2) green infrastructure scenarios assumed a range of practices would be applied to 5% of all developed areas in the Zumbro River watershed. The top sediment yielding developed land segments were targeted for green infrastructure implementation. 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 out of the total area of implementation (5% of the developed area in this instance, Table 5). 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 stream segments. Constant removal fractions were used for flow and all constituents.

### *Green infrastructure – 25% Implementation (F)*

The second green infrastructure scenario assumed practices would be applied to 25% of all developed areas in the Zumbro River watershed. The top sediment yielding land segments were targeted for green infrastructure implementation. The same overall removal efficiencies applied in the 5% green infrastructure scenario were used in this scenario, assuming the same proportion of various green infrastructure practices would be scaled up to treat the larger area (Table 5).

**Table 5. Green infrastructure removal efficiencies and assumed fractions of implementation for individual green infrastructure types used to compute an overall, weighted efficiency for each constituent.**

| Green Infrastructure Type | Removal Efficiency (%) | | | Assumed Implementation (%) for Scenario E | Assumed Implementation (%) for Scenario F |
|---|---|---|---|---|---|
| | TN | TP | TSS | | |
| Green Roof | 43 | 45 | 31 | 0.25 | 1.25 |
| Porous Pavement | 47 | 50 | 70 | 0.25 | 1.25 |
| Bioretention | 58 | 68 | 75 | 1.0 | 5.0 |
| Filtration Type | 40 | 60 | 80 | 0.5 | 2.5 |
| Infiltration Type | 80 | 85 | 95 | 0.5 | 2.5 |
| Bioswale | 10 | 10 | 50 | 0.5 | 2.5 |
| Retention Pond | 20 | 45 | 60 | 1.0 | 5.0 |
| Detention Basin | 20 | 20 | 60 | 1.0 | 5.0 |
| OVERALL | **37** | **47** | **67** | **5.0** | **25.0** |

### *Pre-settlement vegetation (G)*

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, that 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 atmospheric deposition of nitrogen. 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/yr). The reservoirs remained unchanged from the baseline in the model to represent more realistic, present-day hydrologic conditions.

### *Cover crops (H)*

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 30% of the cropland acres in the watershed. The areas where cover crops were implemented in the model were based on a comprehensive evaluation of the following three elements:

1. Identification of high sediment and phosphorus yielding cropland land segments based on the ZRWHSPF model baseline landscape predictions;
2. Identification of sensitive groundwater areas; and
3. Location of tiled lands in the watershed.

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.

### *Sedimentation Ponds (I)*

A scenario was constructed to represent the addition of sediment basins and grade stabilization structures (hereafter referred to as ponds) in the Zumbro River watershed. The ponds serve to reduce peak flows and sediment and nutrient loading. The location selection for the addition of new ponds was based on the ZRWHSPF model baseline landscape predictions in conjunction with the critical source areas identified in the Zumbro River Watershed Restoration Prioritization study (L. Svien and P. Wotzka personal communication, ZWP 2014). Some general assumptions, based on the typical characteristics of the ponds in the watershed, 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 Water Conservation Districts (SWCDs). The ponds were represented as “dry ponds” (B. Kennedy and M. Kruger personal communication) and designed to capture the approximate 10-year, 24-hour rain event (B.

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.

The existing inventory of pond structures and their respective drainage areas were used in selecting locations for the new ponds (i.e., new ponds were not added to locations where a pond already exists and is treating X acres of land). The 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 watershed.

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.

### *Combined management scenario (J)*

To understand the benefits of implementing multiple BMPs, for both point and nonpoint sources, a scenario was constructed that combined the following actions represented in scenarios C, H and I:

- Point source effluent set at 0.40 or 0.50 mg-P/L and 70% of average wet weather design flow (see scenario C);
- Cover crops applied to 30% of cropland acres (see scenario H); and
- Retention basins capturing runoff from 30% of cropland acres (see scenario I).

Assumptions were the same in this scenario as described above for the individual scenarios with respect to which point sources were modified, the locations of cropland acres receiving treatment, and the representation of the new ponds in the model.

## Management Scenario Results

The ZRWHSPF 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 Zumbro 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 ZRWHSPF model runs are described below:

- The "**baseline**" run represents existing conditions in the watershed for the 1996 through 2009 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 2009 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).

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 and keep in mind 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. The level of implementation for each scenario must be taken into consideration when using the information for making management decisions.

For reference, the management actions considered for each scenario are listed below, along with the prescribed "level of implementation":

A. Point sources at permitted limits, 100% implementation

B. Point sources at RES and 70% AWWDF, 100% implementation

C. Point sources 0.50 mg P/L and 70% AWWDF for Byron, Dodge Center, Kasson, Mantorville, Pine Island and at 0.40 and 70% AWWDF for Rochester.

D. Conservation tillage, 30% of cropland acres

E. Green infrastructure, 5% of developed land

F. Green infrastructure, 25% of developed land

G. Pre-settlement vegetation, entire watershed

H. Cover crops, 30% of cropland acres

I. Sedimentation Ponds, 30% of cropland acres

J. Combination of point source, cover crop, and retention basin scenario (C, H and I), set at the same implementation levels listed above

### *Sediment*

A comparison of sediment yields and loading for the baseline run and the various management scenarios on an annual average basis over the simulation period (1996-2009) is provided in Tables 6-7 and Figures 11-12 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 Zumbro (in tons/yr). The relative load change is calculated as the annual average scenario load minus the baseline load, divided by the baseline load at the watershed outlet and Lake Zumbro.

For the baseline run, the model calculated an annual average sediment load of 266,264 tons/yr at the watershed outlet and 174,380 tons/yr at Lake Zumbro (Tables 6-7, Figures 11-12). The overall sediment yield calculated for the baseline run was 0.253 tons/acre/yr. The model-estimated annual sediment loading to the watershed outlet and Lake Zumbro for the point source scenarios (A, B, and C) is slightly greater (≤1%) than the baseline run (Tables 6-7, Figures 11-12). The annual sediment load for the point source scenario at the permitted limits (A) is approximately 1% greater than the baseline at the watershed outlet and at Lake Zumbro, which is attributed to permitted effluent flows and/or sediment concentrations that are higher than the baseline. The annual sediment load for the point source scenarios where the effluent flow is set at 70% AWWDF (B and C) is ≤0.4% greater than the baseline at the watershed outlet and at Lake Zumbro, which can be attributed to the 70% AWWDF flows that are higher than the baseline effluent flows.

The green infrastructure implementation scenarios (E and F) resulted in a small reduction of annual sediment loading to the watershed outlet and Lake Zumbro, ranging from ≤1% at the 5% level of implementation to 3% at the 25% level of implementation (Tables 6-7, Figures 11-12). The developed areas (e.g., residential, commercial, industrial, open space, etc.) in the Zumbro River watershed account for 8.9% of the total watershed area. Given the small area of developed land across the watershed, it is not expected that the green infrastructure implementation would result in a substantial sediment load reduction at the watershed outlet or to Lake Zumbro. 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.

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 D) to 30% of the highest sediment yielding cropland acres in the model resulted in an estimated annual sediment load reduction of 14% at the watershed outlet and 25% to Lake Zumbro compared to the baseline run. 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 H) to 30% of the cropland acres in the model resulted in an estimated annual sediment load reduction of 12% at the watershed outlet and 21% at Lake Zumbro compared to the baseline run (Tables 6-7, Figures 11-12). As described earlier, the location of cover crop implementation was based on three elements and included the identification of high sediment and phosphorus yielding cropland acres; the identification of sensitive groundwater areas; and the location of tiled lands in the watershed. 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.

The sedimentation ponds (scenario I) were set up in the model to treat surface runoff from 30% of the cropland acres in the watershed that were not already being treated by a pond. The location of the ponds in this scenario was based on the existing inventory of pond structures and their respective drainage areas were used in selecting locations for the new ponds (i.e., new ponds were not added to locations where a pond already exists). The ponds were then placed in the model subbasins with the highest cropland sediment yields per the baseline model predictions. This location selection strategy resulted in most of the ponds being placed upstream of Lake Zumbro. The results of the sedimentation pond scenario indicate a reduction in annual sediment loading of 8% relative to the baseline at the watershed outlet. The estimated annual sediment load reduction at Lake Zumbro is 18% relative to the baseline. The level of annual sediment load reduction for this scenario is much higher at Lake Zumbro compared to the watershed outlet because the majority of new treatment ponds were added upstream of Lake Zumbro, as noted above. 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 baseline.

The combined management scenario (J) involved the application of conservation tillage practices, cover crops, and point source effluent discharge modification (scenarios C+H+I). The application of multiple management practices does not result in an additive load reduction or water quality benefit. 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). However, as indicated by the model results, there is an additional benefit to applying multiple management practices. The annual sediment load reduction estimated is 17% at the watershed outlet and 32% at Lake Zumbro (Tables 6-7, Figures 11-12). The model results indicate that the combined management scenario provides the greatest overall sediment load reduction with the exception of the pre-settlement vegetation scenario discussed below.

The pre-settlement vegetation scenario (G) results serve as an indicator of the extent to which historical land use changes have affected sediment erosion in the Zumbro River watershed. The results of the pre-settlement vegetation scenario suggest a sediment yield of 0.075 tons/acre/yr under the pre-settlement conditions, which is approximately three-fold lower than the baseline yield of 0.35 tons/acre/yr (Tables 6-7, Figures 11-12). The pre-settlement vegetation sediment yield (0.075 tons/acre/yr) estimated by the model is consistent with the range of unit area sediment loading rates reported in the literature for forested landscape (0.01 – 0.11 tons/acre/yr) (CH2M Hill and AQUA TERRA 2002; Lin 2004). The model-estimated annual sediment loading to the watershed outlet and to Lake Zumbro is 56% and 62% less for the pre-settlement vegetation scenario, respectively, as compared to the baseline run. The results of this scenario indicate the conversion of natural landscape to agriculture and developed land uses in the watershed has significantly increased sediment loading in the Zumbro River watershed.

Sediment landscape yield scenario maps are provided in Appendix A.

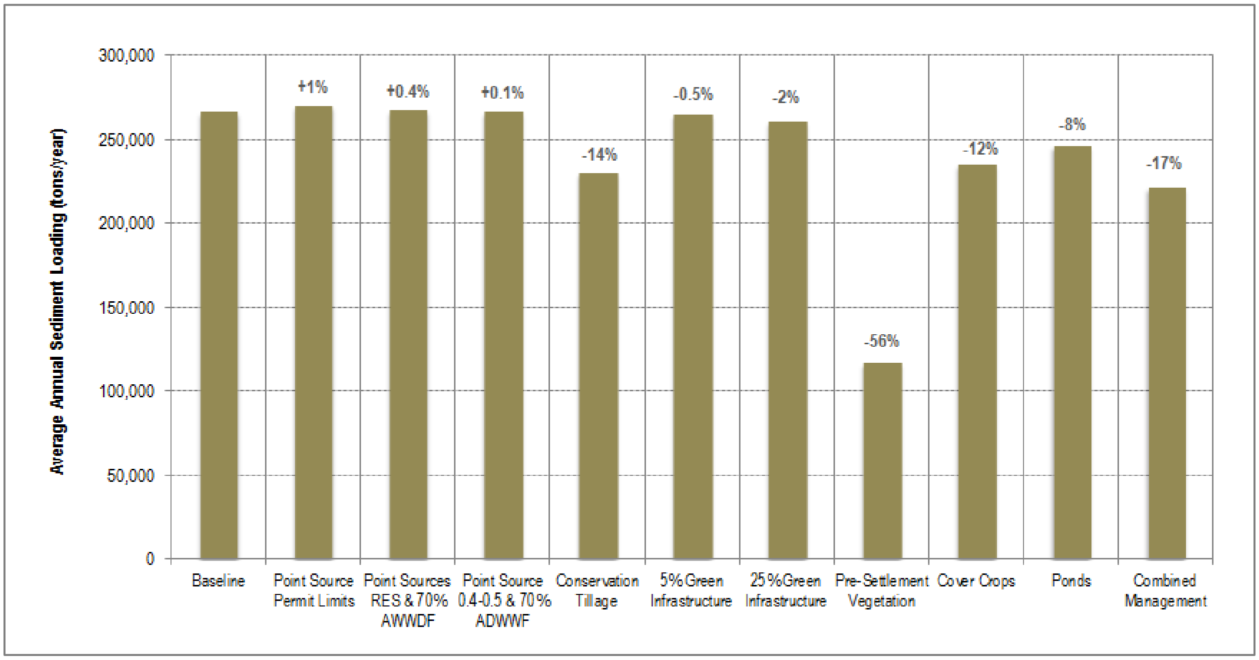


**Figure 11. Annual average simulated total sediment loading at the Zumbro River watershed outlet for the baseline run and management scenarios (1996 – 2009).**

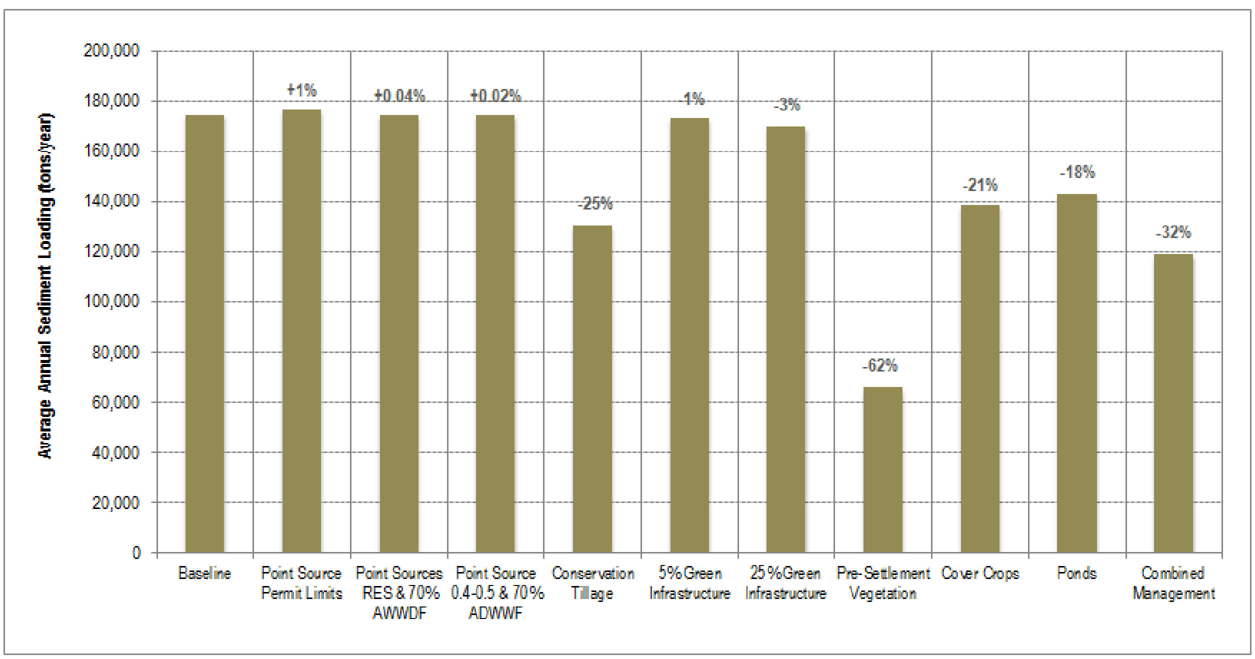


**Figure 12. Annual average simulated sediment loading to Lake Zumbro for the baseline run and management scenarios (1996 – 2009).**

**Table 6. Summary of simulated sediment yields and loading at the Zumbro River watershed outlet for the baseline and management scenarios (1996-2009).**

| Scenario ID | Scenario Description | Sediment Yield (tons/acre/yr)[a] | Sediment Loading (tons/yr)[a] | Relative Sediment Loading Change |
|---|---|---|---|---|
| - | Baseline | 0.253 | 266,264 | - |
| A | Point Sources at Permitted Limits | 0.253[b] | 269,887 | +1% |
| B | Point Sources at RES & 70% AWWDF | 0.253[b] | 267,296 | +0.4% |
| C | Select Point Sources at 0.4-0.5 mg P/L & 70% AWWDF | 0.253[b] | 266,577 | +0.1% |
| D | Conservation Tillage | 0.189 | 230,243 | -14% |
| E | Green Infrastructure - 5% Implementation | 0.252 | 264,978 | -0.5% |
| F | Green Infrastructure - 25% Implementation | 0.248 | 260,740 | -2% |
| G | Pre-Settlement Vegetation | 0.075 | 116,794 | -56% |
| H | Cover Crop | 0.205 | 235,187 | -12% |
| I | Sedimentation Ponds | 0.200 | 246,275 | -8% |
| J | Combined Management | 0.171 | 221,476 | -17% |

[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 7. Summary of simulated sediment yields and loading to Lake Zumbro for the baseline and management scenarios (1996-2009).**

| Scenario ID | Scenario Description | Sediment Loading (tons/yr)[a] | Relative Sediment Loading Change |
|---|---|---|---|
| - | Baseline | 174,380 | - |
| A | Point Sources at Permitted Limits | 176,467 | +1% |
| B | Point Sources at RES & 70% AWWDF | 174,441 | +0.04% |
| C | Select Point Sources at 0.4-0.5 mg P/L & 70% AWWDF | 174,410 | +0.02% |
| D | Conservation Tillage | 130,313 | -25% |
| E | Green Infrastructure - 5% Implementation | 173,065 | -1% |
| F | Green Infrastructure - 25% Implementation | 169,789 | -3% |
| G | Pre-Settlement Vegetation | 65,657 | -62% |
| H | Cover Crop | 138,547 | -21% |
| I | Sedimentation Ponds | 142,924 | -18% |
| J | Combined Management | 118,769 | -32% |

[a]*Tons are in English tons*

## *Phosphorus*

A comparison of phosphorus yields and loading (TP and orthophosphate (PO4)) for the baseline run and the various management scenarios on an annual average basis over the simulation period (1996-2009) is provided in Tables 8-9 and Figures 13-14 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 Zumbro (in lbs/yr). The relative load change is calculated as the annual average scenario load minus the baseline load, divided by the baseline load at the watershed outlet and Lake Zumbro. The scenario results described below focus on TP; however, the relative change in load between the baseline run and the scenarios for orthophosphate is, in general, consistent with the TP results. As noted above, the transport of phosphorus can occur in dissolved and particulate forms. The forms of particulate phosphorus include phosphorus sorbed by soil particles and organic matter eroded during runoff and may comprise a major proportion of phosphorus transported from land, which is the case in the Zumbro River watershed.

For the baseline scenario, the model calculated annual average TP loads of 1,066,650 lbs/yr at the watershed outlet and 596,738 lbs/yr to Lake Zumbro. The TP yield calculated for the baseline run was 0.73 lbs/acre/yr. For the point source scenario set at the permitted effluent flow and constituent limits (A), the model-estimated annual TP loading to the watershed outlet and to Lake Zumbro is 6% and 11% greater, respectively, than the baseline run (Tables 8-9, Figures 13-14). The increase in the TP load is attributed to higher effluent flows and/or TP concentrations specified in the permitted limits compared to the effluent flows and TP concentrations in the baseline run, which reflects historical effluent discharges based on reported measurements.

The point source scenario where the effluent flow is set at 70% AWWDF and TP concentrations are set at the RES (B), the TP load reduction is 1% at the watershed outlet and 2% at Lake Zumbro (Tables 8-9, Figures 13-14). The decrease in TP load can be attributed to the lower TP concentrations specified by the RES. It is important to note that while the TP concentrations are lower in this scenario, the effluent flow is set at 70% AWWDF, which is higher than the baseline. The point source scenario where the effluent flow is set at 70% AWWDF and TP concentrations are set at 0.5 mg P/L for the Byron, Dodge Center, Kasson, Mantorville, and Pine Island WWTPs and 0.4 mg P/L for the Rochester WWTP (C), the TP load reduction is 0.2% at the watershed outlet and 1% at Lake Zumbro (Tables 8-9, Figures 13-14). The TP load reduction in this scenario is less than for the RES scenario (B) and is attributable to the effluent flow and TP concentrations set at the baseline for the other point sources. It should be noted that the low flow summer periods (i.e., June - September) will have different percent reductions from the annual percent reductions described above.

Similar to sediment, the green infrastructure implementation scenarios (E and F) resulted in a small reduction of annual TP loading to the watershed outlet and to Lake Zumbro, ranging from ≤1% at the 5% level of implementation to 2% at the 25% level of implementation (Tables 8-9, Figures 13-14). As with sediment it was not expected that the green infrastructure implementation would result in a substantial TP load reduction at the watershed outlet or to Lake Zumbro given the small area of developed land across the watershed. However, as with sediment, greater water quality benefits would be expected at the local, tributary scale where developed land cover dominates.

The application of conservation tillage (scenario D) to 30% of the highest sediment yielding cropland acres in the model resulted in an estimated annual TP load reduction of 13% at the watershed outlet and 22% at Lake Zumbro compared to the baseline run (Tables 8-9, Figures 13-14). The application of cover crops (scenario H) to 30% of the cropland acres in the model resulted in an estimated annual TP load reduction of 11% at the watershed outlet and 18% at Lake Zumbro compared to the baseline run (Tables 8-9, Figures 13-14). The results of the sedimentation pond scenario (I) indicate a reduction in annual TP loading of 6% at the watershed outlet and 12% at Lake Zumbro relative to the baseline (Tables 8-9, Figures 13-14). Similar to sediment, the higher level of reduction at Lake Zumbro compared to the watershed outlet for this scenario can be attributed to the majority of new treatment ponds being added upstream of Lake Zumbro. Since TP is primarily transported via surface runoff, the reduction in TP loading is consistent with the capture and "treatment" of surface runoff simulated in the detention pond scenario as compared to no "treatment" in the baseline run.

For the combined management scenario (J), the annual TP load reduction estimated is 15% at the watershed outlet and 26% at Lake Zumbro (Tables 8-9, Figures 13-14). As with sediment, the combined management scenario is estimated to provide the greatest overall load reduction with the exception of the pre-settlement vegetation scenario discussed below.

The pre-settlement vegetation scenario (G) provides a pre-settlement reference for the TP loading rates in the Zumbro River watershed. The pre-settlement loading rate of TP is 0.062 lb/acre/yr, which is approximately eleven-fold lower than the baseline run of 0.730 lbs/acre/yr (Tables 8-9, Figures 13-14). The pre-settlement vegetation TP yield (0. 062 lbs/acre/yr) estimated by the model is consistent with the range of unit area TP loading rates reported in the literature for forested landscape across the US (0.012 – 0.178 lbs/acre/yr) (CH2M Hill and AQUA TERRA 2002). Under pre-settlement vegetation conditions, the estimated annual TP loading at the watershed outlet is approximately 69% lower at the watershed outlet and 81% lower at Lake Zumbro when compared to the baseline scenario (Tables 8-9, Figures 13-14). The results of this scenario indicate the conversion of natural landscape to agriculture and developed land uses in the watershed has significantly increased the phosphorus sources and loading in the Zumbro River watershed.

Phosphorus landscape yield scenario maps are provided in Appendix B.

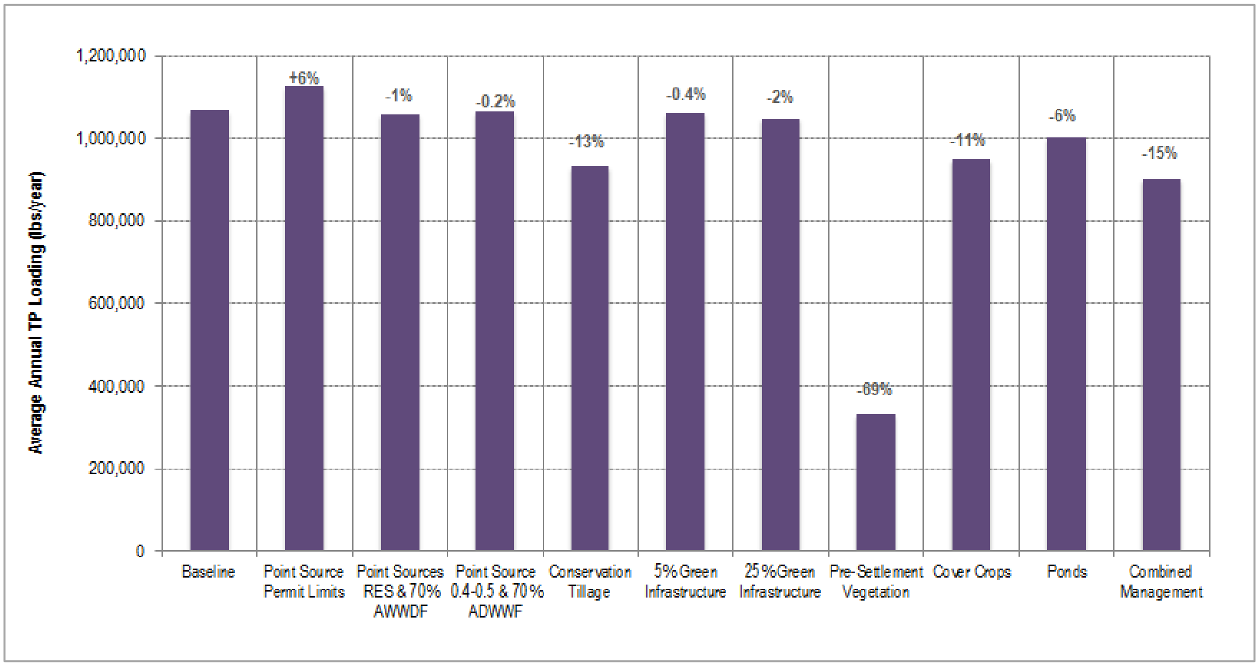


**Figure 13. Annual average simulated total phosphorus loading at the Zumbro River watershed outlet for the baseline run and management scenarios (1996 – 2009).**

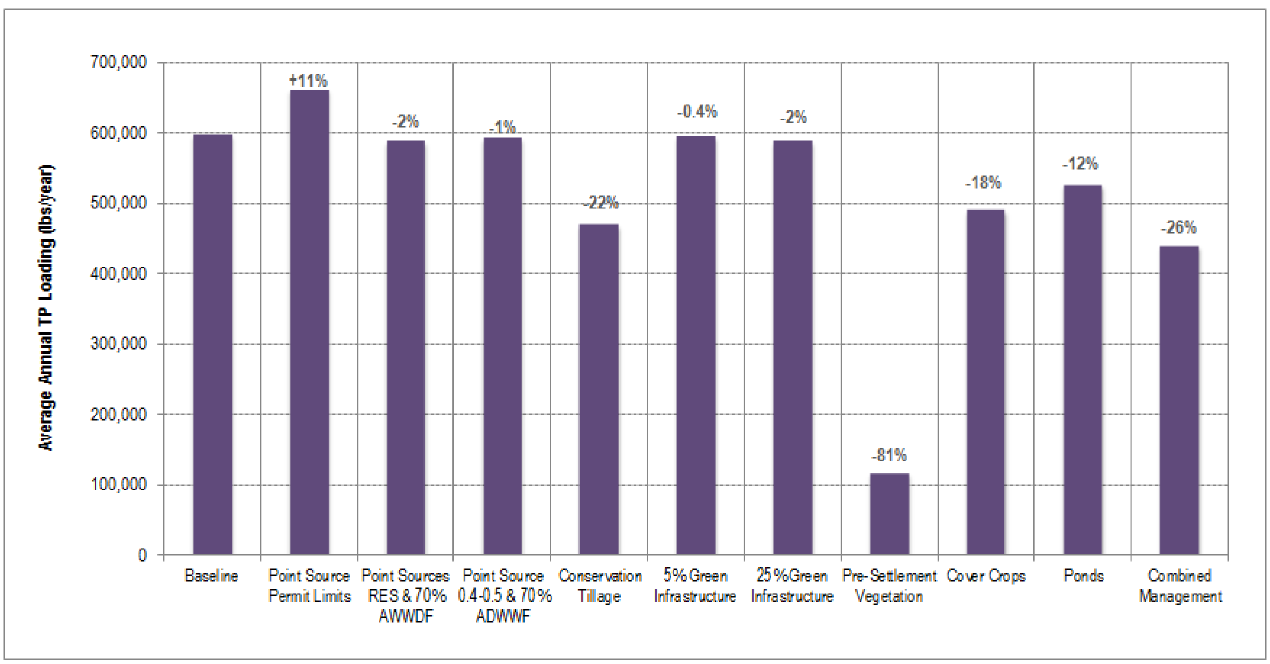


**Figure 14. Annual average simulated total phosphorus loading to Lake Zumbro for the baseline run and management scenarios (1996 – 2009).**

**Table 8. Summary of simulated phosphorus yields and loading at the Zumbro River watershed outlet for the baseline and management scenarios (1996-2009).**

| Scenario ID | Scenario Description | TP Yield[a] (lbs/acre/yr) | TP Loading (lbs/yr) | Relative TP Loading Change | PO4 Yield (lbs/acre/yr) | PO4 Loading (lbs/yr) | Relative PO4 Loading Change |
|---|---|---|---|---|---|---|---|
| - | Baseline | 0.730 | 1,066,650 | - | 0.659 | 962,285 | - |
| A | Point Sources at Permitted Limits | 0.730[b] | 1,126,569 | +6% | 0.659[b] | 1,006,688 | +5% |
| B | Point Sources at RES & 70% AWWDF | 0.730[b] | 1,058,992 | -1% | 0.659[b] | 960,243 | -0.2% |
| C | Select Point Sources at 0.4-0.5 mg P/L & 70% AWWDF | 0.730[b] | 1,064,702 | -0.2% | 0.659[b] | 961,748 | -0.1% |
| D | Conservation Tillage | 0.562 | 932,498 | -13% | 0.500 | 839,339 | -13% |
| E | Green Infrastructure - 5% Implementation | 0.729 | 1,062,163 | -0.4% | 0.657 | 958,183 | -0.4% |
| F | Green Infrastructure - 25% Implementation | 0.723 | 1,048,508 | -2% | 0.653 | 945,715 | -2% |
| G | Pre-settlement Vegetation | 0.062 | 331,001 | -69% | 0.045 | 305,344 | -68% |
| H | Cover Crop | 0.602 | 949,688 | -11% | 0.538 | 854,695 | -11% |
| I | Sedimentation Ponds | 0.626 | 1,003,553 | -6% | 0.551 | 901,826 | -6% |
| J | Combined Management | 0.533 | 902,321 | -15% | 0.467 | 810,821 | -16% |

[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.*

**Table 9. Summary of simulated phosphorus yields and loading to Lake Zumbro for the baseline and management scenarios (1996-2009).**

| Scenario ID | Scenario Description | TP Loading (lbs/yr) | Relative TP Loading Change | PO4 Loading (lbs/yr) | Relative PO4 Loading Change |
|---|---|---|---|---|---|
| - | Baseline | 596,738 | | 524,669 | |
| A | Point Sources at Permitted Limits | 661,130 | +11% | 562,843 | +7% |
| B | Point Sources at RES & 70% AWWDF | 587,740 | -2% | 518,549 | -1% |
| C | Select Point Sources at 0.4-0.5 mg P/L & 70% AWWDF | 592,080 | -1% | 521,406 | -1% |
| D | Conservation Tillage | 468,121 | -22% | 406,169 | -23% |
| E | Green Infrastructure - 5% Implementation | 594,353 | -0.4% | 522,551 | -0.4% |
| F | Green Infrastructure - 25% Implementation | 587,705 | -2% | 516,756 | -2% |
| G | Pre-Settlement Vegetation | 114,695 | -81% | 99,195 | -81% |
| H | Cover Crop | 489,164 | -18% | 425,499 | -19% |
| I | Sedimentation Ponds | 525,436 | -12% | 455,883 | -13% |
| J | Combined Management | 438,662 | -26% | 378,330 | -28% |

## *Nitrogen*

A comparison of nitrogen yields and loading (TN and nitrate (NO3)) for the baseline run and the various management scenarios on an annual average basis over the simulation period (1996-2009) is provided in Tables 10-11 and Figures 15-16 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 Zumbro (in lbs/yr). The relative load change is calculated as the annual average scenario load minus the baseline load, divided by the baseline loadat the watershed outlet and to Lake Zumbro. 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 Zumbro River watershed, a large majority of the model simulated TN (about 90%) is in the form of nitrate. The results for nitrate are presented in detail in Tables 10 and 11.

For the baseline scenario, the model calculated an annual average TN load of 14,491,430 lbs/yr at the watershed outlet and 9,377,835 lbs/yr to Lake Zumbro. The TN yield calculated for the baseline run was 15.6 lbs/acre/yr. For the point source scenario set at the permitted effluent flow and constituent limits (A), the model-estimated annual TN loading to the watershed outlet and to Lake Zumbro is 9% and 14% greater, respectively, than the baseline run (Tables 10-11, Figures 15-16). The increase in the TN load is attributed to higher effluent flows and TN concentrations specified in the permitted limits compared to the effluent flows and TN concentrations in the baseline run, which reflects historical effluent discharges based on reported measurements. The annual TN load for the point source scenarios where the effluent flow is set at 70% AWWDF (B and C) is 1% greater at the watershed outlet and 2% greater to Lake Zumbro relative to the baseline, which can be attributed to the 70% AWWDF flows that are higher than the baseline.

Similar to sediment and phosphorus, the green infrastructure implementation scenarios (E and F) resulted in a small reduction of annual TN loading to the watershed outlet and Lake Zumbro, ranging from ≤1% at the 5% level of implementation to 1% at the 25% level of implementation (Tables 10-11, Figures 15-16). As with sediment and phosphorus, it is not expected that the green infrastructure implementation would result in a substantial TN load reduction at the watershed outlet or to Lake Zumbro given the small area of developed land across the watershed where practices were implemented in the scenario. However, an increased level of water quality benefits would be expected at the local, tributary scale where developed land cover dominates.

The application of conservation tillage (D) to 30% of the highest sediment yielding cropland acres in the model resulted in an estimated annual TN load reduction of 5% at the watershed outlet and 6% to Lake Zumbro relative to the baseline run (Tables 10-11, Figures 15-16). The application of cover crops (H) to 30% of the cropland acres in the model resulted in an estimated annual TN load reduction of 8% at the watershed outlet and 11% to Lake Zumbro compared to the baseline run (Tables 10-11, Figures 15-16). These results appear to be fairly consistent with a Minnesota study reported by Miller et al. (2012), which consisted of a three-year study in Lamberton, Minnesota where nitrate loss was reduced by 13% with cover crop implementation on a corn-soybean rotation.

The results of the sedimentation pond scenario (I) indicate a reduction in annual TN loading of 1% at the watershed outlet and 1% to Lake Zumbro relative to the baseline (Tables 10-11  Figures 15-16). Given that the majority of nitrogen is in the form of nitrate andt the residence time of the ponds is short, the low TN reduction from the implementation of ponds is expected. For the combined management scenario (J), the annual TN load reduction estimated is 8% at the watershed outlet and 10% at Lake Zumbro (Tables 10-11, Figures 15-16). The cover crop scenario is estimated to provide the greatest overall load reduction with the exception of the pre-settlement vegetation scenario discussed below. The model results indicate the combined management scenario is slightly less effective in reducing TN loads compared to the cover crop scenario. This is likely attributable to the expected low reduction of TN load with the addition of sedimentation ponds and the increase in point source discharge that result from effluent flows set to 70% AWWDF.

The pre-settlement vegetation scenario provides a pre-settlement reference for the nitrogen loading rates in the Zumbro River watershed. The pre-settlement vegetation loading rates of TN is 1.1 lb/acre/yr, which is approximately fourteen-fold lower than the baseline run of 15.6 lbs/acre/yr (Tables 10-11, Figures 15-16). The pre-settlement loading rate of TN is 1.1 lb/acre/yr is consistent with the range of unit area sediment loading rates reported in the literature for forested landscape across the US (0.635 – 5.692 lbs/acre/yr) (CH2M Hill and AQUA TERRA 2002; Lin et. al 2004). For pre-settlement conditions, the model-estimated annual TN loading at the watershed outlet is 93% lower at the watershed outlet and 94% lower at Lake Zumbro when compared to the baseline run (Tables 10-11, Figures 15-16). 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 Zumbro River watershed.

Nitrogen landscape yield scenario maps are in Appendix C.

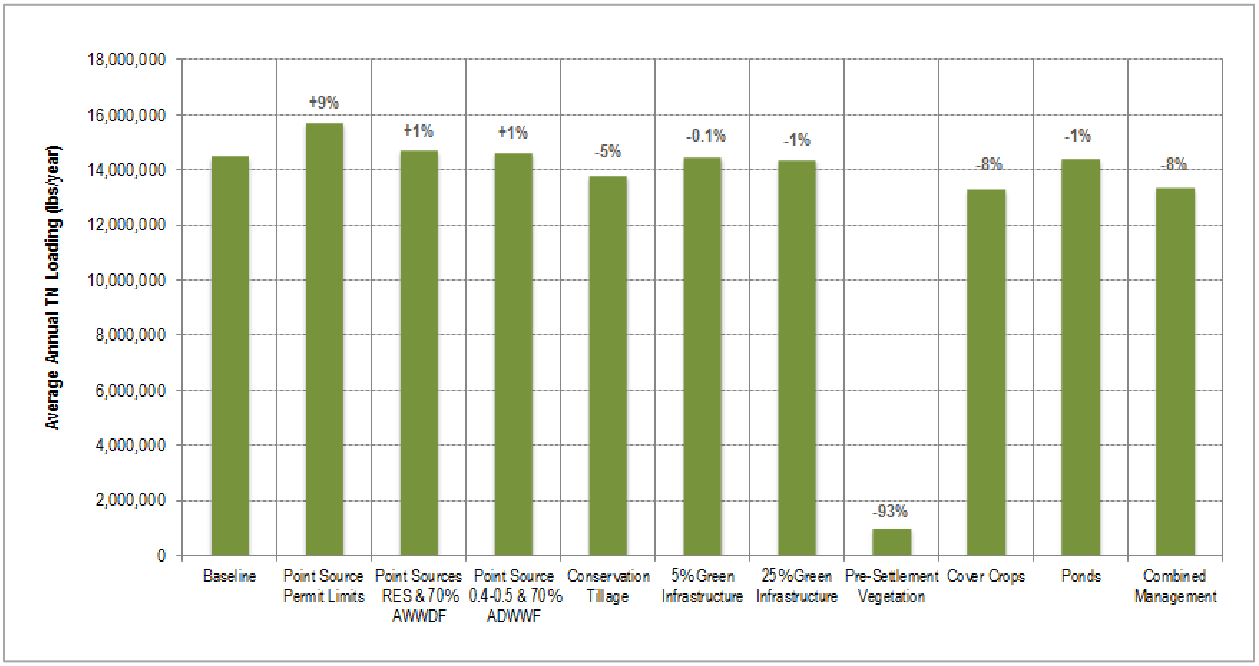


**Figure 15. Annual average simulated total nitrogen loading at the Zumbro River watershed outlet for baseline and management scenarios (1996 – 2009).**

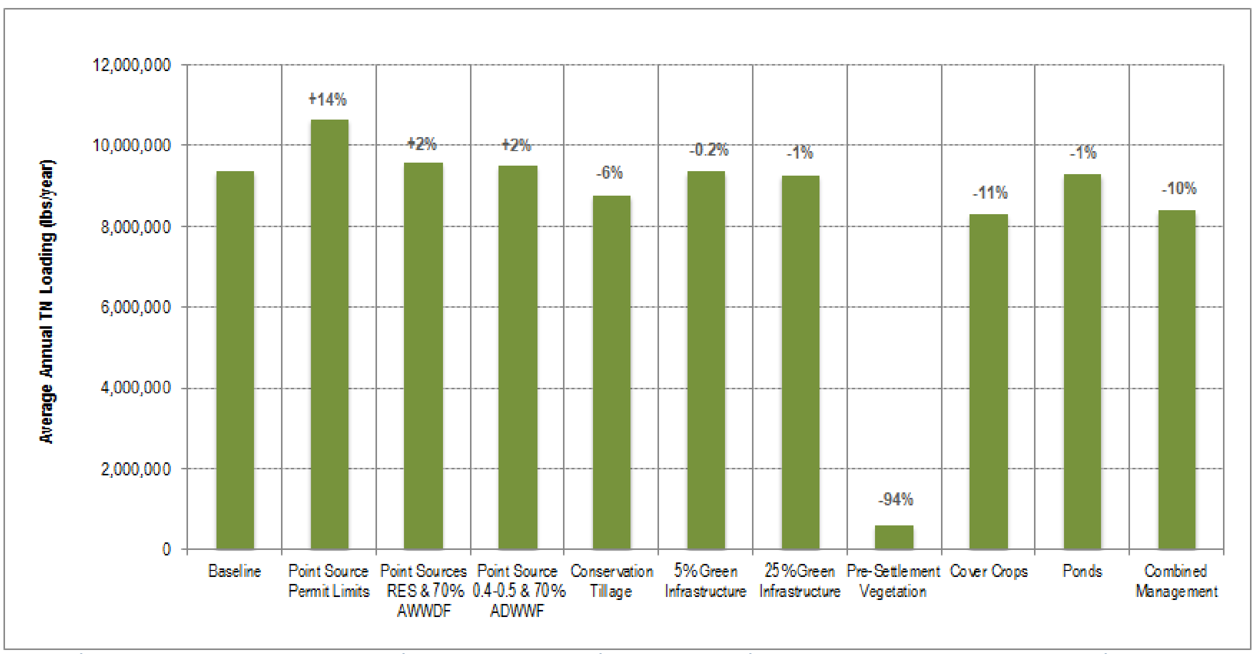


**Figure 16. Annual average simulated total nitrogen loading to Lake Zumbro for baseline and management scenarios (1996 – 2009).**

**Table 10. Summary of simulated nitrogen yields and loading at the Zumbro River watershed outlet for the baseline and management scenarios (1996-2009).**

| Scenario ID | Scenario | TN Yield[a] (lbs/acre/yr) | TN Loading (lbs/yr) | Relative TN Loading Change | NO3 Yield (lbs/acre/yr) | NO3 Loading (lbs/yr) | Relative NO3 Loading Change |
|---|---|---|---|---|---|---|---|
| - | Baseline | 15.6 | 14,491,430 | - | 14.2 | 13,267,079 | - |
| A | Point Sources at Permitted Limits | 15.6[b] | 15,728,277 | +9% | 14.2[b] | 14,105,670 | +6% |
| B | Point Sources at RES & 70% AWWDF | 15.6[b] | 14,705,576 | +1% | 14.2[b] | 13,485,826 | +2% |
| C | Select Point Sources at 0.4-0.5 mg P/L & 70% AWWDF | 15.6[b] | 14,638,951 | +1% | 14.2[b] | 13,417,747 | +1% |
| D | Conservation Tillage | 14.8 | 13,795,291 | -5% | 13.5 | 12,677,813 | -4% |
| E | Green Infrastructure - 5% Implementation | 15.5 | 14,469,738 | -0.1% | 14.2 | 13,251,253 | -0.1% |
| F | Green Infrastructure - 25% Implementation | 15.4 | 14,376,662 | -1% | 14.1 | 13,176,544 | -1% |
| G | Pre-Settlement Vegetation | 1.1 | 1,018,348 | -93% | 0.9 | 747,566 | -94% |
| H | Cover Crop | 14.2 | 13,287,958 | -8% | 12.9 | 12,156,770 | -8% |
| I | Sedimentation Ponds | 15.1 | 14,395,750 | -1% | 13.8 | 13,215,126 | -0.4% |
| J | Combined Management | 13.8 | 13,359,586 | -8% | 12.5 | 12,269,164 | -8% |

[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 11. Summary of simulated nitrogen yields and loading to Lake Zumbro for the baseline and management scenarios (1996-2009).**

| Scenario ID | Scenario | TN Loading (lbs/yr) | Relative TN Loading Change | NO3 Loading (lbs/yr) | Relative NO3 Loading Change |
|---|---|---|---|---|---|
| - | Baseline | 9,377,835 | | 8,466,255 | |
| A | Point Sources at Permitted Limits | 10,667,114 | +14% | 8,938,253 | +6% |
| B | Point Sources at RES & 70% AWWDF | 9,588,601 | +2% | 8,651,405 | +2% |
| C | Select Point Sources at 0.4-0.5 mg P/L & 70% AWWDF | 9,524,906 | +2% | 8,612,133 | +2% |
| D | Conservation Tillage | 8,780,637 | -6% | 7,965,981 | -6% |
| E | Green Infrastructure - 5% Implementation | 9,357,622 | -0.2% | 8,452,819 | -0.2% |
| F | Green Infrastructure - 25% Implementation | 9,281,879 | -1% | 8,395,041 | -1% |
| G | Pre-Settlement Vegetation | 605,849 | -94% | 437,628 | -95% |
| H | Cover Crop | 8,315,072 | -11% | 7,487,565 | -12% |
| I | Sedimentation Ponds | 9,296,690 | -1% | 8,422,734 | -1% |
| J | Combined Management | 8,400,022 | -10% | 7,603,067 | -10% |

## Management Scenario Summary

A suite of potential management practices or BMPs were evaluated with the ZRWHSPF 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 and keep in mind 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% for specific targeted land areas. The land area coverage also differs by land use type across the watershed (i.e., more agricultural land area than developed land area). Finally, the location of management practice or BMP implementation is not the same across the scenarios. Therefore, the level of implementation, the land area coverage, and the location of implementation for each scenario must be taken into consideration when using the information to help inform management decisions. Management scenario results have been generally expressed as the "percent change relative to 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 (J), conservation tillage (D), cover crops (H) and sedimentation ponds (I);
- Total Phosphorus (TP) and Orthophosphate (PO4): combined management (J), conservation tillage (D) and cover crops (H); and
- Total Nitrogen (TN) and Nitrate (NO3): cover crops (H) and combined management (J).

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. A refined watershed model with improved accuracy was developed for assessing impairment issues.
2. 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.
3. 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.

# References

CH2M Hill and AquaTerra Consultants. 2002. BASINS Training California Water Board. Technical Memorandum. Prepared for California State Water Resources Control Board. Prepared by CH2M Hill and AquaTerra Consultants. September 30, 2002.

Ellison, C.A., Savage, B.E. and G.D. Johnson. 2014. Suspended-Sediment Concentrations, Loads, Total Suspended Solids, Turbidity, and Particle-Size Fractions for Selected Rivers in Minnesota, 2007 through 2011. U.S. Geological Survey. Prepared in cooperation with the Minnesota Pollution Control Agency. Scientific Investigations Report 2013–5205.

Federal Land Managers' Air Quality Related Values Work Group (FLAG). 2002. Guidance on Nitrogen and Sulfur Deposition Analysis Thresholds.

Kennedy, B. 2015. Email from Beau Kennedy, Goodhue, Soil and Water Conservation District (SWCD) to Justin Watkins, Minnesota Pollution Control Agency (MPCA). Subject: RE: FW: Zumbro: Pond Scenario. May 6, 2015.

Kruger, M. 2015. Email from Matt Kruger, Wabasha, Soil and Water Conservation District (SWCD) to Justin Watkins, Minnesota Pollution Control Agency (MPCA). Subject: RE: FW: Zumbro: Pond Scenario. May 5, 2015.

LimnoTech. 2014. Zumbro River Watershed HSPF Model Development Project, Minnesota Pollution Control Agency, One Water Program. Prepared for the Minnesota Pollution Control Agency. Prepared by LimnoTech. May 12, 2014.

LimnoTech. 2015. Zumbro River Sediment Calibration Evaluation for Potential Refinement: Summary of Approach for Sediment Calibration Refinement and Enhancement. Prepared for the Minnesota Pollution Control Agency. Prepared by LimnoTech. January 5, 2015.

Lin, J.P. 2004. Review of Published Export Coefficient and Event Mean Concentration (EMC) Data. U.S. Army Corps of Engineers, Wetlands Regulatory Assistance Program. ERDC TN-WRAP-04-3. September 2004.

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

Minnesota Pollution Control Agency (MPCA). 2015. Using the treatment train approach to BMP selection. URL: http://stormwater.pca.state.mn.us/index.php/Using_the_treatment_train_approach_to_BMP_selection [Accessed September 1, 2015]. July 29, 2015.

RESPEC. 2014. Evaluation of Resource Management and Climate Change Scenarios using HSPF Model Applications. October 15, 2014. URL: https://www.wrc.umn.edu/sites/wrc.umn.edu/files/track_d_session_iv.pdf [Accessed November 19, 2014.]

Simpson, T. and S. Weammert. 2009. Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay Watershed.

Prepared for U.S. EPA's Chesapeake Bay Program Office. Prepared by University of Maryland Mid-Atlantic Water Program December 2009.

Svien, L. 2015. Email from Lawrence Svien, Zumbro Watershed Partnership to Justin Watkins, Minnesota Pollution Control Agency (MPCA). Subject: Re: FW: Zumbro: Pond Scenario. May 1, 2015.

United States Environmental Protection Agency (USEPA). 2007. EPA BASINS Technical Note 2. Two Automated Methods for Creating Hydraulic Function Tables (FTABLES). May 8, 2007.

Wotzka, P. 2015. Email from Paul Wotzka, Zumbro Watershed Partnership to Justin Watkins, Minnesota Pollution Control Agency (MPCA). Subject: Re: FW: Zumbro: Pond Scenario. May 7, 2015.

Zumbro Watershed Partnership (ZWP). 2012. Zumbro Watershed Comprehensive Management Plan, Sediment Reduction Component. wq-iw9-13c. August 9, 2012.

Zumbro River Watershed Partnership (ZWP). 2014. Zumbro River Watershed Restoration Prioritization. June 30, 2014.

# 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.

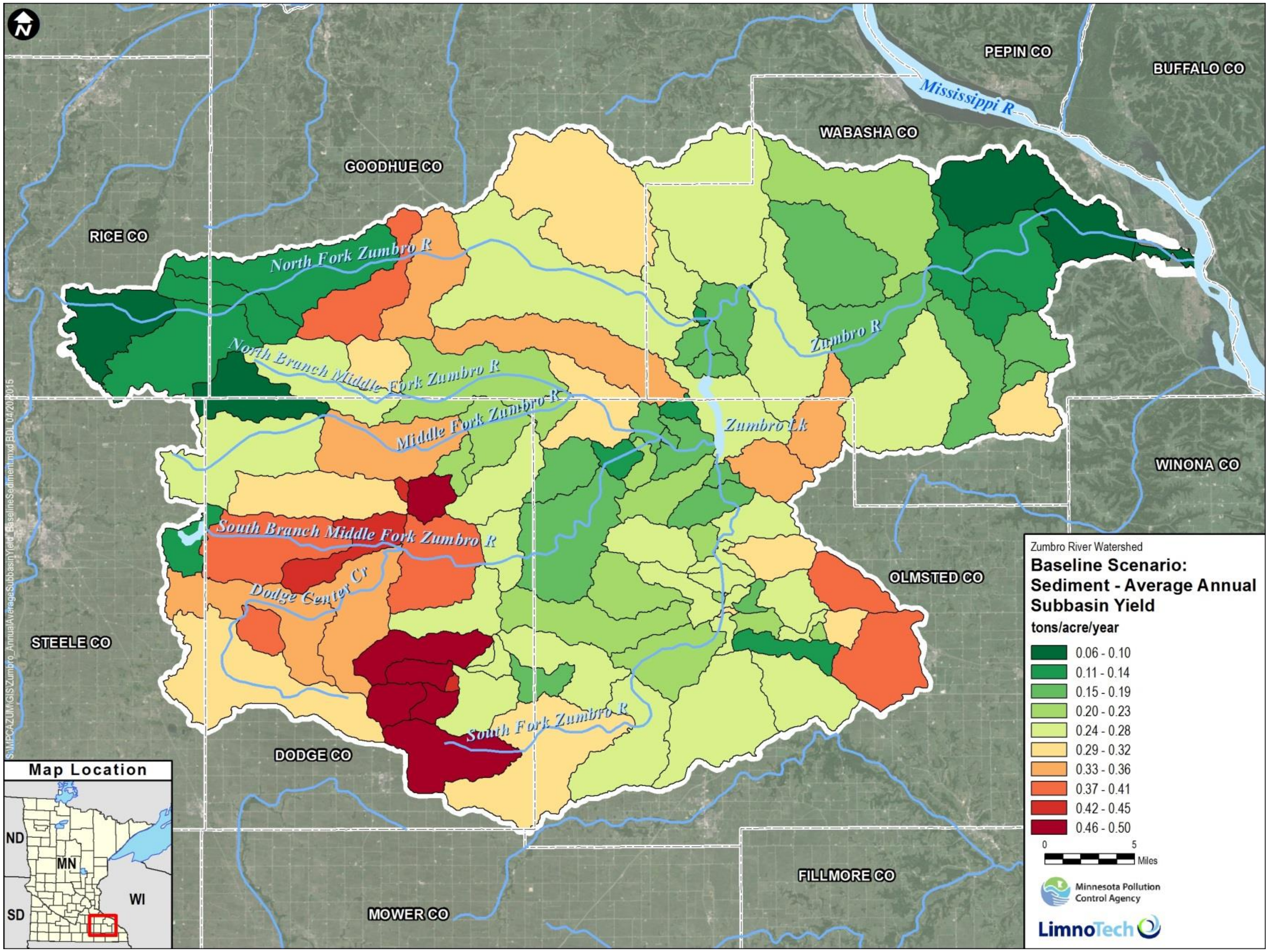


**Figure A-1. Average annual sediment subbasin yield for the baseline simulation.**

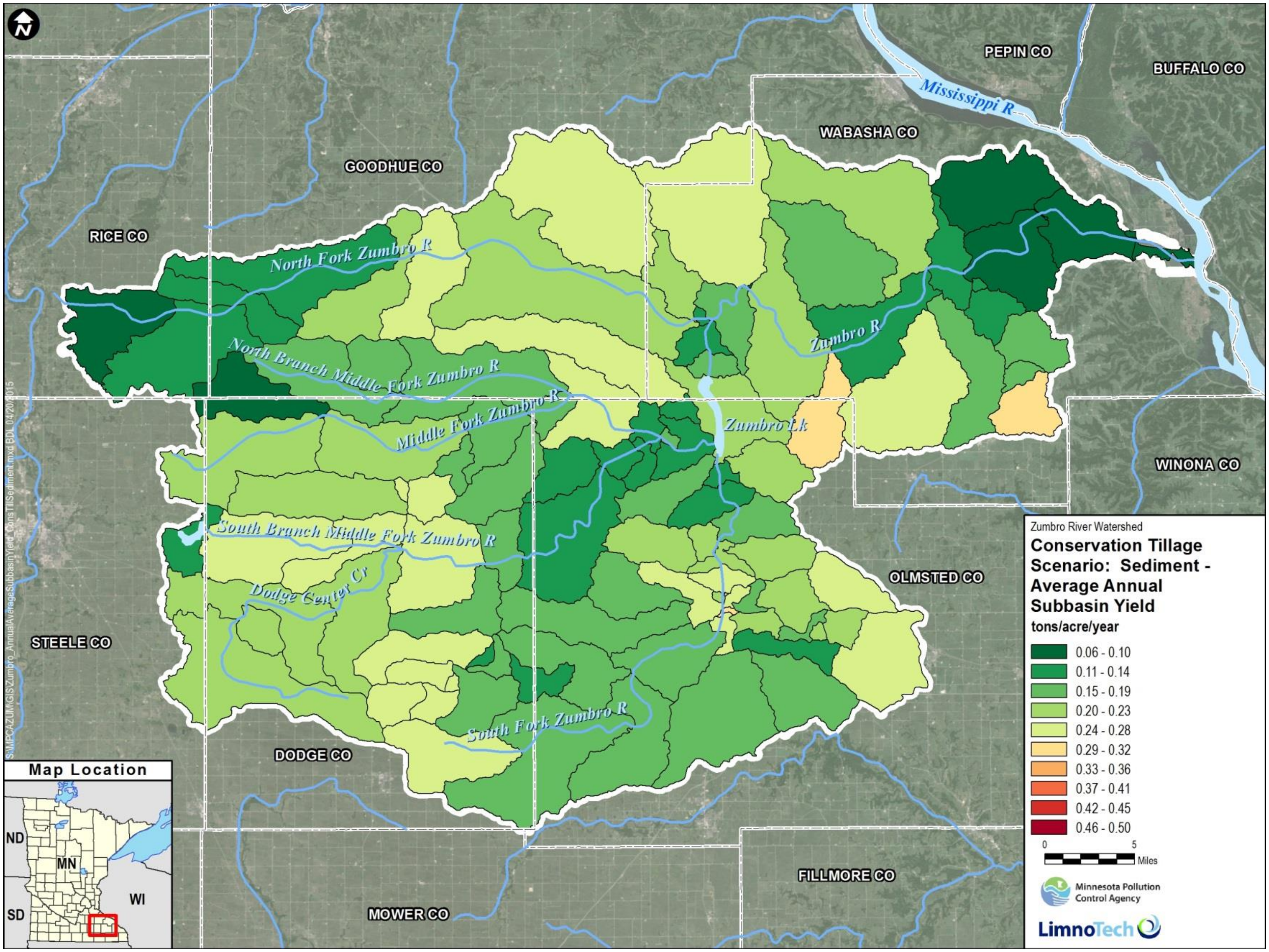


**Figure A-2. Average annual sediment subbasin yield for the conservation tillage scenario.**

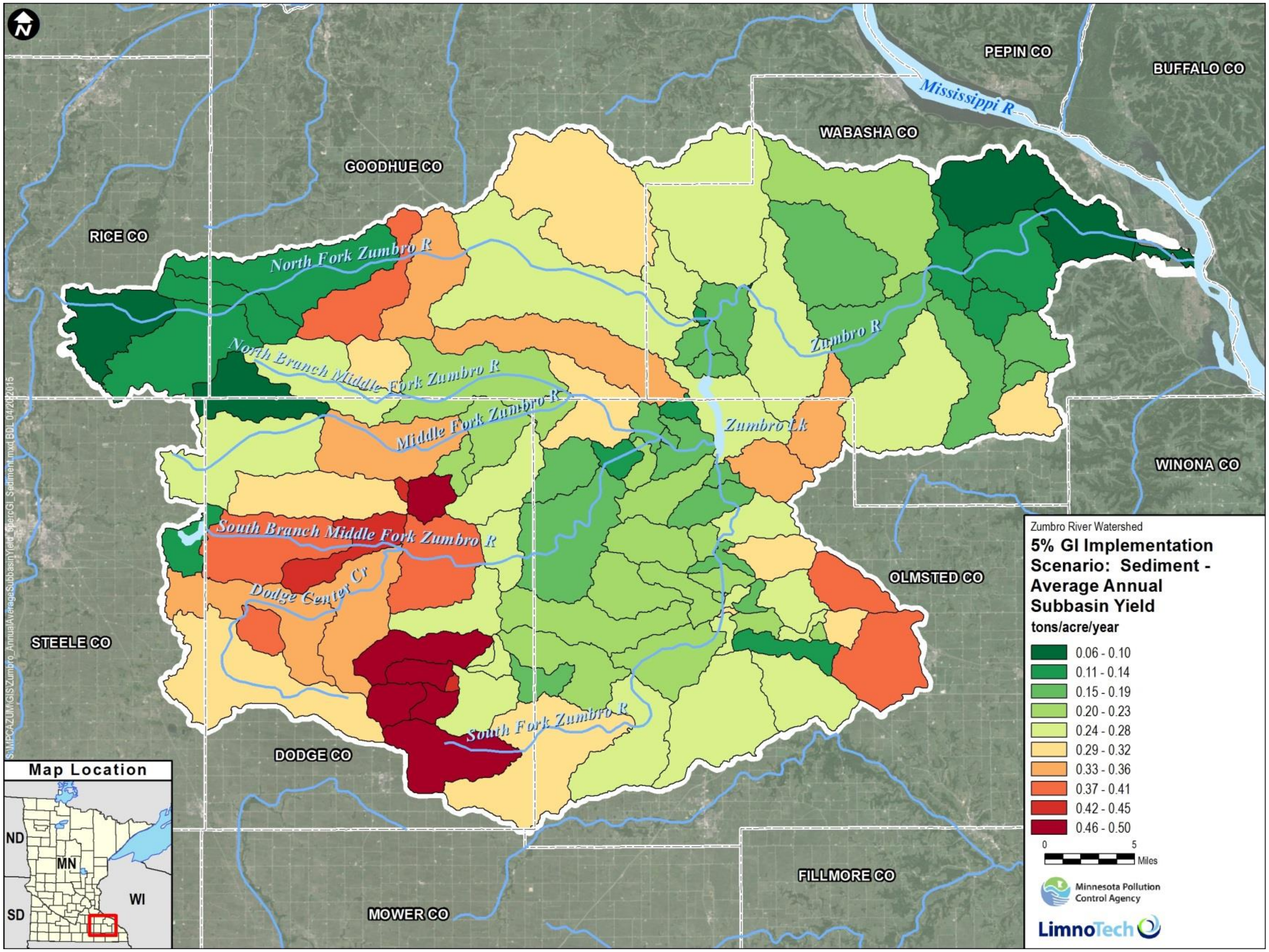


**Figure A-3. Average annual sediment subbasin yield for the green infrastructure - 5% implementation scenario.**

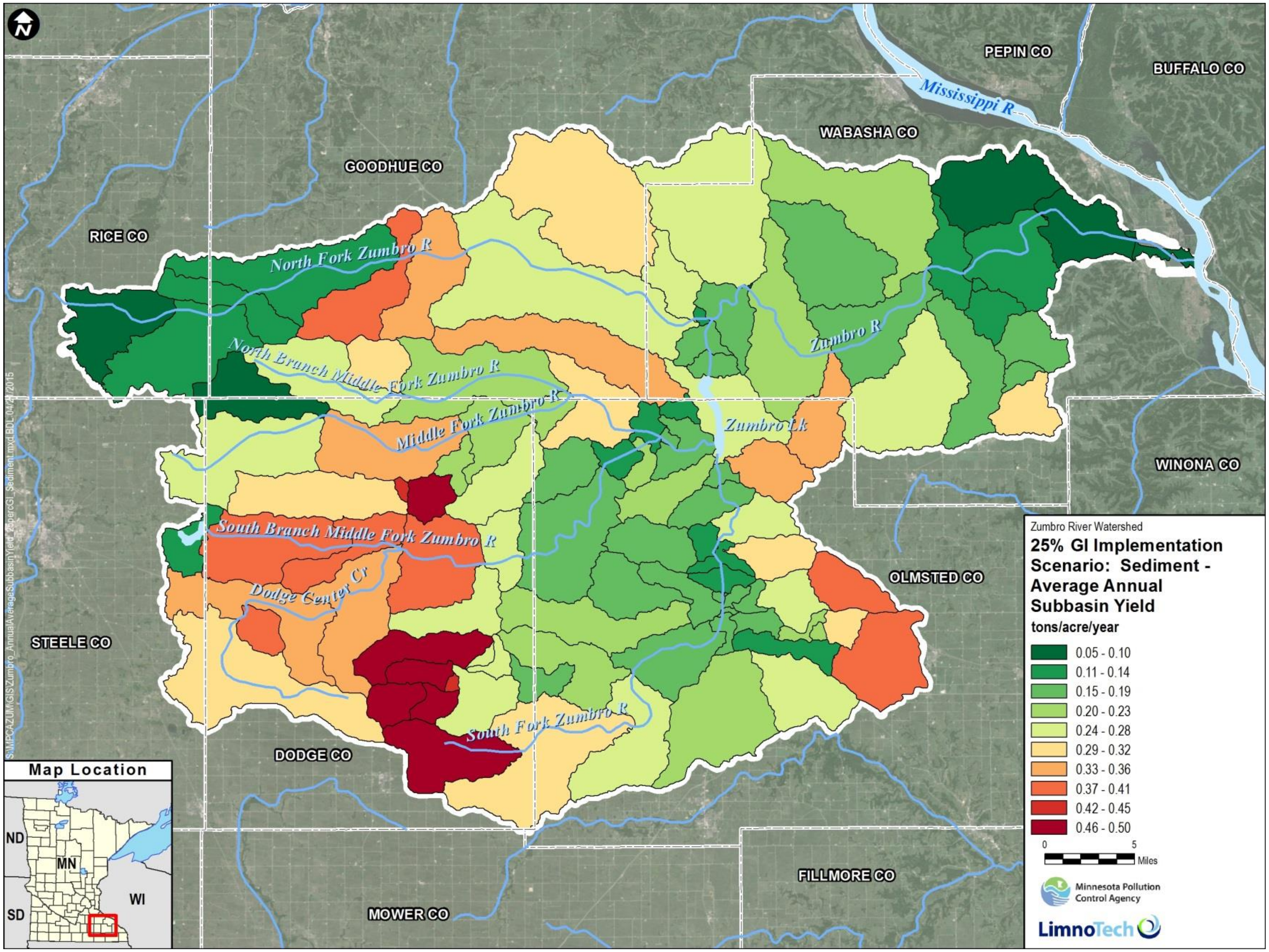


**Figure A-4. Average annual sediment subbasin yield for the green infrastructure - 25% implementation scenario.**

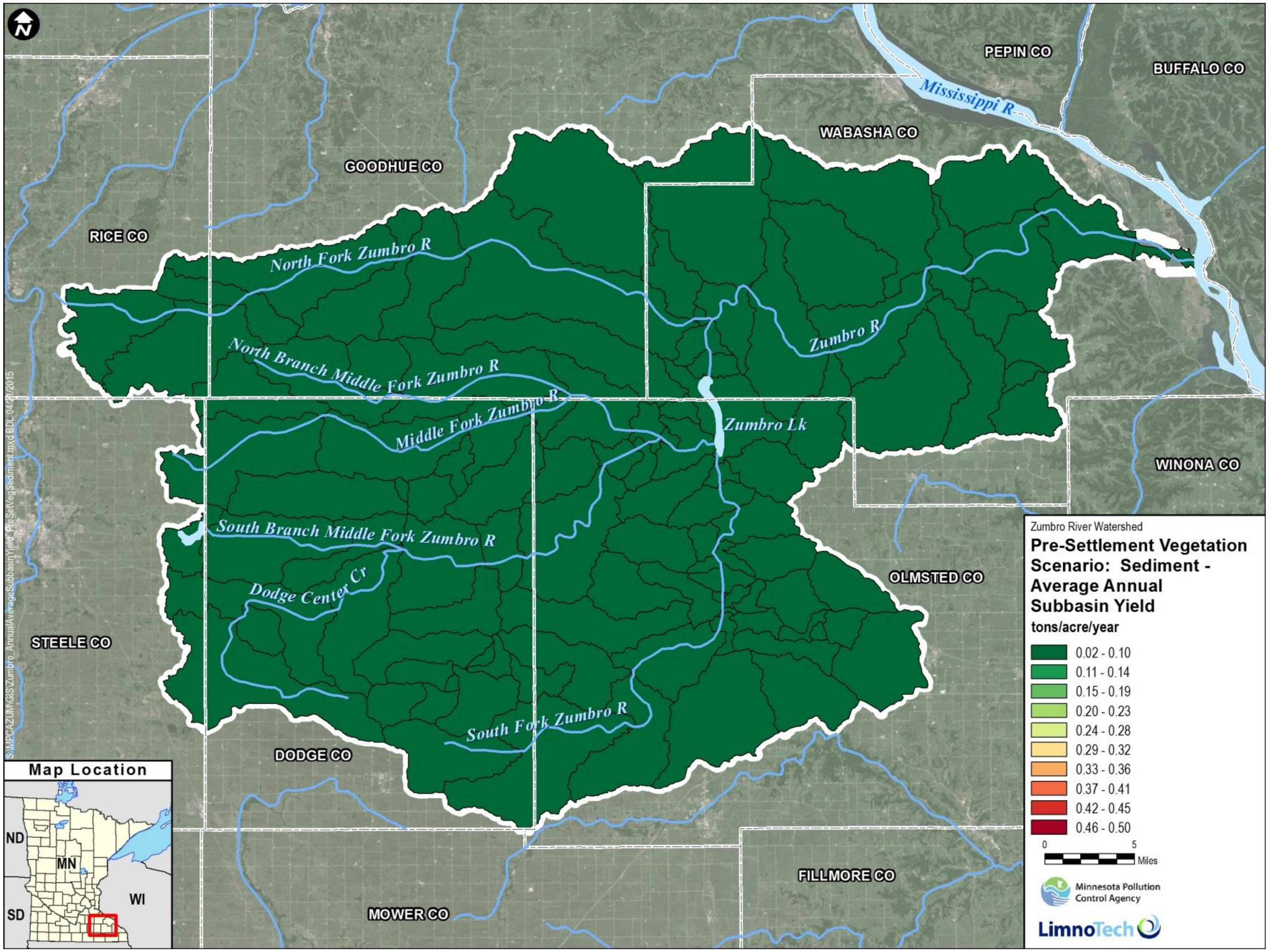


**Figure A-5. Average annual sediment subbasin yield for the pre-settlement vegetation scenario.**

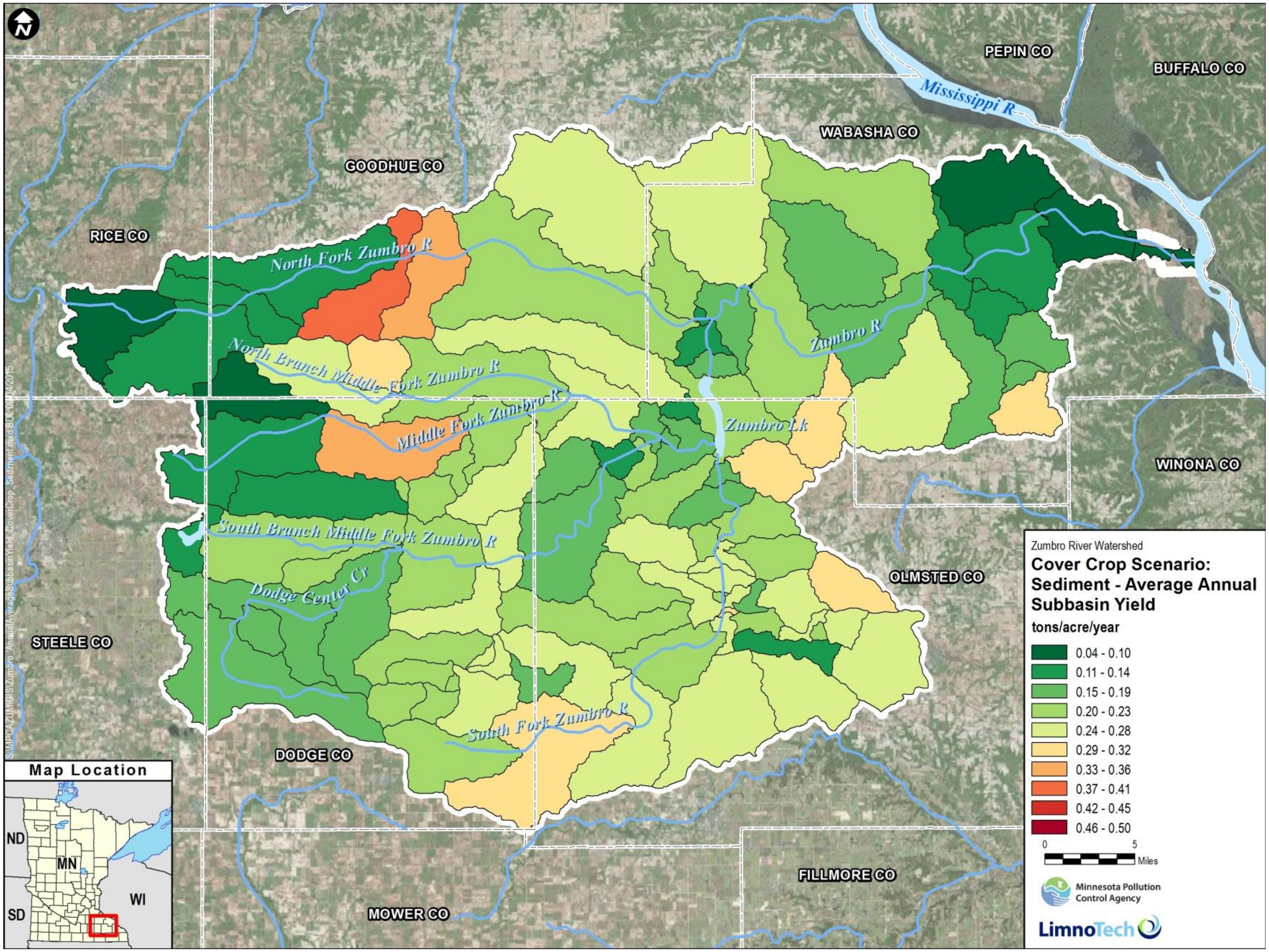


**Figure A-6. Average annual sediment subbasin yield for the cover crops scenario.**

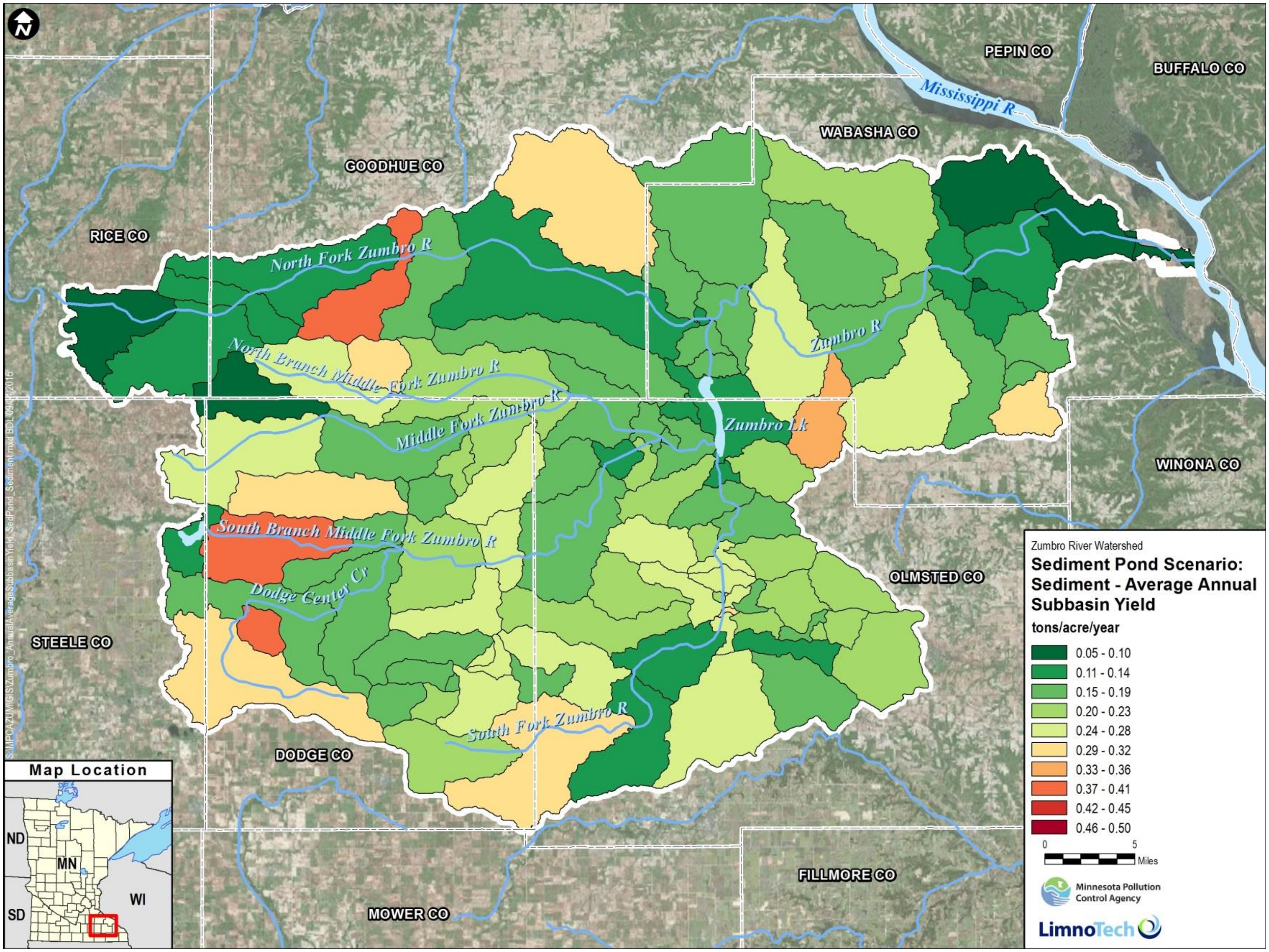


**Figure A-7. Average annual sediment subbasin yield for the sedimentation pond scenario.**

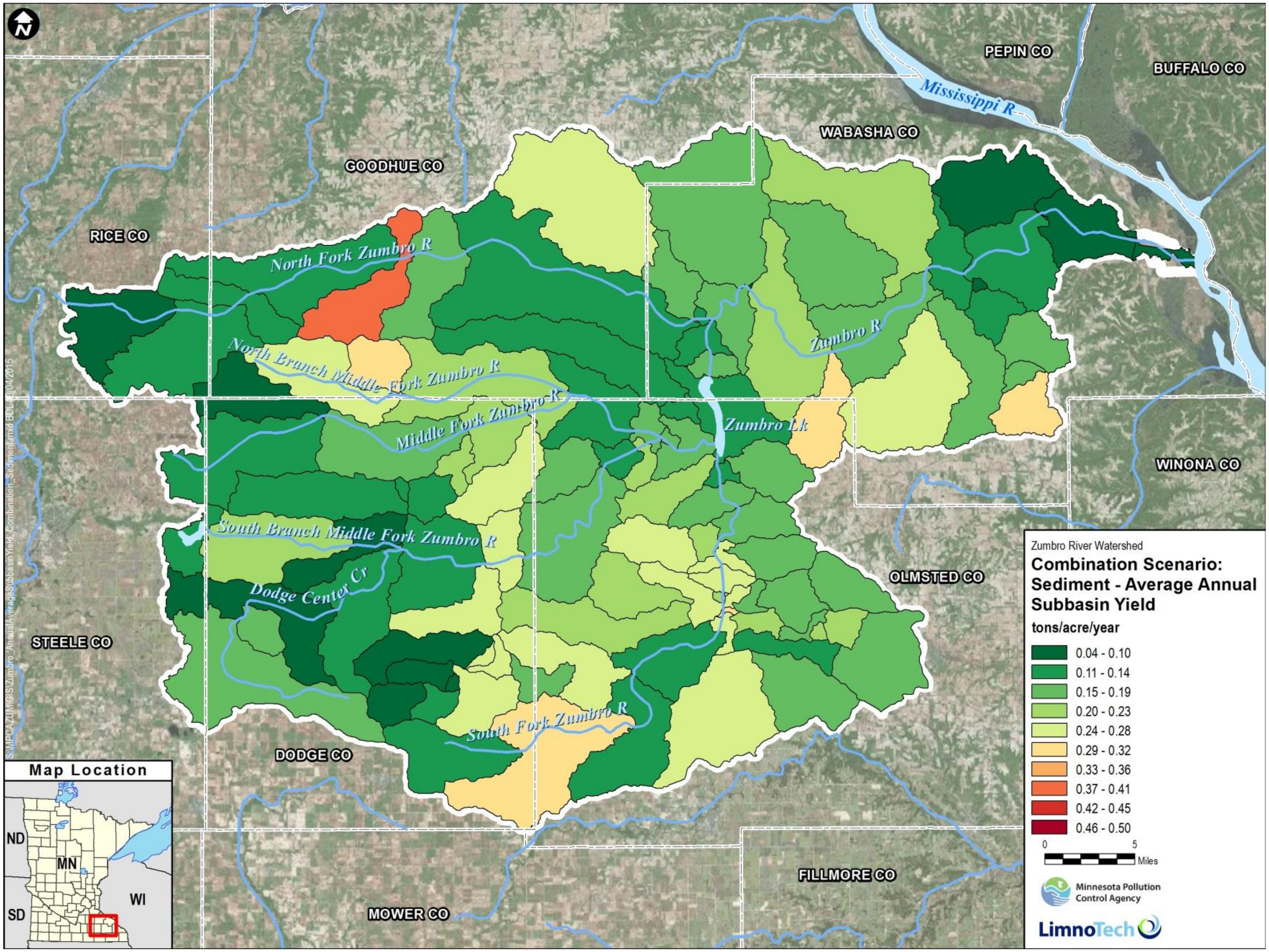


**Figure A-8. Average annual total sediment subbasin yield for the combination scenario. Note that the maps only represent landscape yields and do not account for changes in point source discharge.**

# 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.

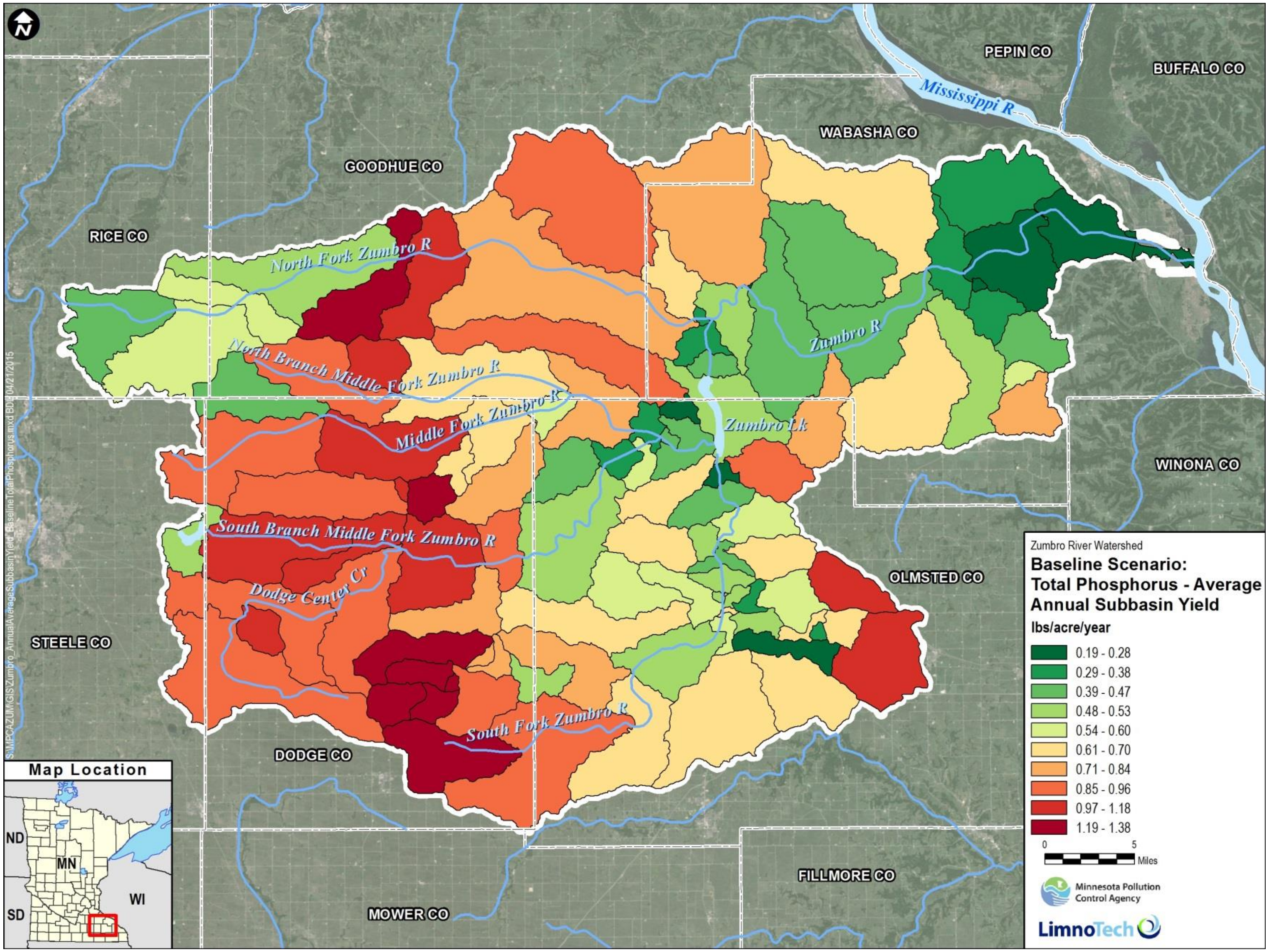


**Figure B-1. Average annual total phosphorus subbasin yield for the baseline simulation.**

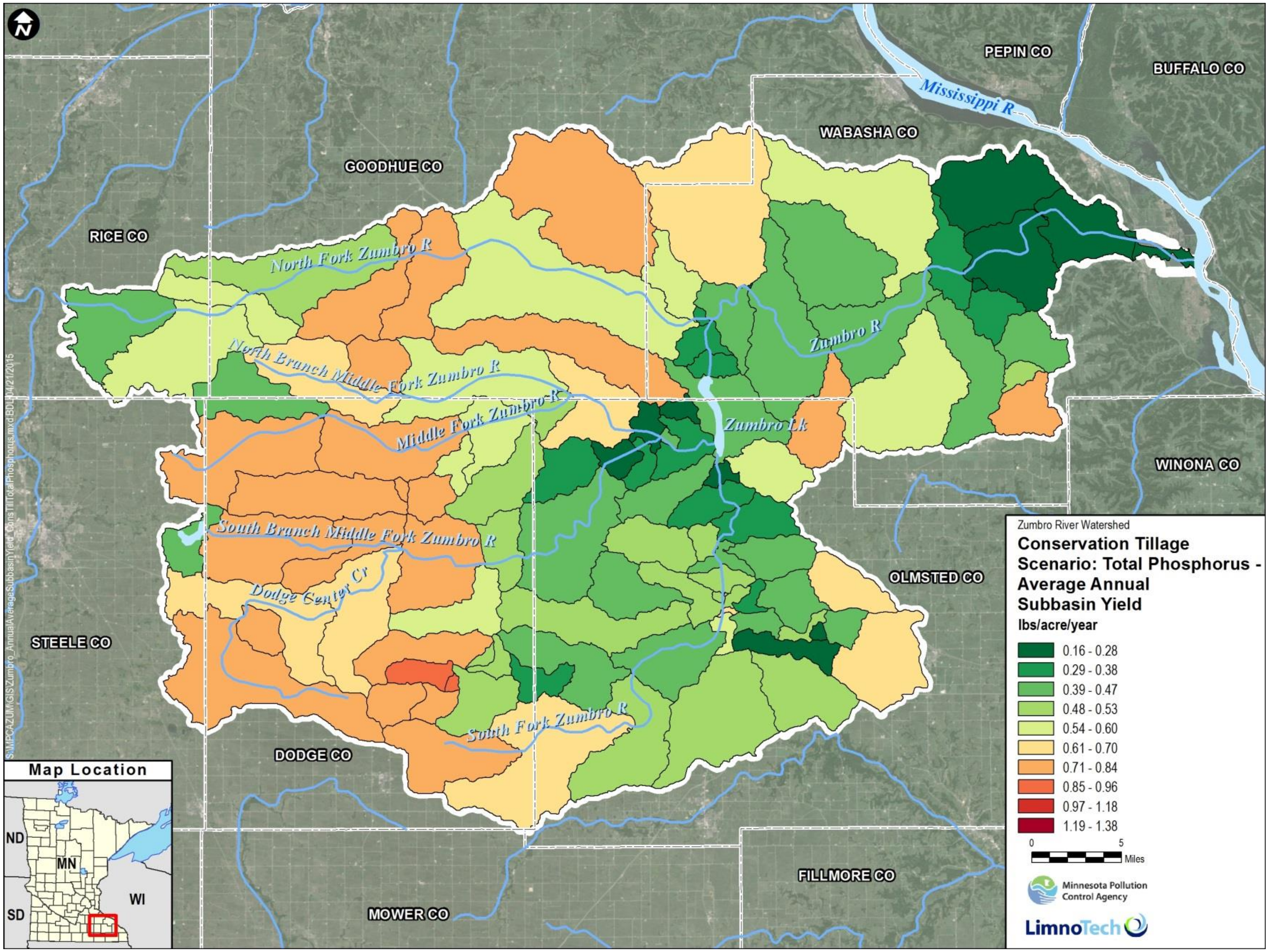


**Figure B-2. Average annual total phosphorus subbasin yield for the conservation tillage scenario.**

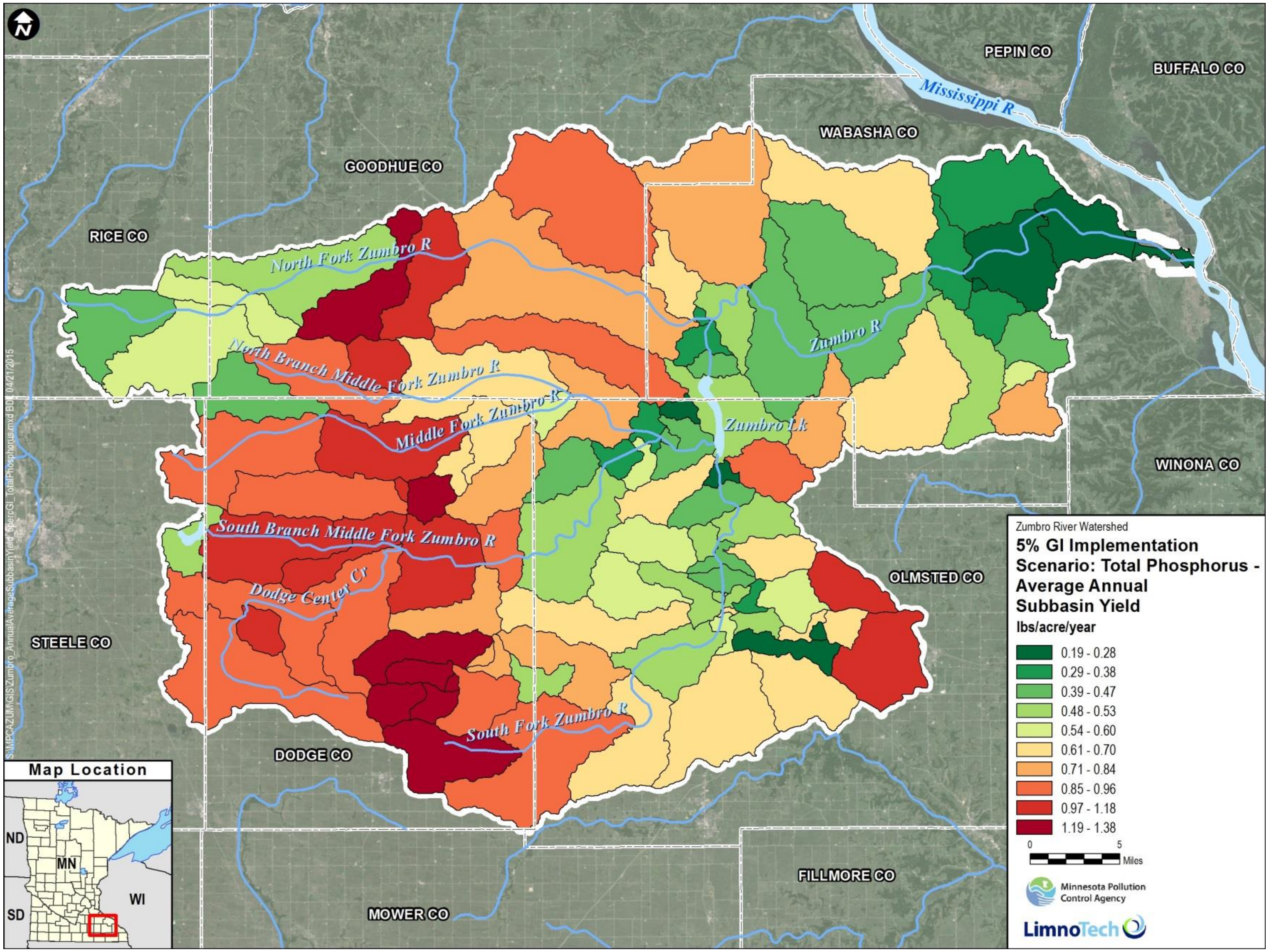


**Figure B-3. Average annual total phosphorus subbasin yield for the green infrastructure - 5% implementation scenario.**

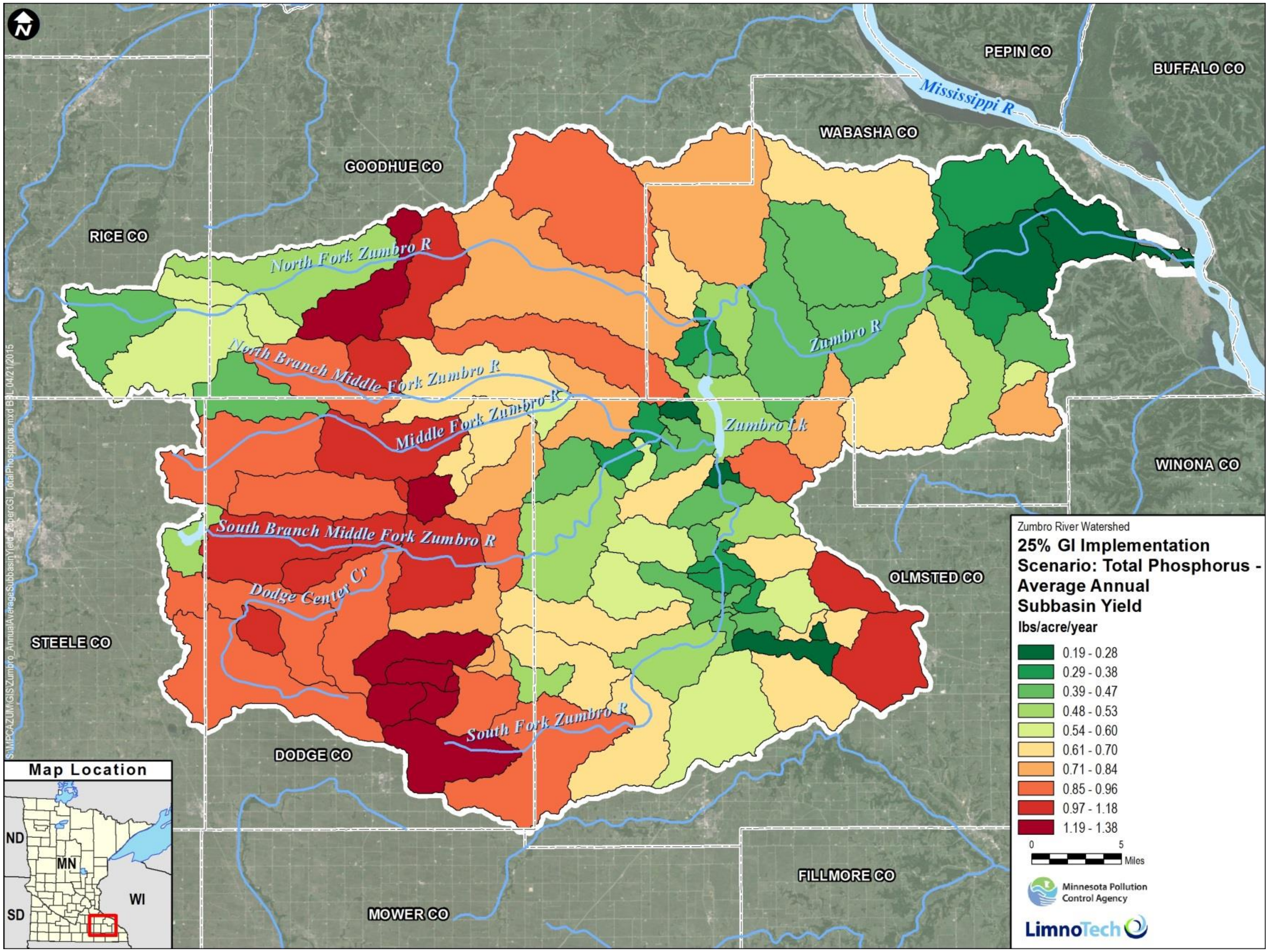


**Figure B-4. Average annual total phosphorus subbasin yield for the green infrastructure - 25% implementation scenario.**

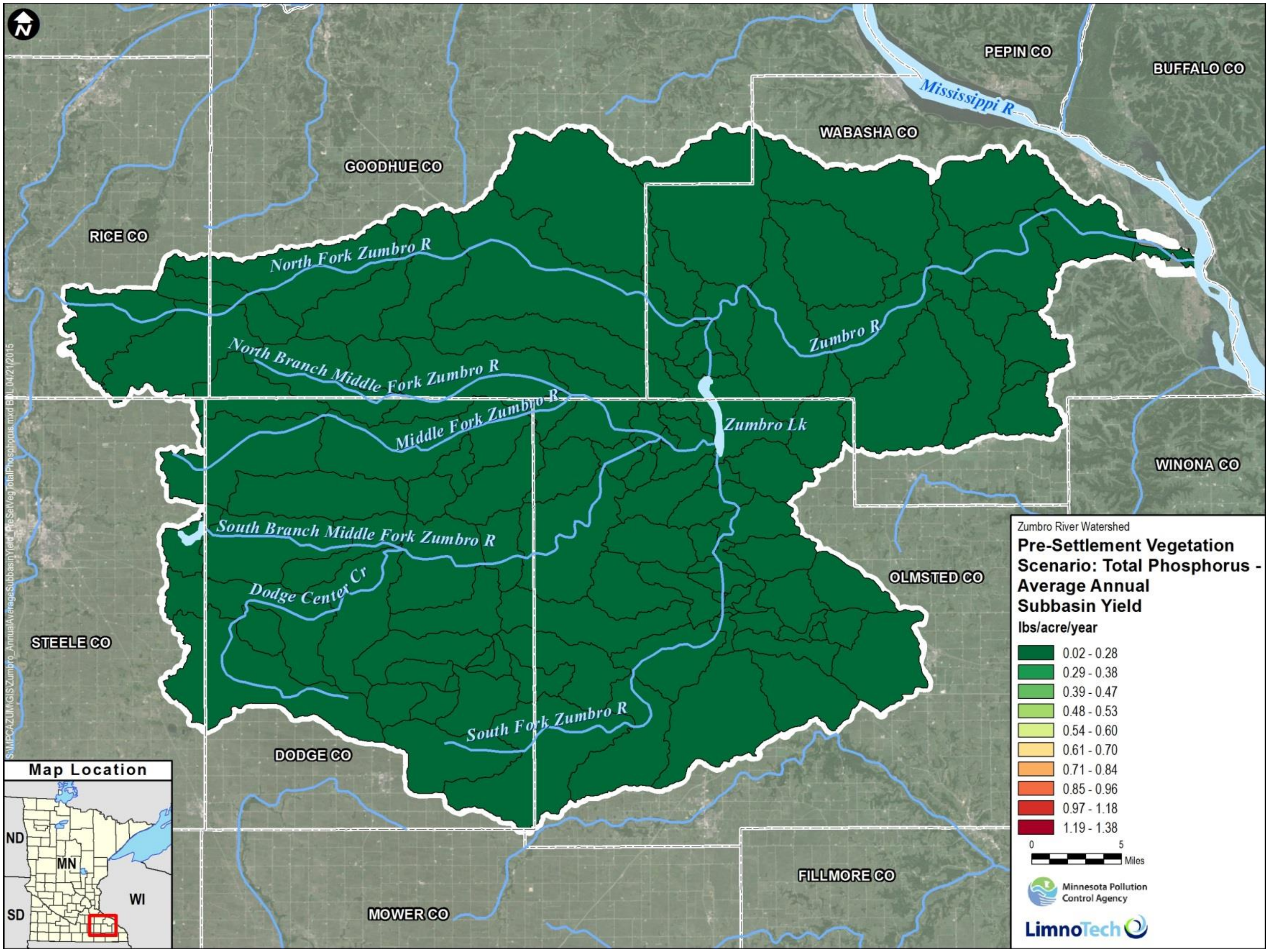


**Figure B-5. Average annual total phosphorus subbasin yield for the pre-settlement vegetation scenario.**

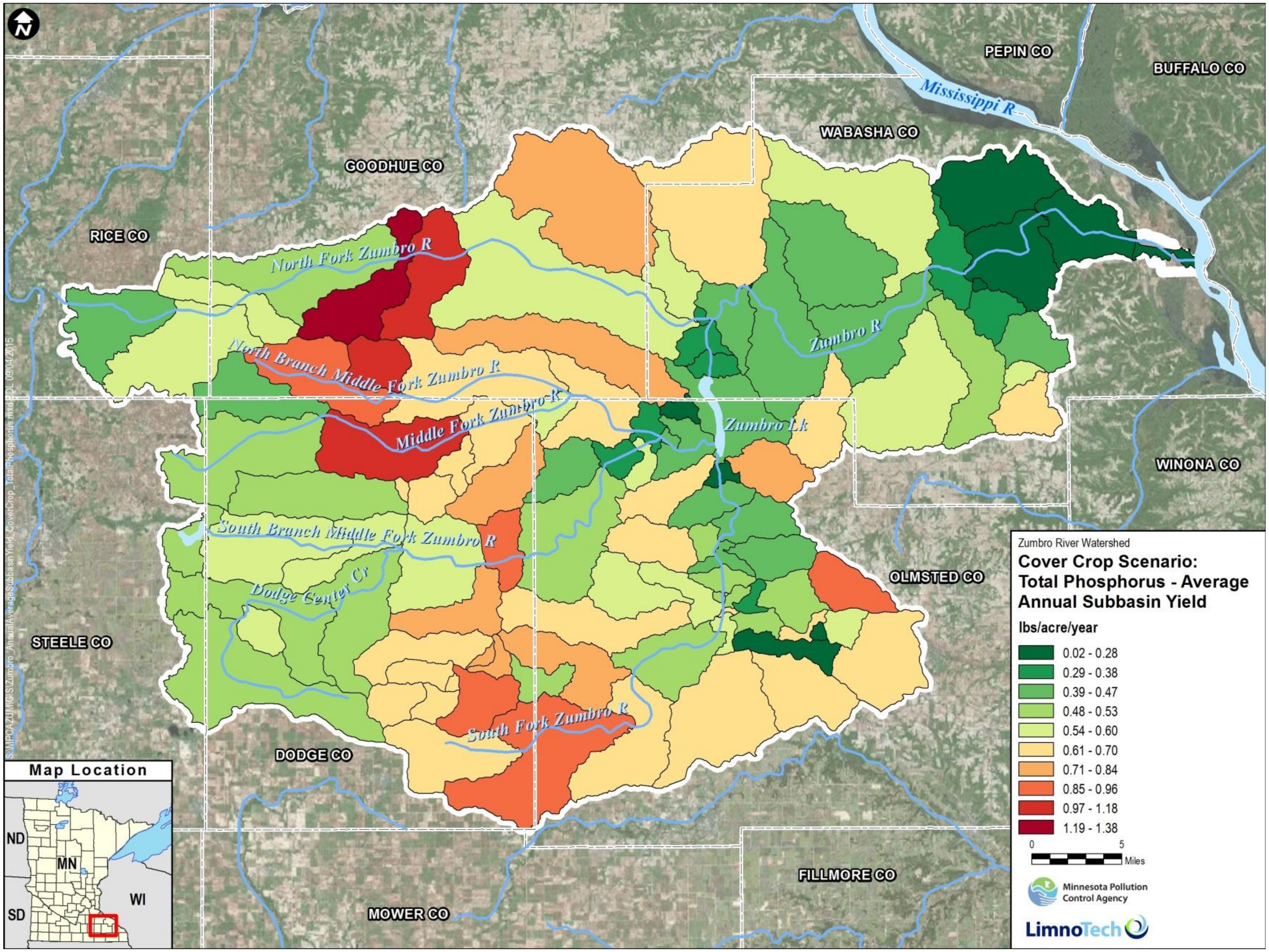


**Figure B-6. Average annual total phosphorus subbasin yield for the cover crops scenario.**

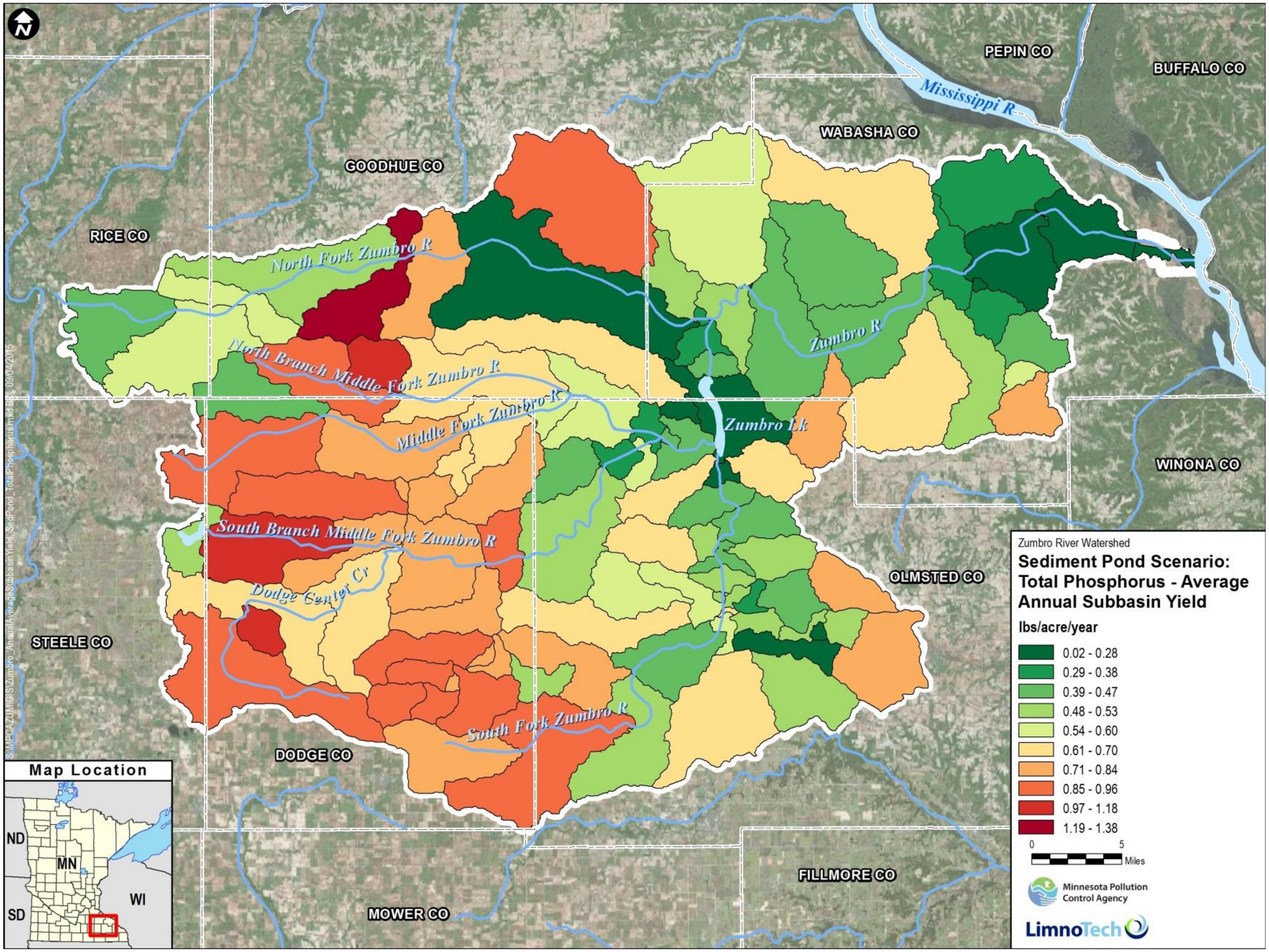


**Figure B-7. Average annual total phosphorus subbasin yield for the sedimentation pond scenario.**

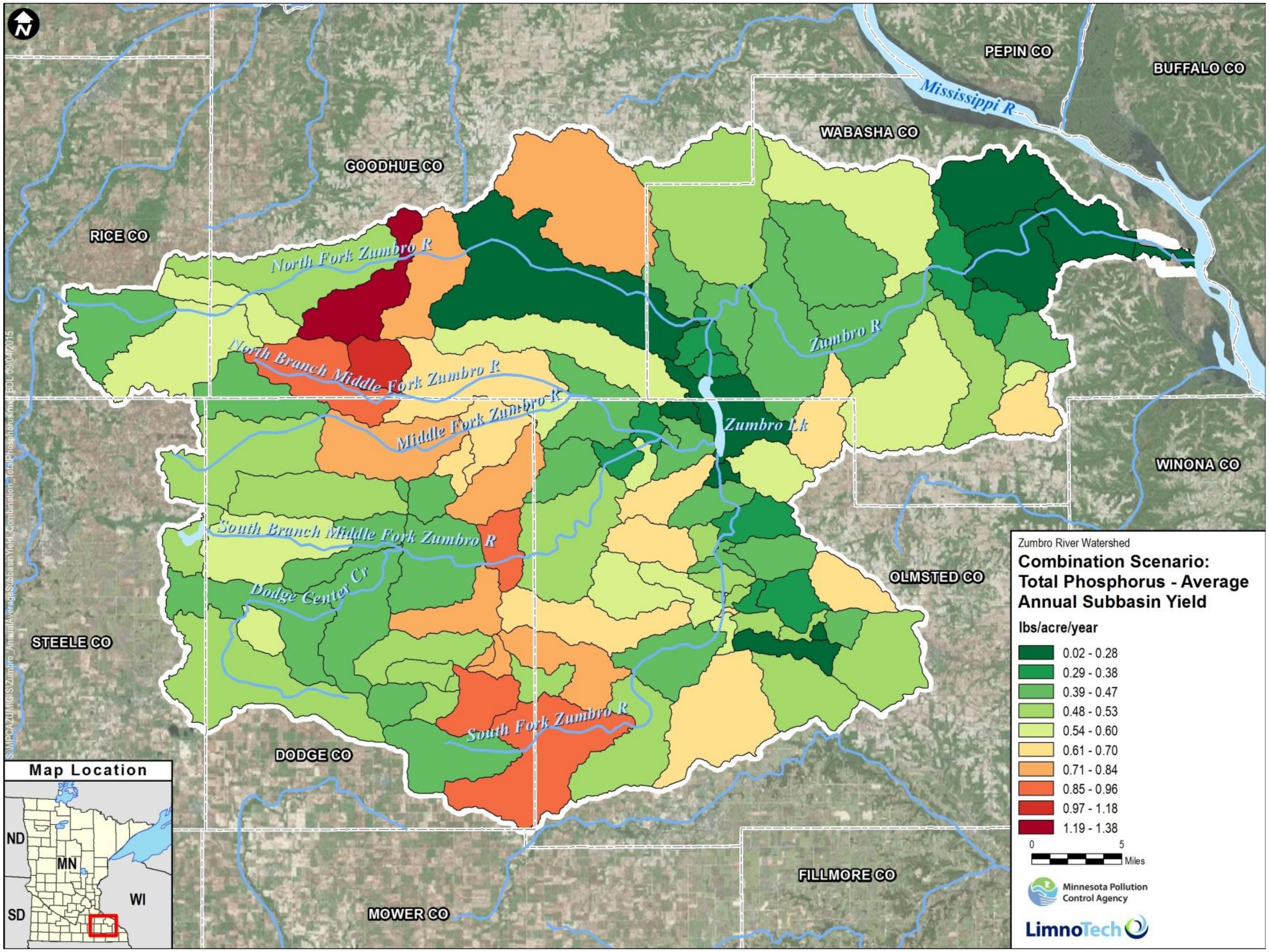


**Figure B-8. Average annual total phosphorus subbasin yield for the combination scenario. Note that the maps only represent landscape yields and do not account for changes in point source discharge.**

# Appendix C - 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.

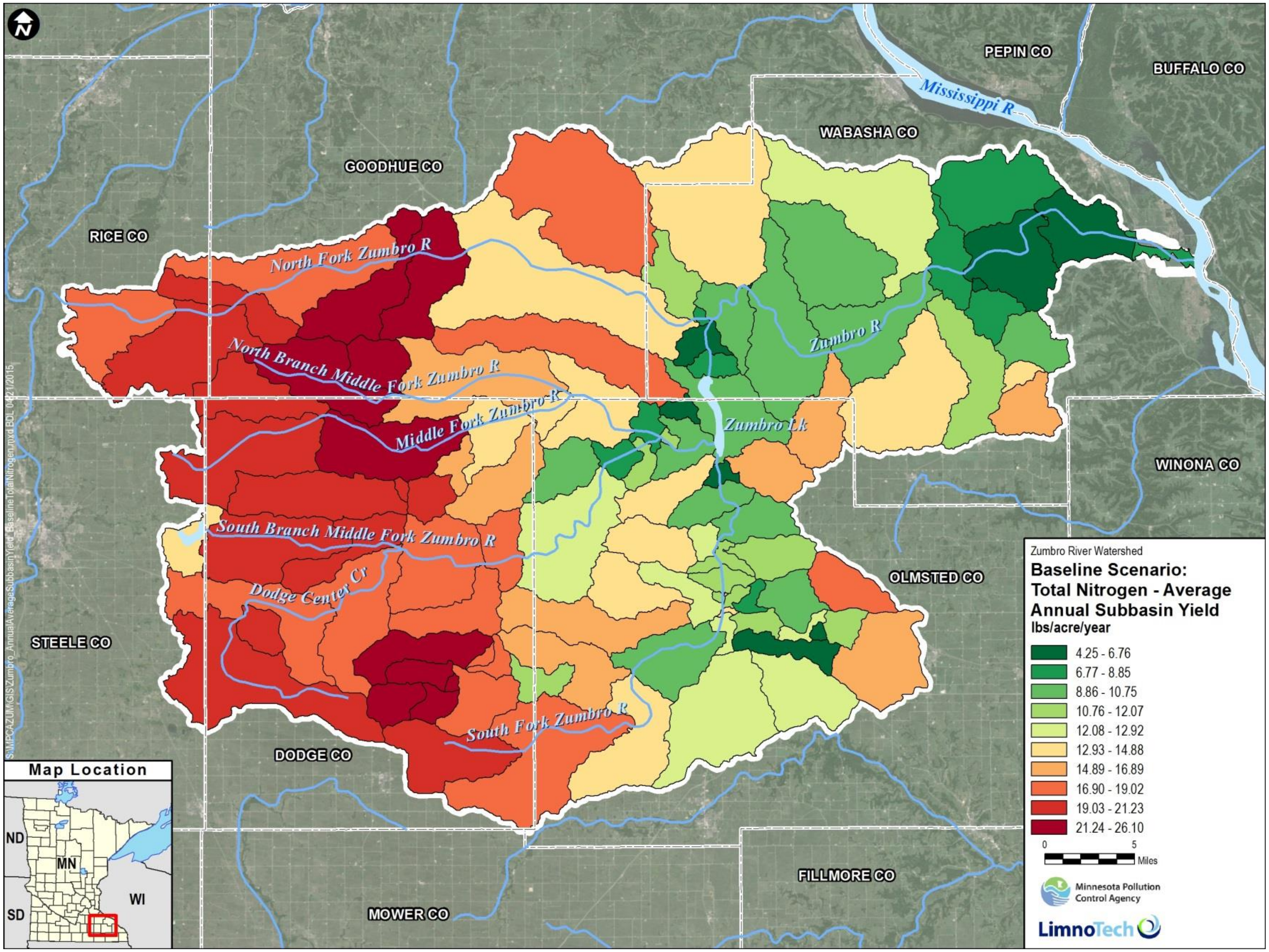


**Figure C-1. Average annual total nitrogen subbasin yield for the baseline simulation.**

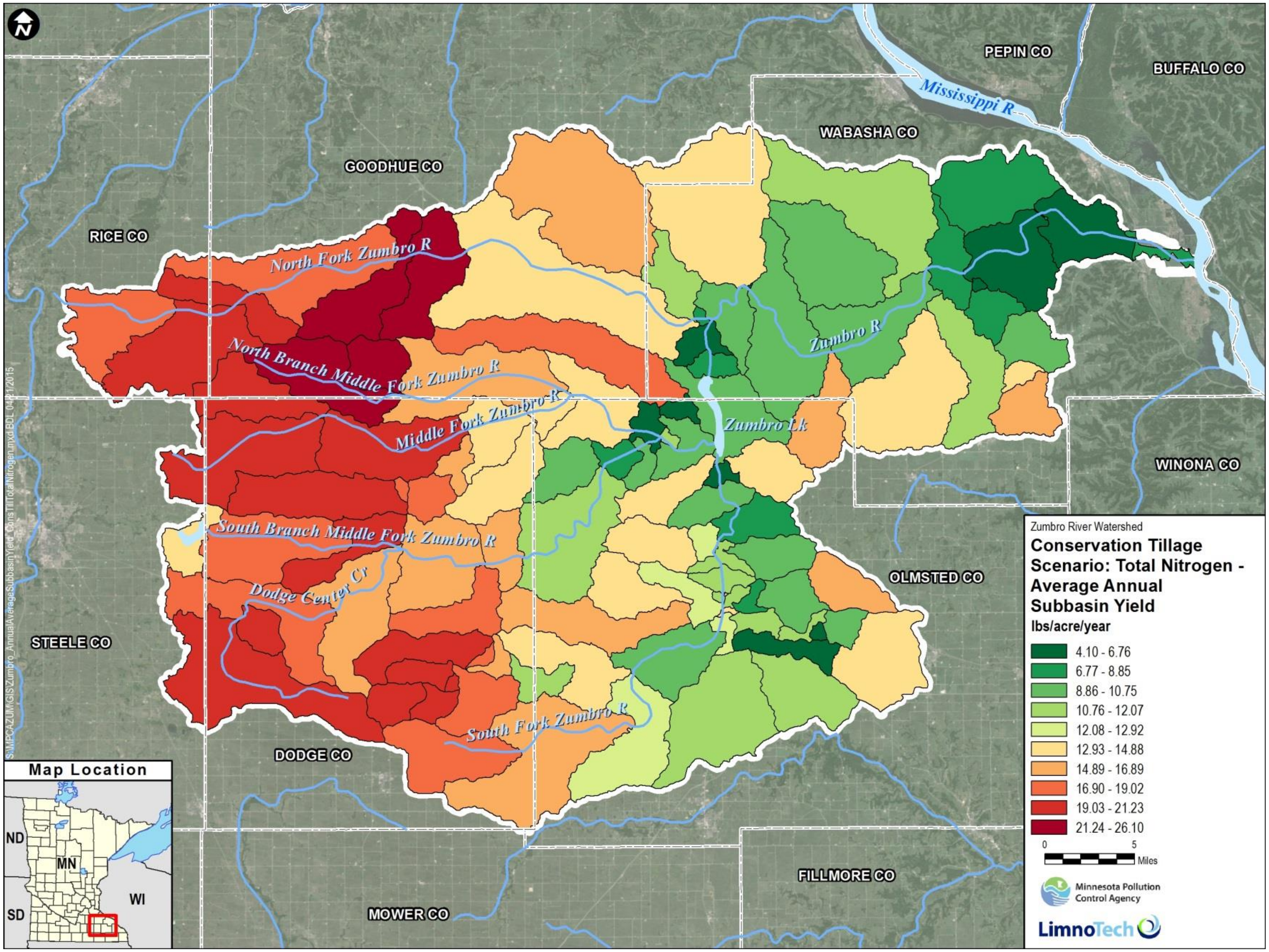


**Figure C-2. Average annual total nitrogen subbasin yield for the conservation tillage scenario.**

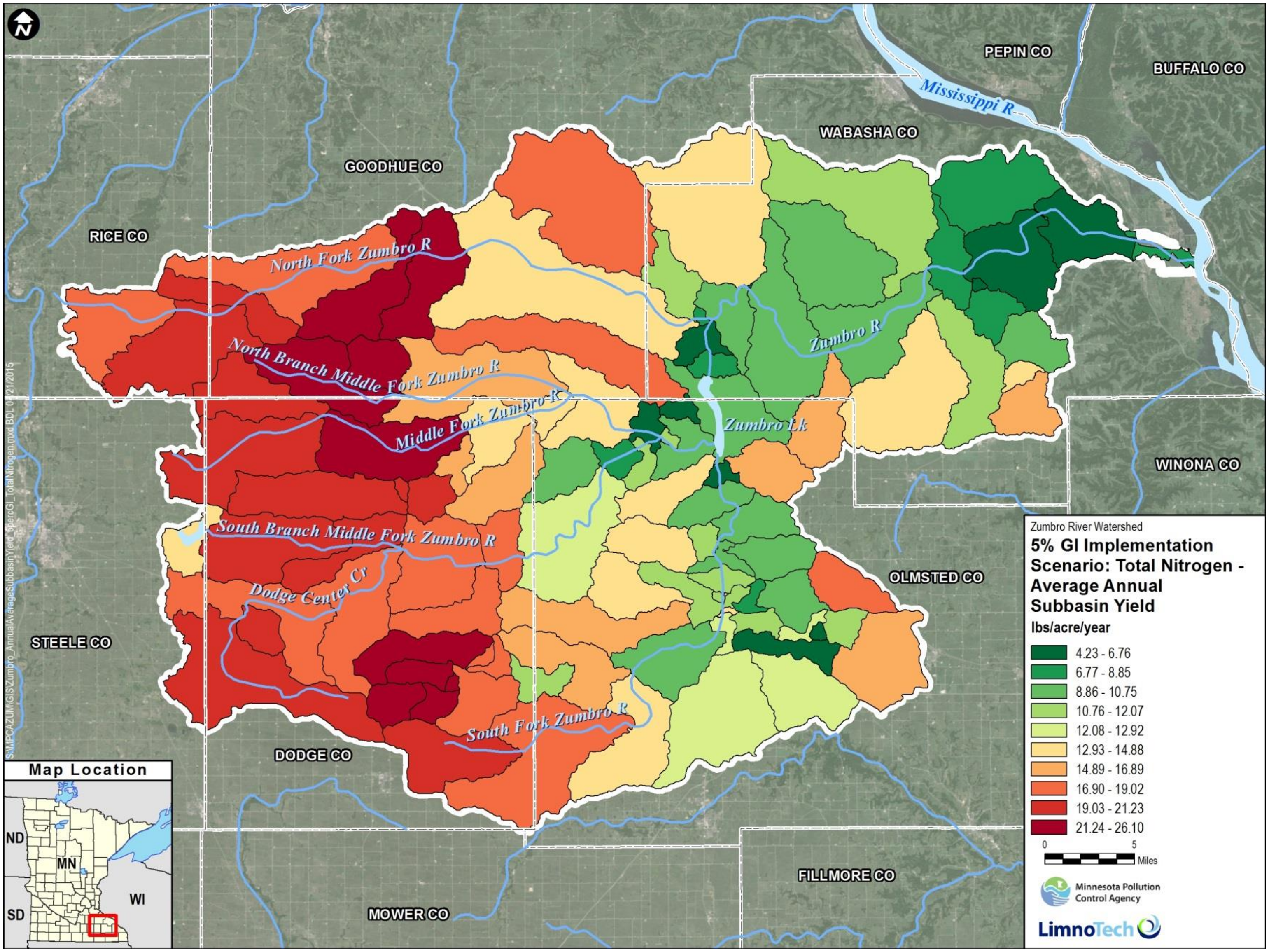


**Figure C-3. Average annual total nitrogen subbasin yield for the green infrastructure - 5% implementation scenario.**

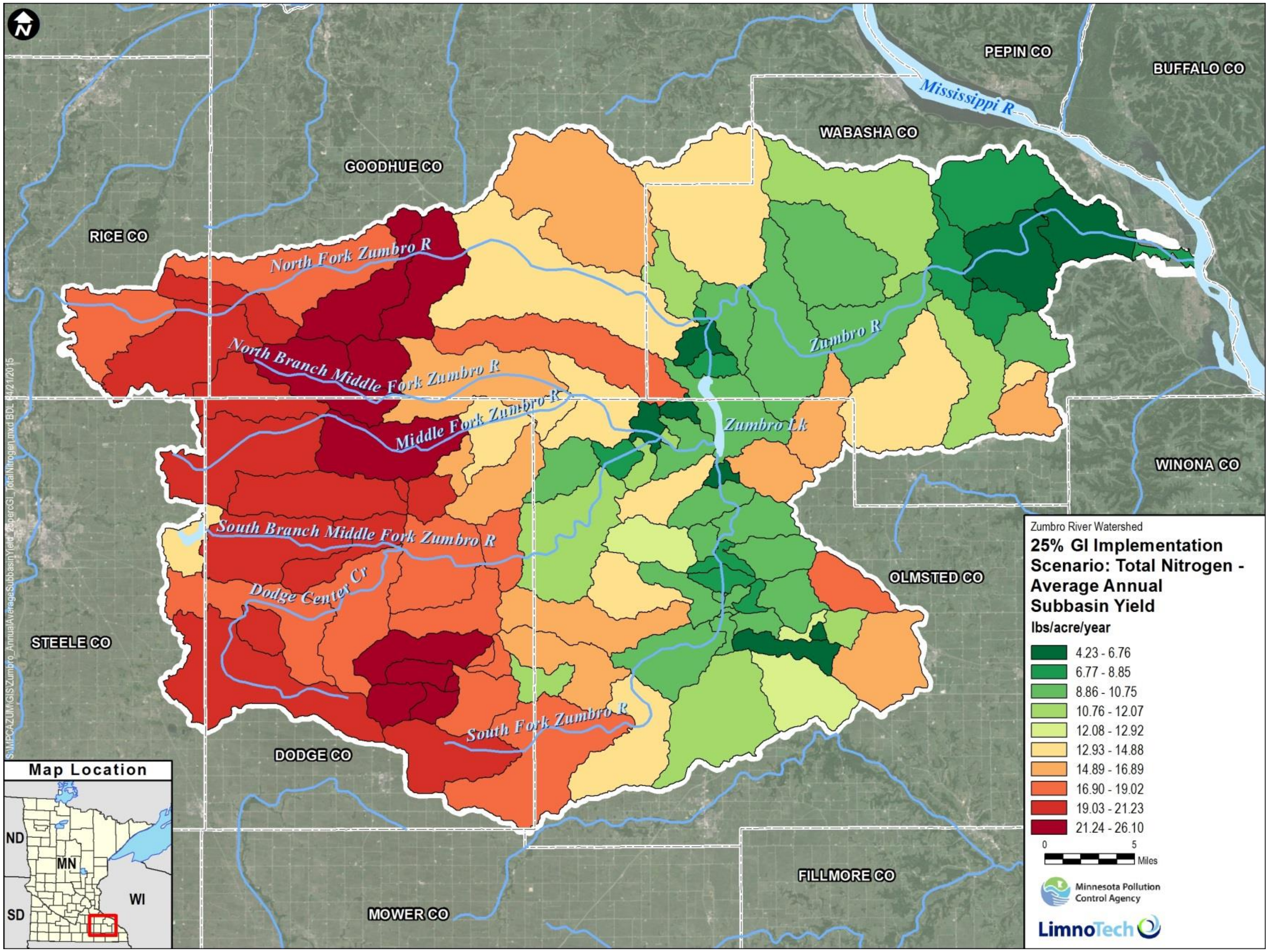


**Figure C-4. Average annual total nitrogen subbasin yield for the green infrastructure - 25% implementation scenario.**

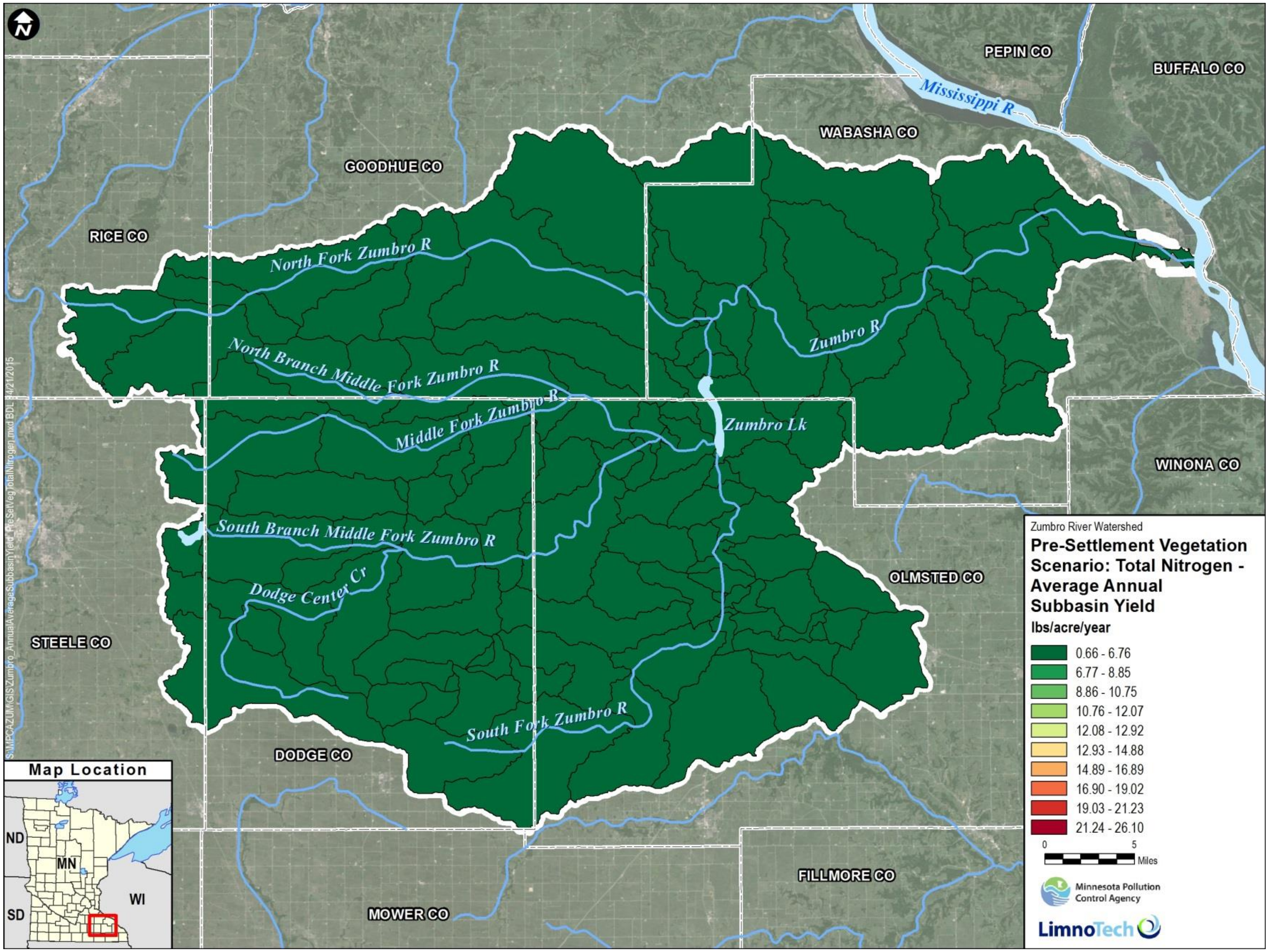


**Figure C-5. Average annual total nitrogen subbasin yield for the pre-settlement vegetation scenario.**

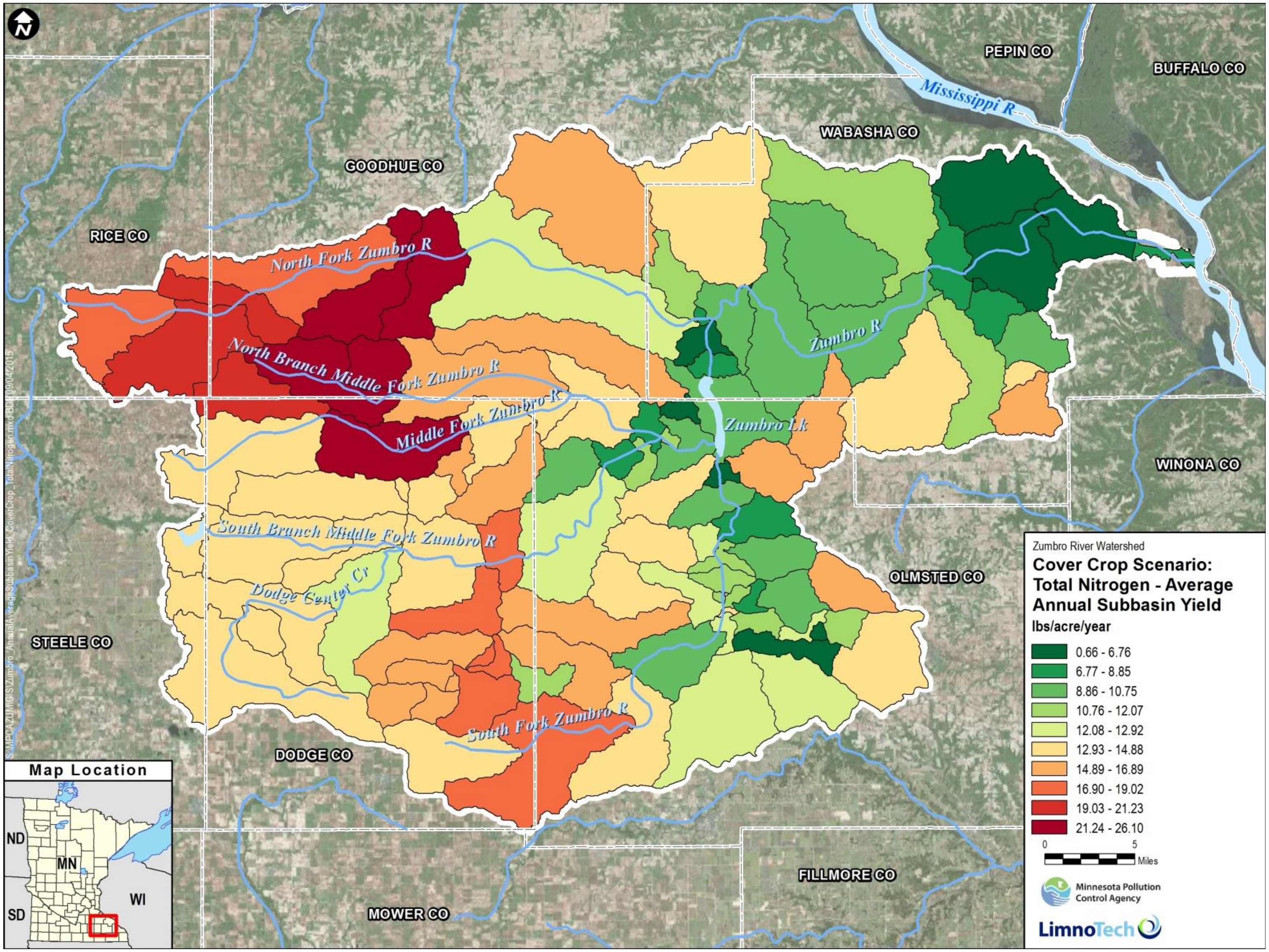


**Figure C-6. Average annual total nitrogen subbasin yield for the cover crops scenario.**

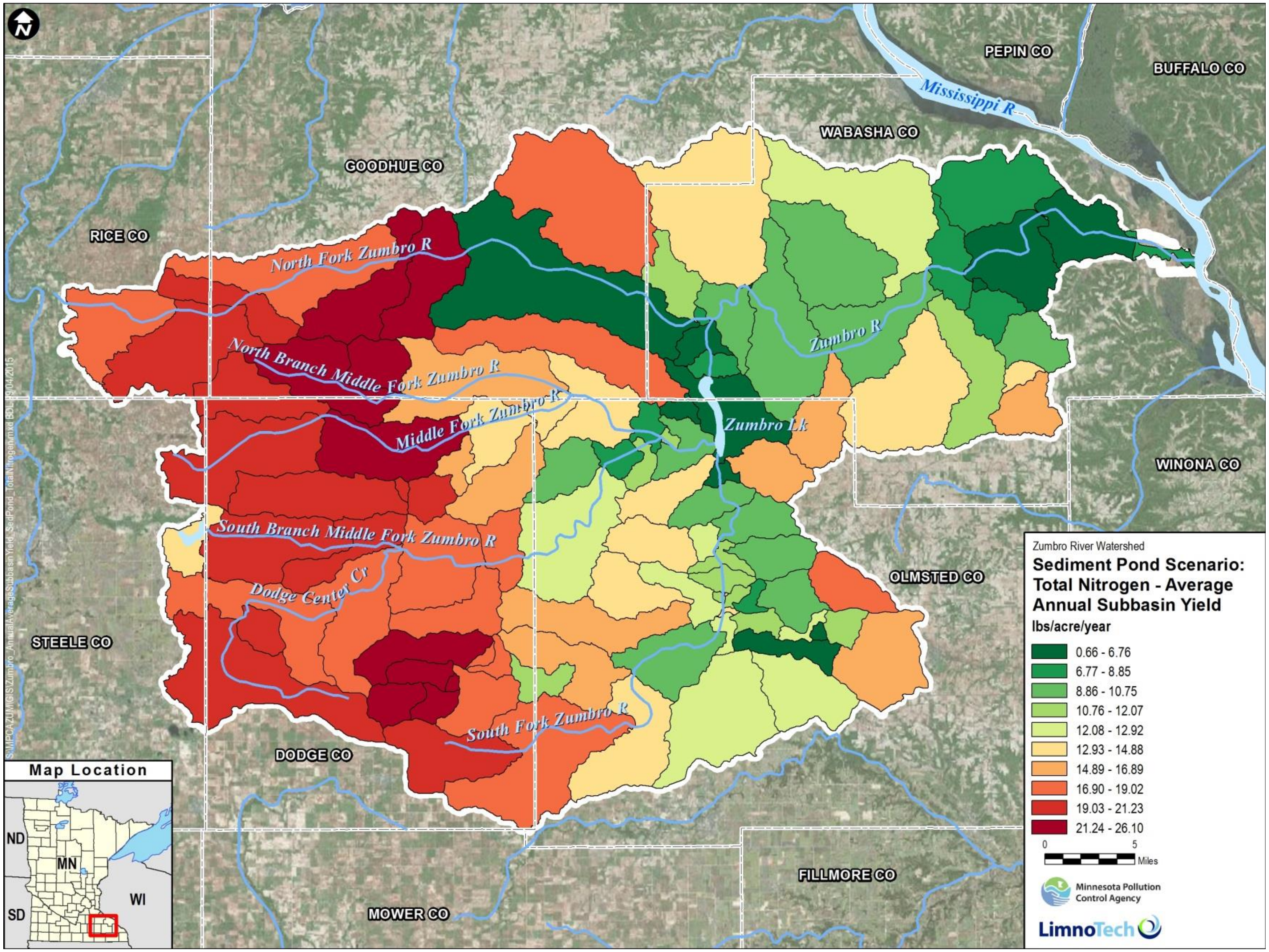


**Figure C-7. Average annual total nitrogen subbasin yield for the sedimentation pond scenario.**

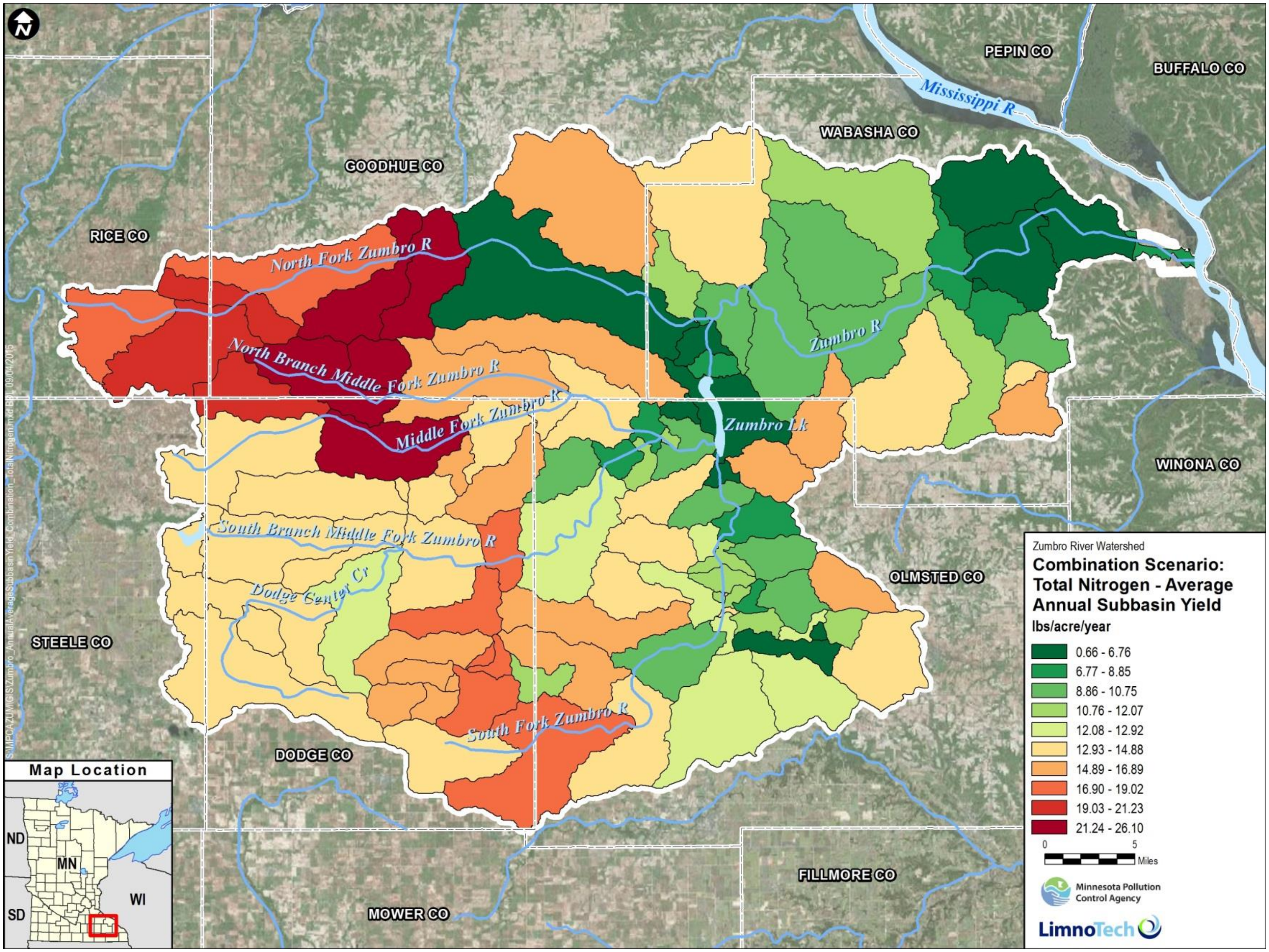


**Figure C-8. Average annual total nitrogen subbasin yield for the combination scenario. Note that the maps only represent landscape yields and do not account for changes in point source discharge.**