MISSISSIPPI HEADWATERS WATERSHED SCENARIOS

Topical Report RSI-2622
Revision 1

prepared for

Hubbard County Conservation District
212½ 2nd Street SW
Park Rapids, Minnesota 56470

February 2018

RESPEC

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by

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1.0 SCENARIO EVALUATION

The Mississippi Headwaters Watershed contains many high-quality surface waters; however, potential impacts to increased development, land-use change, and other potential threats to water quality are of primary concern. While much effort has been focused on characterizing past and present conditions of area waterbodies, the Mississippi Headwaters Watershed Restoration and Protection Strategies (WRAPS) team members have also assessed potential impacts of future threats. Realized changes in the landscape and waters provide perspectives for generalizing future conditions. As part of the future forecasting, stakeholder inputs and local and regional experts' professional judgment were used to define a range of potential, future land-use changes. The Mississippi Headwaters Basin Hydrological Simulation Program – FORTRAN (HSPF) model was calibrated based on 14 years of hydrologic, climate, and monitoring data and was used to predict impacts of future land-use changes as well as restorative or protective effects from employing generalized best management practices (BMPs). For this purpose, estimates are provided by percent change, which should be used for a relative comparison of effects. Further, representative sites were selected to depict estimated changes in total suspended solids (TSS) and total phosphorus (TP) flow-weighted mean concentrations (FWMCs) by scenario. For the purposes of this assessment, the Mississippi Headwaters Basin has been organized into West, Big Lakes (central area), and East Basin management zones, as depicted in each of the loading graphics. These assessments allow a broad-brush projection of potential impacts (both geographically and propagated along flow networks).

Most of the focus of these future projections are based on changes in loading for TSS and TP, which are well defined in the scientific literature and by Minnesota water quality rules. Total nitrogen (TN) loading changes were added to reflect increasing concern related to groundwater protection and cumulative effects of altered nitrogen to phosphorus (N:P) ratios in receiving waters. As N:P ratios decline, conditions may begin to favor nuisance cyanobacteria.

Six potential future land-use change scenarios that can be appropriately evaluated with the HSPF model were developed to predict potential impacts on watershed flows and water quality as estimated by percent change in annual average loading for TSS, TP, and TN. Modeling-period average runoff and average loads are tabulated in Appendix A. Evaluated scenarios included the following changes:

1. Conversion of forests to agriculture
2. A. Conversion of forest and agricultural land to developed land with increased wastewater and septic loads, representing growth of cities and development near easily accessible lakes and stream corridors
   B. Conversion to developed lands (Scenario 2A) AND employing urban BMPs
3. Intensified forest harvest
4. Cumulative effects from increases in agricultural lands (Scenario 1), developed land (Scenario 2A), and intensified forest harvest (Scenario 3)
5. Implementation of water quality buffers to portions of agricultural croplands.

Each scenario was developed from information provided by stakeholders and local experts and described herein by scenario. Not all subwatershed areas were predicted as having substantial land-use changes;

therefore, no changes will be noted in summary graphics unless impacted by upgradient changes. Explicitly modeled subwatersheds have been indicated as stippled areas in graphics for each scenario.

Note that the Leech Lake River, which is not considered part of this headwaters analysis, drains into the Mississippi River above Grand Rapids, which causes a dilution effect in the Mississippi River. In a similar fashion, the large headwater reservoirs, such as Winnibigoshish, are effective nutrient/sediment traps and, therefore, can strongly mute TSS and TP loads discharged to downstream waters. Hence, projecting cumulative impacts of upland changes on the most downstream portion of Headwaters Mississippi River reflects dilution and trapping effects, thereby influencing apparent load reductions estimated for downstream most reaches. Assessing the potential cumulative impacts of changing land uses on the smaller upgradient and large lakes (Wolf, Cass, Andrusia, and Winnibigoshish) could not be fully addressed in this assessment and should be considered in future efforts. Potential increases resulting from lake sediment internal recycling of phosphorus is one such impact noted by Wilson and McCutcheon [2016] for Lakes Irving and Little Turtle.

1.1 SCENARIO 1

Scenario 1 estimates the impacts from converting 25 percent of forestland covers to agricultural lands for select subwatersheds, as indicated by the stippled areas in Figures 1-1 through 1-4. For this modeling, agricultural land is broadly defined as a mix of pasture/hay, cultivated crops, and feedlots.

HSPF-estimated watershed responses for modeled parameters are depicted by subwatershed in Figures 1-1 through 1-4 for flow, TSS, TP, and TN, respectively.

- Runoff increases of approximately 5–15+ percent were noted for West-Basin-assessed subwatersheds with estimated cumulative increases propagated to downstream waters (e.g., Lake Bemidji). Similar, but lower runoff increases were predicted for areas with estimated land uses within the East Basin flowing toward Lake Pokegama. Relatively small increases in flows were estimated in the Big Lakes Basin because of the much smaller geographic extent of expected land-use changes.
- Substantial increases (e.g. 25–90+ percent) of TSS and TP loadings were widely noted for assessed subwatersheds, particularly for the upper flow path subwatersheds in the West and East Basins. These impacts were propagated downstream along flow paths. If realized, loadings of this magnitude can cause perceptible and measureable negative impacts to receiving waters.
- Estimated, increased TN loadings were generally of a lower magnitude for all of the modeled areas.
- In the context of the broad Upper Mississippi Headwaters Watershed, the estimated changes appear to be much more subtle, with cumulative basin increases of annual flow of 2 percent, TSS loads of 11 percent, TP loads of 9 percent, and TN loads of 4 percent.

1.2 SCENARIO 2

Scenario 2A estimates watershed response that results from increased developed land covers. For this scenario, in subwatersheds identified by stakeholders to be at risk for each conversion, 10 percent of forestland was converted to developed land, and 15 percent of agricultural land was converted to

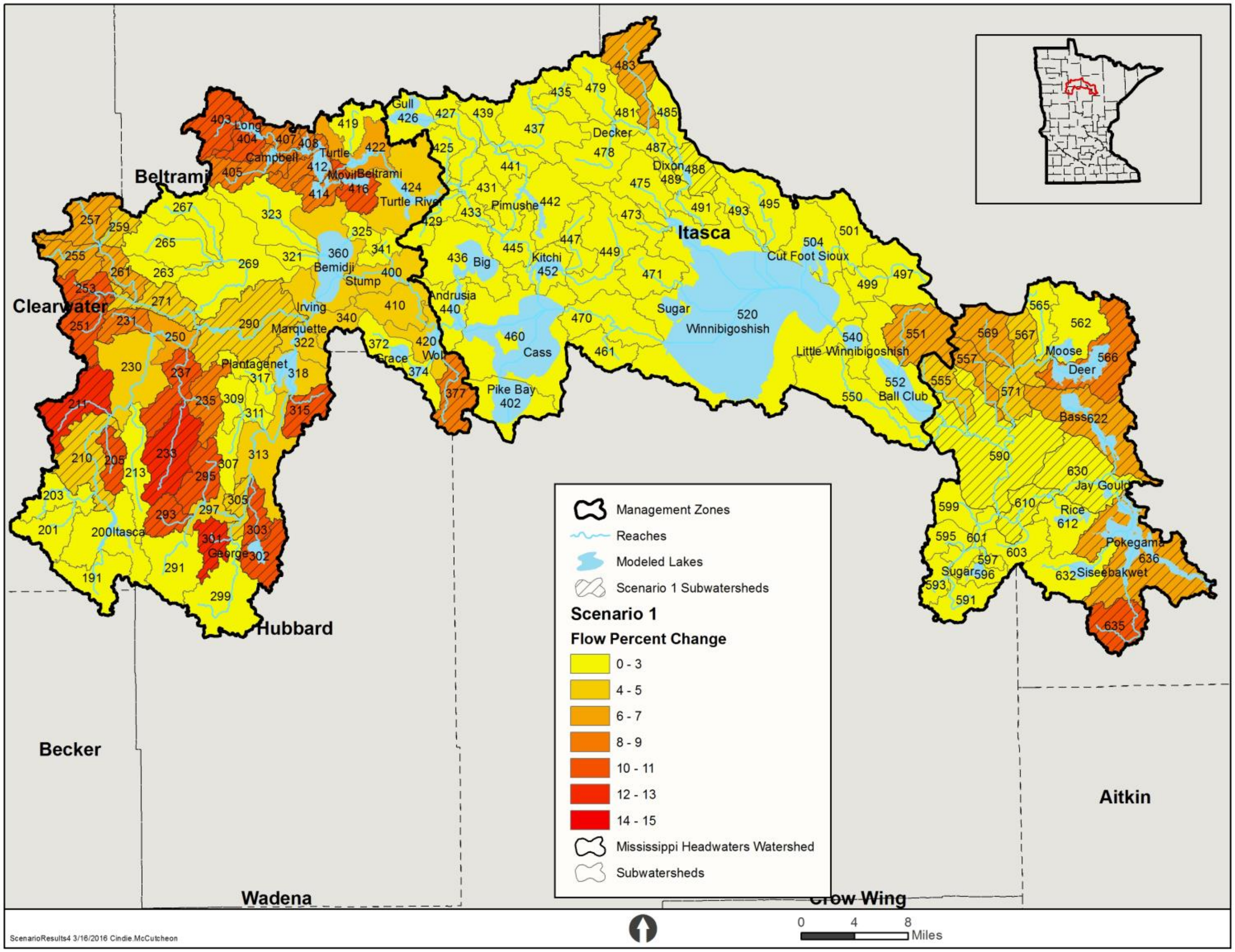

Figure 1-1. Scenario 1 Flow Percent Change.

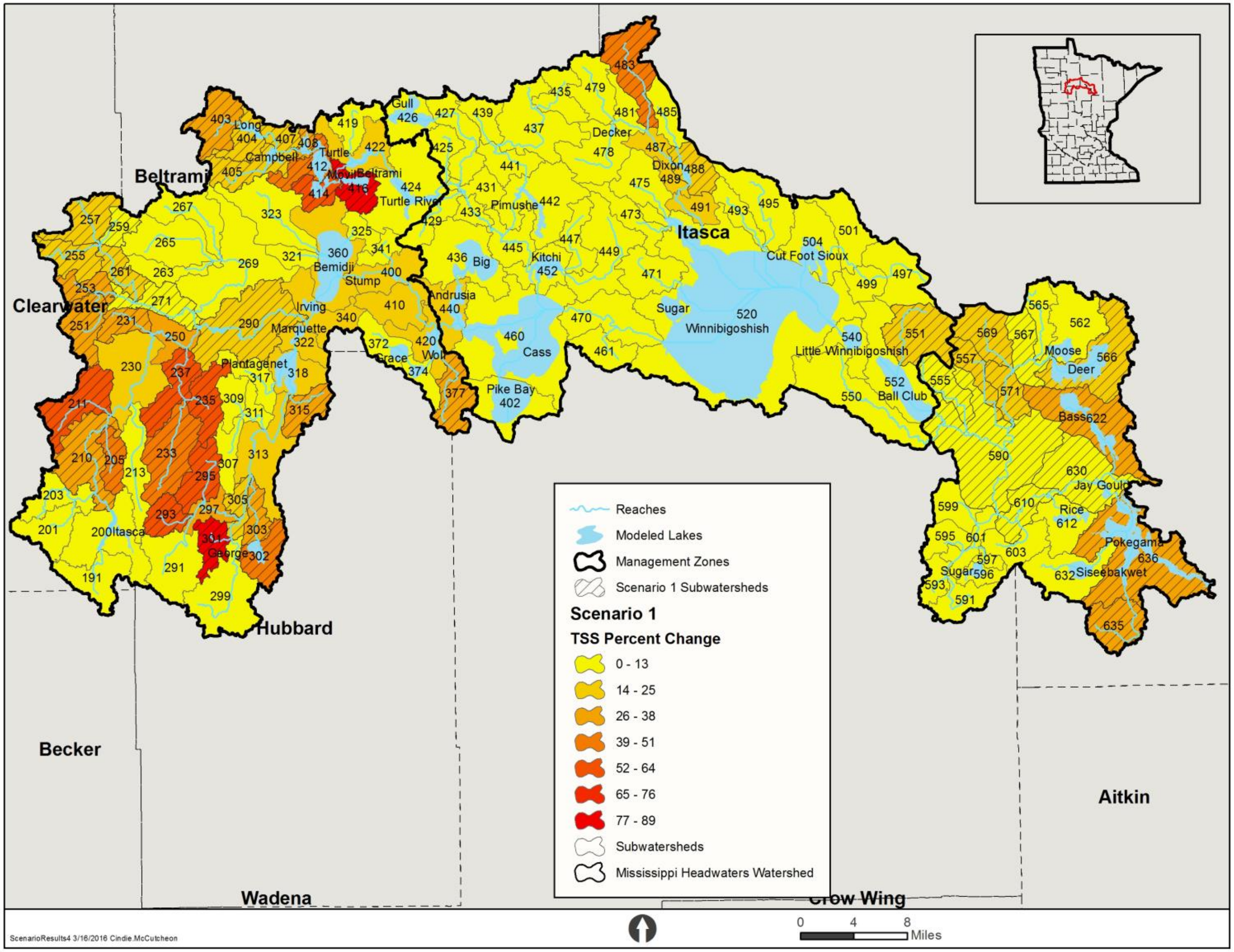

Figure 1-2. Scenario 1 Total Suspended Solids Percent Change.

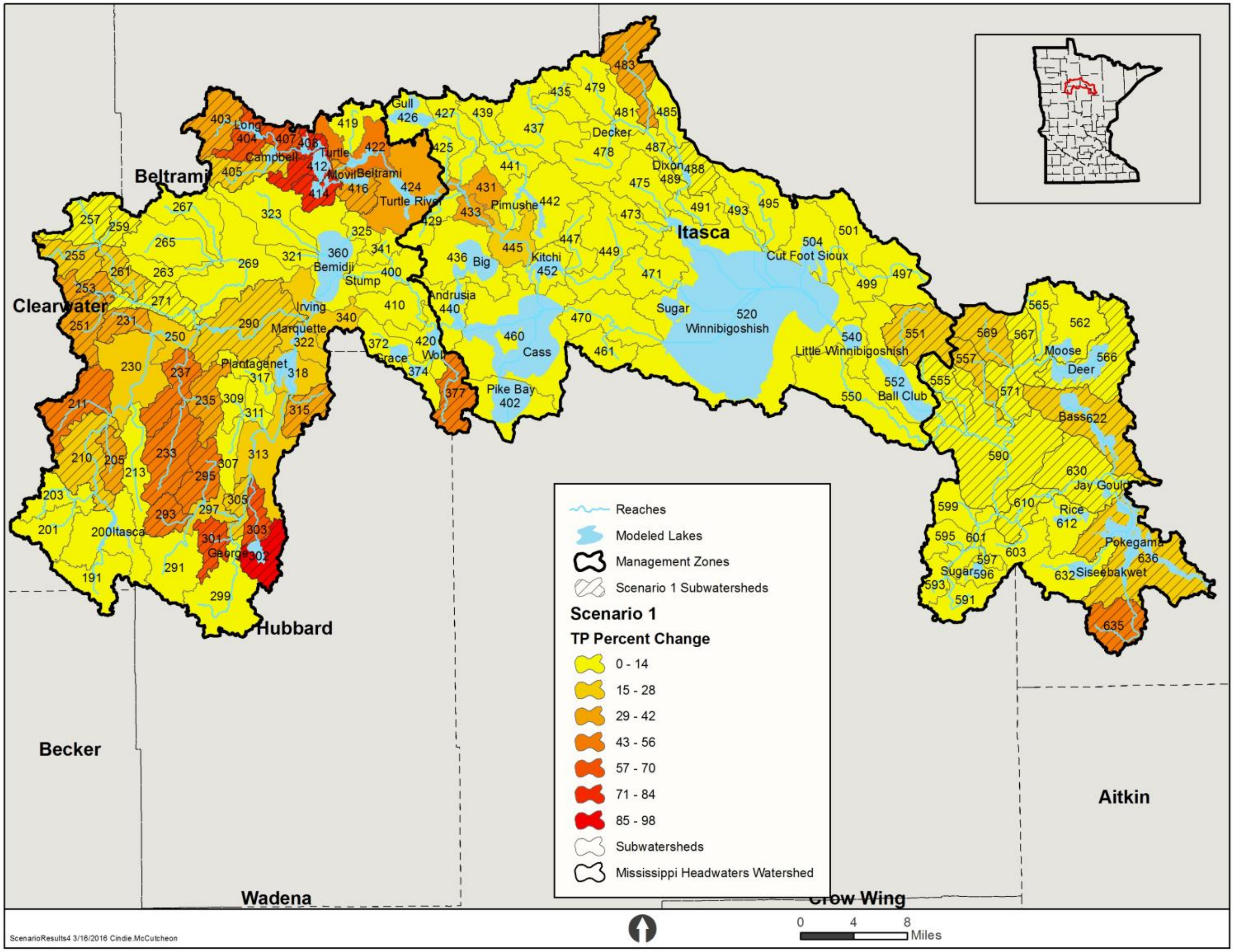

Figure 1-3. Scenario 1 Total Phosphorus Percent Change.

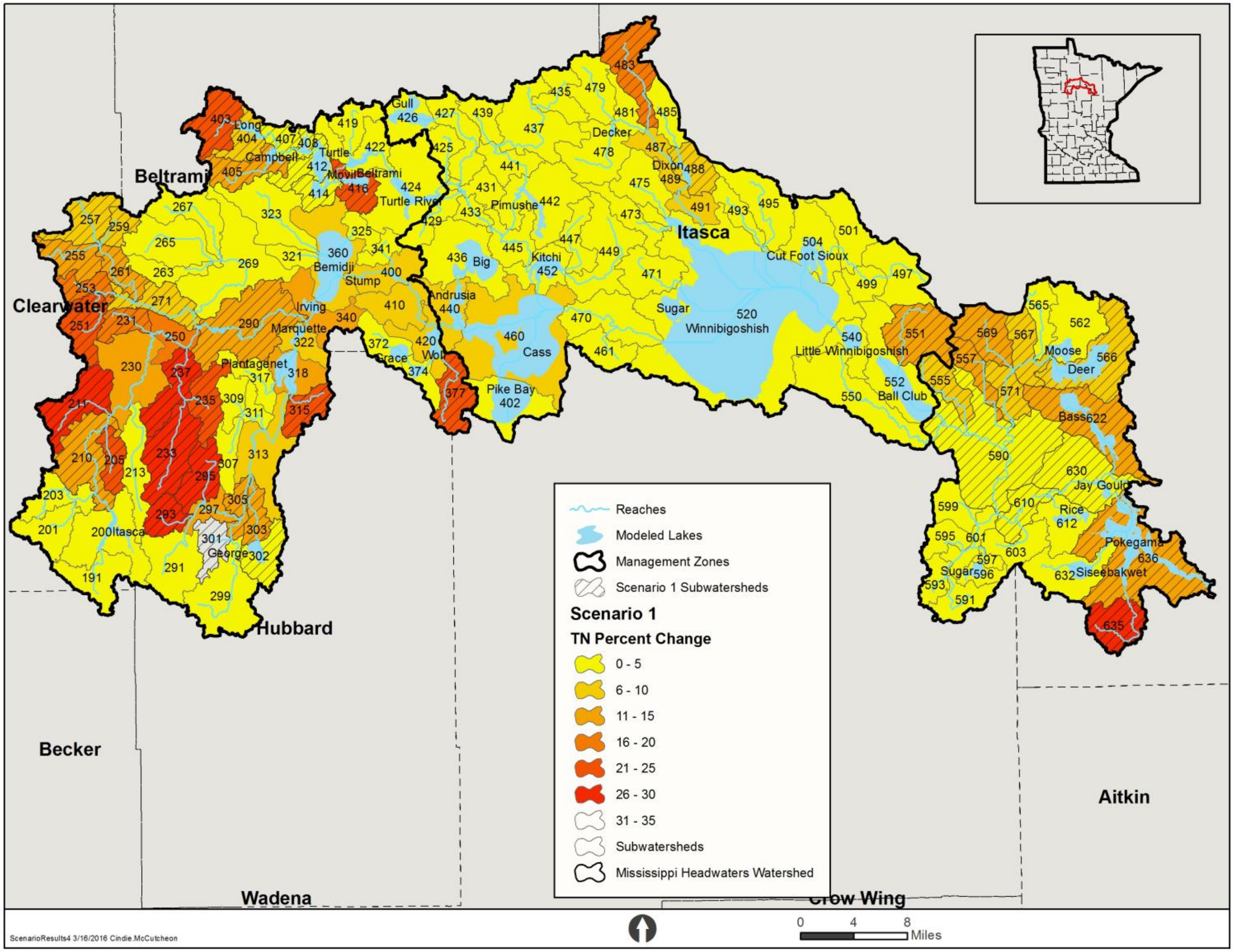

Figure 1-4. Scenario 1 Total Nitrogen Percent Change.

developed land. Converted lands are represented as stippled areas in the associated graphics by scenario. In addition to these conversions, point-source loads from Bemidji and Deer Creek facilities and from septic systems were increased by 15 percent in selected subwatersheds identified by stakeholders to be at risk for conversion to developed lands.

Scenario 2B estimates the combined impacts of developing Scenario 2A as moderated by broadly implementing urban BMPs defined by Minimal Impact Development Standards (MIDS) [Minnesota Pollution Control Agency (MPCA), 2014] over 20 percent of developed lands in subwatersheds that have been identified by stakeholders to be potentially converted to developed land. MIDS reductions that were used in this analysis included 81 percent for TP, 91 percent for TSS, 20 percent for TN, and 91 percent for flows. TP, TSS, and flow reductions were based upon removal efficiencies to match present-day native forest and prairie conditions [Barr Engineering, Inc. 2011]. Conservative TN removal efficiencies for multiple BMPs were based on Chesapeake Bay recommendations [Hirschman et al., 2008].

Modeled watershed responses by subwatershed are depicted first for Scenario 2A and then by Scenario 2B in Figures 1-5 through 1-12 for flow, TSS, TP, and TN, respectively.

- Assessed developed lands extend over much smaller geographic areas than agricultural lands; therefore, estimated changes are smaller than for Scenario 1.
- Runoff increases of approximately 1–7 percent were noted for West-Basin-assessed subwatersheds with estimated cumulative increases propagated to downstream waters (e.g., Lake Bemidji). Similar runoff increases were predicted for subwatersheds with estimated developed areas within the East Basin that flow to various lakes, including Lake Pokegama. Relatively small increases in flows were estimated in the Big Lakes Basin because of the much smaller geographic extent of expected land-use changes.
- Projections for the core lake areas of the West and East Basins include TSS load increases from 4 to 23 percent and TP increases from 2 to 11 percent.
- Implemented MIDS practices were predicted to reduce the effects of increased urban development. However, the net impacts of broad development increases were estimated to result in net increased TSS and TP loads, which would again involve the core lake and riparian areas of the West and East Basins.
- In the context of the broad Upper Mississippi Watershed, Scenario 2A's estimated changes appear to be much more subtle, with cumulative basin increases of annual flow of 1 percent, TSS loads of 3 percent, TP loads of 1 percent, and TN loads of 1 percent. Implementing MIDS practices for expanded urban areas was estimated to result in basin-wide increases of 0 percent for flow, 1 percent for TSS, 0 percent for TP, and 1 percent for TN for the entire Mississippi Headwaters Drainage Basin.

1.3 SCENARIO 3

Scenario 3 estimates the impacts of converting 25 percent of mature forestland cover to new forests in subwatersheds identified by stakeholders as lands for potential forest harvest. These subwatersheds are indicated by the stippled areas in the graphics for this scenario.

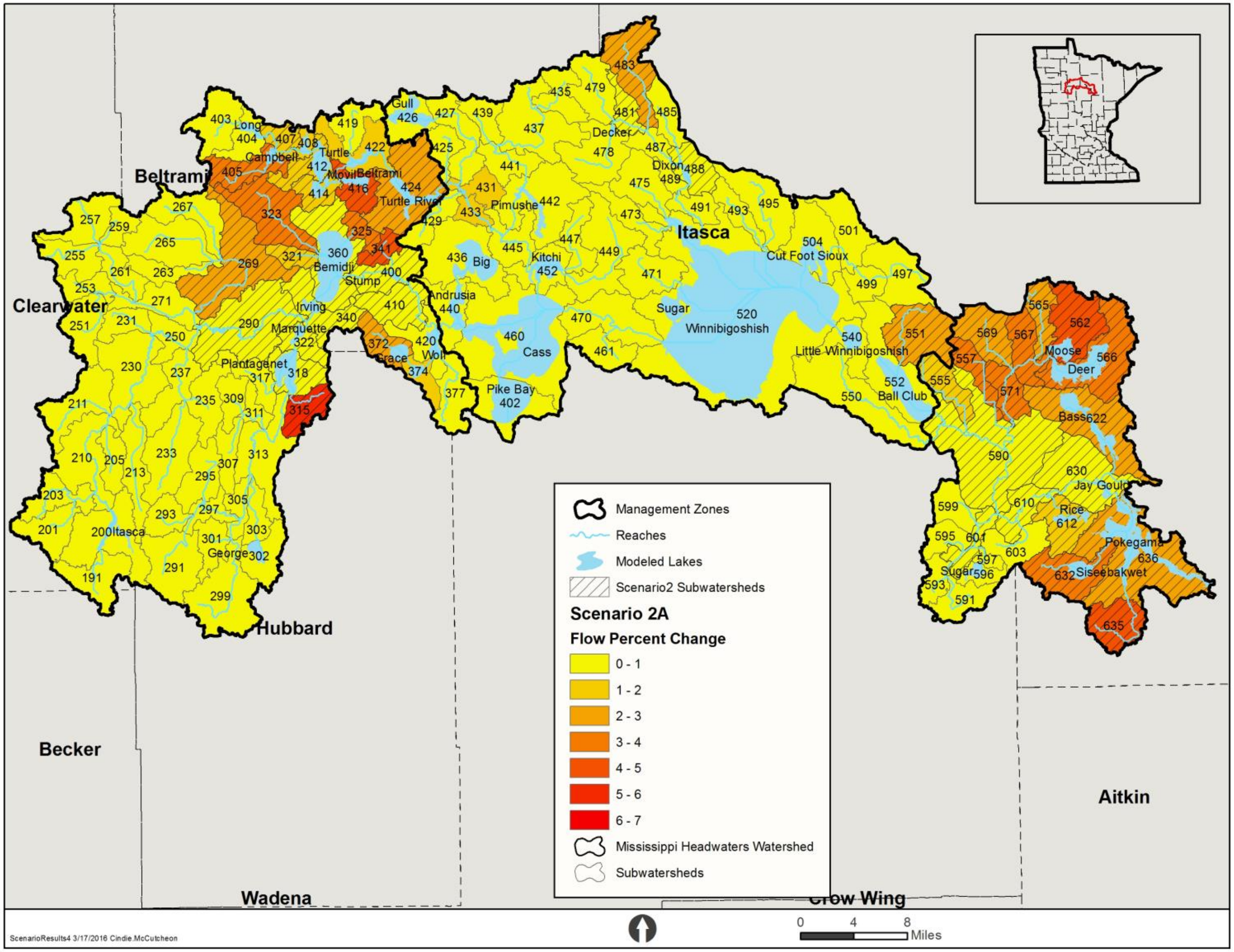

Figure 1-5. Scenario 2A Flow Percent Change.

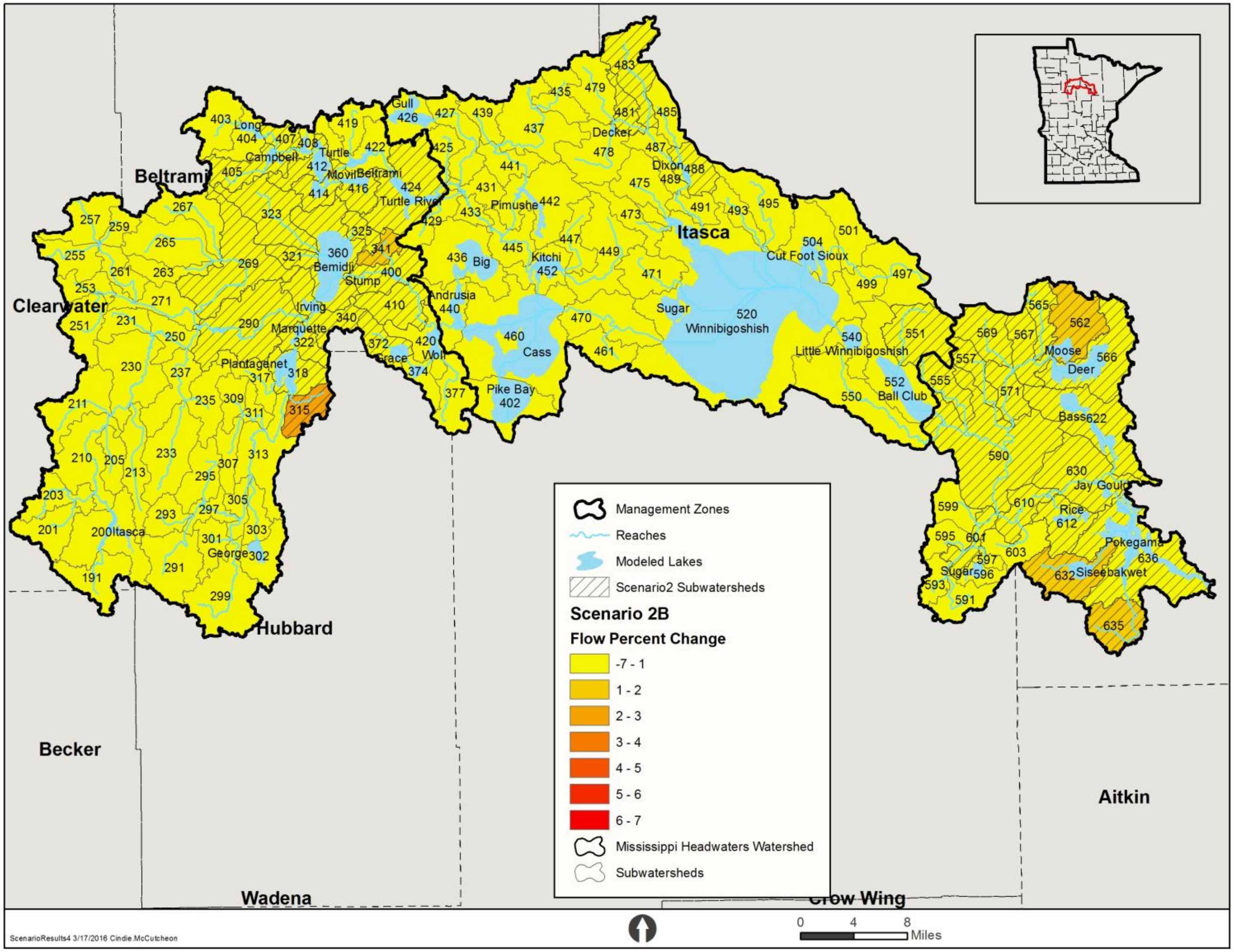

Figure 1-6. Scenario 2B Flow Percent Change.

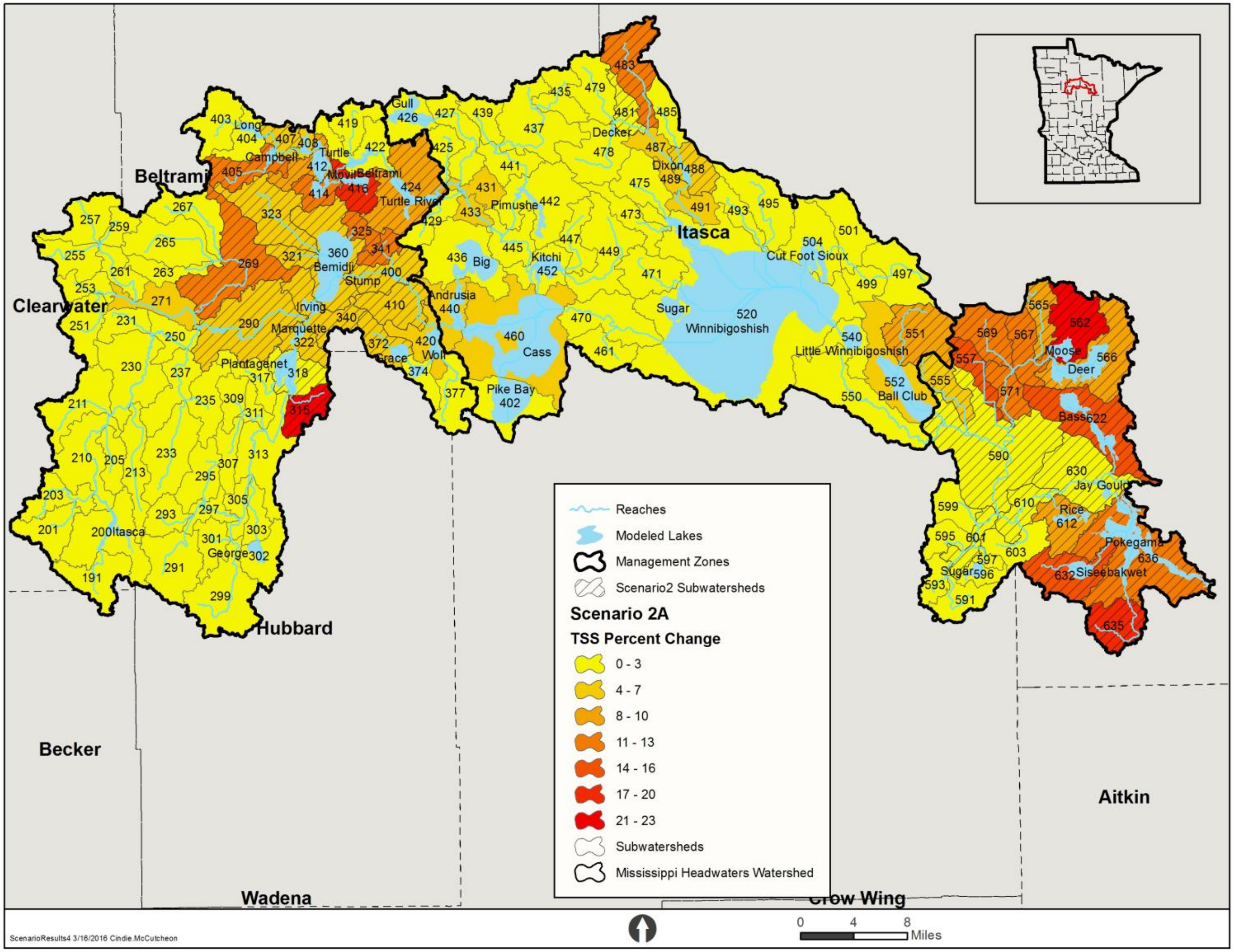

Figure 1-7. Scenario 2A Total Suspended Solids Percent Change.

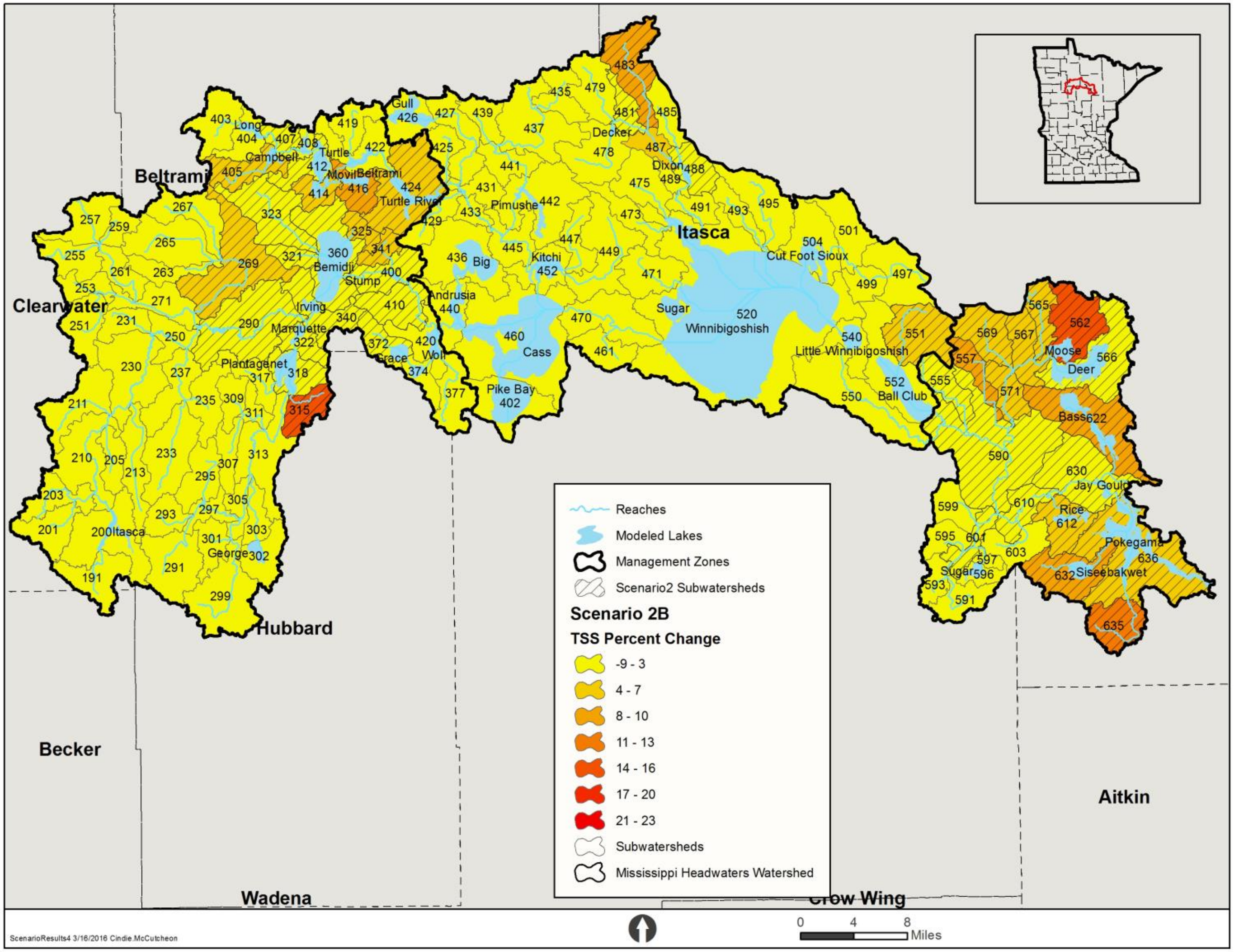

Figure 1-8. Scenario 2B Total Suspended Solids Percent Change.

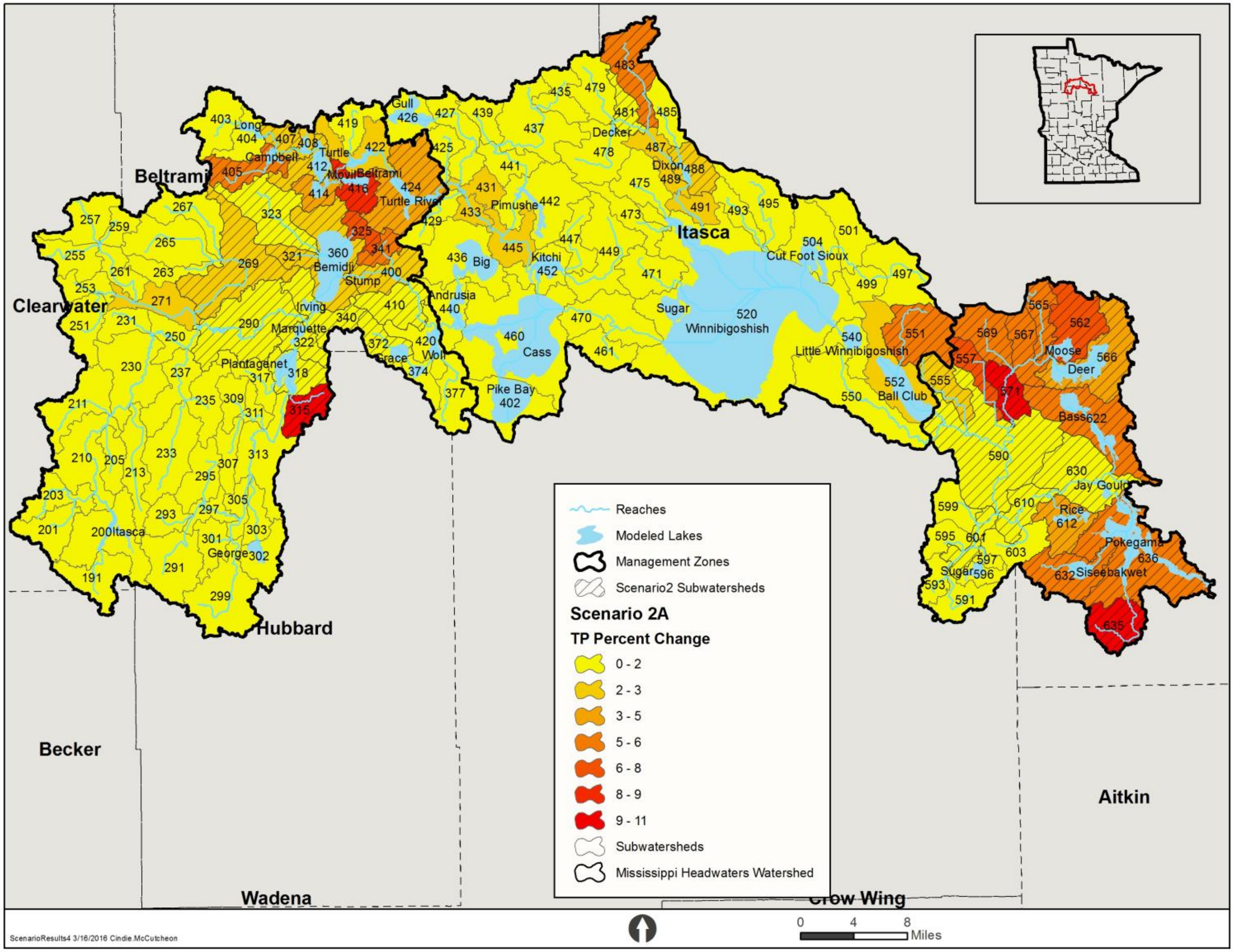

Figure 1-9. Scenario 2A Total Phosphorus Percent Change.

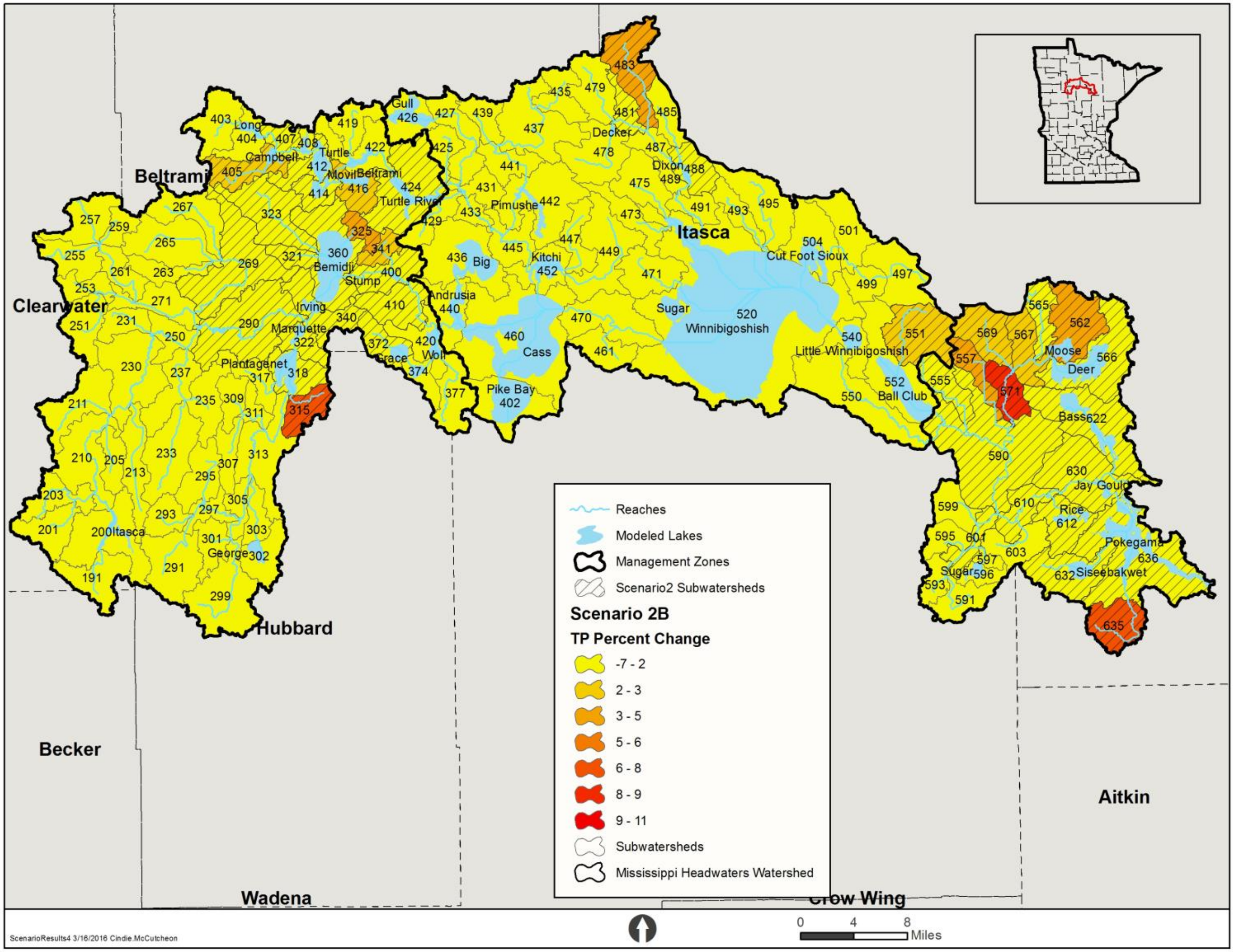

Figure 1-10. Scenario 2B Total Phosphorus Percent Change.

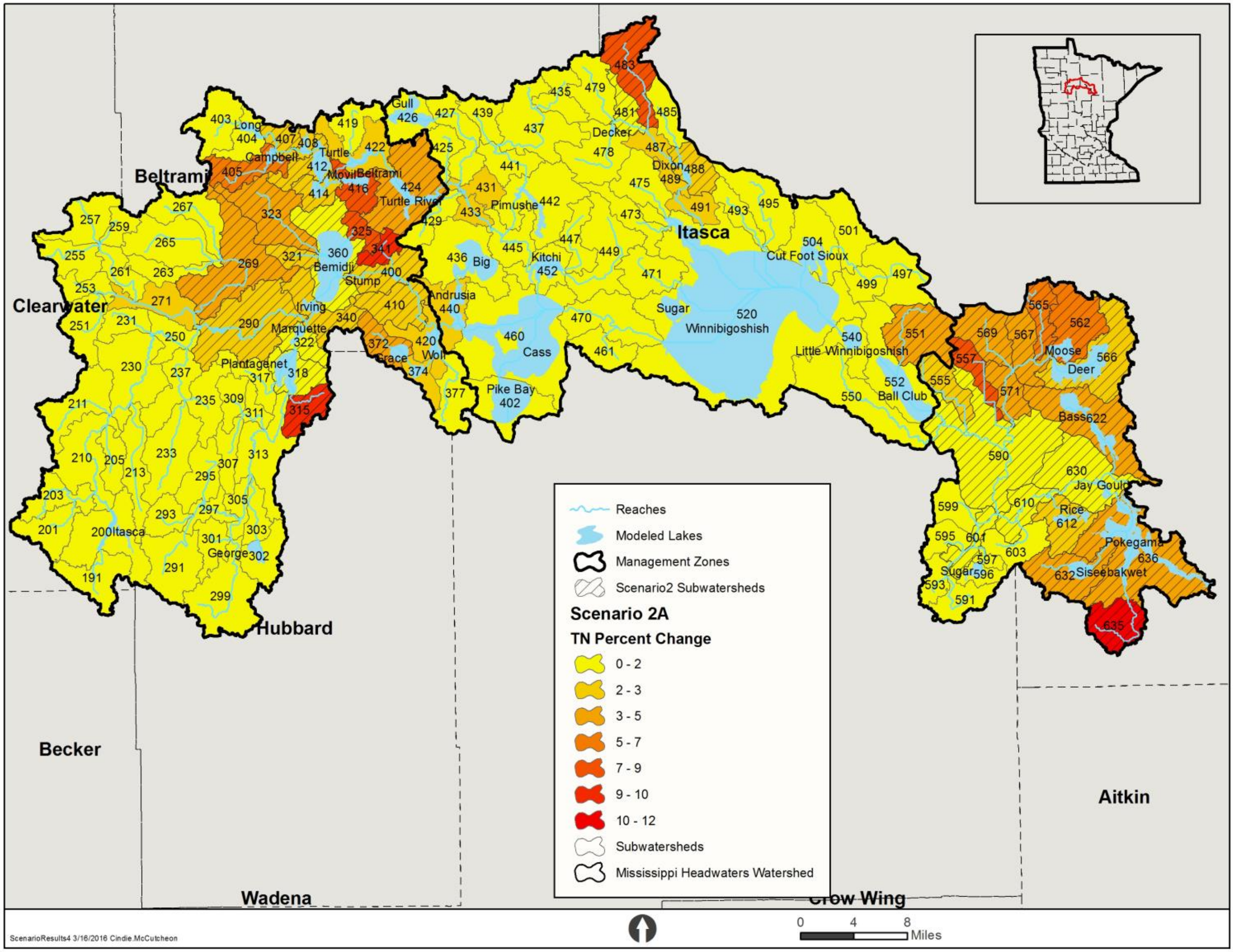

Figure 1-11. Scenario 2A Total Nitrogen Percent Change.

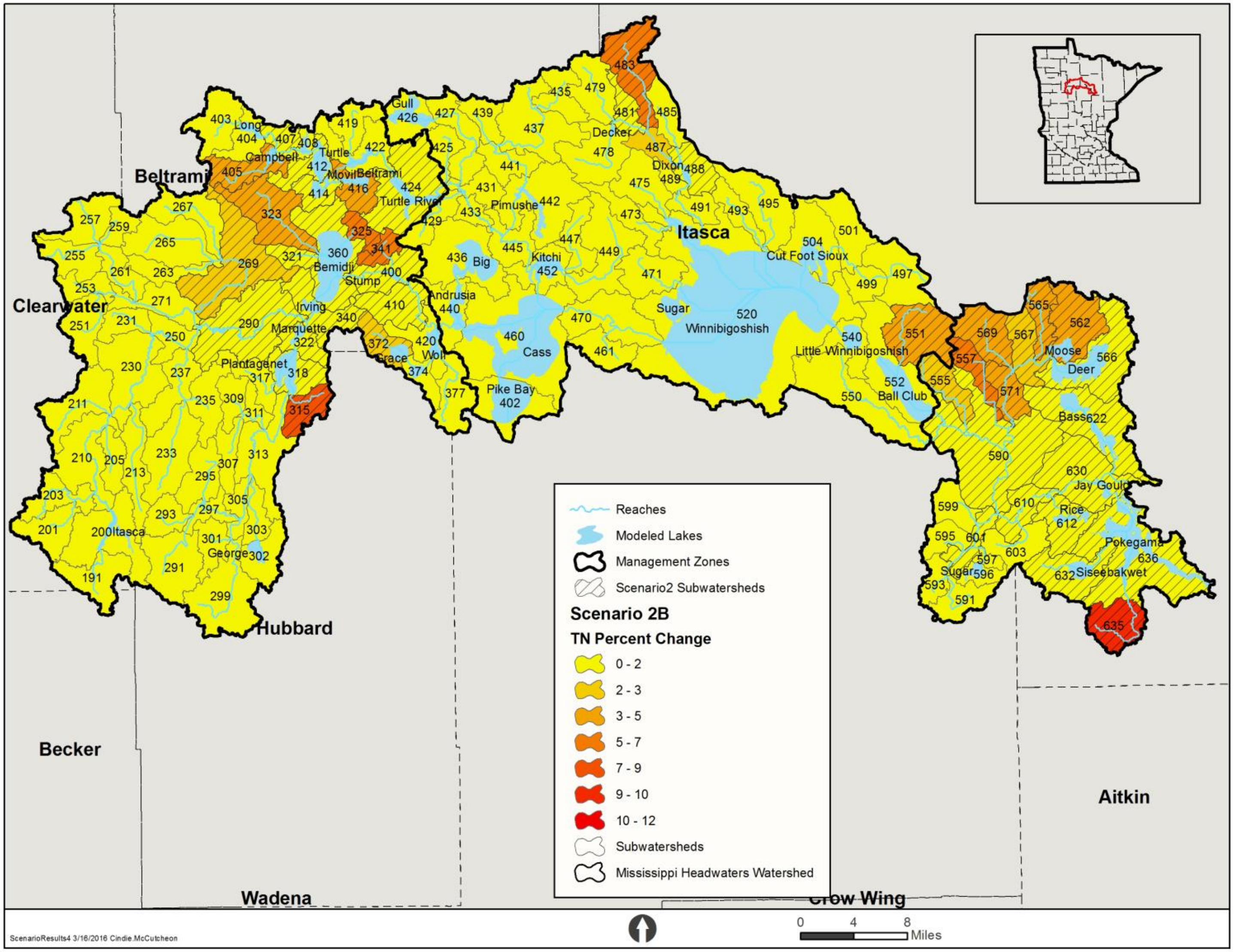

Figure 1-12. Scenario 2B Total Nitrogen Percent Change.

HSPF-estimated watershed responses for modeled parameters are depicted by subwatershed in Figures 1-13 through 1-16 for flow, TSS, TP, and TN, respectively. The highest runoff increases (approximately 1–7 percent) were noted particularly for West-Basin-assessed subwatersheds with increases propagated to downstream waters. Similar, but lower runoff increases were generally predicted for East Basin areas with increased forest conversion. In this scenario, converting forest was estimated to result in general runoff increases in select subwatersheds of Big Lakes Basin and particularly in its eastern portion.

- Projections indicate that the greatest increases of TSS loadings for West Basin subwatersheds vary from low to 43 percent. Increases in TSS loading in subwatersheds in the Big Lakes and East Basin were generally lower. These impacts were propagated downstream along flow paths.
- Projections indicated that the greatest increases in TP loading (3–7 percent) were evident in the southern reaches of the West Basin and the northern lake district of the West Basin with 3-5 percent increased loadings centering on key northern lake districts of the East Basin. The northeastern portion of the Big Lakes Basin was estimated to have 3–5 percent TP-loading increases.
- Estimated, increased TN loadings were generally of a lower magnitude for all of the modeled areas.
- Expressed across the broad Mississippi Headwaters Watershed, the estimated changes again appear to be much more subtle with estimated increases of 1 percent for flow, 3 percent for TSS, 1 percent for TP, and 1 percent for TN.

1.4 SCENARIO 4

Scenario 4 estimates the cumulative impacts of the previous scenarios, including increases in agricultural lands, developed lands, and intensified forest harvest (Scenarios 1, 2A, and 3) in the subwatersheds that were identified by stakeholders to be at risk for each conversion.

HSPF-estimated watershed responses for modeled parameters are depicted by assessed subwatershed in Figures 1-17 through 1-20 for flow, TSS, TP, and TN, respectively.

- The cumulative impacts from the increases in intensified land uses were substantial (in excess of 50 percent) for TSS and TP loadings for many of the assessed subwatersheds of the West and East Basin. Loading projections of this magnitude from this worst-case analysis, if realized, would result in substantial and measureable water quality degradation of many of the assessed subwatersheds and downstream waters, including portions of the Mississippi River. Established lake and stream beneficial uses could also be negatively affected by more subtle increases in flow and TSS and TP loading.
- Estimated TN loadings increased but were generally at a lower magnitude for all of the modeled areas. Increased TN loading may reduce N:P ratios in receiving waters and influence cyanobacteria (blue-green algae) dynamics that affect recreational uses.
- The Mississippi Headwaters Basin increased by an average of 3 percent for flow, 16 percent for TSS, 11 percent for TP, and 6 percent for TN.

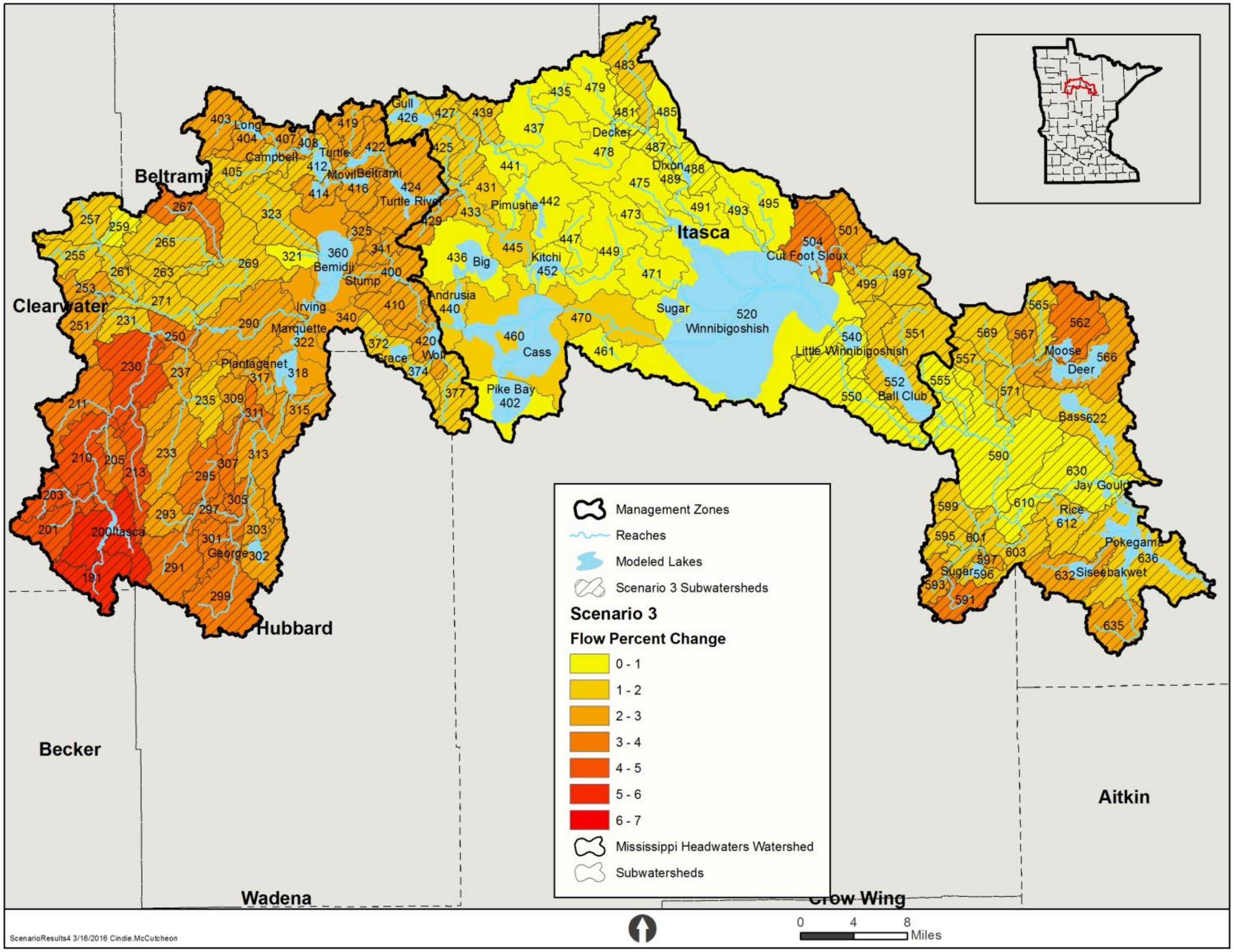

Figure 1-13. Scenario 3 Flow Percent Change.

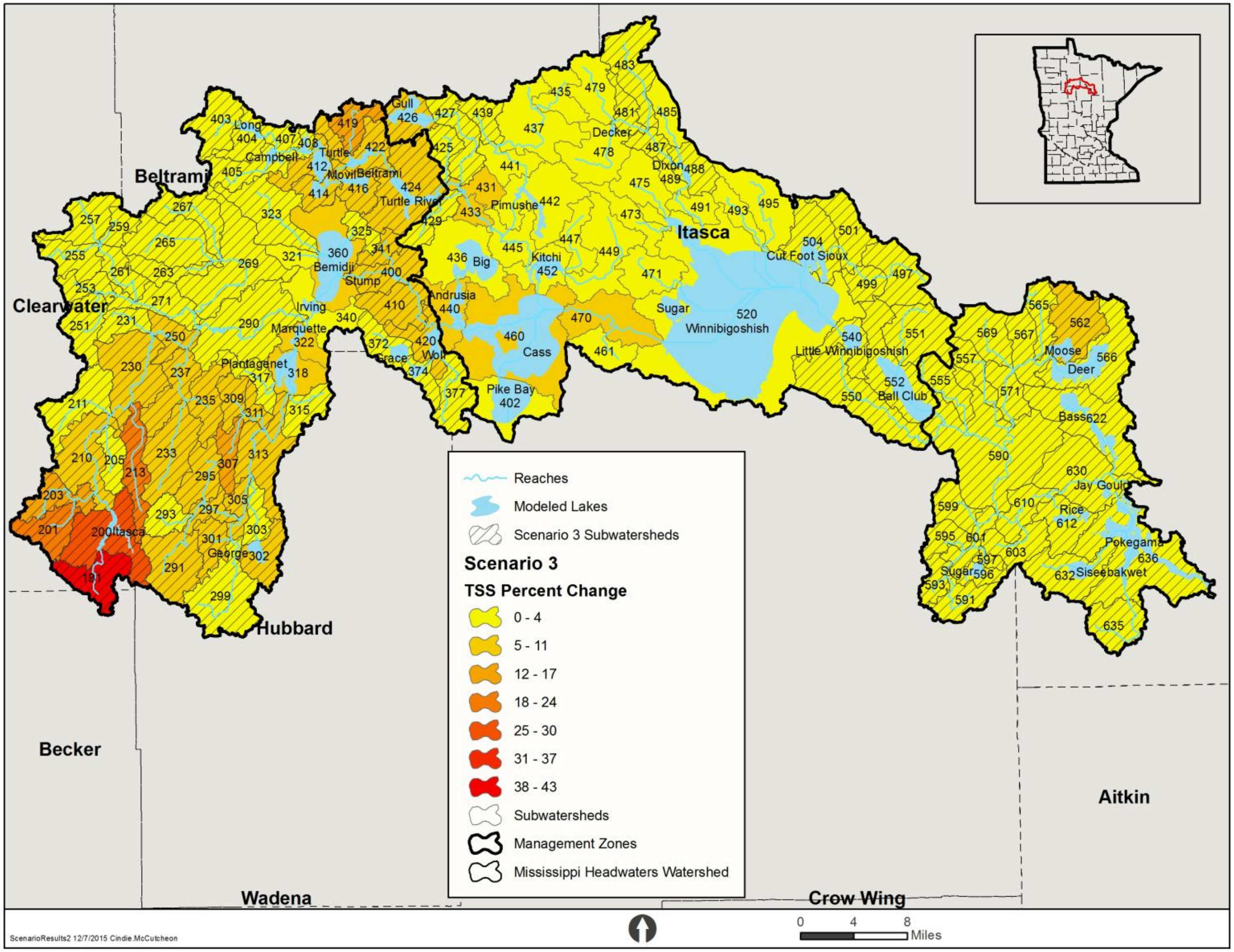

Figure 1-14. Scenario 3 Total Suspended Solids Percent Change.

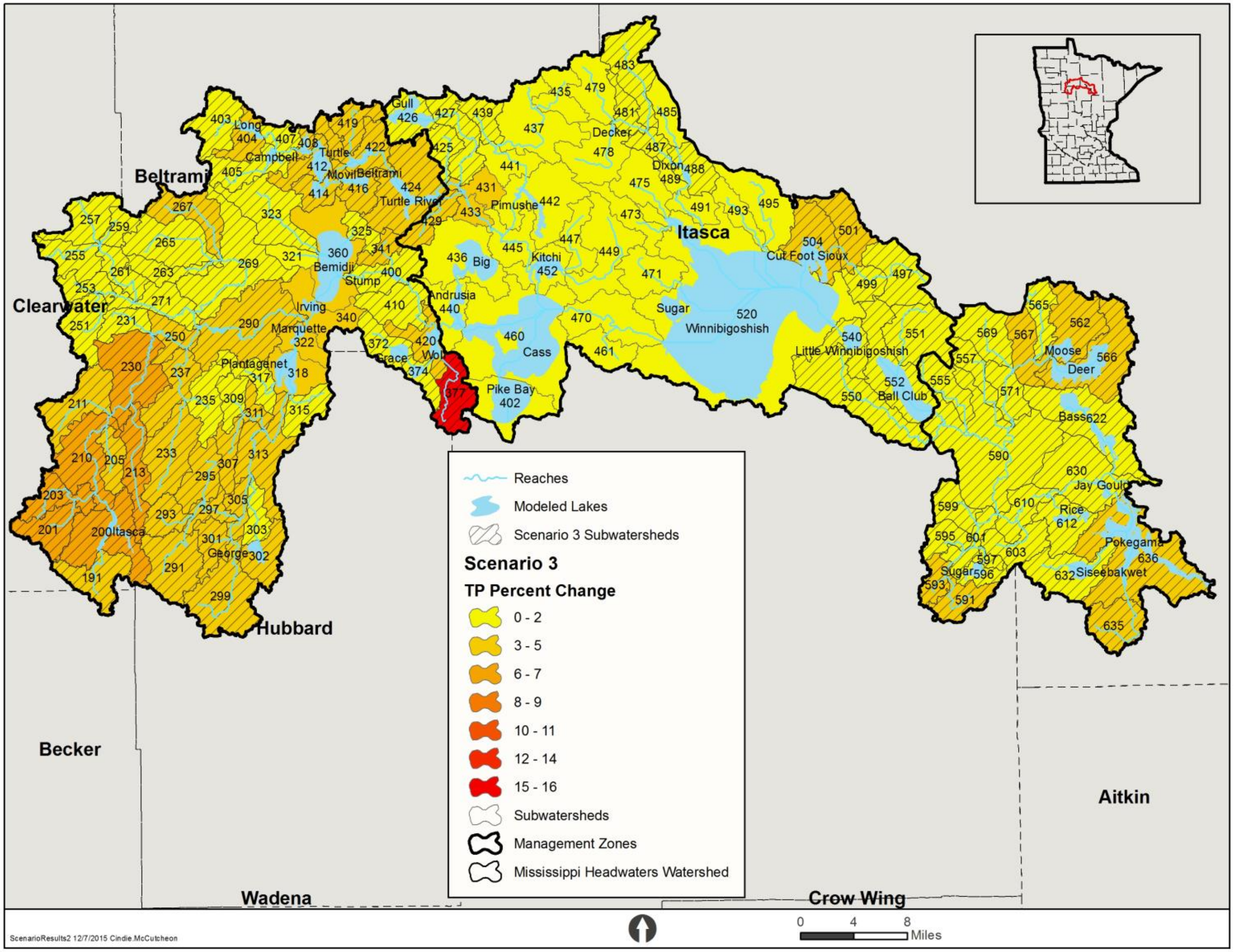

Figure 1-15. Scenario 3 Total Phosphorus Percent Change.

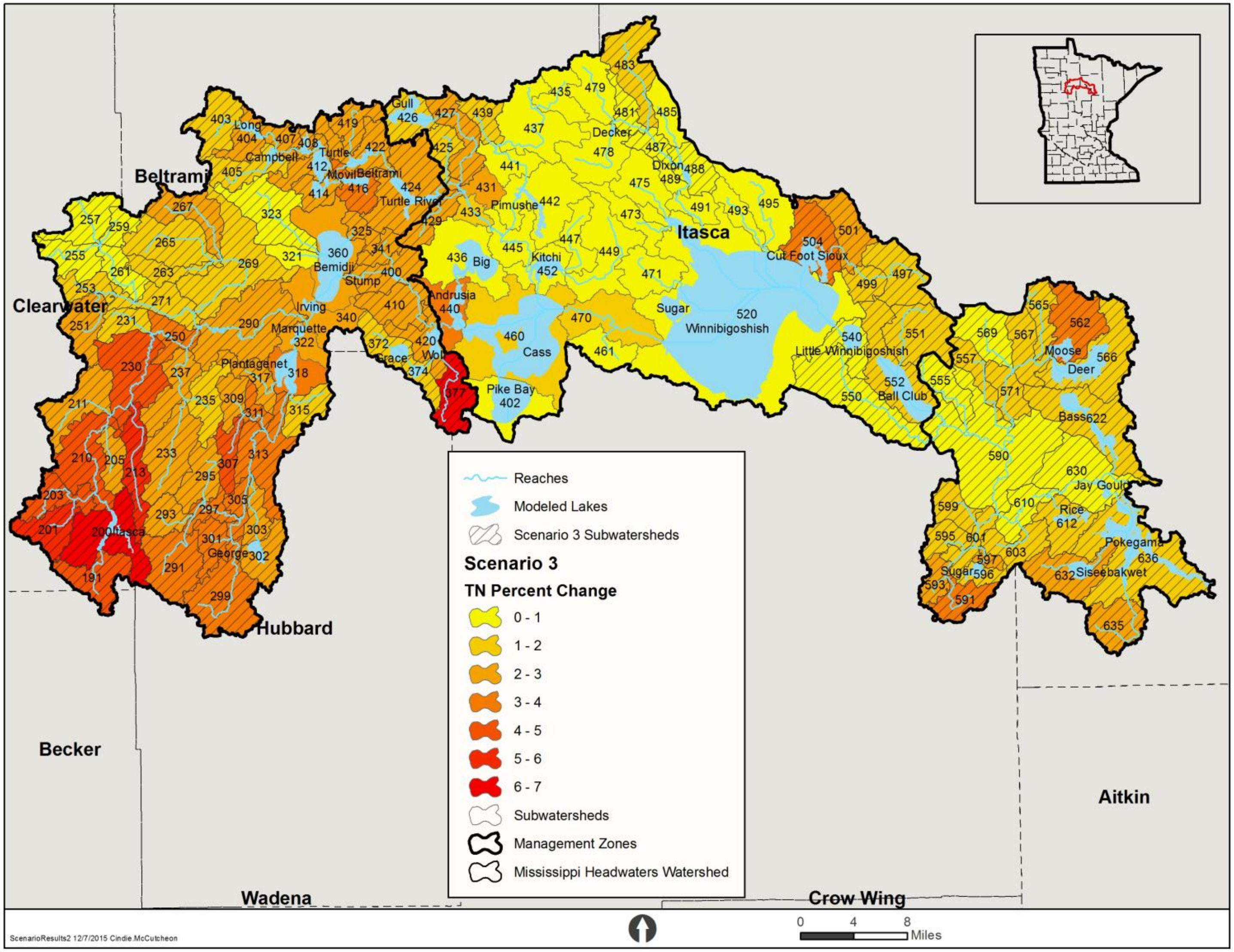

Figure 1-16. Scenario 3 Total Nitrogen Percent Change.

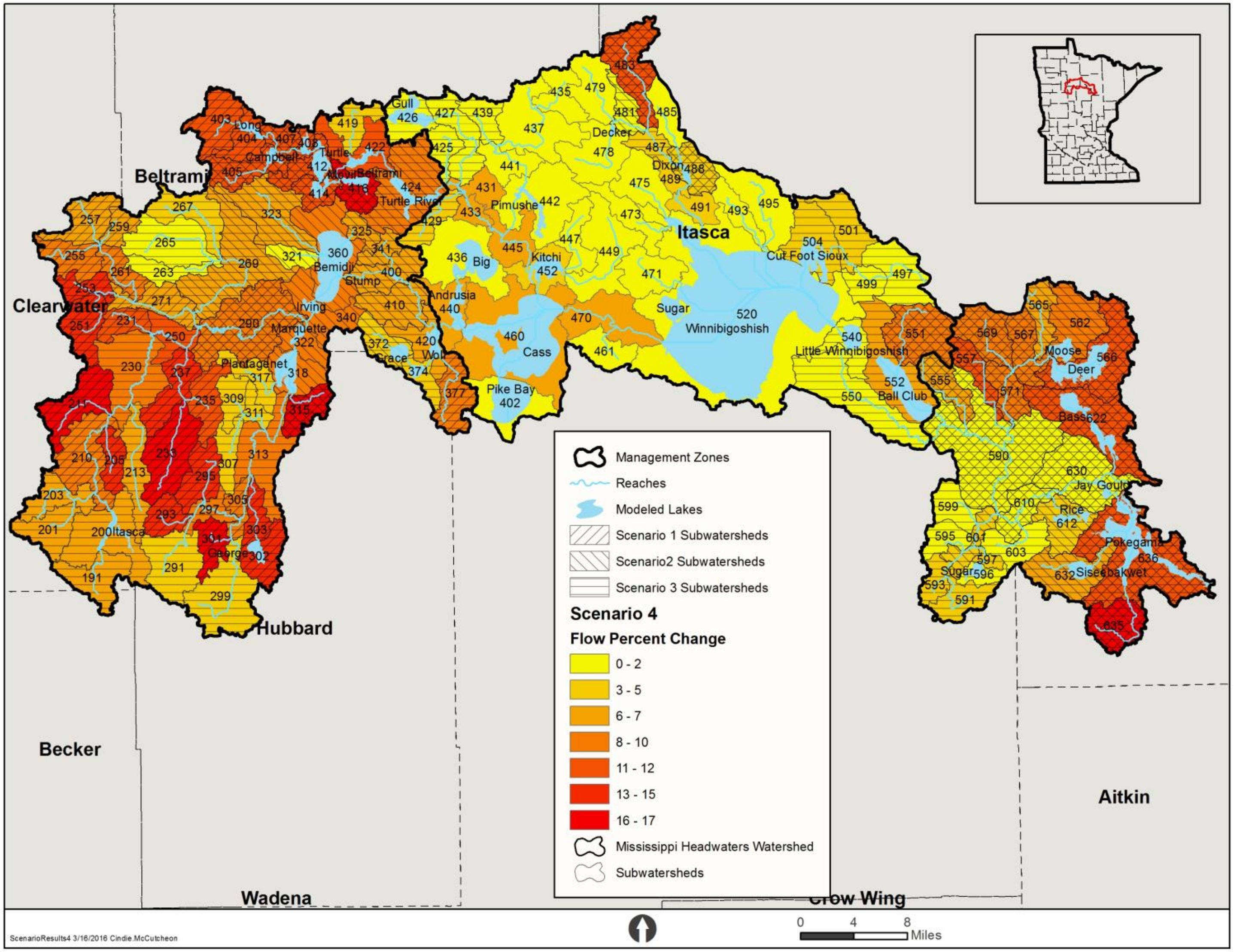

Figure 1-17. Scenario 4 Flow Percent Change.

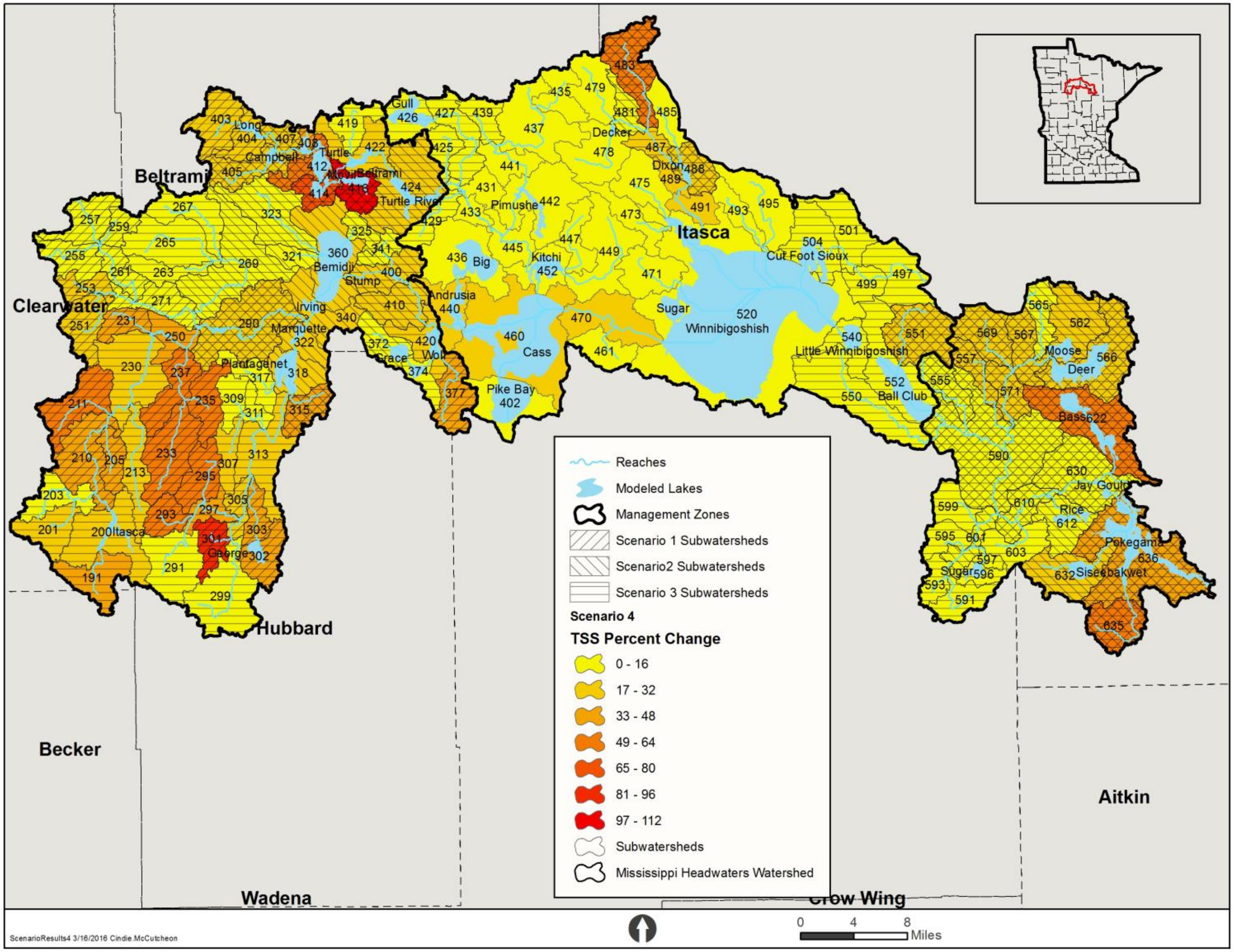

Figure 1-18. Scenario 4 Total Suspended Solids Percent Change.

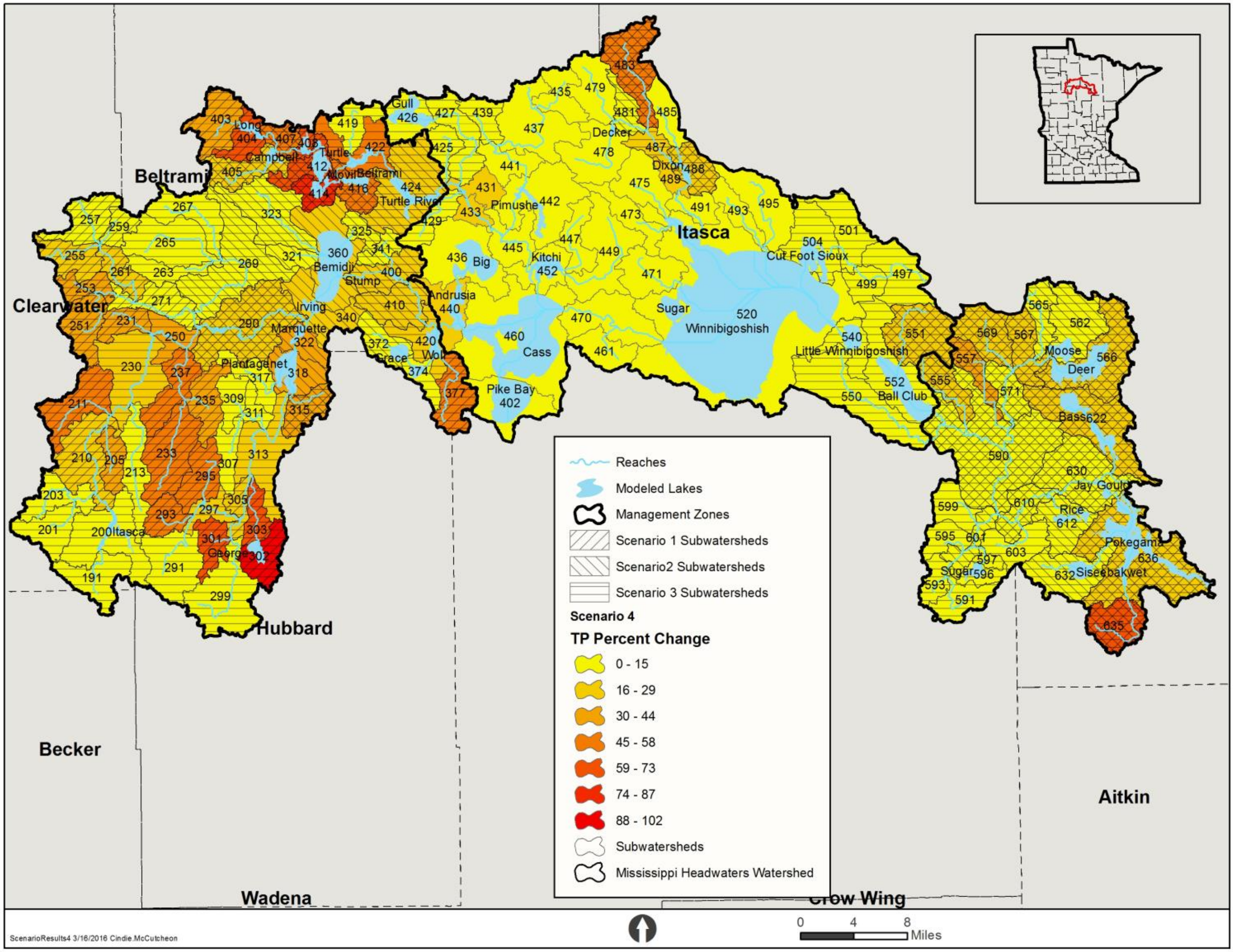

Figure 1-19. Scenario 4 Total Phosphorus Percent Change.

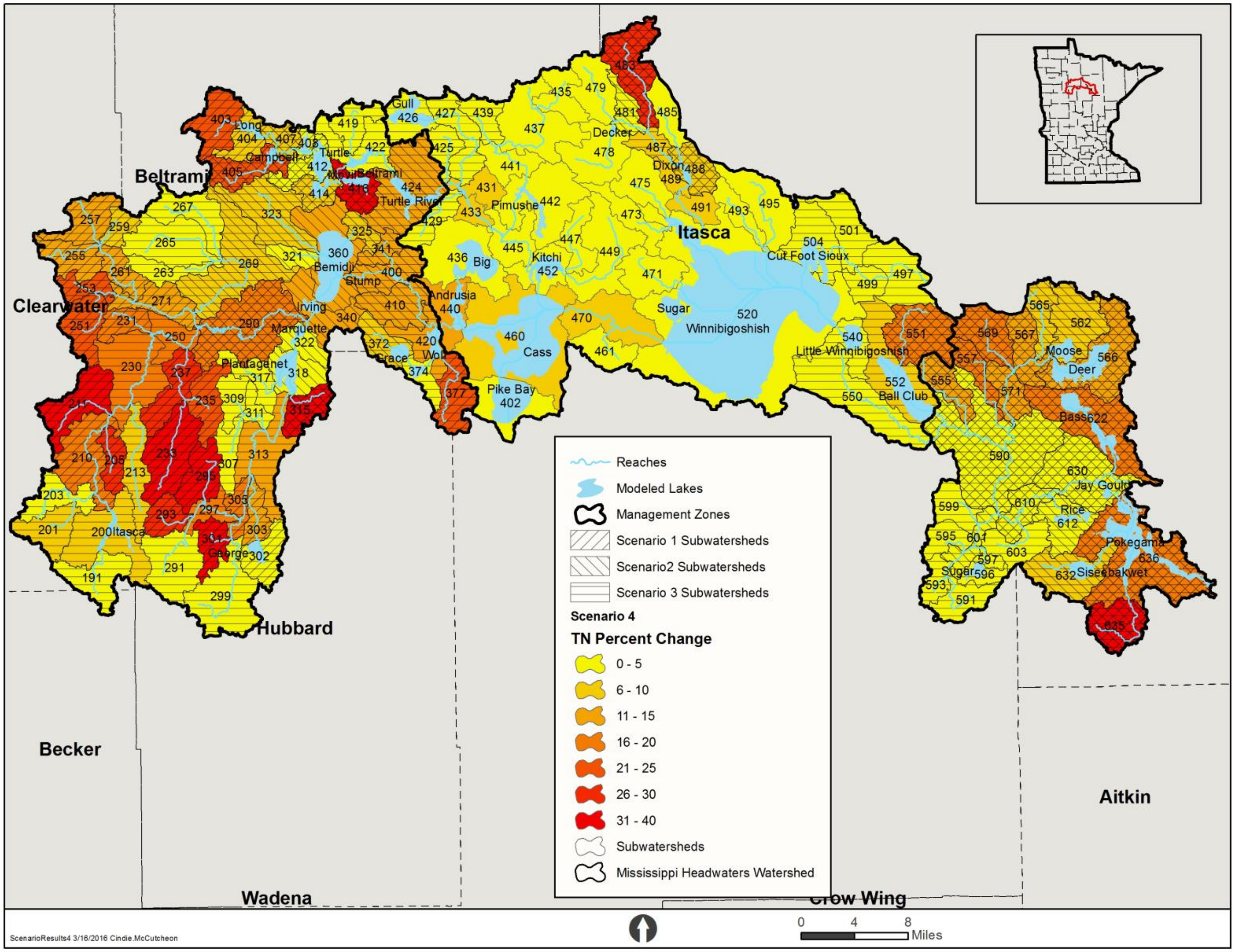

Figure 1-20. Scenario 4 Total Nitrogen Percent Change.

1.5 SCENARIO 5

Scenario 5 estimates the impacts of buffers being applied to 50 percent of the cropland in each subwatershed. Buffer reductions used in this assessment were based on values cited by the Minnesota Department of Agriculture's (MDA's) BMP Handbook [Miller et al., 2012] and included 76 percent for TSS, 67 percent for TP, 68 percent for TN, and 0 percent reductions for flow.

HSPF-estimated watershed responses are depicted by assessed subwatersheds in Figures 1-21 through 1-23 for TSS, TP and TN, respectively.

- Based on the cited reference, no change in flows was estimated.
- Estimated reductions in TSS loading (approximately 4–28 percent) and TP loading (approximately 3–34 percent) were widely noted for the assessed subwatersheds, particularly in the upper flow path subwatersheds of the West Basin. Similar, but lower reductions of TSS and TP loads were estimated for the Big Lakes and East Basin subwatersheds. These positive impacts were propagated downstream along all flow paths.
- In a similar fashion, estimated reductions in TN loading (approximately 3–27 percent) were widely noted for the assessed subwatersheds, particularly in the upper flow path subwatersheds of the West Basin. Similar, but lower declines in TN loads were estimated for the Big Lakes and East Basin subwatersheds. These positive impacts were propagated downstream along all flow paths.
- In the context of the broad Mississippi Headwaters Watershed, the estimated changes appear again to be subtle, but substantial, with cumulative basin reductions of 8 percent for TSS, 6 percent for TP, and 4 percent for TN.

1.6 SUMMARY OF SCENARIO RESULTS

To convey the range of potential changes from the six future land-use scenarios, 11 subwatersheds were selected as pulse points along the flow networks of the West, Big Lakes, and East Basin management areas. These pulse points are described in Table 1-1 and depicted in the simplified Mississippi Headwaters flow network diagram in Figure 1-24. West Basin locations that were used in this analysis as relative change pulse points focused on the upper Mississippi River above Lake Irving and select tributaries that included the Schoolcraft River (above Lake Plantagenet), Little Mississippi River, and the Turtle River (above Gull River). Big Lakes Basin locations focused on the Mississippi River above and below Lake Winnibigoshish (Reaches 470 and 550, respectively) and tributaries that included the Turtle River and Third River. East Basin locations included the Mississippi River at Grand Rapids and at the Hydrologic Unit Code (HUC) outlet of Reach 630, as well as tributaries that included Smith Creek and Bass Brook.

To provide context for scenario results, an analysis was carried out to compare average present-day and estimated future scenario-derived TSS and TP FWMCs at key pulse-point locations in each of the three Mississippi Headwaters management basins. Modeling-period FWMCs were estimated as the mean annual load divided by mean annual discharge for the 14-year modeling period. From a water quality standard perspective, the North River Nutrient Region standards are 15 milligrams per liter (mg/L) for TSS and 50 mg/L for TP. The Northern Lakes and Forests (NLF) lake TP standard is 30 mg/L. Hence, as stream and river TP concentrations increase toward the river phosphorus standard, lakes

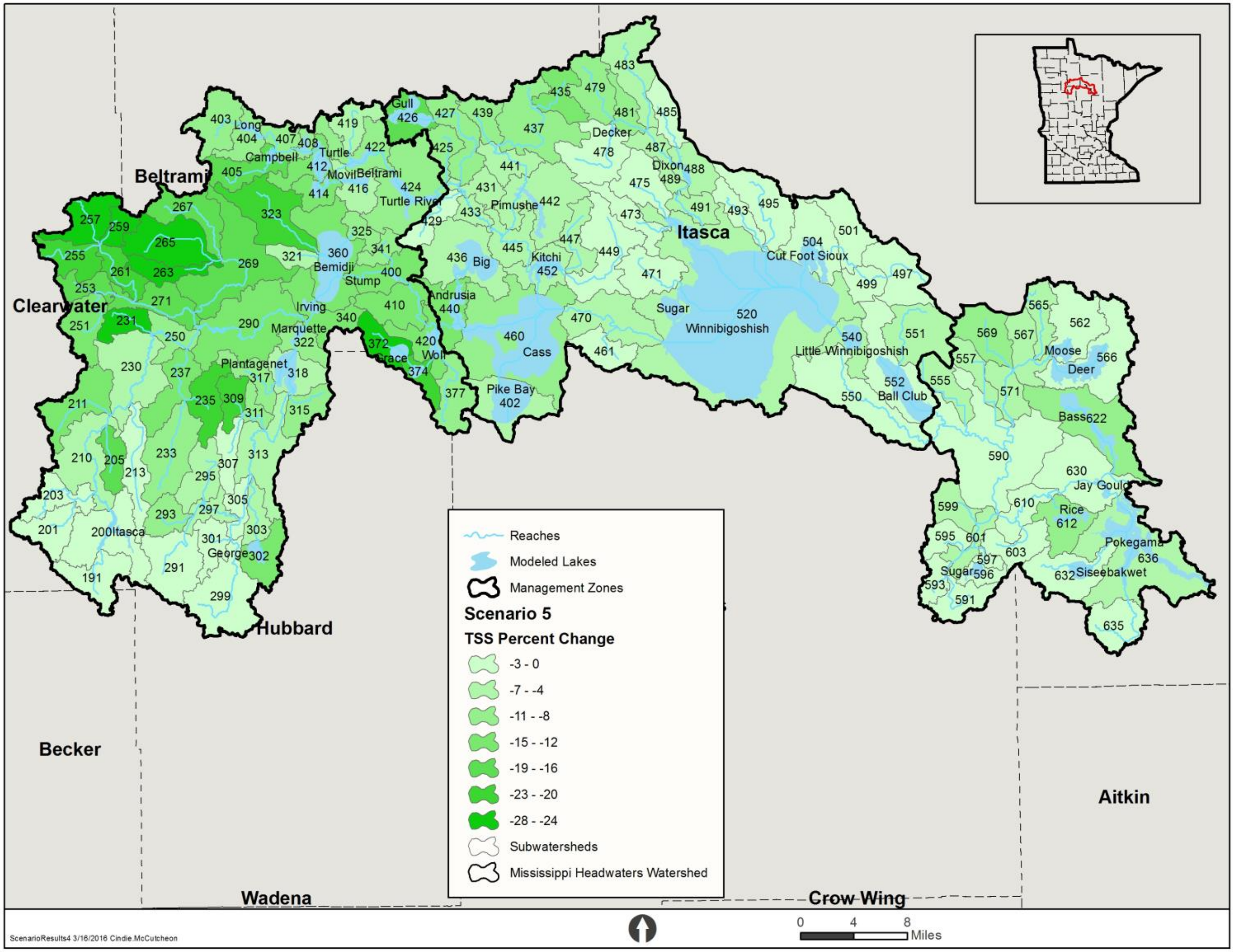

Figure 1-21. Scenario 5 Total Suspended Solids Percent Change.

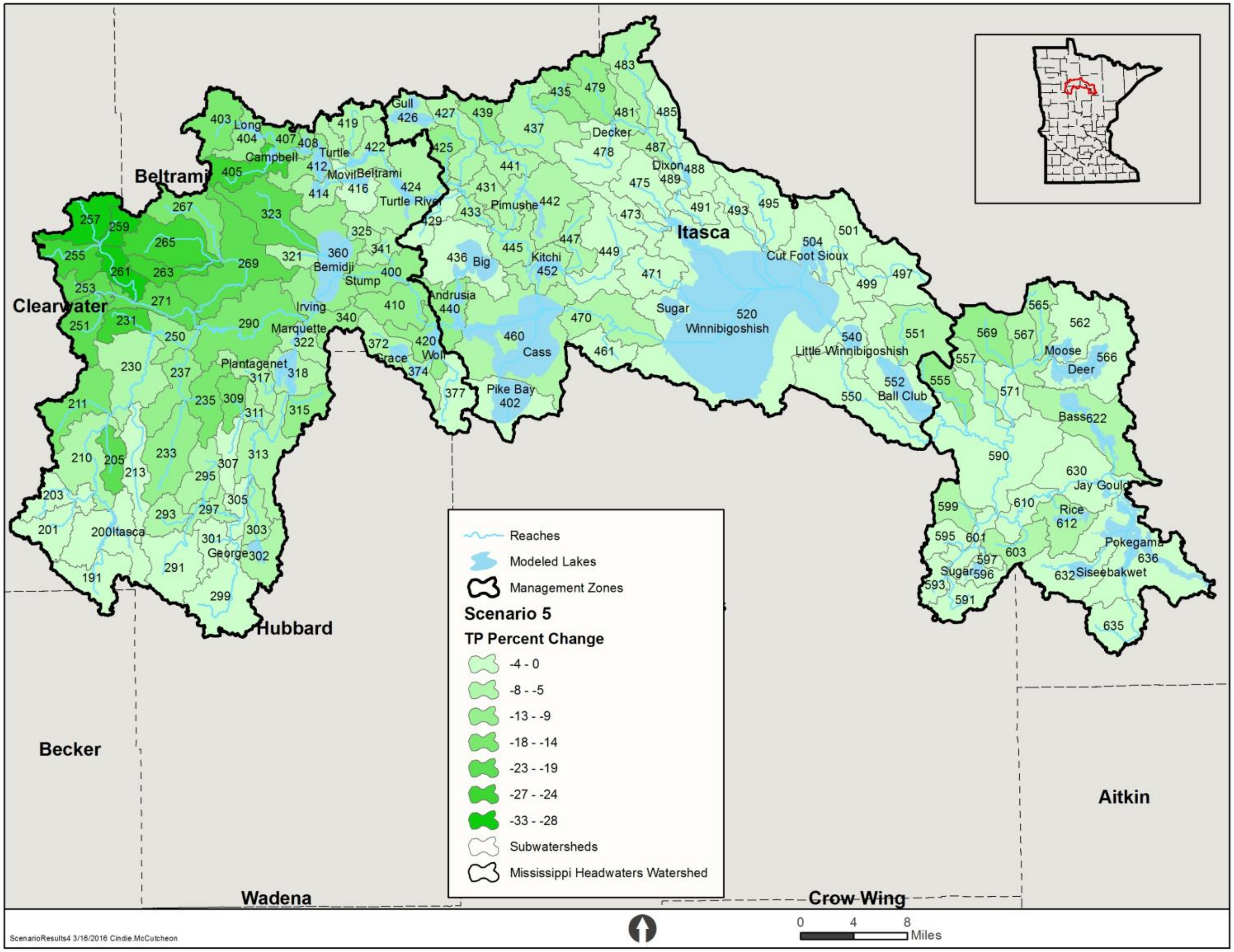

Figure 1-22. Scenario 5 Total Phosphorus Percent Change.

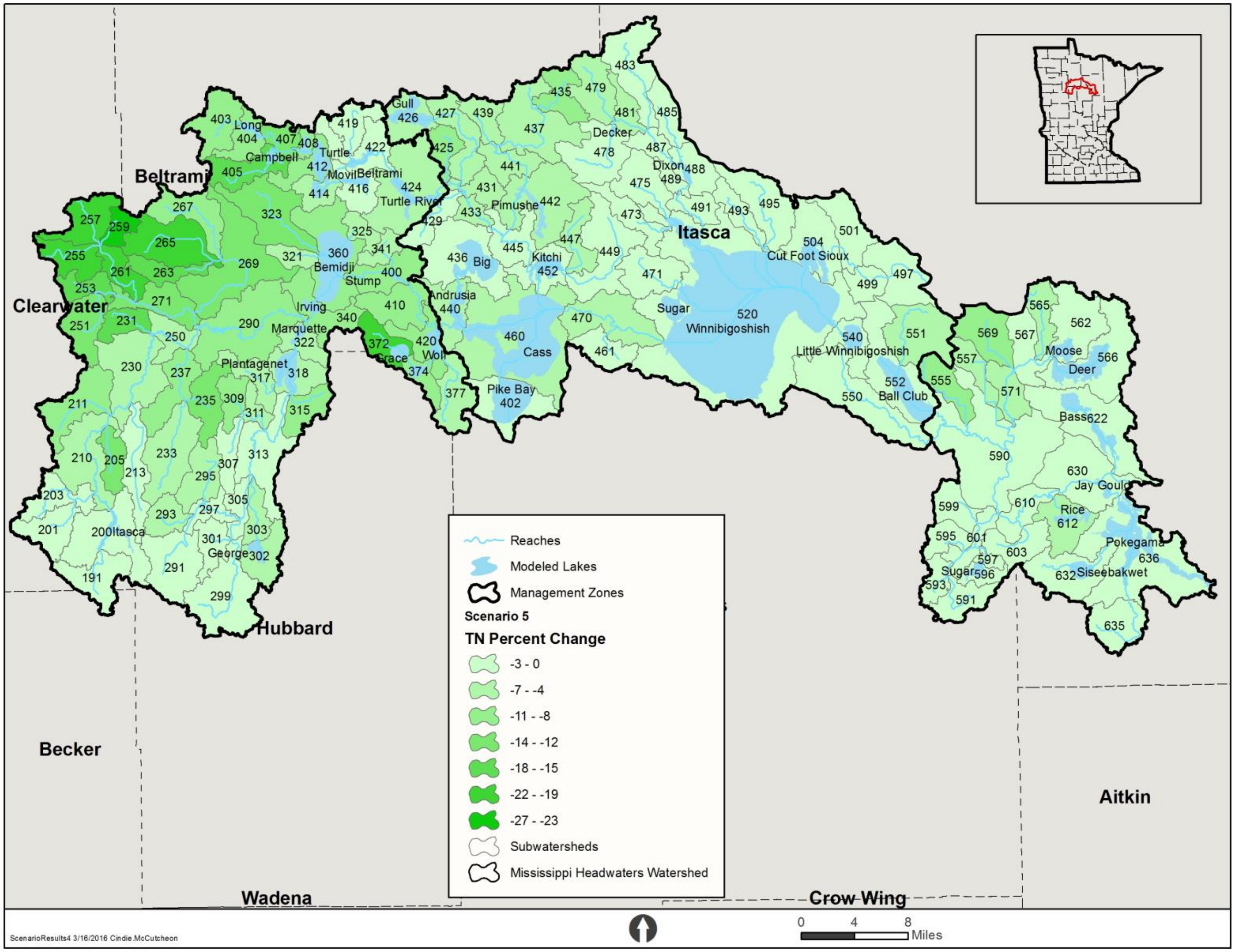

Figure 1-23. Scenario 5 Total Nitrogen Percent Change.

along major flow paths will be more likely to experience increased TP and potentially exceed lake eutrophication standards, as seen in Lake Irving. River water quality standards collection periods are as follows: (1) April 1 to September 30 for TSS and (2) June 1 to September 30 for TP and eutrophication response variables [Minnesota Rule 7050.0222]. FWMCs reported in this report are based on annual averages and, therefore, do not directly correspond to the river water quality standard time periods. Comparing relative scenario changes in FWMCs allow for assessing the effects of numerous impacts along the three Mississippi Headwaters Watershed Basin flow networks. FWMC estimates for TSS and TP are shown in Figures 1-25 and 1-26 and in Tables 1-2 and 1-3, respectively.

Table 1-1. Watershed Scenario Reaches

Management Area	Description	Reach
West Basin	Schoolcraft Above Plantagenet	313
West Basin	Mississippi Above Irving	330
West Basin	Little Mississippi River Outlet	271
West Basin	Turtle River Above Gull River	424
Big Lakes Basin	Turtle River Above Kitchi	445
Big Lakes Basin	Third River Above Winnibigoshish	491
Big Lakes Basin	Mississippi Above Winnibigoshish	470
Big Lakes Basin	Mississippi Above Leech River	550
East Basin	Bass Brook	622
East Basin	Smith Creek	635
East Basin	Mississippi Headwaters Outlet	630

1.6.1 West Basin

Land-conversion scenario results, particularly converting forests to agricultural land cover, indicate the highest increases in TSS concentrations from present-day conditions of the summarized Mississippi Headwater pulse-point locations. Of these sites, the Little Mississippi River's TSS concentrations were predicted to exceed 30 mg/L for the present-day and for all scenarios. The Schoolcraft and Mississippi River concentrations were estimated to exceed 15 mg/L for present-day and all scenarios. Of the West Basin sites, the Turtle River was noted to have lower TSS concentrations; lakes along the Turtle River are likely influencing these results. The cumulative impacts of converted land uses (Scenario 4) showed the highest TSS concentrations noted for the Mississippi Headwaters' pulse point assessed reaches. While using agricultural buffers and MIDS BMPs was noted to reduce TSS concentrations for agricultural and developed land uses, respectively, three of the four sites remained at or above 15 mg/L.

Land-conversion scenario results indicate higher TP increases from converting forests to agriculture than converting mature forests to development or to young forests. As such, the cumulative impacts (Scenario 4) were attributed more to agricultural conversions developed in this assessment. The Little Mississippi River reach was again noted to have the highest West Basin present-day TP concentrations that increased across all scenarios to 60 mg/L or higher concentrations. The Schoolcraft River and Mississippi River (above Irving) were noted to approach or exceed the 50 mg/L level for agricultural and cumulative impact scenarios. The Turtle River (above the Gull River) was predicted to increase from about 33 to as much as 48 mg/L, primarily because of agricultural conversions. Increasing river TP concentrations will increase the odds of degrading this basin's core lake districts located along stream flow paths, particularly the smaller lakes, with cascading effects on larger, downstream lakes (e.g., Lakes Irving, Bemidji, and Stump Lake) and downstream waters, as summarized by Wilson and McCutcheon [2016].

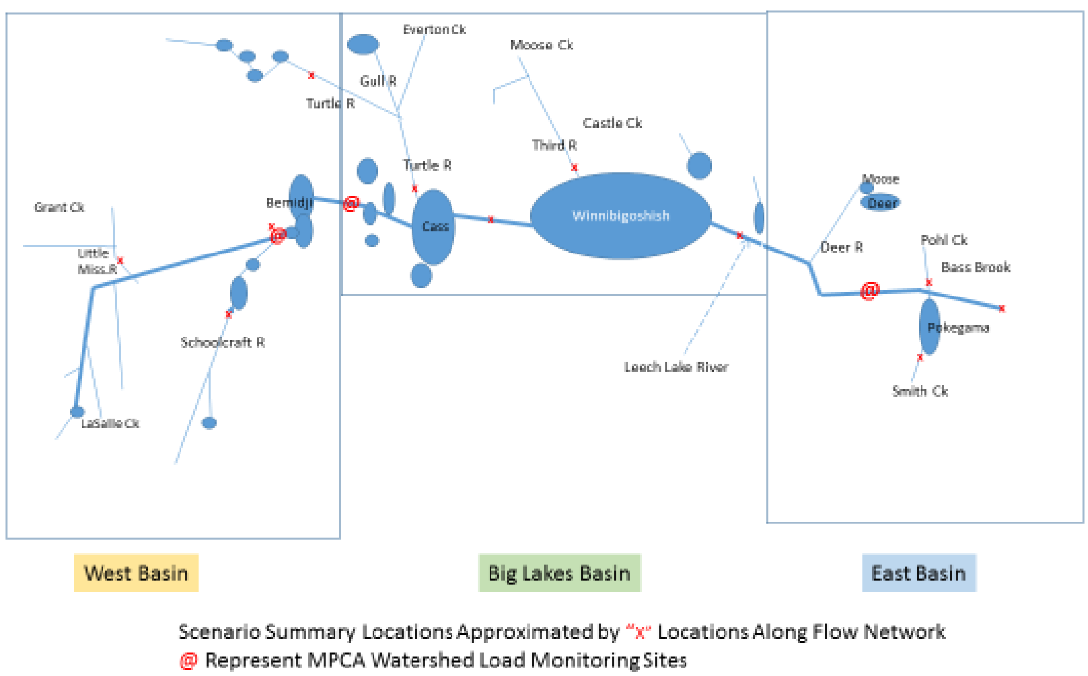

Figure 1-24. Watershed Scenario Pulse Points.

1.6.2 Big Lakes Basin

Assessed reaches of the Big Lakes Basin included two portions of the Mississippi River (above Winnibigoshish and above the Leech Lake River) and tributaries that included the Turtle River (above Kitchi) and Third River (above Winnibigoshish). Scenario areas converted from forest to agriculture, developed lands, and young forests resulted in similar magnitudes of TSS increases with higher concentrations noted for Turtle River and Third River reaches. Peak TSS concentrations were estimated to be well below 15 mg/L with the Mississippi River sites showing the lowest values. Sedimentation within the large lakes of this basin will have significant influences on exporting TSS.

By contrast, present-day modeled average and predicted future TP concentrations were much more homogeneous among the Big Lakes Basin reach scenario areas. Converting forests to agriculture was estimated to generate the largest increases in TP concentrations. Lower amounts of land conversions to developed and young forests was predicted to produce relatively minor increases among sites. Predicted TP reach concentrations approached or exceeded 30 mg/L for all of the converted land-use scenarios for

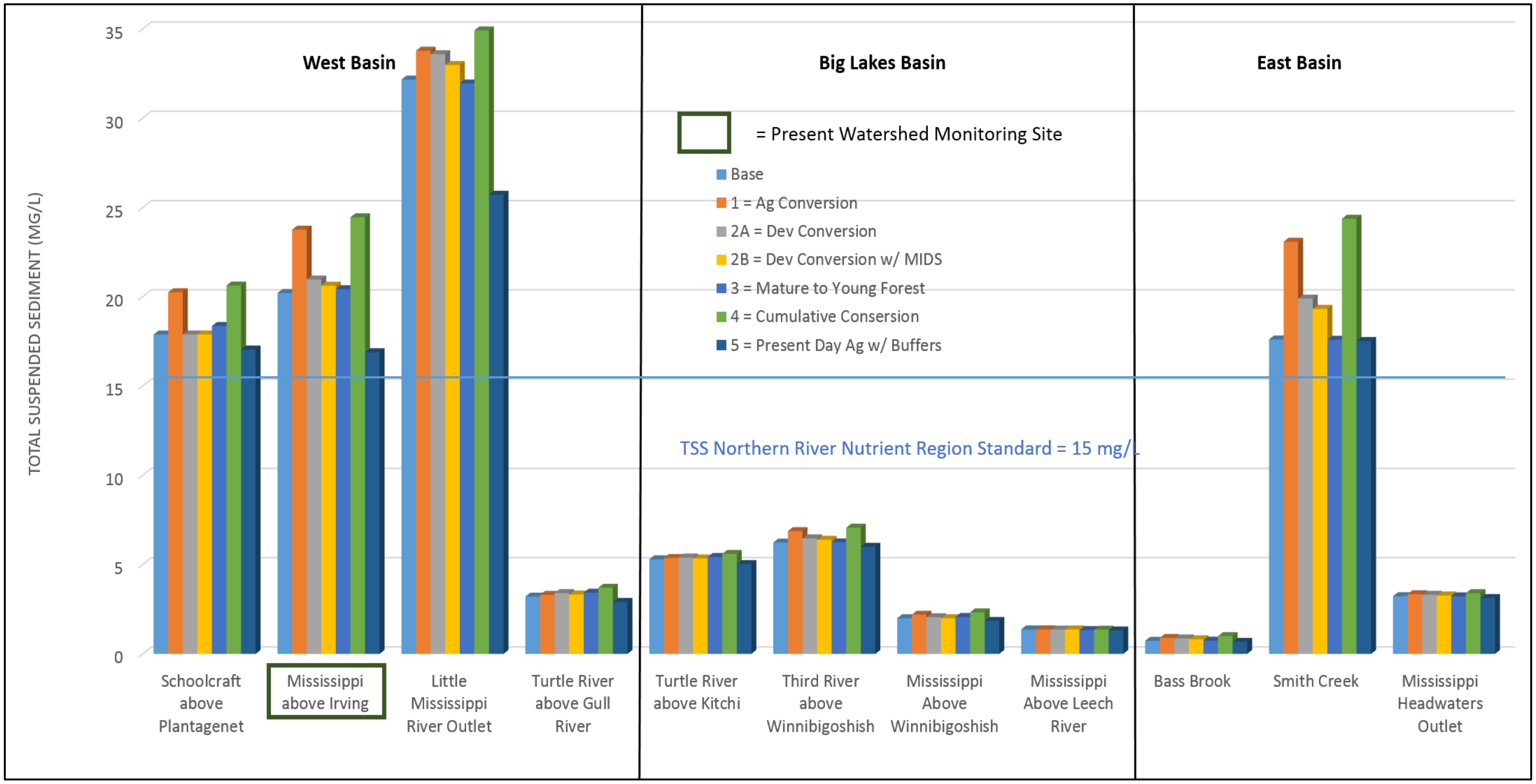

Figure 1-25. Watershed Total Suspended Solids Scenario Summary by Basin and Subwatershed Pulse Point.

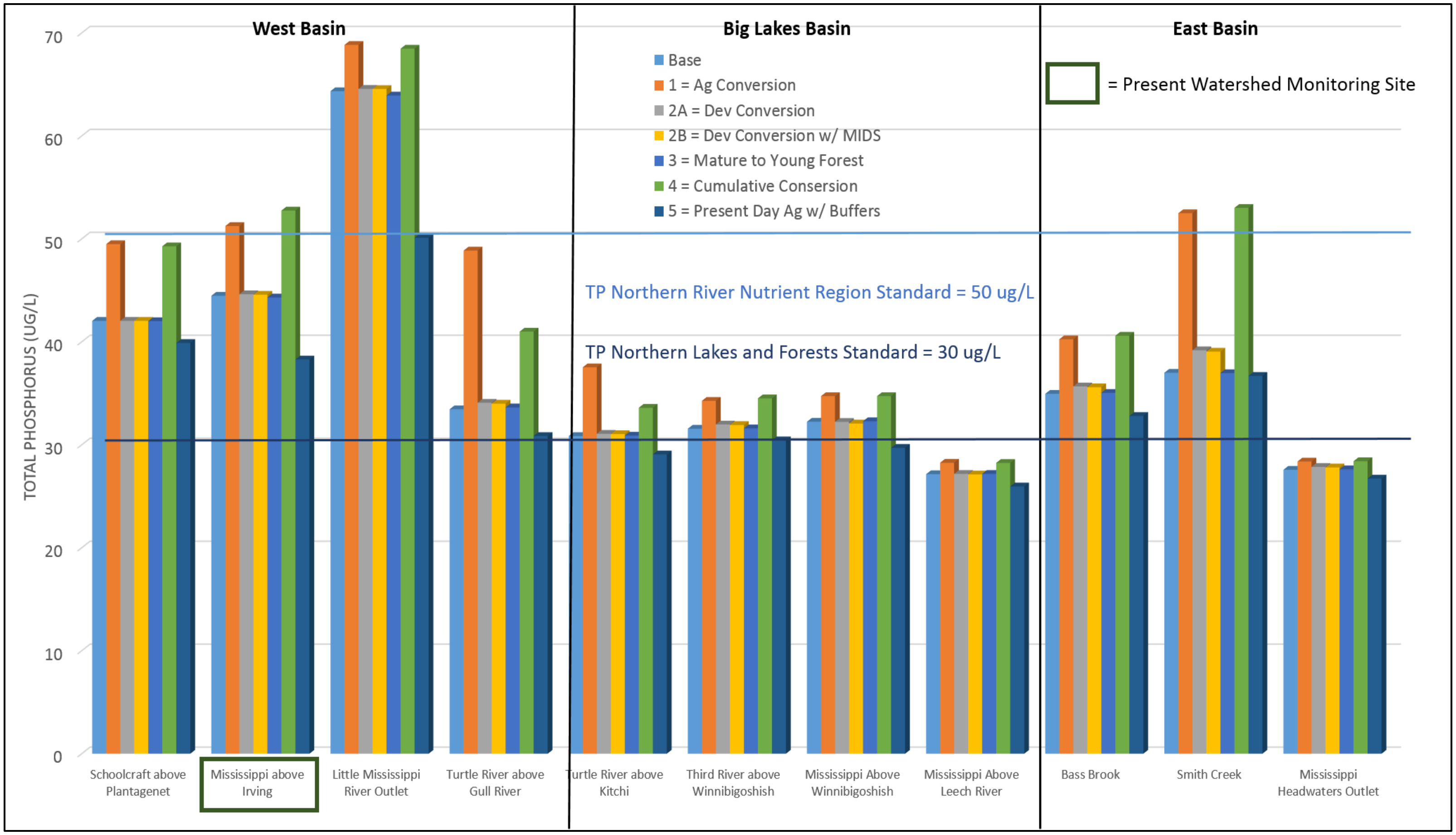

Figure 1-26. Watershed Total Phosphorus Scenario Summary by Basin and Subwatershed Pulse Point.

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Table 1-2. Watershed Scenario Predicted Total Suspended Solids Concentrations by Subwatershed (Significant Digits Presented for Comparison Purposes)

Management Area	Description	Reach	Base (mg/L)	1 = Ag Conversion (mg/L)	2A = Dev Conversion (mg/L)	2B = Dev Conversion w/ MIDS (mg/L)	3 = Mature to Young Forest (mg/L)	4 = Cumulative Conversion (mg/L)	5 = Present-Day Ag w/ Buffers (mg/L)
West	Schoolcraft Above Plantagenet	313	17.9	20.3	17.9	17.9	18.4	20.6	17.0
West	Mississippi Above Irving	330	20.2	23.8	21.0	20.6	20.4	24.5	16.9
West	Little Mississippi River Outlet	271	32.2	33.8	33.6	33.0	32.0	34.9	25.7
West	Turtle River Above Gull River	424	3.2	3.3	3.4	3.3	3.4	3.7	2.9
Big Lakes	Turtle River Above Kitchi	445	5.3	5.4	5.4	5.3	5.4	5.6	5.0
Big Lakes	Third River Above Winnibigoshish	491	6.2	6.9	6.5	6.4	6.2	7.1	6.0
Big Lakes	Mississippi Above Winnibigoshish	470	2.0	2.2	2.1	2.0	2.1	2.3	1.8
Big Lakes	Mississippi Above Leech River	550	1.4	1.4	1.4	1.4	1.3	1.4	1.3
East	Bass Brook	622	0.7	0.9	0.9	0.8	0.7	1.0	0.7
East	Smith Creek	635	17.6	23.1	19.9	19.3	17.6	24.4	17.5
East	Mississippi Headwaters Outlet	630	3.2	3.3	3.3	3.3	3.2	3.4	3.1

Table 1-3. Watershed Scenario Predicted Total Phosphorus Concentrations by Subwatershed (Significant Digits Presented for Comparison Purposes)

Management Area	Description	Reach	Base (mg/L)	1 = Ag Conversion (mg/L)	2A = Dev Conversion (mg/L)	2B = Dev Conversion w/ MIDS (mg/L)	3 = Mature to Young Forest (mg/L)	4 = Cumulative Conversion (mg/L)	5 = Present-Day Ag w/ Buffers (mg/L)
West	Schoolcraft Above Plantagenet	313	42.0	49.5	42.0	42.0	42.0	49.3	39.9
West	Mississippi Above Irving	330	44.5	51.3	44.6	44.6	44.3	52.8	38.3
West	Little Mississippi River Outlet	271	64.3	68.8	64.6	64.6	63.9	68.5	50.1
West	Turtle River Above Gull River	424	33.5	48.9	34.1	34.0	33.6	41.0	30.9
Big Lakes	Turtle River Above Kitchi	445	30.9	37.5	31.1	31.0	30.9	33.6	29.1
Big Lakes	Third River Above Winnibigoshish	491	31.6	34.3	32.0	31.9	31.6	34.5	30.4
Big Lakes	Mississippi Above Winnibigoshish	470	32.2	34.7	32.2	32.1	32.3	34.7	29.7
Big Lakes	Mississippi Above Leech River	550	27.2	28.3	27.2	27.1	27.2	28.2	26.0
East	Bass Brook	622	35.0	40.3	35.7	35.6	35.0	40.6	32.8
East	Smith Creek	635	37.0	52.5	39.2	39.1	37.0	53.0	36.7
East	Mississippi Headwaters Outlet	630	27.6	28.4	27.9	27.8	27.6	28.4	26.7

the Third River, Turtle River, and Mississippi River (above Winnibigoshish). The Mississippi River above the Leech Lake River remained below 30 mg/L, likely because of the influence of Winnibigoshish Reservoir. Predicted increases in river TP concentrations within this basin will increase the odds of exceeding lake phosphorus standards, particularly for the smaller lakes. Implementation of agricultural buffers was predicted to reduce TP concentrations to base levels or average present-day conditions.

1.6.3 East Basin

Of the East Basin's three pulse-point reaches, the highest estimated TSS concentrations were noted for Smith Creek, with predicted concentrations reaching or exceeding 15 mg/L for present and converted land uses. In contrast, Bass Brook's predicted TSS concentrations remained relatively low, again likely caused by upgradient lake sedimentation influences. The Mississippi River at the outlet of the system remained below 4 mg/L.

TP concentrations predicted for Smith Creek resulting from converting forests to agriculture exceeded 50 mg/L with a smaller increase predicted for converting forests to developed land areas. Implementing agricultural buffers was predicted to reduce TP concentrations to present-day average conditions. Implementing MIDS practices on scenario-developed areas was predicted to reduce future development TP concentrations. Present-day and converted land uses in the Bass Brook Watershed were predicted to exceed 35 mg/L; the largest noted increases came from agricultural conversion. The Mississippi River TP concentrations at the outlet were estimated to increase slightly from present-day levels.

1.7 PRIORITY LAKES

For this assessment, priority lakes identified by Mississippi Headwaters Watershed stakeholders included Bemidji, Irving, Grace, Plantagenet, Cass, Little Turtle, Winnibigoshish, and Pokegama. Primary concern has focused on sensitivity of these lakes to degradation, particularly from increases in phosphorus that can generate algae (turbidity), which causes a loss of transparency. The relationship of average summer TP and transparency for Minnesota lakes is depicted in Figure 1-25, which shows that Secchi transparency is extremely sensitive to phosphorus concentrations less than 30 µg/L (or parts per billion [ppb]). Rapid loss of average summer transparency is noted as TP concentrations increase from 10 to 30 µg/L and as Secchi values decline from approximately 5+ meters (or 16.7+ feet) to 2.5 meters (or 8.3 feet), with the greatest loss of transparency occurring as TP values shift from 10 to 20 µg/L.

Summary information for each of the priority lakes is listed in Table 1-4 and begins with generalized phosphorus sensitivity that is based on present average summer TP (noted by MPCA summary lake water quality data retrieved from LakeFinder [Minnesota Department of Natural Resources, 2016]). Pokegama Lake has the highest sensitivity of these lakes based on present average TP; sensitivity was noted in the above TP and Secchi relationships and for protecting pollutant-sensitive cold-/cool-water fisheries. Cass Lake (ultrasensitive) and Winnibigoshish (very sensitive) were similarly classified. Plantagenet, Bemidji, and Grace Lakes were classified as sensitive: Irving and Little Turtle exceeded water quality standards and were classified as impaired because of excess phosphorus.

Worst-case cumulative TP increases (defined by Scenario 4) are listed by lake and range from a very low 1 percent (Grace Lake) to 64 percent (Little Turtle Lake). The TP load increase of 26 percent estimated for Lake Pokegama, if realized, would result in substantial and perceptible degradation. Increases in TP loads to Lakes Plantagenet, Irving, and Bemidji were 33, 24, and 19 percent, respectively. Further sensitivity analysis will be completed for these lakes as part of the WRAPS process.

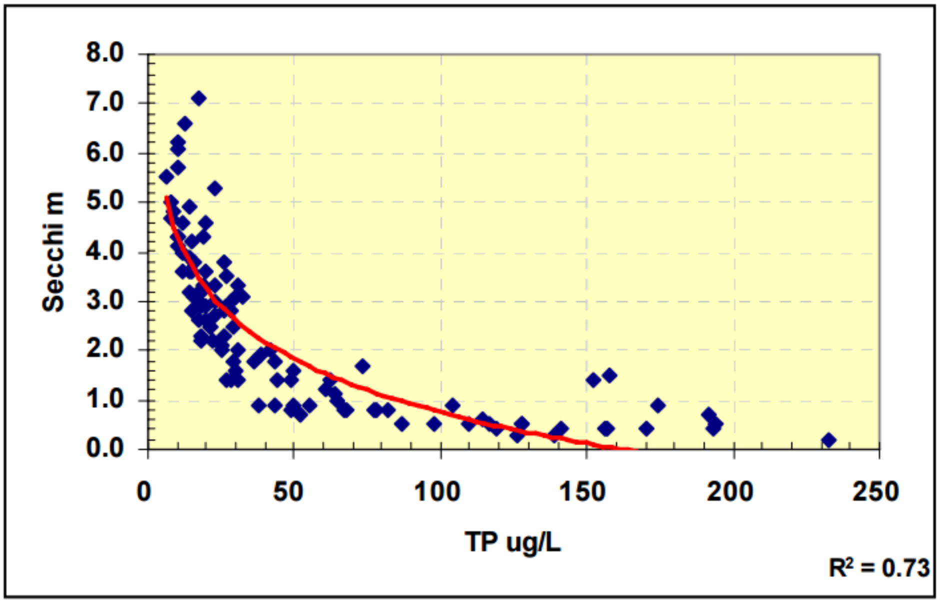

Figure 1-27. Average Summer Total Phosphorus (mg/L) and Secchi Transparency in Meters [Heiskary and Wilson, 2005].

Table 1-4. Worst-Case Scenario (Scenario 4) Percent Change in Priority Lake Subwatersheds

Lake	Lake AUID	Phosphorus Sensitivity	Subwatershed	Lakefinder Summer TP (mg/L)	Scenario 4 TP Load Increase (%)
Plantagenet	29-0156	Sensitive	318	25	33
Irving	04-0140	Impaired	340	65	24
Bemidji	04-0130	Sensitive	360	25	19
Grace	29-0071	Sensitive	372	29	1
Little Turtle	04-0155	Impaired	408	33	64
Cass	04-0030	Ultrasensitive	460	16	13
Winnibigoshish	11-0147	Very Sensitive	540	21	3
Pokegama	31-0532	Highest sensitivity	636	12	26

1.8 SUMMARY

In an effort to forecast the future, broad changes in land uses that most affect water quality were defined by stakeholders and local experts across the Mississippi Headwaters Watershed. Specific subwatersheds were identified as likely candidates for converting (1) forest to agriculture and developed areas and (2) converting mature forests to new forests. The potential impacts of these broad changes were estimated by using a basin runoff model calibrated by 14 years of flow and water quality data. Similarly, the model was employed to predict the impacts from buffer use (agricultural scenario) and urban BMPs. Future predictions of relative water quality changes were based on percent increases or decreases of runoff (flow) and associated key pollutant-loading rates (TSS, TP, and TN) from present-day conditions. Representative pulse points along the basins were chosen to illustrate the changes in TSS and TP FWMCs.

Converting forests to intense land uses (agriculture and developed) was estimated to result in variable, but generally substantial, increases in TSS-, TP-, and TN-loading rates and FWMCs noted for representative pulse points within each of the management basins. The effects of these changes were depicted by subwatershed with effects that propagate through downstream waters, particularly in the West and East Basin management areas, and that affect core lake districts. Widespread buffer use in agricultural areas was noted to reduce pollutant-loading rates. Similarly, widespread use of low-impact development practices in urban areas helped to offset development impacts. The scenario conversions indicated general TSS and TP increases in FWMCs along core lake district areas that would contribute to lake degradation.

Priority lakes that were identified for this evaluation were assessed for sensitivity based on phosphorus-induced changes of average summer transparency. All of these priority lakes have relatively low phosphorus concentrations, which suggests that these lakes will be sensitive or ultrasensitive to changes in TP loading. Estimated, future, cumulative phosphorus loading (Scenario 4, worst-case) was summarized with substantial increases noted for Lake Plantagenet (33 percent) and the impaired lakes: Little Turtle (64 percent) and Irving (24 percent). Note the increased phosphorus loading rates estimated for the lakes with low TP concentrations (e.g., Pokegama, Cass, and Winnibigoshish). The remaining priority lakes can have limited assimilation capacities and, hence, can be perceptibly improved or degraded by relatively low changes in phosphorus loading from watershed sources.

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APPENDIX A
POLLUTANT-LOADING TABLES

APPENDIX A POLLUTANT-LOADING TABLES

Subwatershed loading rates for phosphorus, nitrogen, and sediment are provided in Tables A-1 through A-3. Figure A-1 contains the key of the subwatershed locations.

Table A-1. Average Annual Pollutant Loads and Flow Rates by Subwatershed (Western Management Zone), 2000–2009 (Page 1 of 4)

Subwatershed	Area (acres)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit Area Rate (in/yr)	Rate (ac-ft/yr)
191	8,388	0.05	434	1.3	10,843	0.006	50	4.3	2,991
200	13,747	0.05	726	1.3	17,787	0.006	88	4.2	4,798
201	7,106	0.05	387	1.4	9,635	0.007	50	4.4	2,615
203	6,524	0.06	372	1.4	9,341	0.008	50	4.6	2,496
205	4,592	0.09	420	1.9	8,725	0.014	63	5.2	1,973
210	13,019	0.07	910	1.6	20,826	0.010	125	4.8	5,234
211	10,508	0.08	842	1.7	18,186	0.012	125	4.9	4,316
213	7,899	0.06	504	1.4	10,809	0.008	64	4.2	2,773
230	15,192	0.06	975	1.4	21,119	0.008	124	4.1	5,243
231	4,530	0.11	499	2.0	9,194	0.021	95	5.1	1,907
233	12,857	0.08	991	1.6	21,170	0.012	153	4.8	5,097
235	7,139	0.09	663	1.8	12,758	0.017	123	4.8	2,840
237	8,324	0.08	682	1.6	13,700	0.015	125	4.5	3,126
250	5,120	0.06	322	1.4	7,394	0.007	36	4.5	1,924
251	7,784	0.08	587	1.6	12,676	0.007	51	4.4	2,852
253	4,169	0.09	384	1.9	7,817	0.008	35	4.7	1,632
255	6,683	0.10	694	2.1	14,078	0.010	66	5.1	2,859
257	7,760	0.11	869	2.2	17,121	0.010	81	5.1	3,302
259	3,317	0.13	432	2.4	8,098	0.012	40	5.4	1,499
261	5,123	0.10	514	2.0	10,121	0.009	45	4.8	2,062

Table A-1. Average Annual Pollutant Loads and Flow Rates by Subwatershed (Western Management Zone), 2000–2009 (Page 2 of 4)

Subwatershed	Area (acres)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit Area Rate (in/yr)	Rate (ac-ft/yr)
263	4,563	0.12	525	2.1	9,552	0.021	97	5.2	1,992
265	12,395	0.13	1,647	2.3	28,525	0.028	341	5.3	5,516
267	8,729	0.08	706	1.6	14,323	0.014	119	4.5	3,255
269	20,193	0.08	1,705	1.8	37,294	0.017	351	5.1	8,513
271	7,457	0.10	722	1.8	13,691	0.017	127	4.8	2,976
290	20,891	0.10	2,134	2.0	41,351	0.019	396	5.2	8,989
291	11,852	0.07	827	1.5	17,411	0.009	109	4.5	4,404
293	4,790	0.08	407	1.7	8,287	0.011	53	5.0	1,998
295	7,505	0.08	583	1.6	12,130	0.010	78	4.8	3,002
297	3,670	0.07	254	1.5	5,542	0.008	28	4.8	1,457
299	15,523	0.06	930	1.3	20,066	0.003	51	4.1	5,260
301	4,965	0.06	311	1.5	7,239	0.008	39	4.7	1,930
302	5,996	0.08	496	1.6	9,855	0.005	27	4.5	2,259
303	4,284	0.07	321	1.6	6,720	0.005	20	4.6	1,632
305	3,617	0.07	245	1.5	5,289	0.004	15	4.5	1,343
307	4,496	0.06	277	1.3	5,923	0.006	28	4.0	1,505
309	4,283	0.09	380	1.6	6,954	0.015	63	4.3	1,540
311	2,677	0.06	171	1.4	3,709	0.006	17	4.3	956
313	12,664	0.07	903	1.5	19,212	0.004	50	4.6	4,863
315	5,685	0.08	462	1.7	9,430	0.005	26	4.7	2,208
317	5,164	0.07	382	1.5	7,825	0.010	52	4.4	1,884

Table A-1. Average Annual Pollutant Loads and Flow Rates by Subwatershed (Western Management Zone), 2000–2009 (Page 3 of 4)

Subwatershed	Area (acres)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit Area Rate (in/yr)	Rate (ac-ft/yr)
318	4,599	0.09	397	1.7	7,611	0.015	70	4.4	1,682
321	3,141	0.12	384	3.0	9,431	0.031	97	7.7	2,012
322	3,871	0.11	414	2.0	7,752	0.021	83	5.0	1,613
323	13,200	0.12	1,577	2.4	32,128	0.023	297	6.3	6,943
325	3,051	0.08	250	1.9	5,930	0.012	38	5.8	1,465
340[(a)]	8,087	0.16	1,334	3.6	28,823	0.043	347	8.6	5,819
341	3,085	0.08	247	1.9	5,800	0.013	39	5.6	1,443
360[(a)]	9,138	0.21	1,895	4.1	37,863	0.028	254	8.3	6,315
372	4,963	0.14	679	2.7	13,414	0.016	81	6.5	2,691
374	3,118	0.10	317	2.3	7,202	0.012	37	6.4	1,656
377	7,511	0.09	687	2.1	15,530	0.010	73	5.9	3,681
400[(b)]	7,098	0.16	1,138	2.7	19,143	0.017	119	30.1	17,797
403	8,288	0.07	555	1.5	12,374	0.004	37	4.3	2,951
404	4,464	0.07	326	1.6	7,045	0.005	22	4.4	1,647
405	6,831	0.09	587	1.8	12,086	0.006	42	4.7	2,665
407	3,556	0.08	267	1.6	5,682	0.005	17	4.4	1,295
408	1,052	0.09	91	1.9	2,036	0.016	17	5.5	479
410	8,560	0.11	969	2.4	20,383	0.013	109	6.3	4,464
412	3,874	0.10	387	2.1	8,255	0.018	69	5.7	1,856
414	3,441	0.09	311	2.0	6,916	0.016	54	5.6	1,598
416	4,979	0.08	381	1.9	9,227	0.012	60	5.5	2,293

Table A-1. Average Annual Pollutant Loads and Flow Rates by Subwatershed (Western Management Zone), 2000–2009 (Page 4 of 4)

Subwatershed	Area (acres)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit Area Rate (in/yr)	Rate (ac-ft/yr)
419	5,484	0.07	396	1.7	9,507	0.013	69	5.4	2,451
420	5,482	0.09	488	2.0	11,159	0.009	52	5.9	2,685
422	7,735	0.08	617	1.8	14,161	0.014	109	5.4	3,504
424	16,438	0.08	1,308	1.9	30,919	0.013	207	5.6	7,728

(a) Subwatersheds include inputs from one or more NPDES point sources.

(b) Subwatersheds include internal loading additions to lakes in the model application – internal loading is explained as "unexplained residual" in Table 1.

Table A-2. Average Annual Pollutant Loads and Flow Rates by Subwatershed (Big Lakes Management Zone), 2000–2009 (Page 1 of 2)

Subwatershed	Area (acres)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit Area Rate (in/yr)	Rate (ac-ft/yr)
402	6,623	0.08	541	2.0	13,129	0.010	67	5.9	3,235
426	4,619	0.10	461	2.1	9,850	0.019	90	5.8	2,219
427	8,750	0.07	582	1.6	13,890	0.005	42	4.9	3,561
429	5,127	0.06	319	1.6	7,952	0.005	24	4.9	2,098
431	4,294	0.06	255	1.5	6,630	0.004	17	5.1	1,839
433	2,778	0.06	159	1.5	4,060	0.004	11	4.8	1,119
435	6,199	0.09	570	2.1	13,174	0.009	53	6.4	3,324
436	12,124	0.06	762	1.5	18,686	0.004	53	4.9	4,954
437	14,838	0.07	967	1.6	23,589	0.004	66	5.0	6,189
439	4,625	0.07	328	1.7	7,736	0.005	22	5.1	1,961
440	5,853	0.07	429	1.8	10,661	0.007	42	5.6	2,743
441	5,603	0.06	349	1.6	8,947	0.004	22	5.3	2,457
442	15,094	0.06	901	1.5	22,561	0.004	63	4.8	6,081
445	7,236	0.06	430	1.5	11,059	0.004	29	5.1	3,048
447	5,912	0.07	420	1.7	10,104	0.005	30	5.3	2,595
449	14,266	0.06	891	1.6	22,825	0.004	59	5.2	6,239
452	4,781	0.07	328	1.7	7,921	0.005	25	5.1	2,021
460	19,747	0.07	1,459	1.8	35,990	0.007	146	5.6	9,266
461	6,000	0.06	378	1.6	9,811	0.006	35	5.2	2,602
470	12,679	0.06	823	1.7	21,454	0.006	76	5.4	5,741
471	8,540	0.06	510	1.6	13,395	0.004	32	5.3	3,739
473	6,100	0.06	381	1.6	10,034	0.004	24	5.5	2,802

Table A-2. Average Annual Pollutant Loads and Flow Rates by Subwatershed (Big Lakes Management Zone), 2000–2009 (Page 2 of 2)

Subwatershed	Area (acres)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit Area Rate (in/yr)	Rate (ac-ft/yr)
475	8,260	0.07	565	1.8	14,912	0.005	43	6.1	4,168
478	11,045	0.06	642	1.6	17,163	0.004	44	5.1	4,739
479	8,439	0.09	720	2.0	17,143	0.008	64	6.3	4,429
481	3,968	0.09	346	2.1	8,372	0.007	29	6.7	2,209
483	11,911	0.08	946	2.0	23,298	0.007	82	6.2	6,148
485	5,221	0.07	353	1.8	9,243	0.005	27	5.9	2,555
487	3,617	0.06	231	1.7	6,026	0.005	18	5.5	1,661
488	5,421	0.07	374	1.8	9,606	0.006	31	5.7	2,582
489	2,123	0.07	145	1.8	3,787	0.006	12	5.8	1,033
491	4,095	0.06	259	1.7	6,768	0.005	21	5.5	1,868
493	4,805	0.06	309	1.7	8,091	0.005	25	5.5	2,213
495	11,415	0.06	728	1.7	19,069	0.005	60	5.5	5,225
497	10,255	0.06	664	1.7	17,119	0.004	38	5.5	4,710
499	4,365	0.06	262	1.6	6,833	0.004	16	5.2	1,896
501	8,364	0.05	444	1.4	11,516	0.004	30	4.5	3,166
504	8,742	0.05	459	1.3	11,697	0.004	34	4.3	3,143
520[a]	36,660	0.08	2,820	1.6	60,392	0.004	141	9.6	29,346
540	4,515	0.06	274	1.6	7,063	0.004	19	5.1	1,905
550	18,658	0.06	1,116	1.6	29,010	0.004	70	5.1	8,002
551	12,302	0.07	868	1.7	21,407	0.004	52	5.5	5,632
552	10,812	0.06	655	1.5	16,717	0.004	47	5.0	4,488

(a) Subwatersheds include internal loading additions to lakes in the model application – internal loading is defined as "unexplained residual" in Table 1.

Table A-3. Average Annual Pollutant Loads and Flow Rates by Subwatershed (Eastern Management Zone), 2000–2009 (Page 1 of 2)

Subwatershed	Area (acres)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit Area Rate (in/yr)	Rate (ac-ft/yr)
555	6,305	0.07	458	1.7	10,673	0.006	36	5.0	2,643
557	5,093	0.06	328	1.5	7,842	0.006	29	4.7	1,979
562	10,346	0.05	502	1.2	12,636	0.003	35	3.9	3,393
565	5,560	0.06	338	1.5	8,132	0.004	25	4.4	2,060
566	12,589	0.05	685	1.3	16,670	0.004	55	4.1	4,264
567	7,244	0.06	457	1.5	10,888	0.005	33	4.6	2,758
569	8,766	0.07	593	1.6	13,746	0.005	45	4.7	3,425
571[a]	5,746	0.79	4,539	2.1	12,108	0.009	50	6.2	2,959
590[b]	34,585	0.06	2,176	1.5	52,750	0.004	150	4.8	13,758
591	6,214	0.06	395	1.6	10,044	0.005	31	5.3	2,736
593	3,965	0.07	266	1.7	6,787	0.005	20	5.7	1,871
595	4,436	0.07	323	1.8	8,149	0.005	23	6.0	2,222
596	2,175	0.07	162	1.9	4,129	0.007	16	6.0	1,090
597	1,345	0.07	99	1.8	2,442	0.007	9	5.9	660
599	5,350	0.06	296	1.3	7,216	0.003	18	4.3	1,931
601	4,699	0.09	436	2.1	9,932	0.009	41	6.1	2,402
603	6,646	0.08	548	2.0	13,605	0.008	52	6.5	3,575
610	6,365	0.10	614	2.0	12,627	0.008	52	5.2	2,763
612	6,991	0.10	702	2.3	16,167	0.010	71	6.7	3,895
622	16,121	0.07	1,119	1.7	26,691	0.004	69	5.1	6,831
630[a]	15,380	0.09	1,317	1.8	27,912	0.026	404	7.8	10,023

Table A-3. Average Annual Pollutant Loads and Flow Rates by Subwatershed (Eastern Management Zone), 2000–2009 (Page 2 of 2)

Subwatershed	Area (acres)	Total Phosphorus		Total Nitrogen		Total Suspended Solids		Flow	
		Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (lb/ac-yr)	Annual Load (lb/yr)	Unit Area Load (ton/ac-yr)	Annual Load (ton/yr)	Unit Area Rate (in/yr)	Rate (ac-ft/yr)
632	9,771	0.06	570	1.4	14,142	0.004	42	4.6	3,751
635	8,350	0.07	609	1.9	15,521	0.007	58	6.0	4,157
636	27,453	0.08	2,115	1.8	49,771	0.008	228	5.2	11,977

(a) Subwatersheds include inputs from one or more NPDES point sources
(b) Subwatershed does not include loads from Leech Lake River.

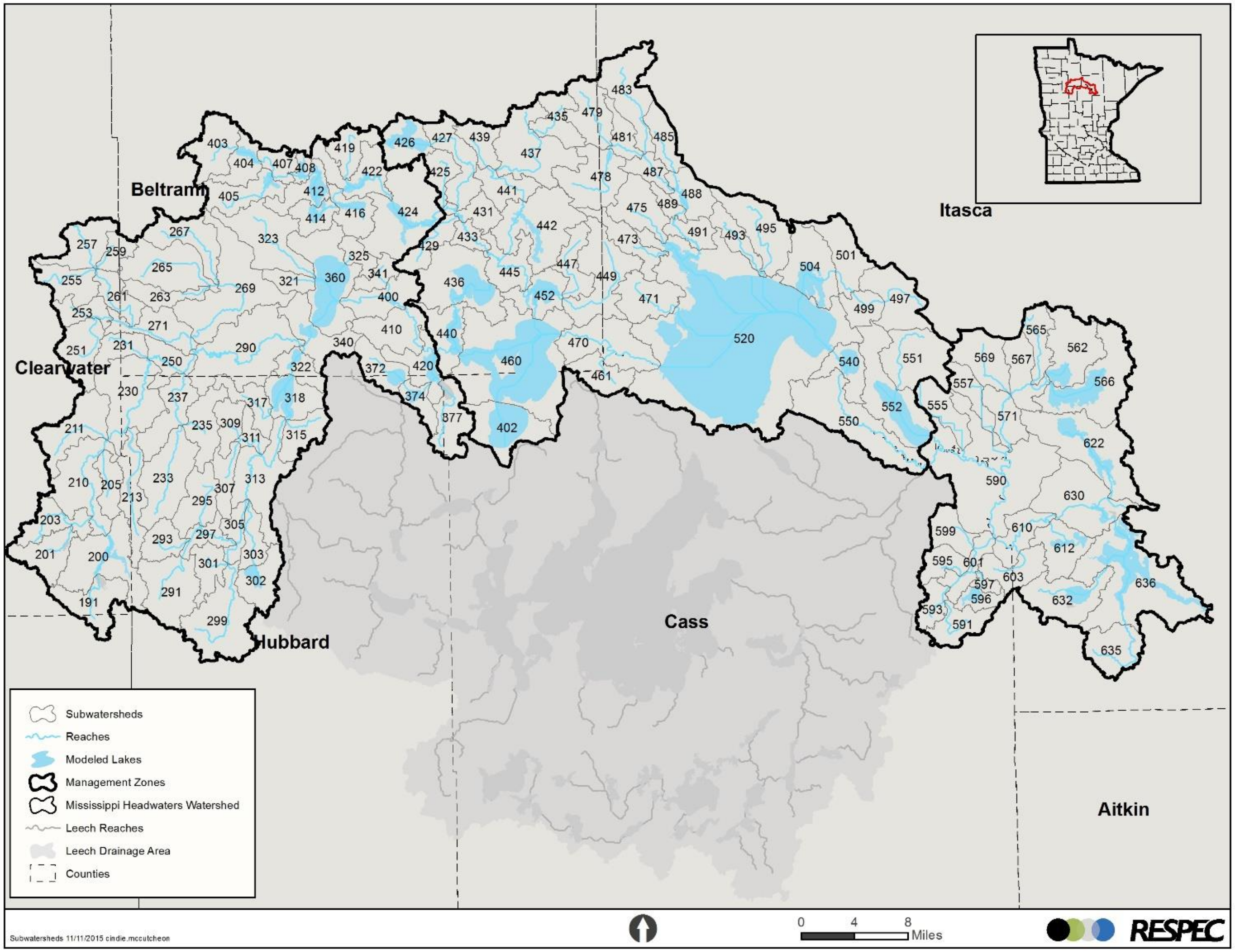

Figure A-1. Subwatershed Key.