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Fox River Watershed Investigation: Stratton Dam to the Illinois River

Phase III
Evaluation of Watershed Management Scenarios

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ILLINOIS

Fox River Watershed Investigation: Stratton Dam to the Illinois River PHASE III

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Abstract

This report documents the development and application of two simulation models for the Fox River: a watershed hydrologic model using the Hydrological Simulation Program - FORTRAN (HSPF), and a receiving stream water quality model using QUAL2K. Both simulation models were calibrated with observed data and subsequently used to simulate the impacts of selected watershed management alternatives (scenarios) on water quality in the Fox River.

The Fox River HSPF model simulates rainfall runoff processes for watersheds adjacent to the Fox River from Stratton Dam to the mouth of the Fox River at the Illinois River. Runoff is simulated using 31 separate tributary watershed models and two models of the Fox River mainstem. The tributary results are then utilized as an input to the mainstem model. Observed flows at Stratton Dam are used as the upstream boundary condition defining inflow from the Fox River watershed above Stratton Dam. The HSPF model hydrology was calibrated for water years 1991-1999 and validated for water years 2000-2003. The hydrology calibration was verified when the model was expanded to simulate water years 2004-2011. The integrated model adequately simulates flows at the mainstem gages based on specified calibration criteria. The water quality portion of the model was calibrated for water years 2004-2010 with an additional focus on water years 1991-2003 and validated for water year 2011.

The QUAL2K model simulates processes affecting the dissolved oxygen regime. Diurnal changes in dissolved oxygen are simulated, although the model is steady state (i.e., flows and other inputs are constant). The QUAL2K model was calibrated using data collected by the ISWS for the Fox River Study Group (FRSG) in June 2012.

Calibrated models were used to simulate several watershed management scenarios. The QUAL2K model was used to evaluate the impacts of altering total phosphorus limits at municipal effluents and the removal of selected dams on the mainstem of the Fox River. Even the most drastic scenario of limiting total phosphorus at municipal effluents to 0.1 milligrams per liter (mg/l) did not result in a significant decrease of phytoplankton due to a large portion of the river being impounded. Removing the dams reduced phytoplankton growth but also led to increased growth of benthic algae in some reaches.

The HSPF model was used to evaluate the impact of practices that control urban runoff, practices that control agricultural runoff, and stricter limits for municipal effluents. The success in reducing average annual loads by targeting these individual pollution sources varied by pollutant. Changing agricultural practices resulted in the largest reduction of average annual sediment load. Limiting total phosphorus in municipal point sources resulted in the largest reduction of average annual total phosphorus load. Urban best management practices (BMPs) affected the most number of constituents, but the relative impact on the average annual load was not significant due to the small area treated by these BMPs.

Acknowledgments

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Introduction

The Fox River watershed is located in southeastern Wisconsin and northeastern Illinois. The Illinois State Water Survey (ISWS) is participating in a study of the portion of the Fox River watershed from below Stratton Dam, IL to the confluence of the Fox River with the Illinois River. This report is one of a series of reports on the Fox River Watershed Investigation prepared by the ISWS. Working with the Fox River Study Group, Inc. (FRSG), the ISWS prepared a plan to investigate water quality in the surface waters of the watershed. The plan has four phases. The first phase included a comprehensive inventory of studies and data for the watershed. The second phase outlined the development of a suite of hydrologic and water quality models to simulate hydrologic and water quality conditions in the watershed. The third phase focuses on data collection, model calibration, and evaluation of selected watershed management alternatives. This report represents a culmination of the third phase. In the fourth phase, the tools developed will be used to guide planning. This work is being conducted for and in consultation with the FRSG and the Illinois Environmental Protection Agency (IEPA).

The FRSG was organized in response to local concerns about Fox River water quality in 2001. The FRSG comprises a diverse group of stakeholders representing municipalities, county government, water reclamation districts, and environmental and watershed groups from throughout the watershed. The goal of the FRSG is to address water quality issues in the Fox River watershed and assist with implementing activities to improve and maintain water quality. The FRSG has initiated activities to more accurately characterize the water quality of the Fox River, including data collection and preparation of comprehensive water quality models.

Project Overview

The Fox River in northeastern Illinois is a focal point of many communities along the river, providing an aesthetically pleasing area and opportunities for fishing, canoeing, and boating. The Fox River is also a working river. Two major cities, Elgin and Aurora, withdraw water for public water supplies, and the river serves as a receptor for stormwater and treated waste water. This highly valued river, however, has been showing signs of impairment over an increasing geographic area.

This study was initiated after the IEPA in their *Illinois Water Quality Report 2000* (IEPA, 2000) listed selected reaches of the Fox River in McHenry and Kane Counties and a portion of Little Indian Creek as impaired. The 2002 IEPA report (IEPA, 2002) listed the entire length of the Fox River in Illinois as impaired, as well as a number of tributaries to the Fox, including Nippersink, Poplar, Blackberry, and Somonauk Creeks, and a portion of Little Indian Creek. The IEPA again included the Fox River and these tributaries on their list of impaired waters, commonly called the 303(d) list, in 2003 (IEPA, 2003). In the 2004 IEPA water quality report (IEPA, 2004), the upper and parts of the lower Fox River were listed as not meeting or only partially meeting aquatic life use. Poplar, Flint, and Little Indian Creeks were also listed as only partially supporting aquatic life.

The 2006 IEPA report (IEPA, 2006) listed the entire length of the Fox River, Nippersink Creek, Tyler Creek, Crystal Lake outlet, Poplar Creek, Ferson Creek, and Blackberry Creek as impaired. The most prevailing potential sources for listing were hydromodification and flow regulation, urban runoff, and combined sewer overflows. The most prevailing potential causes

for listing were flow alterations, habitat, sedimentation/siltation, dissolved oxygen, suspended solids, excess algal growth, fecal coliform bacteria, and PCBs. The 2008, 2010, and 2012 IEPA reports continued to list Fox River and its tributaries as impaired. The recently released draft 2014 IEPA report (IEPA, 2013) lists Fox River, Big Rock Creek, Blackberry Creek, Buck Creek, Clear Creek, Ferson Creek, Indian Creek, Little Indian Creek, Nippersink Creek, North Branch Nippersink Creek, Otter Creek, Somonauk Creek, Sutphens Run, and Tyler Creek as impaired with respect to aquatic life use. The most frequently listed causes include fecal coliforms (20 reaches), polychlorinated biphenyls (PCBs) (19 reaches), other flow regime alterations (16 reaches), alterations in stream-side or littoral vegetative cover (11 reaches), sedimentation/siltation (11 reaches), aquatic algae (11 reaches), total phosphorus (9 reaches), dissolved oxygen (8 reaches), and mercury (8 reaches). Table 1 shows the percentage of stream miles of the Fox River that support its individual beneficial uses. Public water supply use applies only to two reaches in the Fox River and that use was fully supported in both reaches (IEPA, 2013).

Table 1.Level of support of beneficial uses in the Fox River, percent stream length (IEPA, 2013)

Use	*Fully supporting*	*Not supporting*	*Not assessed*
Aquatic Life	22%	78%	0%
Primary Contact	18%	50%	32%
Aesthetics	0%	0%	100%
Fish Consumption	0%	100%	0%

Reporting Structure

This section provides a short description of the various reports that have been published documenting the progress of the watershed investigation through different phases of the project.

The Phase I report (McConkey et al., 2004) reviews the available literature and data for the study area and includes recommendations for developing a suite of models to simulate hydrology and water quality to address key water quality issues in the watershed. The Hydrological Simulation Program - FORTRAN version 12 model (HSPF, Bicknell et al., 2001) was selected to simulate watershed loading and delivery and routing of nonpoint and point sources of pollution from the entire watershed. The QUAL2K model (Chapra et al., 2009) was selected to simulate dissolved oxygen diurnal processes during steady-state low flow conditions along the Fox River mainstem. The HSPF and the QUAL2K models are referred to as watershed loading and receiving stream models, respectively. Each model addresses a different focus area: QUAL2K addresses algae and dissolved oxygen conditions during summer low flows, and HSPF addresses average annual watershed loads. To support model development and other stakeholder activities, a database was constructed to house all water quality, sediment quality, habitat, and biological data (included in Phase II) available for the watershed; this database is called FoxDB. The structure of the database is described in the Phase I report.

A series of reports have been prepared describing the Phase II work. The publications and other products associated with this effort can be found at http://ilrdss.sws.uiuc.edu/fox/.

The report *Overview of Recommended Phase II Water Quality Monitoring, Fox River Watershed Investigation* (Bartosova et al., 2005) outlines a monitoring plan to collect additional data for improved model calibration.

The Phase II, Part 1 report (Singh et al., 2007) describes methods and procedures used in developing the HSPF models. It also discusses sources of uncertainty in these models, as well as the data assimilation procedure conducted to prepare watershed loading models for the study area, and identifies statistical and graphical methods used in evaluating confidence in the model. It serves as a guide for model development, parameterization, calibration, and validation of the watershed loading models for all tributary watersheds and the Fox River mainstem.

The Phase II, Part 2 report (Bartosova et al., 2007a) presents the specific development of the watershed loading models (HSPF) for two pilot watersheds (Blackberry and Poplar Creek) in the Fox River watershed. These pilot watersheds represent contrasting land use and soil conditions. The HSPF models were calibrated to simulate daily streamflow and selected water quality constituents.

The Phase II, Part 3 report (Bartosova et al., 2007b) describes the validation of hydrologic model parameters. Model parameters developed for the pilot watersheds were transferred to five tributary watersheds where flow data were available for at least part of the study period: Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, and Tyler Creek. At this stage, these tributary watersheds were not used in the calibration process, but were used to test the transferability of model parameters to other watersheds. This report provides background information on these five watersheds and compares HSPF-simulated discharges with observed discharges.

Biological data collected within the watershed were inventoried and the FoxDB was expanded to house those data. An assessment of the biological indicators and changes to the database structure are reported in Bartosova, 2008.

The Phase II, Part 4 report (Bartosova et al., 2011) documents the hydrologic model used for the Fox River mainstem. Model parameters developed for the pilot watersheds and subsequently tested on the five validation watersheds were transferred to all remaining tributary watersheds and the Fox River mainstem watershed. Model parameters were further adjusted as needed to reflect the changing conditions among the watersheds. This report presents the results of model calibration and validation.

This Phase III report presents results of the QUAL2K and HSPF model simulations. The models developed previously were calibrated with intensive data collected by ISWS in 2010-2012 (Bartosova, in preparation). The calibrated models were then used to simulate a selected number of watershed management scenarios. The details of the simulated scenarios were determined in collaboration with the FRSG and were approved by the FRSG Board prior to conducting the simulations. The scenarios selected do not represent optimized solutions to water quality issues in the Fox River. The approach was rather focused on defining reasonable and practical options that study team members felt could realistically be achieved in 20 to 30 years. Scenarios were determined separately for two focus areas represented by the two models, (1) algae and dissolved oxygen conditions during summer low flows, and (2) average annual watershed loads.

Algae and Dissolved Oxygen during Summer Low Flow

Many reaches of the Fox River are listed as impaired by the IEPA (IEPA, 2013): 78% of the assessed mainstem miles are categorized as not supporting aquatic life use, 50% as not supporting primary contact use, and 100% as not supporting fish consumption use. Aquatic algae is listed as a cause of impairment for 60% of the assessed mainstem miles, dissolved oxygen for 29%, and total phosphorus for 32% of the assessed mainstem miles.

The modeling effort described in this section focused on critical conditions with respect to the first focus area, algae and dissolved oxygen. In the Fox River, as in most water bodies, the highest algae concentrations and the lowest dissolved oxygen concentrations are typically found on hot, sunny days in summer after a prolonged period without significant precipitation when the flows are low (McConkey et al., 2004). Algae photosynthetic and respiration processes lead to a diurnal flux of dissolved oxygen concentrations with minimums typically occurring before dawn and maximums in late afternoon. Clouds, cold air temperatures, short daylight hours, increased velocities during storms, and other factors can limit algal growth.

Simulation Model

The QUAL2K model is a steady state model simulating diurnal changes in water quality. The model developed for the Fox River was calibrated using data collected during an intensive sampling event (26-28 June 2012) conducted by the ISWS and Deuchler Environmental, Inc. (DEI). Additional data used in the model development include climate data (National Weather Service, NOAA), stream channel geometry data (Flood Insurance Studies), stream flow data (U.S. Geological Survey [USGS]), and effluent flow data for National Pollutant Discharge Elimination System (NPDES) facilities (IEPA and individual facilities).Calibration was considered successful upon reaching the coefficient of determination (R^2) of 0.7 and the correlation coefficient of 0.8.

Three days of intensive monitoring during the low flows in June 2012 (Slowikowski, Russell, and Hill, 2012) produced continuous recordings of dissolved oxygen, temperature, pH, and conductivity and nine discrete water quality samples (three samples each day) at 13 locations on the Fox River. Table 2 shows sites on Fox River that were sampled during the June 2012 sampling event. Phytoplankton (expressed as chlorophyll *a* concentration corrected for pheophytin) and volatile suspended solids were analyzed once a day. Nine discreet water quality samples and instantaneous readings of dissolved oxygen, temperature, pH, and conductivity were also collected in 10 tributaries near their confluence with the Fox River (Little Rock, Big Rock, Blackberry, Indian, Mill, Ferson, Brewster, Poplar, Tyler, and Flint Creeks). All discrete water samples were analyzed for nutrients and supporting parameters. A complete list of parameters can be found in Slowikowski, Russell, and Hill (2012). Sediment oxygen demand and benthic algae were measured at three and five mainstem locations, respectively. Additional information including weather and stream shading at sampling locations was collected.

Many NPDES facilities (see Appendix A) voluntarily participated in the sampling event by either providing nutrient analyses of their effluents or providing effluent samples to the Fox Metro Water Reclamation District (FMWRD) or Fox River Water Reclamation District (FRWRD) laboratories for nutrient analyses as an in-kind contribution to the FRSG. Public water

supply facilities in Aurora and Elgin kindly contributed data on withdrawal and intake sampling. Concentrations and effluent flows from the facilities where direct measurements were not available were approximated either from average values in their monthly Discharge Monitoring Report (DMR) or, where no data were available, using values in Table 3.

Stream flow in the Fox River was 150 cubic feet per second (cfs) at Burtons Bridge and 400 cfs downstream at Dayton during the sampling. Figure 1 shows the simulated flow for the June 2012 sampling period. Selected dams and locations where selected tributaries empty into Fox River are shown in this and other charts with QUAL2K simulations for spatial orientation. Observed flow measured at six locations on the mainstem is also displayed along with a 10% range. Step increases in the simulated flow are due to significant tributaries and/or NPDES facility effluent flows. Two locations with a decrease in flow show the locations of intakes for public water supply facilities in Aurora and Elgin. Simulated flow is within 10% of the observed flow.

Table 2. List of Fox River sites sampled during the June 2012 event

Location Description	*River mile*	*FoxDB Station ID*	*Latitude*	*Longitude*
Fox River at Sheridan	20.1	522	41.53997	-88.6845
Fox River above Yorkville Dam	36.4	542	41.64291	-88.4375
Fox River at Millstone Park (upstream of Waubansee)	43.2	540	41.69328	-88.35
Fox River at Ashland Ave. (Montgomery)	46.7	284	41.73796	-88.3312
Fox River at Aurora (Sullivan Bridge)	50.6	471	41.78894	-88.3173
Fox River at Geneva (Fabyan Forest Preserve)	56.5	40	41.87018	-88.3086
Fox River at St. Charles Pool	60.1	277	41.91692	-88.3155
Fox River at South Elgin (above dam)	67.4	286	41.99766	-88.2943
Fox River at National St.	70.1	35	42.0296	-88.2795
Fox River at Kimball St./Lawrence Ave.	71.0	273	42.04162	-88.2895
Fox River at I-90 (Footbridge)	73.3	240	42.06653	-88.2716
Fox River at Algonquin Rd.	81.6	24	42.16587	-88.29
Fox River at Burton's Bridge	97.6	23	42.27964	-88.2269

Table 3. Concentrations used for NPDES facilities without any data, mg/l

Facility	*BOD_5*	*NH_4-N*	*NO_3-N*	*TON*	*Inorg. P*	*TOP*	*TSS*
Municipal	7	1	5	4	5.0	0.5	3
Other	0	0	0	0	0	0	0

Notes: BOD_5 is 5-day biochemical oxygen demand
TON = total organic nitrogen
TOP is total organic phosphorus
TSS is total suspended solids

The QUAL2K model does not simulate a detailed hydrologic cycle with evaporation and groundwater-surface water interactions, but instead simulates only a simple balance. Any discrepancy in flows is due to uncertainty in the inputs (inflow from tributaries or NPDES facilities). QUAL2K only simulates constant flows (average flow measured during the June 2012 sampling event). While streamflows remained in the same range, they were not exactly the same during the three days of sampling. The effluent flow from NPDES facilities also varies during the day and from day to day. These diurnal and day-to-day variations contribute to a slight discrepancy between the simulated and observed flows. The flow simulation could have been easily adjusted to match the observed flows exactly by establishing diffuse inflows (positive and/or negative). However, those would be only applicable to the June 2012 event and the differences could only be applied over the whole reach between locations with flow measurements. Each measurement, including stream flow, is associated with some uncertainty and inaccuracy. For example, USGS instantaneous flow measurements at Burton's Bridge were 129 cfs, 108 cfs, and 114 cfs on June 26, June 27, and June 28, 2012, respectively, varying between 92% and 110% of the average flow during the June 2012 event (117 cfs).

Phytoplankton (algae) often plays a significant role in nutrient cycling and dissolved oxygen diurnal changes under low flow conditions, particularly in summer. Figure 2 shows simulated and observed phytoplankton expressed as chlorophyll *a* concentration within the study reach. Chlorophyll *a* is a green pigment in algae and plants contributing to photosynthesis. It is used as a surrogate for algae biomass. There are several analytical methods that can be used to determine chlorophyll *a*, each giving a slightly different numerical value, but most methods produce values within the same range. The State of Illinois does not have numerical standards for chlorophyll *a* in streams. In lakes, chlorophyll *a* concentrations above 20 micrograms per liter (µg/l) indicate a eutrophic lake. An oligotrophic lake (pristine water) would have chlorophyll *a* below 2.6 µg/l (Carlson and Simpson, 1996). Royer et al (2008) reported that 90% of over 100 sites sampled in Illinois in 2004 had sestonic chlorophyll *a* values of less than or equal to 35 µg/l, significantly lower than values observed in Fox River in June 2012.

Observed concentrations are displayed in three series: minimum, average, and maximum concentrations reported during the three-day sampling event. Chlorophyll *a* samples were collected once each day. Although stream conditions remained relatively stable, there is still a significant variation in sampled chlorophyll *a* concentrations at some locations. The largest absolute difference was found at the Fox River at Millstone Park (upstream of Waubonsee Creek); the chlorophyll *a* concentration varied between 70 µg/l (June 28, 2012) and 104 µg/l (June 26, 2012). While chlorophyll *a* decreased at this site during the three days of sampling; overall, the same trend was not observed at all the sites.

While simulated average dissolved oxygen concentrations match observed concentrations at most sites, diurnal changes in dissolved oxygen observed in the Fox River exceed the simulated diurnal changes in dissolved oxygen (Figure 3). Considering that chlorophyll *a* concentrations that drive diurnal changes are simulated rather well, the possible causes of this discrepancy are unclear. The QUAL2K model does not represent the diurnal variation of the dissolved oxygen well despite a good match for phytoplankton chlorophyll *a* and benthic algae chlorophyll *a*. A simulation model is only an approximation of the reality. Unique characteristics of the Fox River, such as its numerous impoundments, NPDES effluents constituting a significant proportion of the stream flow, and gentle slope, as well as the model shortcomings combined with the extreme temperatures and low flows during the June 2012 event, contribute to the less than ideal simulated diurnal variation in dissolved oxygen.

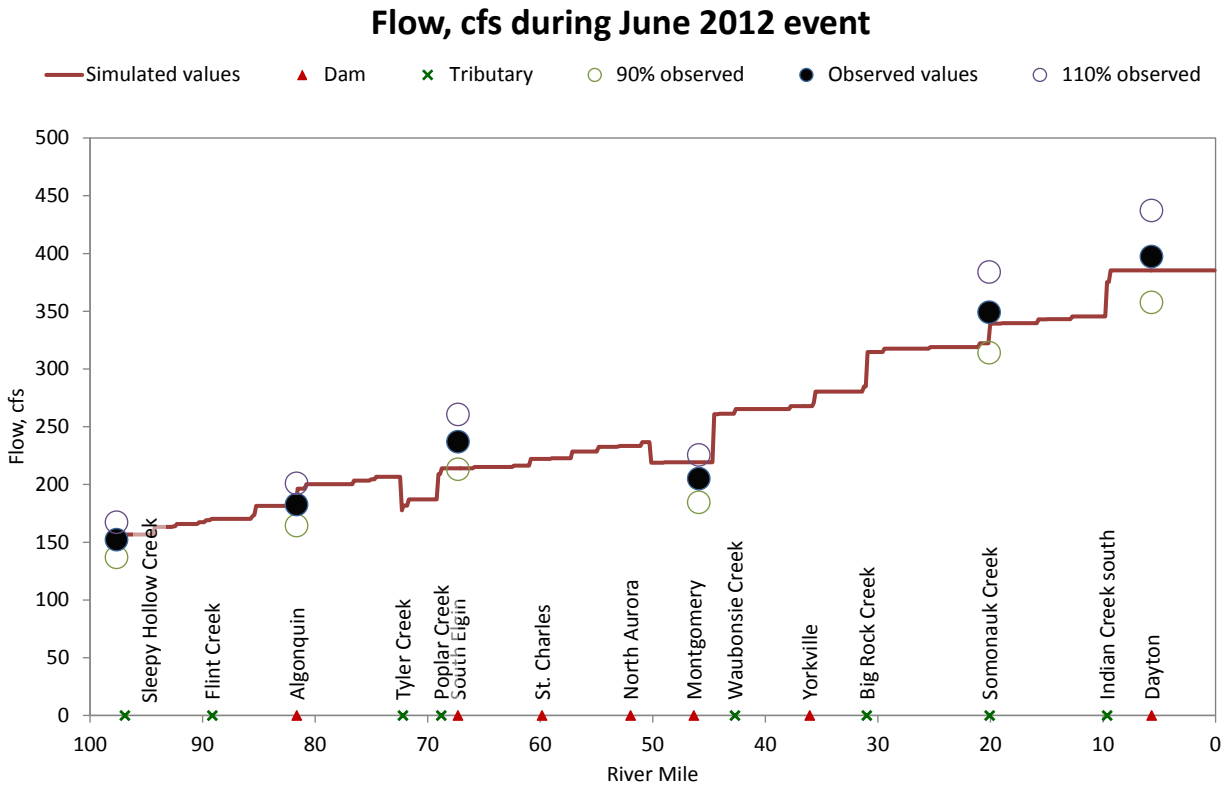


Figure 1. Simulated and observed flow during June 2012 event

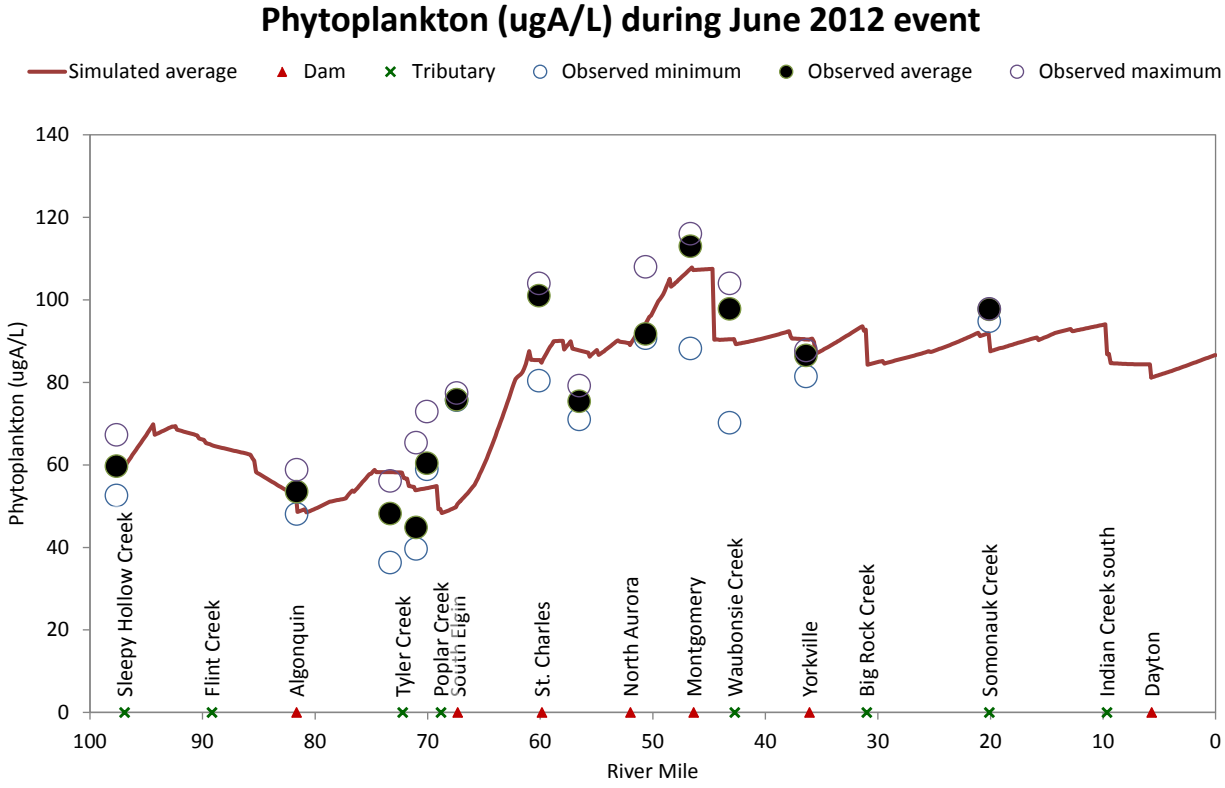


Figure 2. Simulated and observed phytoplankton as chlorophyll *a*

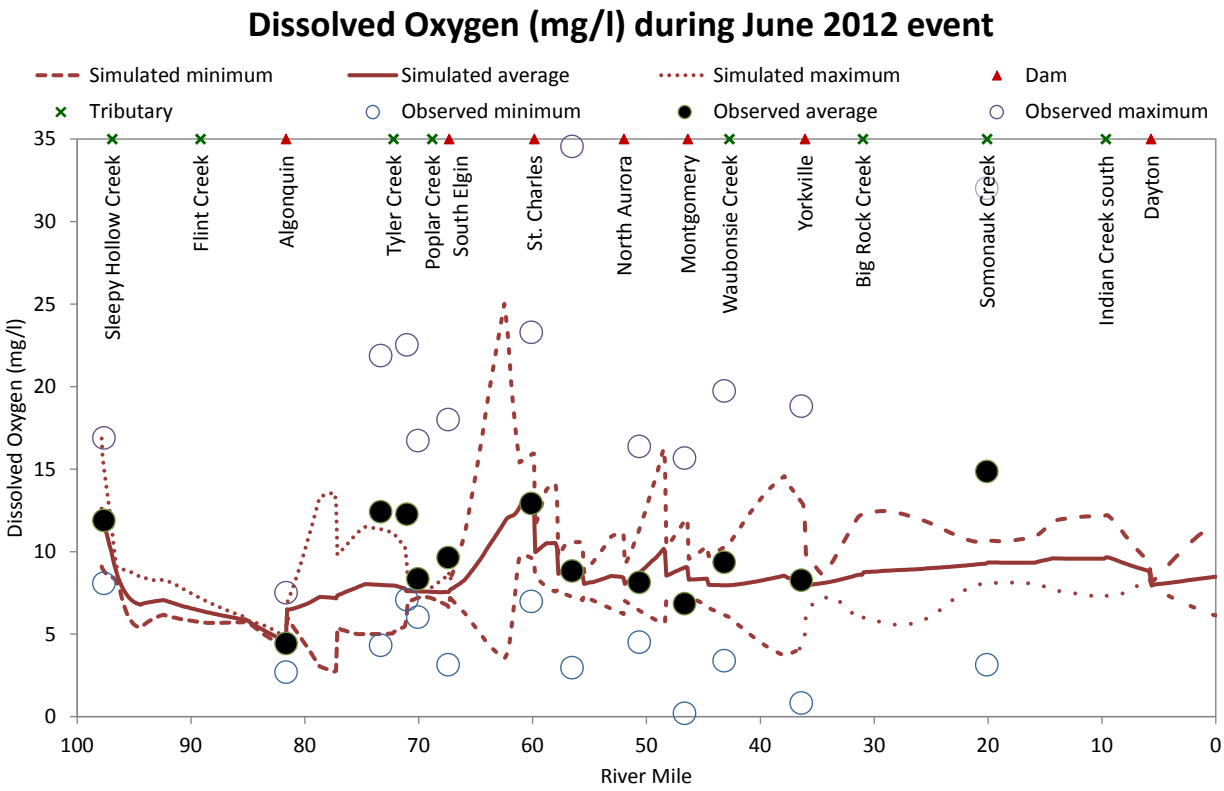


Figure 3. Simulated and observed dissolved oxygen concentrations

Data sondes were placed in the river cross-section at a location determined to have average dissolved concentrations. Spatial variability within the cross-section can be significant at some sites and may even change during the day. Much variation was found between different depths at some locations where two sondes were placed during the sampling (Figure 4). The following examples illustrate the measured variation of dissolved oxygen concentrations in the cross-section and associated uncertainty when using simulation models to determine average dissolved oxygen concentration in a river reach. Figure 5 shows an example of cross-sectional measurement for dissolved oxygen concentrations obtained at a free-flowing, shallow reach at Sullivan Road Bridge in Aurora, IL. The Fox River at Sullivan Road Bridge was 260 feet wide and 2.2 feet deep at its deepest point. Despite this location being relatively uniform in depth, dissolved oxygen concentrations showed a maximum difference of 3.65 mg/l (observed range 7.8 mg/l to 11.45 mg/l with an area-weighted vertical mean of 10.4 mg/l). Measurements were taken between 9:10 am and 9:25 am CST on 20 June 2012.

Figure 6 shows examples of cross-sectional measurements for dissolved oxygen concentrations obtained behind two dams prior to the data sonde placement: St. Charles Dam pool and South Elgin Dam pool. The Fox River at St. Charles Dam pool was about 400 feet wide and 7 feet deep at its deepest place. Yet the dissolved oxygen concentrations were relatively stable with a maximum difference of 1.3 mg/l (observed range 8.33 to 9.63 mg/l with an area-weighted vertical mean of 8.81 mg/l). Measurements were taken between 8:30 am and 9:30 am CST on 21 June 2012. Typically, substantially more variation would be expected behind a dam as was measured at South Elgin Dam. The Fox River at South Elgin Dam was 515 feet wide and 7 feet deep at its deepest place. The dissolved oxygen concentrations showed a maximum

difference of 5.8 mg/l (observed range 5.93-11.73 mg/l with an area-weighted vertical mean of 8.45 mg/l). Measurements were taken between 7:40 am and 9:20 am on 22 June 2012.

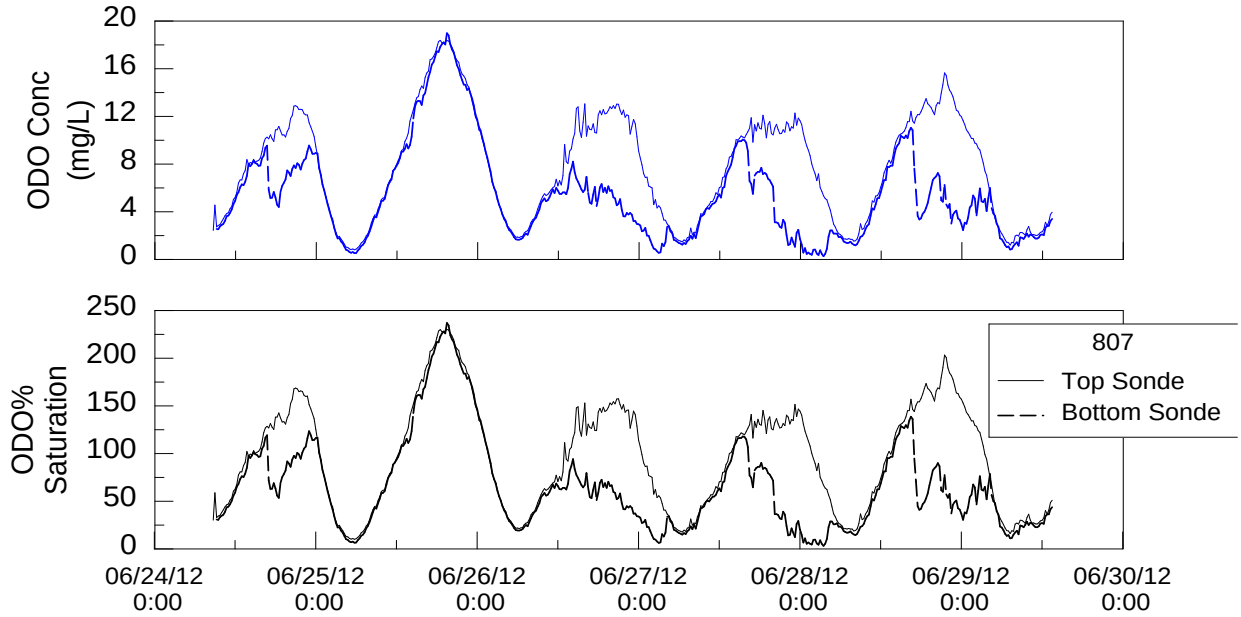


Figure 4. Diurnal changes in observed dissolved oxygen (ODO) at two depths upstream of Yorkville Dam

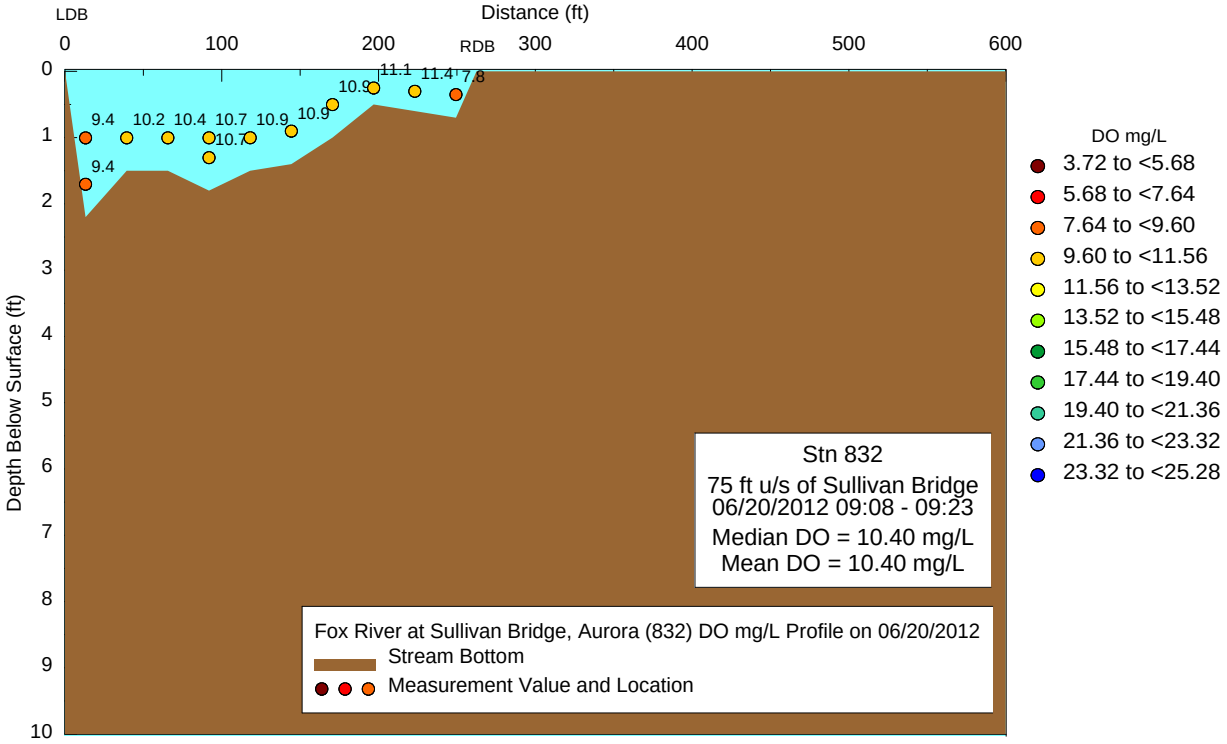


Figure 5. Cross-sectional measurements of dissolved oxygen at Sullivan Bridge, Aurora

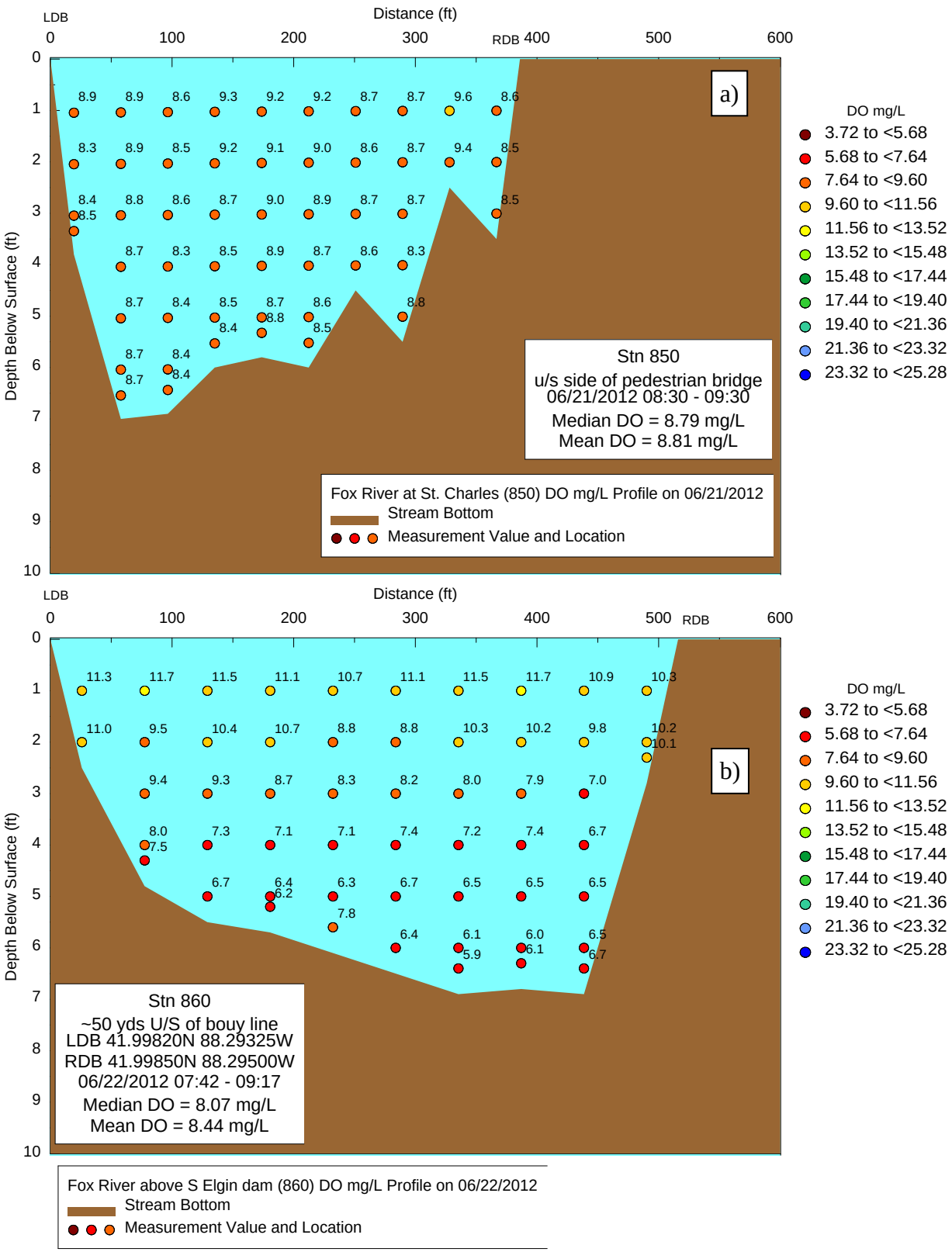


Figure 6. Cross-sectional measurements of dissolved oxygen at two impounded locations: a) St. Charles Dam pool, b) South Elgin Dam pool

Figure 7 and Figure 8 show simulated and observed inorganic phosphorus and total phosphorus, respectively. The QUAL2K model simulates phosphorus in two forms: inorganic phosphorus and organic phosphorus. The terminology surrounding phosphorus measurements is evolving over time. Dissolved (soluble) phosphorus refers to phosphorus that passes through a 0.45 micrometer (μm) filter. The sample can be filtered immediately after collection or at the laboratory. The filtered sample can also undergo additional chemical digestion to convert other dissolved forms of phosphorus to ortho-phosphate that is then measured in the sample. Phosphorus measured in a filtered sample without any digestion is called dissolved (soluble) reactive phosphorus; this method measures phosphorus forms most readily available for algal growth.

Dissolved phosphorus (reactive or total) can be used to approximate inorganic phosphorus represented in the QUAL2K model. Dissolved reactive phosphorus available for the June 2012 event was used in this study. Organic phosphorus is calculated as a difference between total phosphorus and dissolved phosphorus. This division is not exact from a scientific point of view; inorganic phosphorus can bond to sediment particles and organic phosphorus can be dissolved. However, the assumptions used in the Fox QUAL2K model development are largely valid and used in similar studies.

It is apparent that inorganic phosphorus becomes a greater proportion of the total phosphorus from upstream to downstream. The proportion increases from about 4% at the model upstream boundary (downstream of Stratton Dam) to 50 to 80% for about 60 miles downstream of South Elgin. The average simulated phosphorus concentrations match the observed range with the exception of the location at South Elgin Dam where the model overestimates the observed values. Simulated average concentrations are also at the high end of observed concentrations at Millstone Park in Oswego, IL. Both locations are immediately downstream of major NPDES facilities (Fox River WRD and Fox Metro WRD). Incomplete mixing at these sampling locations may have contributed to a larger uncertainty in observed values and, consequently, this discrepancy. The samples were collected using the Equal Width Increment method (Edwards and Glysson, 1999) at 10 different verticals for Fox River mainstem sites. Typically, each vertical is sampled with a vertical integrating sampler using the same transit rate (feet of vertical depth per second of sampler transit time). A sample collected by this method accurately represents the cross-section in areas where the depth is a surrogate for velocity. South Elgin Dam was sampled using the Kemmerer sampler at a mid-depth (sampling procedures for boat sites). This method assumes that the mid-sample represents the full vertical. The uncertainty associated with the sampled concentration increases at cross-sections with significant changes in both horizontal and vertical dimensions. Other sources could have contributed to this discrepancy, such as diurnal and day-to-day variations in flows and concentrations, model segmentation (output represents a segment-average concentration), accuracy of stream geometry parameters, cross-sectional variability of velocities and depths, local variation in model calibration rates, and others.

There is a large variability in inorganic phosphorus observed at the most downstream site on the Fox River in Sheridan. The model simulates inorganic phosphorus within the observed range, albeit at a level below the observed median. Simulated total phosphorus is 0.515 mg/l, below the observed concentration range (0.589 mg/l to 0.756 mg/l with an average of 0.676 mg/l). Simulated velocity at this location is 1.1 foot per second (fps), slightly lower than the observed range during the June 2012 event (1.40 fps to 1.58 fps). Lower velocity likely increases the settling of suspended particles and suspended forms of simulated constituents and contributes to the difference between simulated and observed phosphorus at this location. Hydraulic parameters

were determined from cross-sections in FEMA's Flood Insurance Study (FIS) models of Fox River. While the focus of FISs is on flooding, the models are the most comprehensive source for stream geometry. Fox River at Sheridan is the only location in the free flowing section of Fox River between Yorkville Dam and Dayton Dam where velocity and depth were measured during the event. The model can be forced to match the observed velocity and depth exactly; however, using the original data derived from FISs allows for traceable and reproducible results as well as determination of the impact.

Daily effluent flows and phosphorus concentrations used in the model were reported by the NPDES facilities. Stream concentrations immediately downstream of a point source discharge are calculated by the model using a simple mixing equation; the impact of any in-stream processes related to the model calibration such as sedimentation or uptake by algae on resulting concentrations would be negligible at such location.

Overall, the model simulates phytoplankton as chlorophyll *a* and nutrients within the bounds of observed values for the June 2012 sampling event. Results for additional constituents are included in Appendix B (page 69).

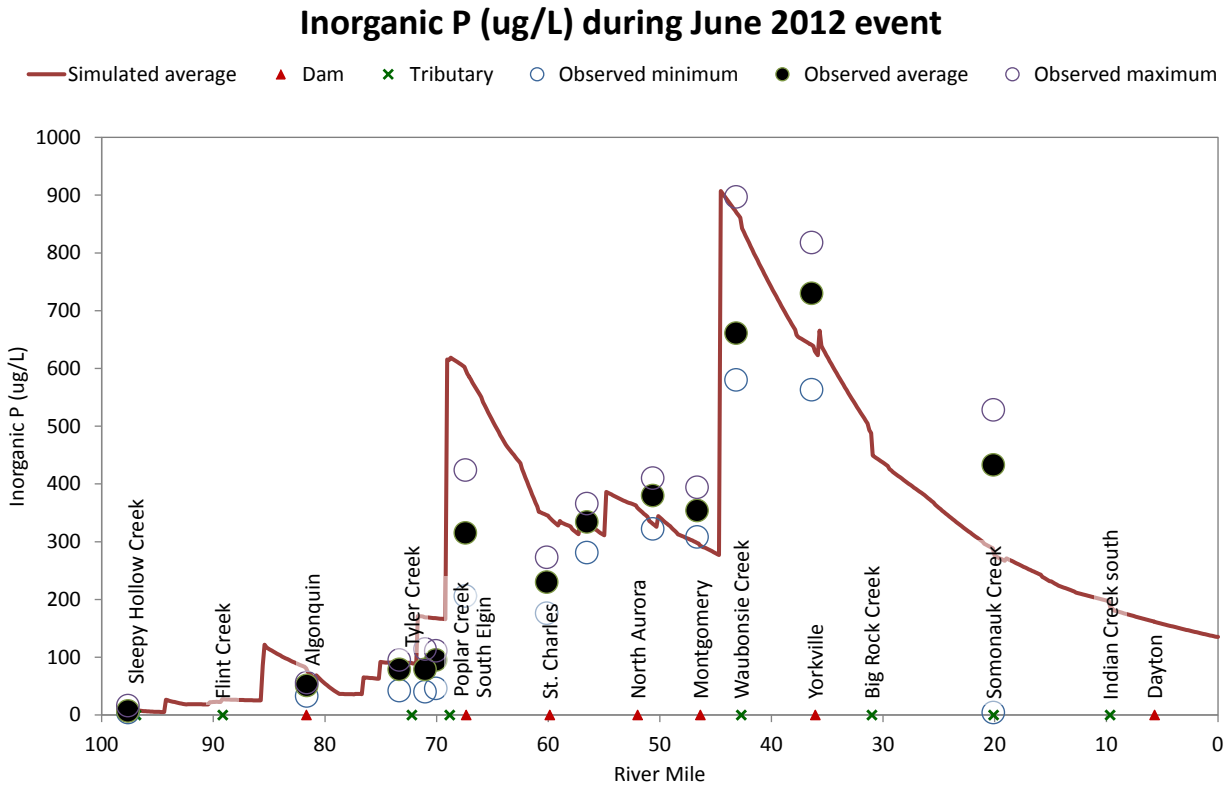


Figure 7. Simulated and observed inorganic phosphorus concentrations

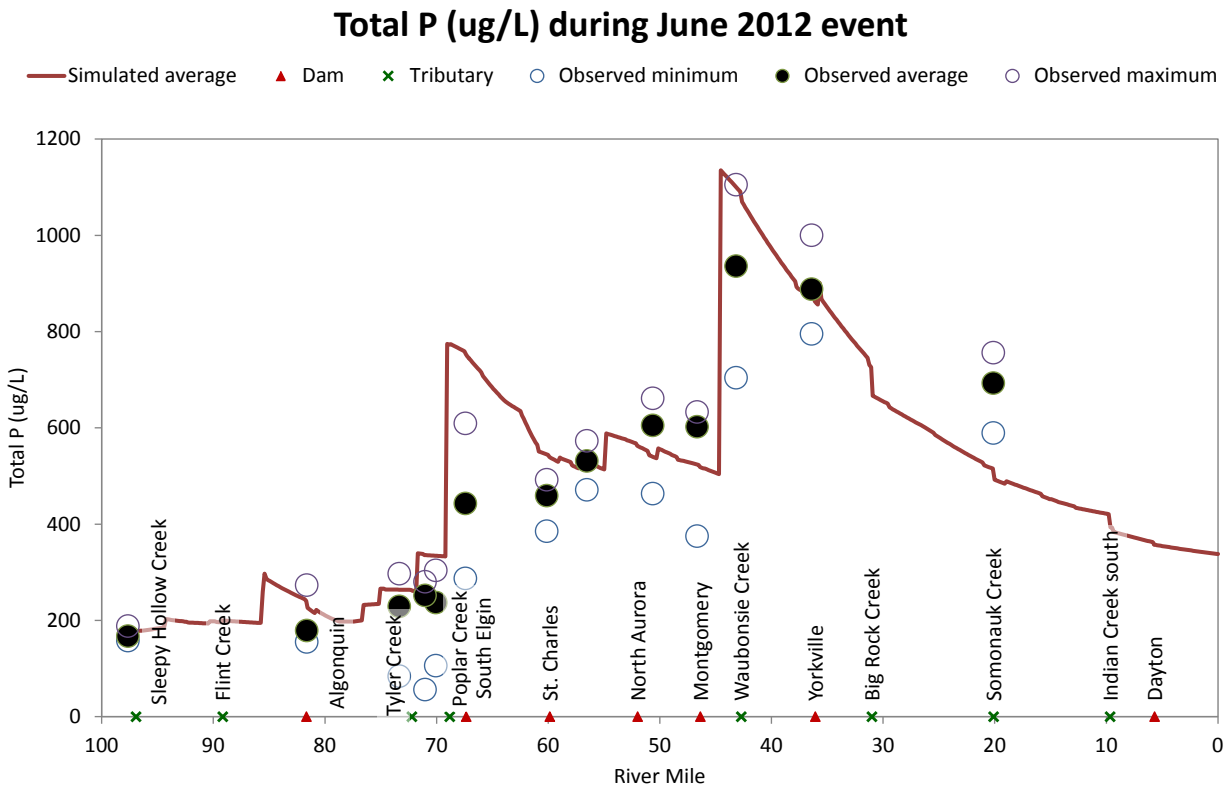


Figure 8. Simulated and observed total phosphorus concentrations

Management Scenarios

Scenarios that were developed for this focus area include total phosphorus limits for municipal dischargers as well as removal of selected dams on the Fox River mainstem. NPDES facilities are significant contributors of nutrients to the Fox River mainstem during low flows. Non-point sources by their definition do not contribute any direct loads during low flows, but considerable loads occur during and after storm events.

The IEPA is developing limits for total phosphorus concentration in effluents from municipal dischargers. Three numerical values for the total phosphorus limit were considered by the FRSG in this study (1 mg/l, 0.5 mg/l, and 0.1 mg/l) for simulating the impact on water quality in the Fox River. The value of 0.1 mg/l represents the lowest achievable limits by best available technologies at this time. The limits are applied based on the facility Design Average Flow (DAF). Facilities with a DAF greater than or equal to 1 mgd are designated as major dischargers. Facilities with a DAF less than 1 mgd are designated as minor dischargers.

Channel characteristics play an important part in stream response to nutrients. Slow moving reaches will often have more sestonic algae than rapid flow reaches of the same stream. Benthic algae will grow more readily in shallow reaches where sufficient light reaches the substrate, while growth may be limited in deeper reaches of the stream. Dams modify stream depth and velocity in the impounded reaches upstream of dams, creating ponds with slow moving water under low flows.

There are 13 dams within the simulated reaches (excluding Stratton Dam located immediately upstream of the simulated reaches). Eight dams were identified by the FRSG as

candidates for removal (Table 4): Algonquin, Carpentersville, Elgin, South Elgin, Geneva, North Batavia, North Aurora, and Montgomery dams (listed in upstream to downstream order). In addition, the effect of removing all dams in the simulated reaches was tested in one scenario. Note that South Batavia dam and North Avenue dam were removed in 2005 and 2007, respectively.

Table 5 shows an overview of the simulated scenarios. The Baseline scenario represents the current level of effluent flows and impoundments. The five numbered scenarios then represent alternative options for dam removals and alternative future NPDES permits with limits on total phosphorus. Concentrations of all other constituent discharges from NPDES facilities are assumed to remain at current levels, either at the permitted level for constituents that are limited but the limit remains the same, or at the average discharged concentration for constituents that are not limited by the NPDES permit. These scenarios were coordinated with the FRSG and were approved by the FRSG Board.

Table 4. Dams on the mainstem of the Fox River

Name	*River* mile	*Length* (feet)	*Height* (feet)	*Crest elevation* (feet, NGVD 1929)	*Notes*
Stratton Lock and Dam	98.90	275	7.0	736.8	Upstream of the study area
Algonquin Dam	82.60	308	10.5	730.3	Considered by FRSG for removal
Carpentersville Dam	78.20	378	9.0	720.7	Considered by FRSG for removal
Elgin Dam	71.90	325	13.0	708.4	Considered by FRSG for removal
South Elgin Dam	68.20	357	8.3	700.0	Considered by FRSG for removal
St. Charles Dam	60.60	294	10.3	684.6	
Geneva Dam	58.70	441	13.0	675.4	Considered by FRSG for removal
North Batavia Dam	56.30	244	12.0	665.1	Considered by FRSG for removal
South Batavia Dam (east)	54.90	143	6.0	653.9	Removed in 2005
South Batavia Dam (west)	54.90	203	5.0	654.2	Removed in 2005
North Aurora Dam	52.60	375	9.0	646.0	Considered by FRSG for removal
East Stolp Island Dam	48.90	177	11.0	628.4	
West Stolp Island Dam	48.90	170	15.0	628.4	
North Avenue Dam (Hurds Island Dam)	48.40	365	2.8	619.0	Removed in 2007
Montgomery Dam	46.80	325	8.0	614.0	Considered by FRSG for removal
Yorkville Dam	36.50	530	7.0	575.0	
Dayton Dam	5.70	600	29.6	498.8	

Table 5. Overview of summer low flow scenarios

Scenario	*TP limit (mg/l)*		*Number of dams removed*
	Major Facility	*Minor Facility*	
Baseline	No limit*	No limit*	0
1	1.0	No limit	0
2	0.1	0.1	0
3	1.0	No limit	8
4	0.5	No limit	8
5	0.5	No limit	13

Note: * TP concentration as currently discharged

All NPDES facilities were simulated at their current permitted level using DAF and concentrations at permitted levels for the constituents limited by their respective NPDES permits. While the actual impact during low flows is expected to be less severe than the impact simulated with permit-level conditions, using the permitted effluent flows allows for determination of the most significant impact the facility may have under its current NPDES permit. Such simulations can be directly used in future determinations of maximum daily loads during the permitting processes.

Stream geometry parameters for currently impounded segments under the free flow regime were estimated using the stream geometry parameters from the nearest free flowing reach. This approach approximates depths and velocities under the assumption that the dam is not present. However, it should be noted that true stream geometry after dam removal is not known and could vary from these assumptions depending on the dam removal strategy and restoration practices selected.

Stream flows in the Fox River and its tributaries have been set to 7-day 10-year low flow (Q7-10) for all scenario simulations. Q7-10 is a statistical estimate of the lowest average flow that would be experienced during a consecutive 7-day period with an average recurrence interval of 10 years. Because it is estimated to recur on average only once in 10 years, it is usually an indicator of low flow conditions during drought (ISWS, 2013). It also represents the lowest flow at which water quality standards must be met (Title 35 of the Illinois Administrative Code, Section 302.103). The values for Q7-10 were extracted from the Illinois Streamflow Assessment Model (ISWS, 2013). Figure 9 shows simulated Fox River flows used in the model development (June 2012 event used in calibration and August 2001 event used in preliminary model development) as well as the flow used in scenario simulations (Q7-10).

The Fox River Q7-10 is smaller than either of the sampled events. The model calibrated under flow conditions during the June 2012 event is used to simulate water quality impacts under flow conditions outside of its calibration range. While this is a common practice, the increase in uncertainty due to different flows needs to be acknowledged. The absolute difference between the flow simulated for the June 2012 event and the simulated Q7-10 varied from 37 cfs to 130 cfs with an average difference of 71 cfs and a median difference of 65 cfs. Flow during the June 2012 event was on average 43% larger than the Q7-10 (ratio ranges from 17% to 88% with a 36% median).

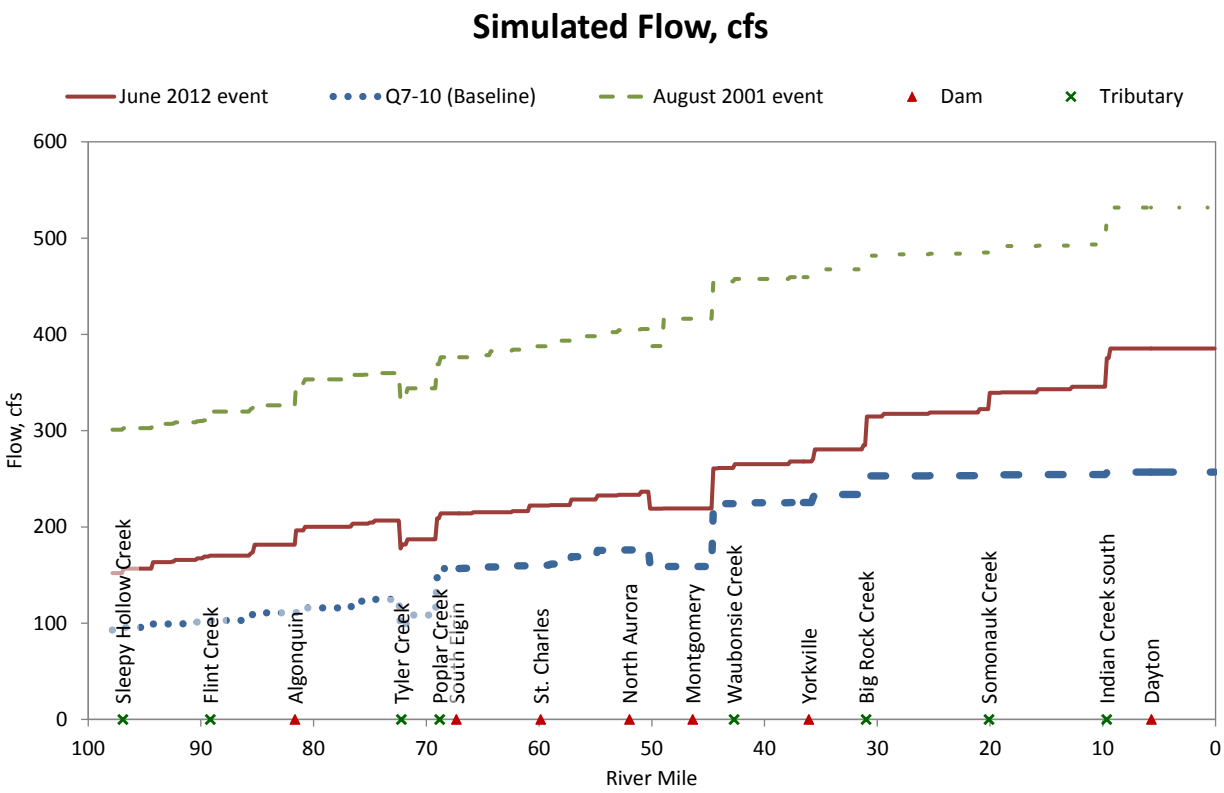


Figure 9. Fox River flows used in model development and scenario simulations

To put this into perspective, look at the flows at Stratton Dam. The flow during the June 2012 event was 152 cfs (exceeded on average 94% of days) and the Q7-10 is 93 cfs (exceeded on average more than 99% of days). Mean flow at the same location is 866 cfs (ILSAM, 2013), much larger than either of the simulated flows. The difference between the simulated flows is relatively small when compared to the mean flow and the expected range of flows that occur in the Fox River.

The impact of upstream total phosphorus concentrations was also simulated. The scenarios listed in Table 5 were simulated with two different upstream total phosphorus concentrations: one matching concentrations measured in June 2012, representing the existing concentration under critical summer low flow conditions, and another matching the water quality standard adopted by the State of Wisconsin, representing possible future conditions. The State of Wisconsin set a water quality standard of 0.1 mg/l for total phosphorus in their portion of the Fox River (Wisconsin Legislative Documents NR 102.06(3)(a)). Median total phosphorus and dissolved phosphorus measured at Burtons Bridge, the study area's upstream boundary, during the June 2012 event was 0.167 mg/l and 0.007 mg/l, respectively. The ratio between inorganic and total phosphorus concentrations was kept constant, resulting in an upstream dissolved phosphorus concentration of 0.004 mg/l when simulating the impact of Wisconsin regulations.

The laboratory method detection limit for total and dissolved phosphorus sampled during the June 2012 event was 0.004 mg/l, significantly lower than the method detection limit of 0.01 mg/l or 0.02 mg/l depending on the organization collecting the data and a time period. Figure 10 and Figure 11 show historical data for total and dissolved phosphorus, respectively, at Burtons

Bridge. This location was sampled by the IEPA, FRSG, McHenry County, and ISWS. Data collected during the June 2012 event are displayed separately. Note that ISWS sampled at this location during water years 2010-2011 to aid the HSPF model development. The FRSG sampled at this location from April 2002 to September 2003. Total phosphorus concentrations do not exhibit any significant trend over time. Dissolved phosphorus concentrations exhibit only a slight decrease over time. However, this conclusion may be partially affected by the lower method detection limit and higher frequency of sampling in water years 2010-2011.

Total phosphorus concentrations collected at Burtons Bridge during the June 2012 event were relatively high; 70% of historical samples and 80% of historical samples collected in June had a total phosphorus concentration at or below 0.167 mg/l. Dissolved phosphorus concentrations collected during the June 2012 event were relatively low but not uncommon; 25% of historical samples and 40% of historical samples collected in June had a dissolved phosphorus concentration at or below 0.01 mg/l, the method detection limit. The difference in method detection limits does not allow a direct determination of percent samples that exceeds the June 2012 event concentrations. June 2012 total phosphorus concentrations are higher than typical June conditions. June 2012 dissolved phosphorus concentrations adequately represent typical June conditions.

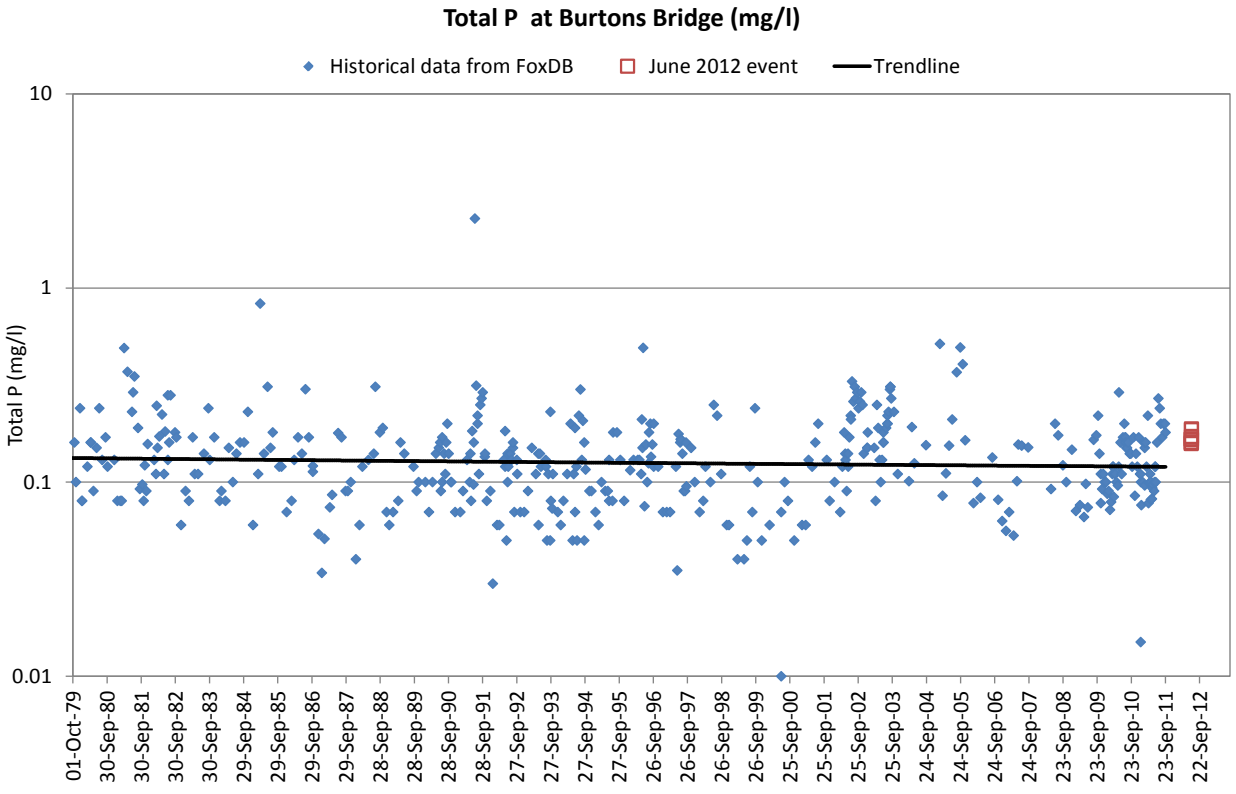


Figure 10. Historical data for total phosphorus at Burtons Bridge

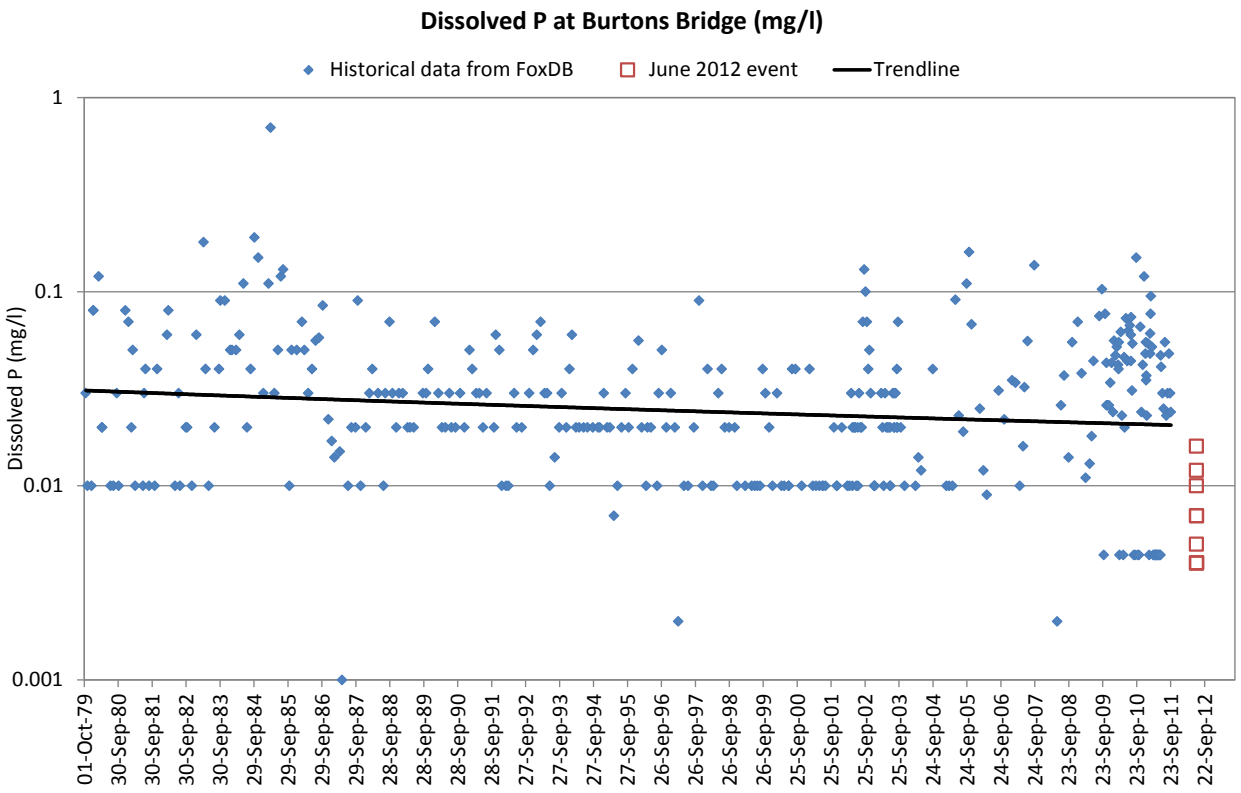


Figure 11. Historical data for dissolved phosphorus at Burtons Bridge

The FRSG samples also at Chapel Hill Road about 9 miles upstream of Burtons Bridge. Statistical analyses show both total and dissolved phosphorus concentrations at Chapel Hill Road are generally higher than total and dissolved phosphorus concentrations at Burtons Bridge. At Chapel Hill Road, about 50% of historical samples and 60% of historical samples collected in June had a total phosphorus concentration at or below the median concentration sampled during the June 2012 event at Burtons Bridge (0.167 mg/l). Only 7% of historical samples and 15% of historical samples collected in June at Chapel Hill Road had dissolved phosphorus concentration at or below the median concentration sampled during the June 2012 event at Burtons Bridge (0.007 mg/l). The difference in percentages of historical samples collected at Burtons Bridge and Chapel Hill that are at or below the median concentration sampled during the June 2012 event is probably due to a combination of factors. There are several municipal wastewater treatment plants (including McHenry STP) that contribute phosphorus to the Fox River reach between the two sites. A significant source of phosphorus would be expected to cause an opposite relationship between phosphorus concentrations at these two sites unless additional tributaries counteract the impact of the facility discharge. There are several tributaries, including Dutch Creek, Boone Creek, and Sleepy Hollow Creek, that enter the Fox River between the Chapel Hill Road and Burtons Bridge and contribute an additional volume of water. The actual flows and water quality concentrations at tributaries as well as NPDES discharge characteristics combined determine the relationship between phosphorus concentrations at these sites. Last but not least, boating traffic on Chain of Lakes can affect sediment and, consequently, phosphorus concentrations due to resuspension of bottom sediments.

Impacts of Management Scenarios on Fox River Water Quality

The management scenarios described in the previous section (Table 5) were simulated using the calibrated QUAL2K model. Median concentrations of total phosphorus and other constituents for all scenarios are summarized for the Fox River mainstem in Table 6. Median Fox River concentrations should not be used to interpret compliance with water quality standards. The values are only used to numerically compare the simulated scenarios and assess an overall change. Simulated daily average concentrations (or daily minimum concentrations for dissolved oxygen) are at or below the median concentrations at 50% of the simulated stream length.

Figure 12 shows total phosphorus simulated in the Fox River mainstem for all six scenarios including the Baseline scenario and both upstream conditions with respect to total phosphorus. Resulting total phosphorus concentrations are very similar for Scenarios 1 and 3 (both use 1.0 mg/l total phosphorus limit) as well as for Scenarios 4 and 5 (both use 0.5 mg/l total phosphorus limit). All scenarios show a significant reduction in total phosphorus concentrations at Fox River reaches downstream of NPDES facilities, especially in the middle section (river miles 70-30). The overall reduction for the study reach is quantified by calculating the median of the average simulated concentrations for individual reaches.

Table 6. Median concentrations of simulated averages for the management scenarios, µg/l

	Average phosphorus		*Average*	*Average*	*Minimum*
Scenario	*Total*	*Inorganic*	*Phytoplankton**	*Benthic algae*[+]*	*Dissolved oxygen[$]*
Baseline	756 (733)	498 (495)	80 (67)	84.1 (102.8)	4.89 (4.89)
Scenario 1	329 (309)	125 (123)	80 (67)	81.4 (99.1)	4.88 (4.87)
Scenario 2	157 (127)	16 (14)	80 (67)	72.0 (76.6)	4.87 (4.90)
Scenario 3	326 (303)	122 (120)	73 (55)	101.8 (114.4)	4.84 (4.82)
Scenario 4	242 (217)	63 (61)	73 (55)	99.4 (111.4)	4.86 (4.82)
Scenario 5	224 (196)	60 (57)	56 (38)	114.5 (127.6)	5.24 (5.22)

Notes: Results for current upstream conditions are listed first with results for modified upstream conditions in parenthesis

* Expressed as chlorophyll *a* concentration

[+] Measured in mg chlorophyll *a* per square meter

[$] Measured in mg/l

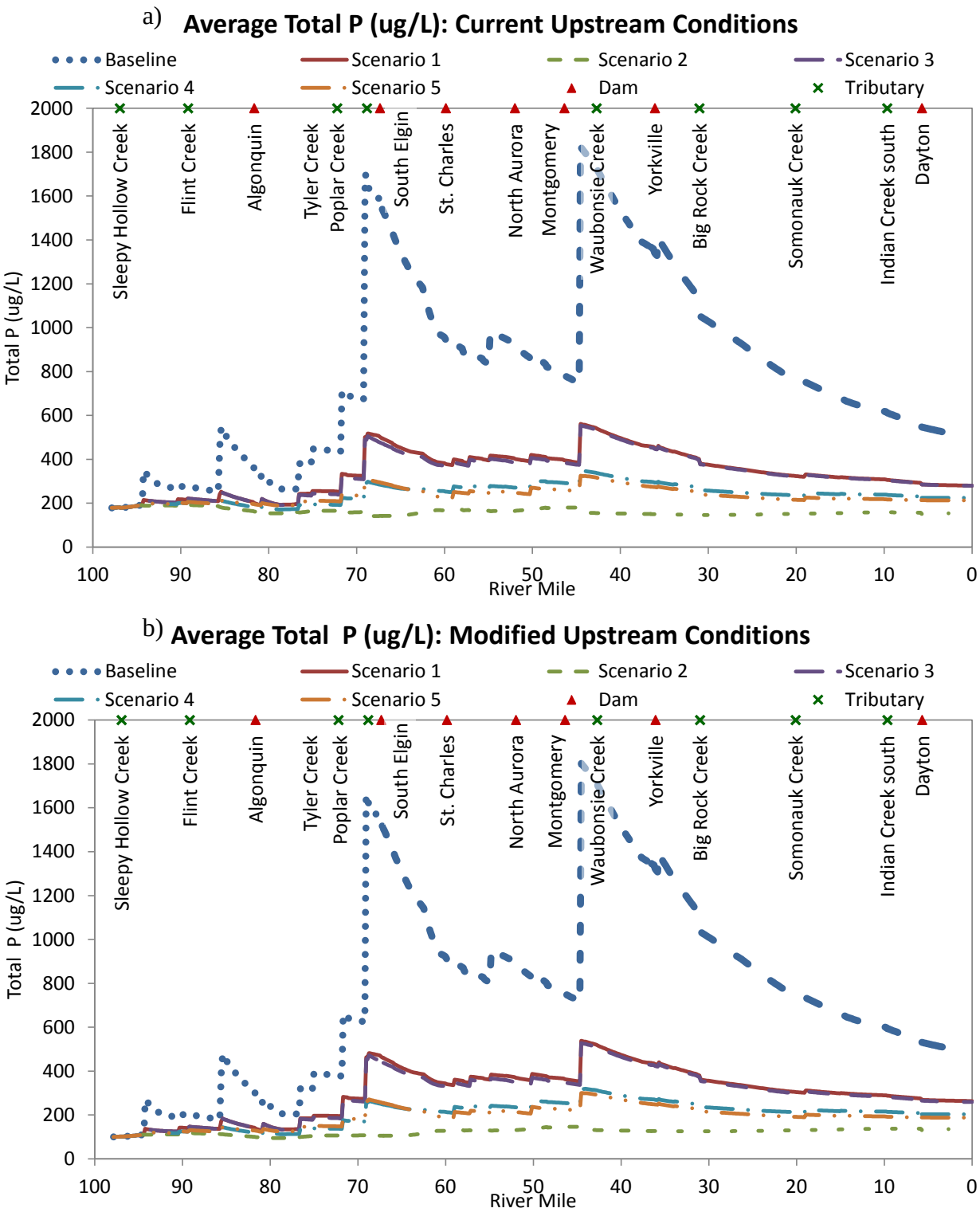


Figure 12. Average total phosphorus for management scenarios
a) current upstream conditions, b) modified upstream conditions.

The lowest total phosphorus concentrations were achieved under the most drastic modification of NPDES permits, limiting total phosphorus in the effluent to 0.1 mg/l (Scenario 2). The median simulated total phosphorus concentration in Scenario 2 is 0.16 mg/l and 0.13 mg/l for current upstream conditions and modified upstream conditions, respectively (Table 6). The maximum simulated total phosphorus concentration in Scenario 2 is 0.19 mg/l and 0.15 mg/l for current upstream conditions and modified upstream conditions, respectively.

The dissolved, inorganic portion of total phosphorus is more readily available to phytoplankton. Figure 13 shows inorganic phosphorus simulated in the Fox River mainstem for all six scenarios including the Baseline scenario and both upstream conditions with respect to total phosphorus. The impact of selected management scenarios on inorganic phosphorus mirrors the impact on total phosphorus because effluent from NPDES facilities treating municipal wastewater contains mostly inorganic forms of phosphorus. Scenario 2 shows the lowest simulated inorganic phosphorus concentrations with Scenarios 4 and 5 following.

Figure 14 shows phytoplankton chlorophyll *a* simulated in the Fox River mainstem for all six scenarios including the Baseline scenario and both upstream conditions with respect to total phosphorus. There are only small differences in phytoplankton chlorophyll *a* among the first group of scenarios, the Baseline scenario and Scenarios 1 and 2, although there are large differences in the phosphorus concentrations discharged from NDPES facilities under these scenarios (current level, 1 mg/l, and 0.1 mg/l, respectively). Small differences are also found between phytoplankton chlorophyll *a* for the second group of scenarios, Scenarios 3 and 4. However, significant differences in phytoplankton were simulated among the scenario groups based on the number of dams present. The first group of scenarios has all dams currently present, the second group of scenarios represents the Fox River without eight dams, and the last scenario (Scenario 5) represents the Fox River without any dams.

There is a slight decrease in phytoplankton chlorophyll *a* under Scenarios 3 and 4 (eight dams removed) when compared to the Baseline scenario (Table 6). The median difference is 8 µg/l and 12 µg/l as chlorophyll *a* for current upstream conditions and modified upstream conditions, respectively (Figure 14). The maximum difference is 13 µg/l and 17 µg/l as chlorophyll *a* for current upstream conditions and modified upstream conditions, respectively. The difference between Scenario 5 and the Baseline scenario is even bigger. The median difference is 32 µg/l and 35 µg/l as chlorophyll *a* for current upstream conditions and modified upstream conditions, respectively. The maximum difference is 51 µg/l as chlorophyll *a* for both current and modified upstream conditions.

There is an increase in phytoplankton chlorophyll *a* simulated in Scenario 5 between river miles 85 and 70. The reason for this increase is unclear. Algonquin Dam impounds a long reach on the Fox River. When the dam is removed, depth and residence time decreases, velocity increases, and consequently there is less sedimentation in the reach. With the smaller depth and volume of water stored in the reach, there is also a larger variability in temperature that subsequently affects transformation rates.

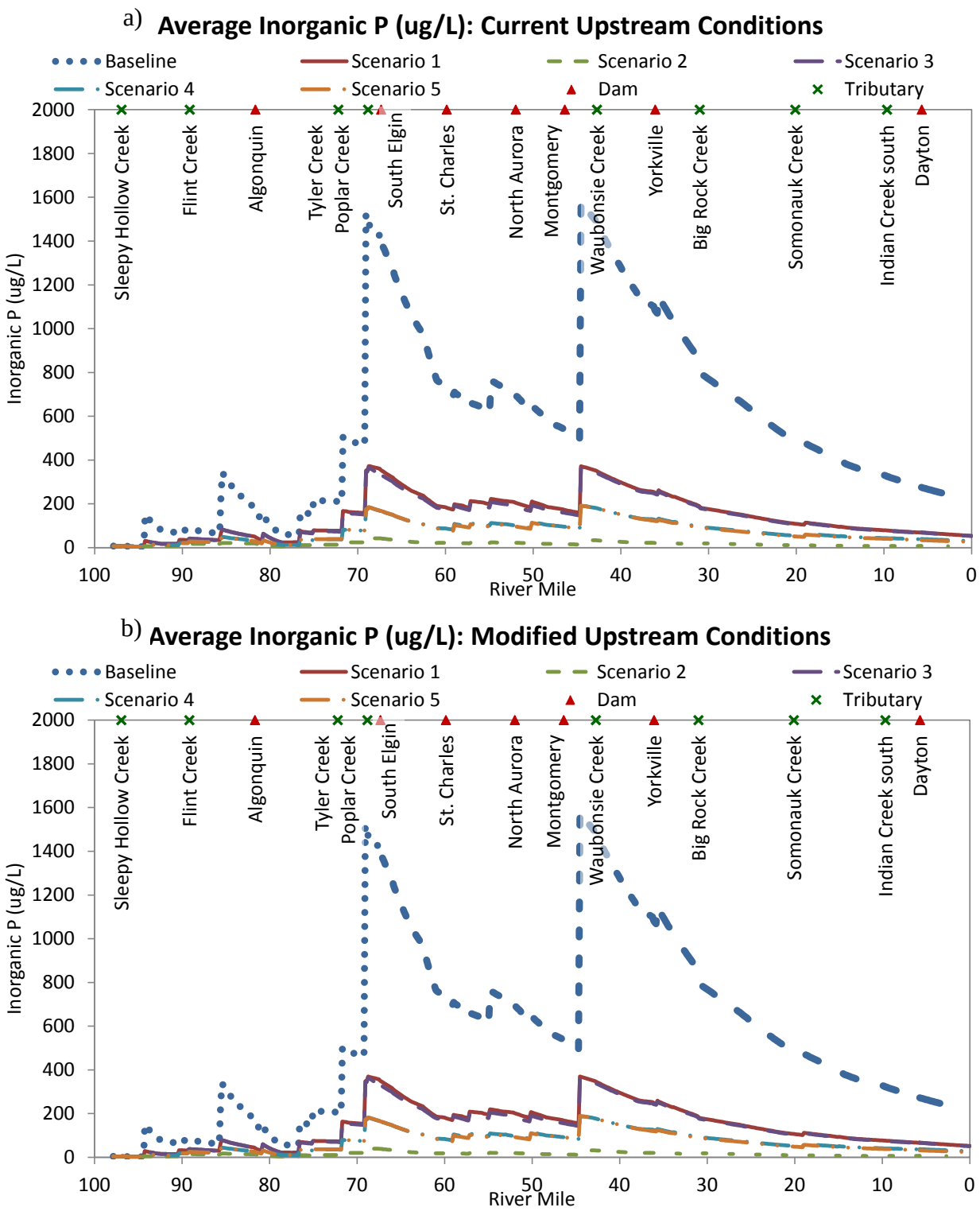


Figure 13. Average inorganic phosphorus for management scenarios
a) current upstream conditions, b) modified upstream conditions.

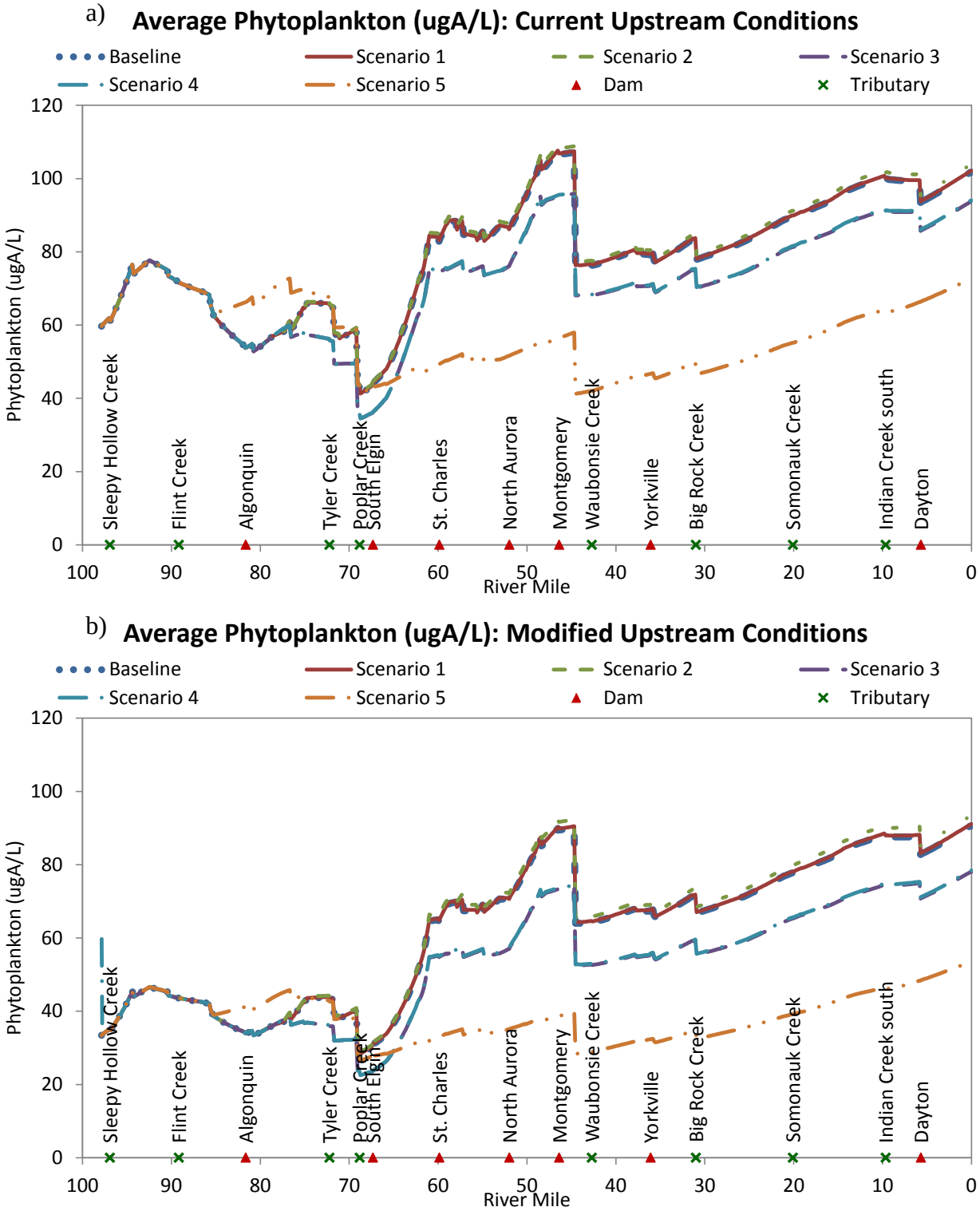


Figure 14. Average phytoplankton as chlorophyll *a* for management scenarios a) current upstream conditions, b) modified upstream conditions.

Figure 15 shows dissolved oxygen simulated in the Fox River mainstem for all six scenarios including the Baseline scenario and both upstream conditions with respect to total phosphorus. Similar to phytoplankton chlorophyll *a* concentrations, there are only small differences between minimum dissolved oxygen for the first group of scenarios: Baseline and Scenarios 1 and 2. Only small differences are also found between scenarios in the second group, Scenarios 3 and 4. However, significant differences in minimum dissolved oxygen were simulated among the scenario groups based on the number of dams present. The first group has all dams currently present, the second group represents the Fox River without eight dams, and the last scenario (Scenario 5) represents the Fox River without any dams. Scenario 5 results in the greatest overall improvement in minimum dissolved oxygen concentrations, although the minimum concentrations simulated in Scenario 5 still fall below 5 mg/l for about half of the simulated stream length (Table 7).

Scenario 5 simulates a situation in which all dams are removed and all major municipal NPDES facilities discharge 0.5 mg/l total phosphorus. When the 0.5 mg/l total phosphorus is discharged from the facilities under extremely low flow of Q7-10, the simulated inorganic phosphorus concentration is sufficient to support unhindered growth of phytoplankton and benthic algae at most of the simulated mainstem. The simulated inorganic phosphorus combines the effects of permitted NPDES discharges, upstream conditions, conditions in tributaries, and sediment contributions. It should be noted that Fox River has a significant contribution of flow from NPDES facilities under low flow conditions, accentuating the impact of NPDES facilities on water quality in Fox River especially when permitted conditions are simulated. Removing the dams provides physical conditions to control phytoplankton, but it needs to be accompanied by lower phosphorus concentrations to significantly limit combined phytoplankton and benthic algal growth that causes diurnal variation in dissolved oxygen.

There is a slight increase in the percentage of stream length below the dissolved oxygen thresholds in Scenarios 3 and 4 that can be attributed to increased benthic algae in certain sections of the Fox River that became shallower and more prone to benthic algal growth when free-flowing. A similar increase is found in some sections of Fox River for Scenario 5, although there is an overall decrease of the mainstem length where minimum dissolved oxygen falls below the thresholds. While the thresholds were selected to represent numerical values of dissolved oxygen water quality standard, caution must be exercised when interpreting compliance with the water quality standard. As demonstrated when discussing the model calibration, the extreme minima and maxima observed in Fox River are not simulated well in all reaches. Observed minimum dissolved oxygen concentrations in most were typically lower than those simulated.

Illinois water quality standards (Title 35 Illinois Administrative Code, Part 302, Section 206) require dissolved oxygen in all Illinois streams not specifically listed in its Appendix D, i.e., in most of the Fox River mainstem, at or above 5 mg/l at any time during the period of March through July and not to fall below 3.5 mg/l at any time during the period of August through February. During the period of August through February, dissolved oxygen must not be less than 4 mg/l as a daily minimum averaged over seven days. A small section of the Fox River in Aurora is listed in Appendix D of Part 302 or Title 35 with minimum dissolved oxygen required at or above 5 mg/l at any time during the period of March through July and 4.0 mg/l at any time during the period of August through February. During the period of August through February, dissolved oxygen must not be less than 4.5 mg/l as a daily minimum averaged over seven days. Requirements are also set for daily mean averaged over seven days (6 mg/l and 5.5 mg/l for most of the Fox River mainstem during the periods of March through July and August through

February, respectively, and 6.25 mg/l for the reach listed in Appendix D of Title 35 Part 302 during the period of March through July) and daily mean averaged over 30 days (6.0 mg/l for the reach listed in Appendix D of Title 35 Part 302) during the period of August through February.

Figure 16 shows benthic algae simulated in the Fox River mainstem as chlorophyll *a* for all six scenarios including the Baseline scenario and both upstream conditions with respect to total phosphorus. The response of benthic algae to changing phosphorus concentrations and dam impoundments varies. Scenario 2 results in the overall lowest benthic algae chlorophyll *a* (Table 6). Note that the response of each river section may vary due to local flow regime and a change in phosphorus concentrations among the simulated scenarios. However, Scenarios 3, 4, and 5 lead to an increase in benthic algae chlorophyll *a* concentrations in some sections when compared to the Baseline scenario simulation. Removing dams creates conditions that are more suitable for benthic algal growth than impoundments. Shallow waters allow light to penetrate to the river bottom which stimulates benthic algae growth. The increased benthic algae then contribute to diurnal changes in dissolved oxygen in a manner similar to phytoplankton.

Table 7. Percent stream length with minimum dissolved oxygen concentrations below threshold

	Minimum dissolved oxygen below		
Scenario	*5 mg/l*	*4 mg/l*	*3.5 mg/l*
Baseline	56% (55%)	23% (23%)	17% (16%)
Scenario 1	55% (55%)	23% (23%)	16% (16%)
Scenario 2	55% (54%)	23% (22%)	14% (13%)
Scenario 3	56% (60%)	26% (26%)	17% (19%)
Scenario 4	56% (59%)	26% (26%)	17% (18%)
Scenario 5	46% (46%)	14% (15%)	7% (7%)

Note: Results for current upstream conditions listed first with results for modified upstream conditions in parenthesis

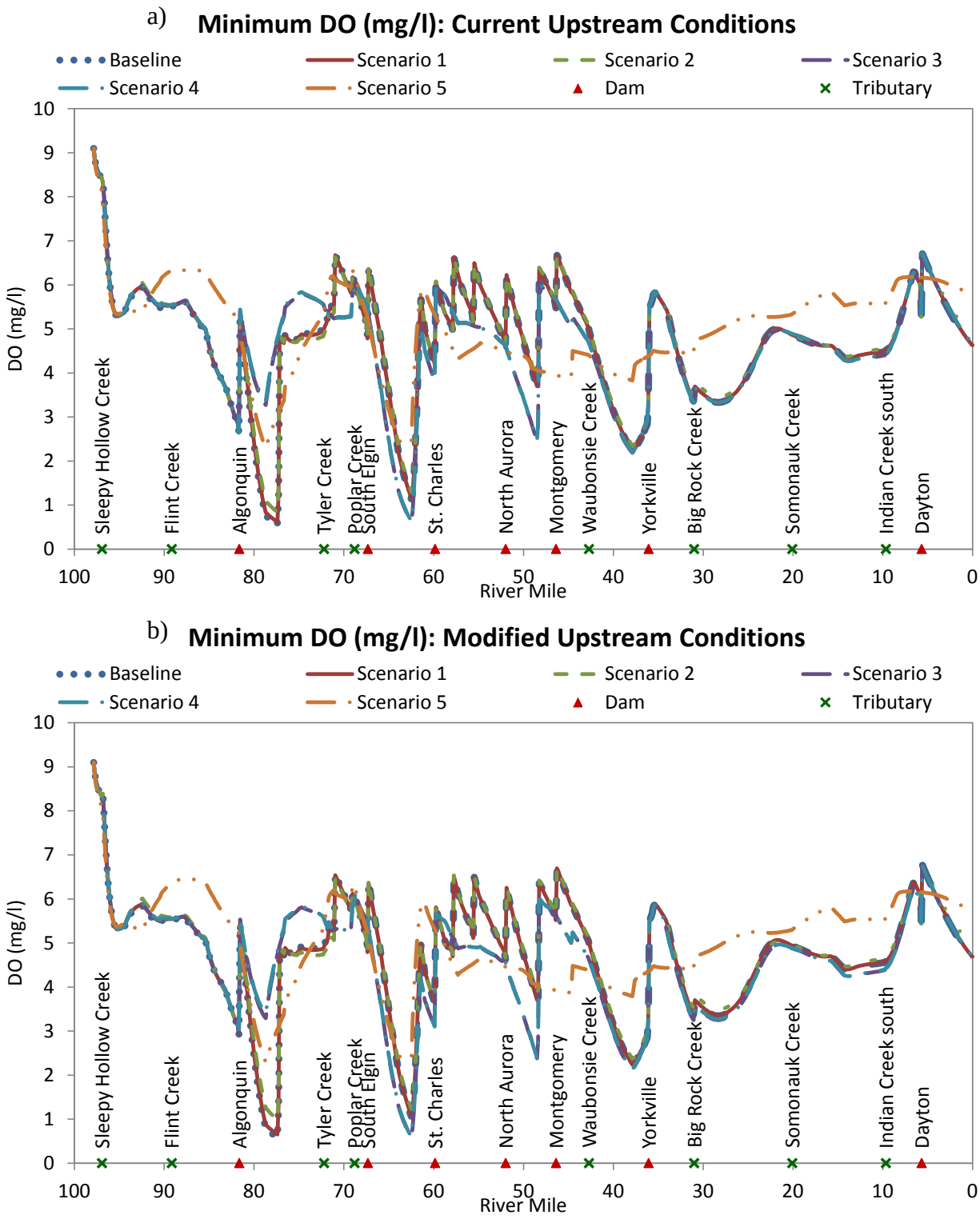


Figure 15. Minimum dissolved oxygen for management scenarios
a) current upstream conditions, b) modified upstream conditions.

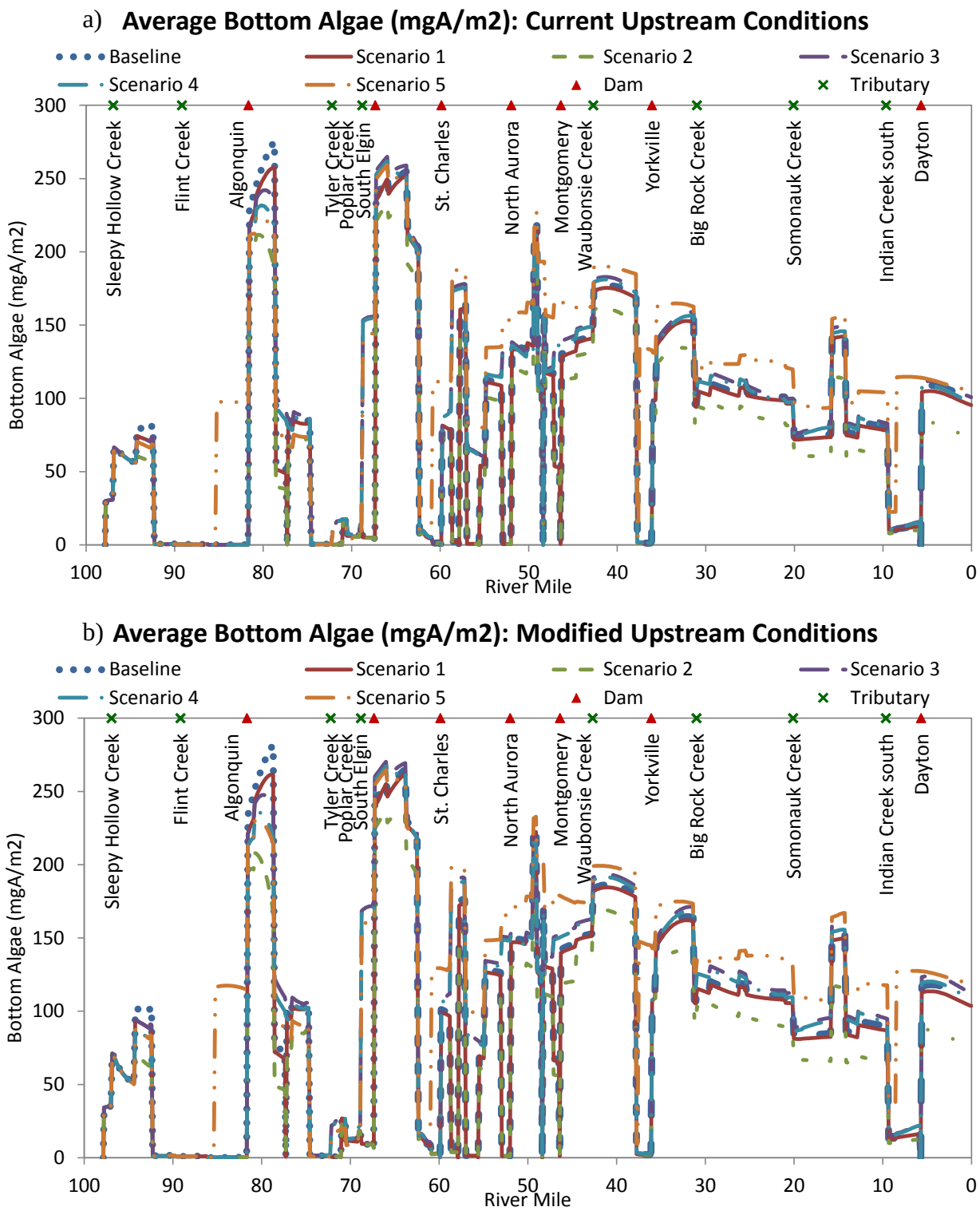


Figure 16. Average benthic algae as chlorophyll *a* for management scenarios a) current upstream conditions, b) modified upstream conditions.

Long-term Watershed Loads

The modeling efforts described in this section focus on critical conditions with respect to the second focus area, watershed loads of nutrients, sediment, and fecal coliforms. Sedimentation/siltation is listed as a cause of impairment for 38% of assessed mainstem miles, total suspended solids for 32% of assessed mainstem miles, fecal coliforms for 50% of assessed mainstem miles, and total phosphorus for 32% of assessed mainstem miles (IEPA, 2013).

These causes of impairments are impacting the beneficial use of tributaries to the Fox River. Sedimentation/siltation is listed as a cause of impairment for Slocum Lake Drain and Fiddle Creek, and total suspended solids are listed as a cause of impairment for Poplar Creek. Fecal coliforms are listed as a cause of impairment for 10 tributaries to the Fox River: Blackberry Creek, Brewster Creek, Crystal Lake Outlet, Ferson Creek, Flint Creek, Indian Creek, Mill Creek, Nippersink Creek, Poplar Creek, and Tyler Creek.

High sediment concentrations in the Fox River are associated with high flows (McConkey et al., 2004). When evaluating sediment and nutrients, total load delivered to the stream is also important. Settling and resuspension of previously settled materials can be an important source or pathway for certain constituents and can play an important role in the overall water quality of a water body. Fecal coliforms were found to exceed the numerical value of the water quality standard of 200 colony forming units (cfu) per 100 milliliters (ml) at all flow regimes (McConkey et al., 2004). While nitrogen is not currently listed as a cause of impairment, it is included here since nitrogen management is likely to be a component of any future watershed planning efforts.

Simulation Model

HSPF is a long-term watershed loading model used to simulate daily flows and selected constituent loads delivered to streams during precipitation events as well as the subsequent transport and transformation of the constituent within the stream channel. The development and calibration of the HSPF model is described in detail in Singh et al. (2007) and Bartosova et al. (2007a, 2007b, 2011). The model was pre-calibrated using water quality data collected from the Fox River and its tributaries by various organizations (IEPA, FRSG, FRWRD, FMWRD, and many others) during water years 1991-1999. Subsequently, the model was validated using data from water years 2000-2003. Many additional data were used in HSPF model development including land use, soil types, elevation, watershed boundaries, crop production and tillage statistics, stream geometry, precipitation and other climate data, stream flow, dams, public water supply, and NPDES discharges.

Final calibration and validation were conducted using data collected by the ISWS for the FRSG (Slowikowski and Russell, 2012) during water years 2010 and 2011. Water quality samples were collected at bi-weekly intervals as well as during storms to provide more complete information on concentrations under different flow conditions in the mainstem as well as in selected tributaries.

Several data sources were used to determine effluent flow and concentrations for NPDES facilities. A survey was conducted twice during the course of the study; all facilities were contacted and asked for data by Camp Dresser & McKee Inc. (CDM) in 2005 (CDM, 2006), and

selected facilities discharging to the Fox River mainstem were contacted and asked for data by the FRSG Board in 2011. The monthly Discharge Monitoring Reports were provided by the IEPA and processed for all facilities. The data were used to prepare time series needed for the model in this order: 1) daily data provided by the facilities, 2) monthly data provided by the facilities, and 3) monthly data from the IEPA. Missing data points were identified and replaced either with interpolated data or monthly averages, depending on the constituents. Fecal coliform bacteria are reported for most facilities only during May–October when the water quality standard for fecal coliforms is in place. Most facilities do not disinfect in winter months (November–April). The fecal coliform concentration at facilities without winter data was estimated at 1,000 cfu for winter months. Higher values can be found in municipal effluent without disinfection; however, calibration results did not show any significant bias for winter months that would justify using different values. Low temperatures contribute to lower survival rates in streams during winter.

Table 8 shows general calibration targets and terms used to assess the success of HSPF calibration as they are used throughout this report. Monthly and daily flows were also compared statistically by calculating the coefficient of correlation (r) and Nash-Sutcliffe Efficiency (NSE, Nash and Sutcliff, 1970) between observed and simulated flows. The NSE indicates how well the plot of observed versus simulated data fit the 1:1 line. Both NSE and r values of 1 indicate a perfect fit. NSE values should be larger than 0.0 to indicate a minimally acceptable performance; a value less than 0.0 indicates that mean observed flow is a better predictor than the model. Detailed results of the calibration are discussed in individual sections below for each calibrated output.

Table 8. General calibration targets or tolerances for HSPF applications (after Donigian et al., 1984)

	Simulated and Recorded Values, % Difference (Dv)		
Modeled variable	*Very Good*	*Good*	*Fair*
Hydrology/Flow	< 10	10 - 15	15 - 25
Sediment	< 20	20 - 30	30 - 45
Water temperature	< 7	8 - 12	13 - 18
Water quality/Nutrients	< 15	15 - 25	25 - 35
Pesticides/Toxics	< 20	20 - 30	30 - 40

Streamflow

There are five USGS streamflow gages on the Fox River mainstem within the study area which extends from Stratton Dam downstream to the junction of the Fox River and the Illinois River. These gages are located at Algonquin (USGS ID 05550001), South Elgin (USGS ID 05551000), Montgomery (USGS ID 05551540), and Dayton (USGS ID 05552500). Note that in 2009, the USGS discontinued discharge measurements at gage 05550000 (Algonquin Dam headwater) and began collecting discharge measurements at the Algonquin Dam tailwater (USGS ID 05550001). The USGS gage at Yorkville (USGS ID 05551580) became operational in 2012, outside of the model simulation period, and reports only stage, not discharge. The Yorkville gage has not been used in the model development. In addition, the ISWS operated a stream gage at Fox River Drive during water years 2010-2011.

Stream flow data were available for calibration and validation from eight additional gages on seven tributaries: Blackberry Creek at Yorkville, Blackberry Creek at Montgomery, Brewster Creek, Ferson Creek, Flint Creek, Mill Creek, Poplar Creek, and Tyler Creek. Stream flow reported by DEI for Indian Creek in Aurora was not used for calibration due to the short period of record, problematic data during periods of ice, and because flows were only provided for days when stream flow fell at or above 5 cfs.

Table 9 shows statistics comparing simulated and observed stream flow for the mainstem gages on annual, monthly, and daily scales. Statistics are provided for the full simulation period, water years 2004-2010, used to calibrate the water quality portion of the model, and water year 2011, used to validate the water quality portion of the model. Note that the flows were calibrated with data from water years 1991-1999 and validated with data from water years 2000-2003. Details of hydrologic calibration can be found in Bartosova et al. (2011). Simulated annual flows are within 10% of observed flows for all mainstem gages and within 5% of observed flows for three of the five gages. The annual NSE is above 0.85 for four of the five mainstem gages, indicating again a very good fit to the annual scale. The Fox River Drive gage has an annual NSE of 0.352 but monthly and daily NSE values are 0.915 and 0.948, respectively, indicating that the annual NSE value may be affected by having only two years of data available for annual statistics at this gage. The minimum calculated NSE value for all other mainstem gages and time periods is 0.757 and most are above 0.900.

Table 10 shows statistics comparing simulated and observed stream flow for tributary gages for annual, monthly, and daily scales. Statistics are provided for the full simulation period, water years 2004-2010, used to calibrate the water quality portion of the model, and water year 2011 used to validate the water quality portion of the model. Statistics for the streamflow calibration and validation periods were presented in Bartosova et al., 2011.

Simulated annual flows are within 10% of observed flows for all tributary gages and within 5% of observed flows for five of the eight gages during the full simulation period. All watersheds show larger errors for annual flow during the validation period (water year 2011). The minimum calculated monthly and daily NSE values for all gages are 0.686 and 0.677, respectively, during the full simulation period. Periods used for water quality calibration and validation may show lower NSEs, depending on the flow conditions and number of years with available data.

Some of the climate stations used in the original model development were discontinued before the end of the simulation period, creating a complex situation with respect to model development. The inconsistencies in the precipitation stations coverage contributed to larger errors in stream flows simulated for tributaries towards the end of the simulation period. Observed flows during water year 2011 were slightly higher than long-term averages at most gages. The ratio of the observed flow during water year 2011 to the observed flow during all water years available during the simulation period (1991-2011) varied from 88% to 143% with an average ratio of 123% for tributary sites. For mainstem sites, the ratio of the observed flow during water year 2011 to the observed flow during all water years available during the simulation period (1991-2011) did not vary as much: 98% to 108% with an average ratio of 104% (excluding Fox River Drive and Montgomery gages with a short period of record).

The model was calibrated to simulate medium flows. High flows and low flows are simulated with lower accuracies. Low flows are typically slightly overestimated and high flows are generally slightly underestimated by the model. Overall, the HSPF model simulates flows in the Fox River mainstem adequately.

Table 9. Statistics for the stream flow model calibration and validation periods at mainstem gages

	Algonquin			*South Elgin*			*Montgomery*			*Fox River Drive*		
Statistics	*All 1991-2011*	*Calib. 2004-2010*	*Valid. 2011*	*All 1991-2011*	*Calib. 2004-2010*	*Valid. 2011*	*All 1991-2011*	*Calib. 2004-2010*	*Valid. 2011*	*All 2010-2011*	*Calib. 2010*	*Valid. 2011*
O, cfs	1209.0	1399.4	1262.5	1420.7	1883.0	1387.5	1622.4	1740.5	1438.3	2245.1	2497.4	1992.7
S, cfs	1157.5	1333.9	1215.7	1415.5	1947.5	1437.9	1590.4	1721.4	1444.2	2048.4	2282.6	1814.2
S-O, cfs	-51.4	-65.4	-46.8	-5.2	64.5	50.4	-32.0	-19.1	5.9	-196.7	-214.8	-178.5
Dv, %	-4.3	-4.7	-3.7	-0.4	3.4	3.6	-2.0	-1.1	0.4	-8.8	-8.6	-9.0
Annual												
NSE	0.976	0.976	*	0.977	0.878	*	0.991	0.992	*	0.352	*	*
R	0.996	0.998	*	0.990	0.993	*	0.997	0.997	*	1.000	*	*
Years with Dv within ±10%	19 90%	6 86%	1 100%	12 100%	3 100%	1 100%	8 89%	7 100%	1 100%	1 100%	1 100%	1 100%
Years with Dv within ±25%	21 100%	7 100%	1 100%	12 100%	3 100%	1 100%	9 100%	7 100%	1 100%	1 100%	1 100%	1 100%
Total years	21	7	1	12	3	1	9	7	1	1	1	1
Monthly												
NSE	0.982	0.976	0.971	0.948	0.822	0.961	0.981	0.982	0.963	0.915	0.820	0.938
r	0.993	0.990	0.987	0.974	0.914	0.987	0.991	0.991	0.984	0.978	0.962	0.983
Months with Dv within ±10%	176 70%	49 58%	5 42%	100 73%	15 52%	6 50%	61 56%	51 61%	7 58%	7 58%	6 50%	7 58%
Months with Dv within ±25%	245 97%	79 94%	11 92%	135 99%	27 93%	12 100%	99 92%	78 93%	11 92%	9 75%	12 100%	9 75%
Total months	252	84	12	137	29	12	108	84	12	12	12	12
Daily												
r	0.980	0.978	0.978	0.952	0.897	0.961	0.977	0.977	0.992	0.948	0.932	0.960
1-day NSE	0.958	0.953	0.954	0.900	0.757	0.893	0.954	0.954	0.983	0.880	0.846	0.904
3-day NSE	0.968	0.962	0.972	0.926	0.808	0.930	0.968	0.968	0.946	0.907	0.879	0.925
7-day NSE	0.974	0.967	0.981	0.940	0.801	0.956	0.976	0.977	0.958	0.922	0.904	0.932

Table 9. Statistics for the stream flow model calibration and validation periods at mainstem gages (concluded)

	Dayton		
Statistics	*All 1991-2011*	*Calib. 2004-2010*	*Valid. 2011*
O, cfs	2415.0	2754.7	2618.2
S, cfs	2238.7	2494.0	2431.7
S-O, cfs	-176.3	-260.7	-186.5
Dv, %	-7.3	-9.5	-7.1
Annual			
NSE	0.911	0.897	*
r	0.985	0.991	*
Years with Dv within ±10%	14	4	0
	67%	57%	0%
Years with Dv within ±25%	21	7	1
	100%	100%	100%
Total years	21	7	1
Monthly			
NSE	0.937	0.941	0.907
r	0.975	0.982	0.970
Months with Dv within ±10%	109	33	4
	43%	39%	33%
Months with Dv within ±25%	223	75	11
	88%	89%	92%
Total months	252	84	12
Daily			
r	0.888	0.935	0.965
1-day NSE	0.764	0.864	0.924
3-day NSE	0.862	0.908	0.946
7-day NSE	0.918	0.929	0.960

Notes: S = simulated flow
O = observed flow
Dv = error in simulated and observed streamflow volumes for a given period
r = correlation coefficient
* statistics cannot be calculated, only 1 year available

Table 10. Statistics for the stream flow model calibration and validation periods at tributary gages

	Blackberry-13						*Brewster-20*			*Ferson-18*		
	Yorkville			*Montgomery*			*Valley view*			*St. Charles*		
Statistics	*All 1991-2011*	*Calib. 2004-2010*	*Valid. 2011*	*All 2002-2011*	*Calib. 2004-2010*	*Valid. 2011*	*All 2002-2011*	*Calib. 2004-2010*	*Valid. 2011*	*All 1991-2011*	*Calib. 2004-2010*	*Valid. 2011*
O, cfs	58.0	63.2	71.6	47.6	50.8	51.0	9.7	9.7	12.8	43.7	58.4	62.6
S, cfs	60.0	64.6	54.4	45.3	52.2	43.0	9.1	9.7	10.5	43.8	54.0	51.0
S-O, cfs	2.0	1.4	-17.2	-2.2	1.4	-8.1	-0.6	0.1	-2.3	0.1	-4.5	-11.6
Dv, %	3.5	2.3	-24.0	-4.7	2.7	-15.8	-5.7	0.8	-18.2	0.2	-7.7	-18.6
Annual												
NSE	0.700	0.772	*	0.588	0.655	*	0.680	0.669	*	0.875	0.827	*
r	0.843	0.895	*	0.783	0.820	*	0.836	0.843	*	0.960	58.416	*
Years with Dv within ±10%	8	2	0	5	2	0	2	1	0	8	4	0
	38%	29%	0%	36%	29%	0%	25%	20%	0%	62%	57%	0%
Years with Dv within ±25%	14	4	1	8	3	1	4	2	1	13	6	1
	67%	57%	100%	57%	43%	100%	50%	40%	100%	100%	86%	100%
Total years	21	7	1	14	7	1	8	5	1	13	7	1
Monthly												
NSE	0.686	0.787	0.788	0.763	0.755	0.873	0.744	0.720	0.769	0.803	0.770	0.601
r	0.848	0.893	0.951	0.881	0.878	0.959	0.868	0.849	0.926	0.905	0.884	0.889
Months with Dv within ±10%	43	18	1	25	14	3	13	9	3	41	15	1
	17%	21%	8%	16%	17%	25%	15%	16%	27%	26%	18%	8%
Months with Dv within ±25%	109	41	7	69	36	7	27	19	6	93	38	5
	43%	49%	58%	43%	43%	58%	32%	35%	55%	60%	45%	42%
Total months	251	84	12	160	84	12	85	55	11	155	84	12
Daily												
r	0.784	0.848	0.790	0.867	0.886	0.858	0.748	0.744	0.742	0.737	0.688	0.565
1-day NSE	0.573	0.711	0.588	0.739	0.765	0.723	0.368	0.415	0.298	0.425	0.364	-0.203
3-day NSE	0.661	0.795	0.771	0.791	0.816	0.817	0.728	0.722	0.711	0.662	0.648	0.752
7-day NSE	0.648	0.781	0.762	0.775	0.796	0.834	0.790	0.797	0.833	0.765	0.793	0.517

Table 10. Statistics for the stream flow model calibration and validation periods at tributary gages (concluded)

	Flint-26			*Mill-17*			*Poplar-21*			*Tyler-22*		
	Fox River Grove			*Batavia*			*Elgin*			*Elgin*		
Statistics	*All 1991-2011*	*Calib. 2004-2010*	*Valid. 2011*	*All 1991-2011*	*Calib. 2004-2010*	*Valid. 2011*	*All 1991-2011*	*Calib. 2004-2010*	*Valid. 2011*	*All 1991-2011*	*Calib. 2004-2010*	*Valid. 2011*
O, cfs	37.8	52.7	45.9	22.3	23.0	27.2	34.6	38.1	40.4	38.1	43.6	44.0
S, cfs	37.5	34.9	34.5	24.2	27.6	26.6	34.6	38.0	37.9	40.3	43.9	47.2
S-O, cfs	-0.2	-17.7	-11.4	1.9	4.6	-0.7	0.0	-0.1	-2.4	2.2	0.3	3.1
Dv, %	-0.6	-33.7	-24.7	8.7	19.9	-2.4	0.1	-0.2	-6.0	5.8	0.7	7.1
Annual												
NSE	0.203	*	*	0.695	*	*	0.753	0.781	*	0.896	0.890	*
r	0.664	*	*	0.850	*	*	0.906	0.885	*	0.956	0.949	*
Years with Dv within ±10%	1	0	0	7	3	1	15	5	1	6	3	1
	13%	0%	0%	50%	43%	100%	71%	71%	100%	43%	43%	100%
Years with Dv within ±25%	5	0	0	8	3	1	20	6	1	12	6	1
	63%	0%	0%	57%	43%	100%	95%	86%	100%	86%	86%	100%
Total years	8	1	1	14	7	1	21	7	1	14	7	1
Monthly												
NSE	0.744	0.331	0.618	0.799	0.787	0.900	0.851	0.888	0.298	0.739	0.715	0.577
r	0.863	0.890	0.901	0.904	0.910	0.953	0.930	0.945	0.894	0.864	0.846	0.873
Months with Dv within ±10%	8	0	1	27	12	5	49	17	4	23	11	3
	8%	0%	8%	17%	14%	42%	19%	20%	33%	14%	13%	25%
Months with Dv within ±25%	37	4	5	69	28	8	134	43	9	72	36	6
	39%	33%	42%	43%	33%	67%	53%	51%	75%	45%	43%	50%
Total months	96	12	12	160	84	12	252	84	12	160	84	12
Daily												
r	0.677	0.638	0.606	0.695	0.701	0.605	0.794	0.840	0.644	0.779	0.754	0.729
1-day NSE	0.267	0.329	0.232	0.411	0.409	0.121	0.538	0.691	-0.049	0.434	0.398	-0.370
3-day NSE	0.666	0.675	0.595	0.744	0.769	0.486	0.730	0.795	0.619	0.655	0.634	0.282
7-day NSE	0.731	0.635	0.608	0.776	0.784	0.684	0.815	0.866	0.661	0.724	0.711	0.486

Notes: S = simulated flow
O = observed flow
Dv = error in simulated and observed streamflow volumes for a given period
r = correlation coefficient
* statistics cannot be calculated, only 1 year available

Sediment

The HSPF model simulates inorganic sediment in three particle-size fractions: sand, silt, and clay. Sediment is often not sampled directly in streams. Instead, total suspended solids are analyzed in the sample and accompanied by volatile suspended solids analyses. Total suspended solids include inorganic particles (mostly clay and silt) and organic matter (algae, decomposed leaves or other plant material, etc.). Inorganic suspended solids can then be calculated as total suspended solids minus volatile suspended solids. The sand fraction of the inorganic sediment transport used in the HSPF simulation was not calibrated due to the fact that inorganic suspended solids often underrepresent sand particles. The underrepresentation is due to the differences in laboratory techniques; total suspended sediment is determined for the whole sample, and total suspended solids are determined from an aliquot subsampled from the water quality sample collected at the site. For this report, the term sediment will refer to inorganic suspended solids when HSPF modeling is discussed.

Table 11 shows the number of monitoring sites in selected rankings for average and median error in simulated sediment for mainstem and tributary sites. Statistics are provided for the full simulation period, water years 2004-2010 used to calibrate the water quality portion of the model, and water year 2011 used to validate the water quality portion of the model. Sediment is simulated within 30% error (good simulation) at 11 to 14 out of 16 mainstem sites, depending on the evaluation period and whether the average or median error is considered. Only one mainstem site is simulated with an error greater than 45% during the validation period (52%). Two additional time periods were used for validation: water years 1991-1999 and water years 2000-2004 where data were available for the same sites, with a similar or better performance than for the calibration period. Those statistics were not included for space considerations.

There is a larger variation in simulation error for tributary sites. Sediment is simulated within 30% error at six to ten out of 13 tributary sites, depending on the evaluation period and whether the average or median error is considered. Sediment is simulated with an error above 45% at two to three tributary sites depending on the evaluation period and whether the average or median error is considered.

Table 11. Number of monitoring sites within error categories for sediment

			Fox River mainstem			
	All		*Calibration*		*Validation*	
Dv, %	*Average*	*Median*	*Average*	*Median*	*Average*	*Median*
<20%	*9*	*10*	*8*	*8*	*8*	*9*
20-30%	*4*	*4*	*4*	*5*	*3*	*3*
30-45%	3	2	4	3	4	3
>45%	0	0	0	0	1	1
Total	16	16	16	16	16	16
			Tributaries			
	All		*Calibration*		*Validation*	
	Average	*Median*	*Average*	*Median*	*Average*	*Median*
<20%	6	7	5	4	6	9
20-30%	3	2	1	4	2	1
30-45%	2	2	4	3	3	0
>45%	2	2	3	2	2	3
Total	13	13	13	13	13	13

Figure 17 shows simulated average annual sediment load for all tributary watersheds as well as the Fox River mainstem. Note that values for the mainstem show total load at each subwatershed outlet, i.e., the cumulative contribution from all the watersheds and subwatersheds upstream of the subwatershed outlet.

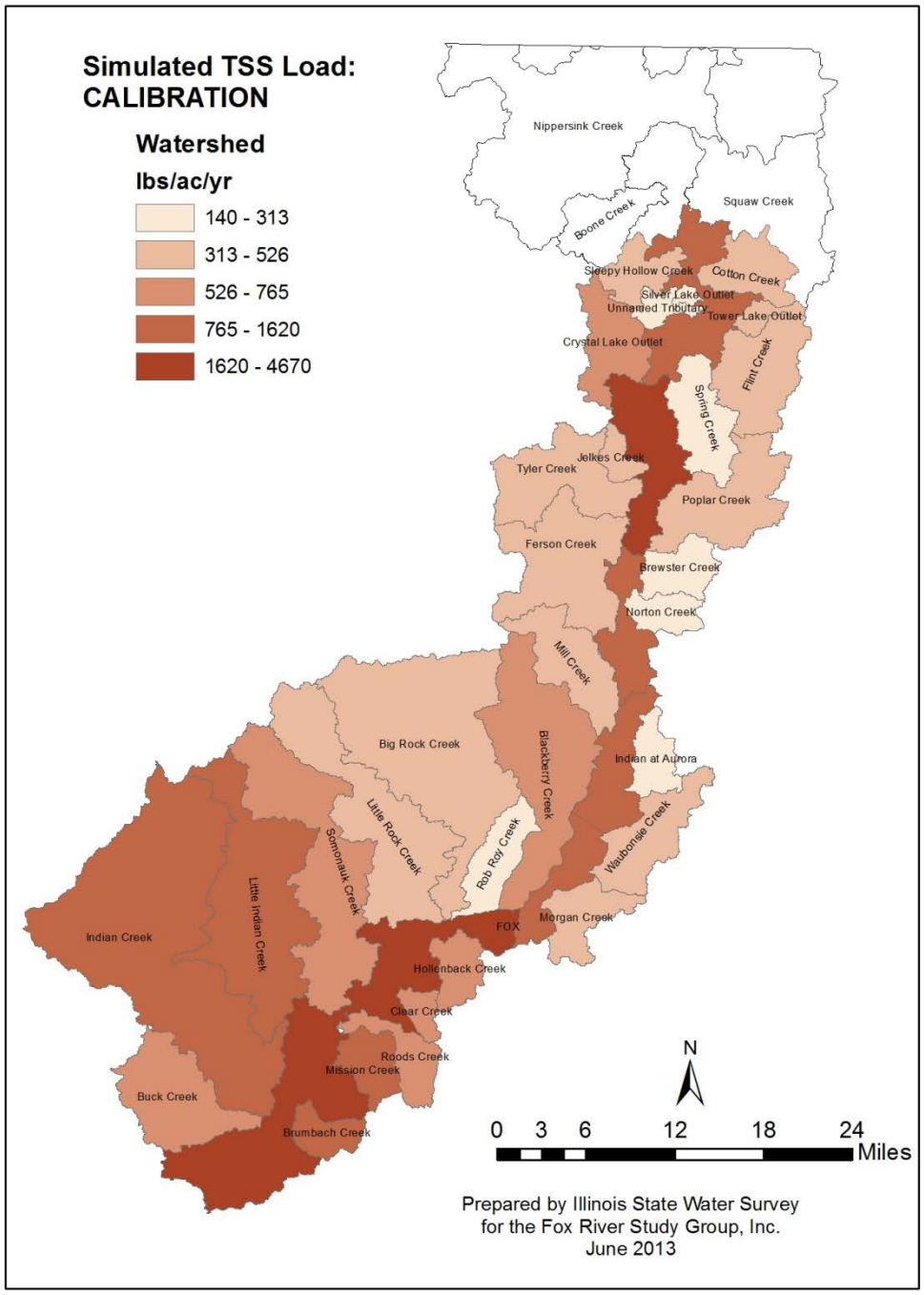


Figure 17. Simulated sediment loading rate per watershed, lbs/acre/year

Total Phosphorus

The HSPF model simulates total phosphorus in three forms: dissolved inorganic phosphorus, particulate inorganic phosphorus, and organic phosphorus. Only dissolved inorganic phosphorus directly stimulates algal growth. Additional processes such as adsorption and desorption, scour and deposition, and phytoplankton uptake and death affect all individual forms of phosphorus.

Table 12 shows the number of monitoring sites with average and median error in simulated total phosphorus for mainstem and tributary sites. Statistics are provided for the full simulation period, water years 2004-2010 used to calibrate the water quality portion of the model, and water year 2011 used to validate the water quality portion of the model. Total phosphorus is simulated within 25% error (good simulation) at 11 to 14 out of 16 sites on the mainstem, depending on the evaluation period and whether the average or median error is considered. Only one to two mainstem sites are simulated with an error between 35% and 50%.

There is a larger variation in simulation error for sites on tributaries. Total phosphorus is simulated within 25% error at nine to 11 out of 13 tributary sites for the calibration period and the full simulation period depending on the evaluation period and whether the average or median error is considered. The remaining sites are simulated within 35% error except one site during the calibration period. Total phosphorus during the validation period (water year 2011) is simulated with lower accuracy; only 2 and 3 sites are simulated within 25% error for average and median error, respectively, and an additional 1 and 2 sites within 35% error for average and median error, respectively. This is not surprising considering the lower accuracy of stream flow simulation during the validation period. Two additional time periods were used for validation: water years 1991-1999 and water years 2000-2004 where data were available for the same sites, with a similar or better performance than for the calibration period. Those statistics were not included for space considerations.

Table 12. Number of monitoring sites within error categories for total phosphorus

	Fox River mainstem					
	All		*Calibration*		*Validation*	
Dv, %	*Average*	*Median*	*Average*	*Median*	*Average*	*Median*
<15%	11	11	9	8	8	8
15-25%	3	3	5	5	3	4
25-35%	0	1	0	2	4	2
35-50%	2	1	2	1	1	2
>50%	0	0	0	0	0	0
Total	16	16	16	16	16	16

	Tributaries					
	All		*Calibration*		*Validation*	
	Average	*Median*	*Average*	*Median*	*Average*	*Median*
<15%	9	10	7	8	2	2
15-25%	2	1	2	2	1	0
25-35%	3	3	4	3	1	2
35-50%	0	0	0	0	0	0
>50%	0	0	1	1	9	9
Total	14	14	14	14	13	13

Figure 18 shows the simulated average annual total phosphorus load for all tributary watersheds as well as the Fox River mainstem. Note that values for the mainstem show total load at each subwatershed outlet, i.e., cumulative contribution of all the upstream watersheds.

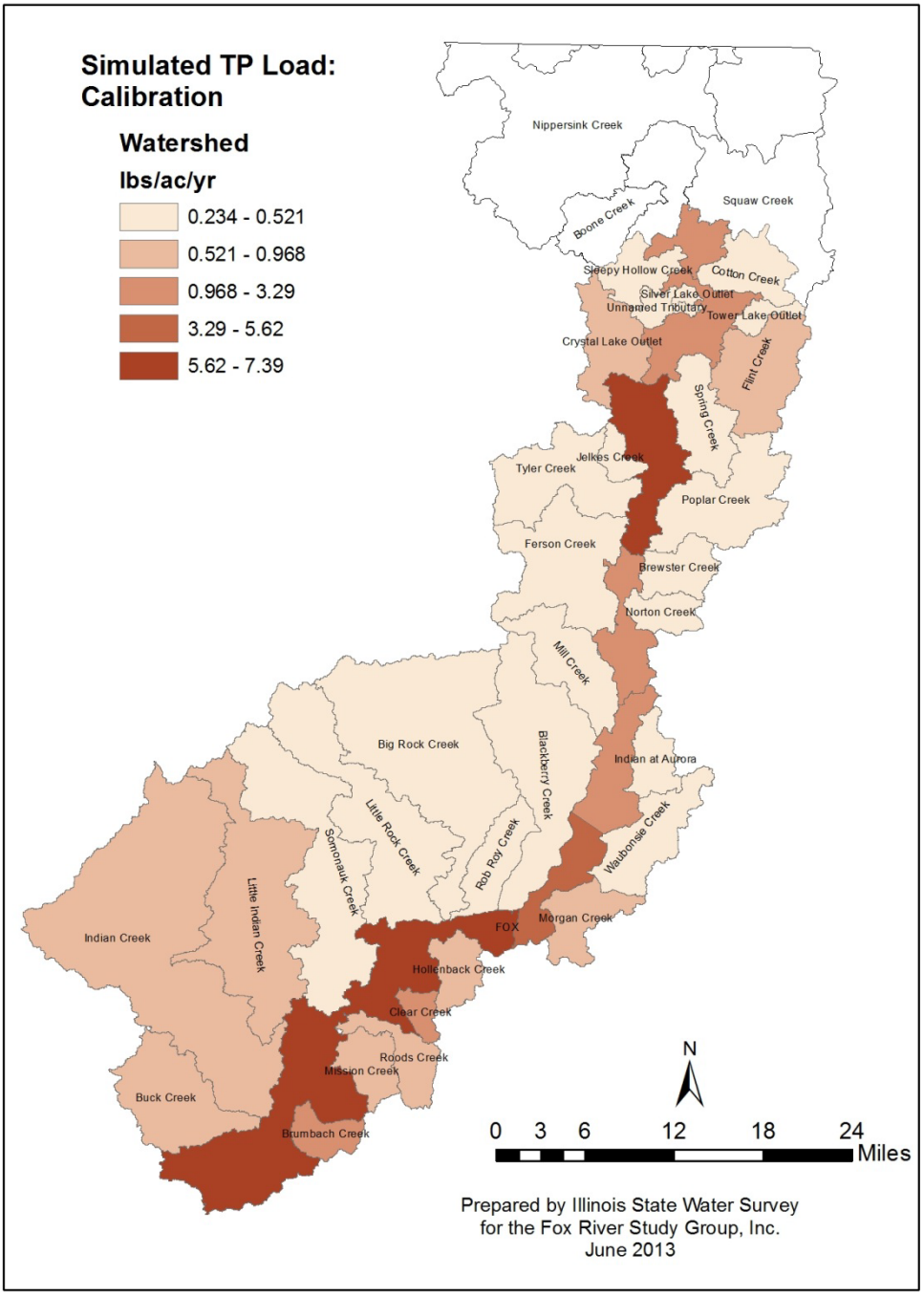


Figure 18. Simulated total phosphorus loading rate per watershed, lbs/acre/year

Total Nitrogen

The HSPF model simulates total nitrogen in several forms: dissolved ammonia nitrogen, particulate ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, and organic nitrogen. Processes such as adsorption and desorption, scour and deposition, nitrification and denitrification, phytoplankton uptake and death, and organic matter decay affect individual forms of nitrogen.

Table 13 shows the number of monitoring sites with an average and median error in simulated total nitrogen for mainstem and tributary sites. Statistics are provided for the full simulation period, water years 2004-2010, used to calibrate the water quality portion of the model, and water year 2011 used to validate the water quality portion of the model. Total nitrogen is simulated within 25% error (good simulation) at 15 to 16 out of 16 sites on the mainstem, depending on the evaluation period and whether the average or median error is considered. The one remaining mainstem site is simulated with an error of 25.2%.

There is a larger variation in simulation error for tributary sites. Total nitrogen is simulated within 25% error at five to 10 out of 12 to 10 tributary sites, depending on the evaluation period and whether the average or median error is considered. Note that two of the tributaries sites had no total nitrogen data during the validation period. Additionally, one to two of the remaining sites are simulated within 35% error. Only one site was outside the 50% range for both average and median errors each during the calibration period: Blackberry Creek with an average error of 63% and Poplar Creek with a median error of 52%. Two different locations at either creek had available nitrogen data for calibration/validation and only one of the sites was outside the 50% error range for the same period, while the other site on the same creek was simulated with a 7% and 9% error for Blackberry Creek and Poplar Creek, respectively, during the same evaluation period and for the same error statistics. Three sites were outside the 50% range for both average and median errors during the validation period. This is again not surprising considering the lower accuracy of stream flow simulation during the validation period.

Table 13. Number of monitoring sites within error categories for total nitrogen

Fox River mainstem

	All		*Calibration*		*Validation*	
Dv, %	*Average*	*Median*	*Average*	*Median*	*Average*	*Median*
<15%	14	14	14	15	14	14
15-25%	2	2	2	0	1	2
25-35%	0	0	0	1	1	0
35-50%	0	0	0	0	0	0
>50%	0	0	0	0	0	0
Total	16	16	16	16	16	16

Tributaries

	All		*Calibration*		*Validation*	
	Average	*Median*	*Average*	*Median*	*Average*	*Median*
<15%	8	5	3	1	6	3
15-25%	1	4	4	4	0	2
25-35%	1	0	1	2	1	2
35-50%	1	2	3	4	0	0
>50%	0	0	1	1	3	3
Total	11	11	12	12	10	10

Two additional time periods were used for validation: water years 1991-1999 and water years 2000-2004 where data were available for the same sites, with a similar or better performance than for calibration period. Those statistics were not included for space considerations.

Figure 19 shows the simulated average annual total nitrogen load for all tributary watersheds as well as the Fox River mainstem. Note that values for the mainstem show the total load at each subwatershed outlet, i.e., the cumulative contributions of all the upstream watersheds.

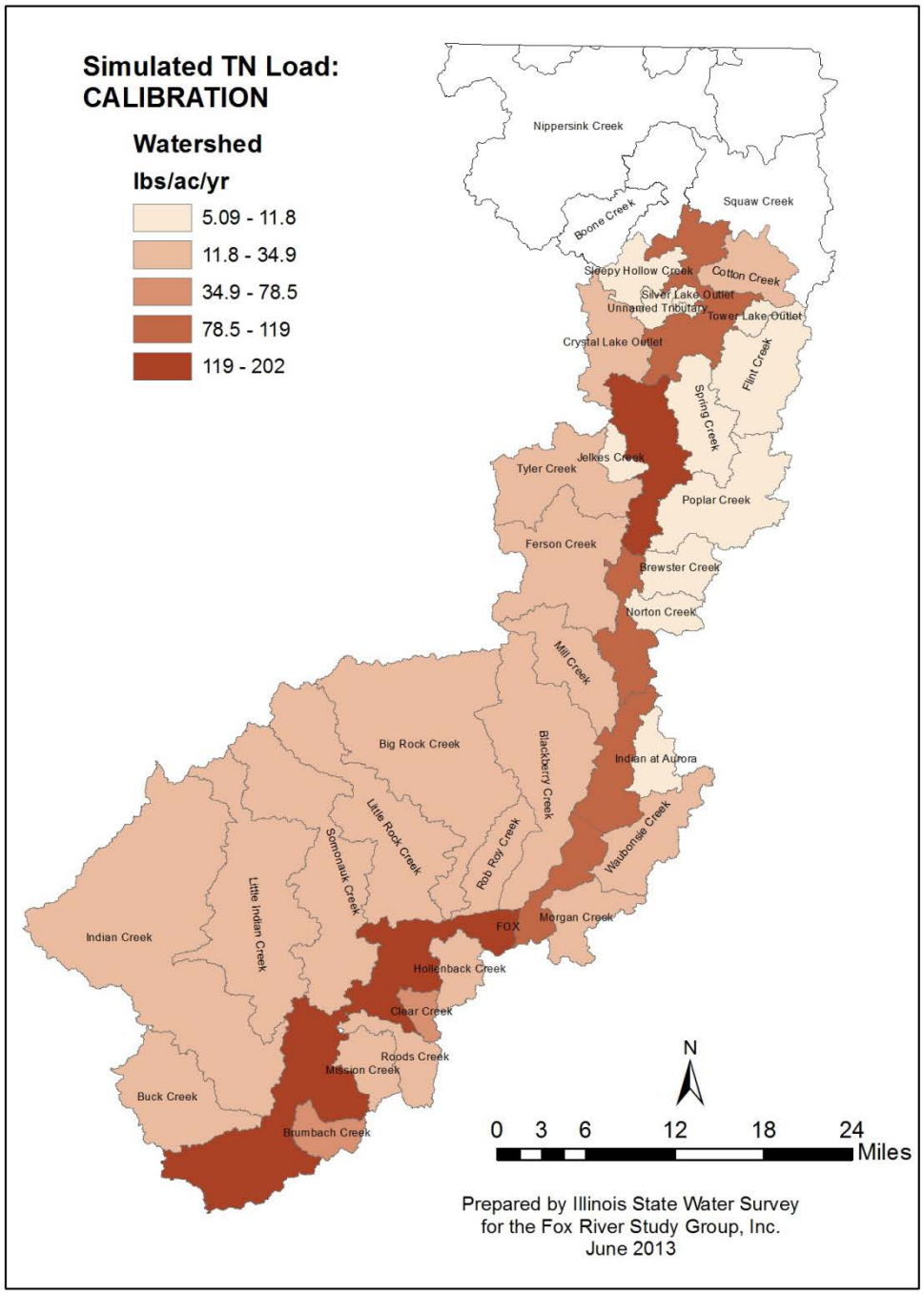


Figure 19. Simulated total nitrogen loading rate per watershed, lbs/acre/year

Fecal Coliforms

The HSPF model simulates fecal coliform bacteria as a dissolved substance with first order decay representing a decline in bacteria concentration due to settling or death. Fecal coliform bacteria are highly variable in receiving waters due to the strong tendency of fecal coliform bacteria to aggregate. Duplicate sampling conducted by the FRSG during their monthly sampling shows the fecal coliform concentration can vary by 40% for two individual samples collected at the same time and location.

Table 14 shows the number of monitoring sites with an average and a median error in simulated fecal coliform for mainstem and tributary sites. Statistics are provided for the full simulation period, water years 2004-2010 used to calibrate the water quality portion of the model, and water year 2011 used to validate the water quality portion of the model. Considering the large variability documented in the FRSG duplicate sampling, simulations within 50% error are considered a good fit and simulations within 75% error are considered a fair fit. Fecal coliform bacteria are simulated within 50% error (good simulation) at five to eight out of 16 sites on the mainstem, depending on the evaluation period and whether the average or median error is considered. Additionally, five to nine mainstem sites are simulated with an error less than 75%.

There is a larger variation in simulation error for tributary sites. Fecal coliform bacteria are simulated within 50% error at three to eight out of 13 tributary sites, depending on the evaluation period and whether the average or median error is considered. Additionally, one to five tributary sites are simulated within 75% error. The lowest accuracy was achieved for the validation period. This is not surprising considering the lower accuracy of stream flow simulation during the validation period.

The information on animal facilities and manure application in the study area is not available in a sufficient spatial detail for simulation. The contribution of fecal coliforms varies with land use only. This assumption of uniform distribution contributes to the uncertainty of simulation.

Figure 20 shows a simulated average annual fecal coliform load for all tributary watersheds as well as the Fox River mainstem. Note that values for the mainstem show the total load at each subwatershed outlet, i.e., the cumulative contribution of all the upstream watersheds.

Table 14. Number of monitoring sites within error categories for fecal coliforms

	Fox River mainstem					
	All		*Calibration*		*Validation*	
Dv, %	*Average*	*Median*	*Average*	*Median*	*Average*	*Median*
<50%	6	6	7	6	8	5
50-75%	7	5	6	6	8	9
>75%	3	5	3	4	0	2
Total	16	16	16	16	16	16

	Tributaries					
	All		*Calibration*		*Validation*	
	Average	*Median*	*Average*	*Median*	*Average*	*Median*
<50%	6	6	3	5	3	4
50-75%	1	1	5	3	1	1
>75%	6	6	5	5	9	8
Total	13	13	13	13	13	13

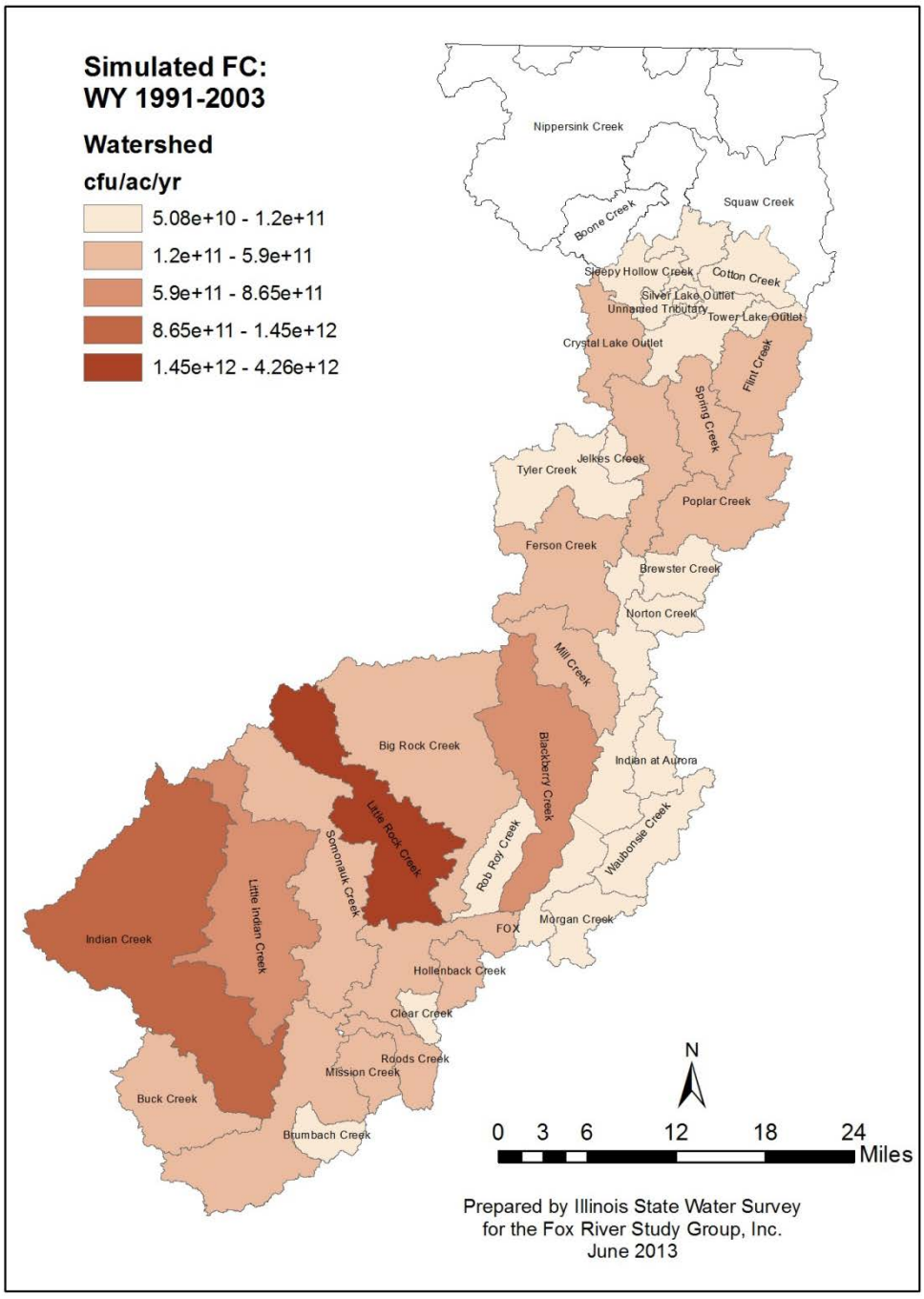


Figure 20. Simulated fecal coliform loading rate per watershed, cfu/acre/year

Management Scenarios

Scenarios in this focus area were designed with practicability in mind; the availability of space and preference for certain practices were considered. The purpose was two-fold: first, to compare the effectiveness of selected measures for each of the three major sources of pollutants, and second, to evaluate future water quality under the assumption of reasonable progress in the implementation of selected best management practices (BMPs) within the watershed. One scenario was developed and evaluated for each type of three common sources of pollutants: urban runoff, agriculture runoff, and point source discharges. Each scenario was simulated independently and in selected combinations. Table 15 shows what pollution sources are addressed in each scenario. Details of the scenarios are described in sections below for each simulated pollution source.

Table 15. Overview of management scenarios simulated with HSPF

Scenario	Urban runoff	Agriculture runoff	Point source discharge
Baseline			
1URB	X		
2AG		X	
3PS			X
4AGUR	X	X	
5AUP	X	X	X

Baseline

The HSPF model simulates stream flow and pollutant loads generated by precipitation events over a long-term period. The Fox HSPF model simulates water years 1991-2011. During this time period, certain watershed characteristics underwent significant changes. Urban development in some watersheds resulted in a change in land use and increased municipal NPDES effluent flows, new NPDES effluent flows appeared and some became inactive, and crop production patterns changed. Scenarios are simulated using the same climate data for water years 1991-2011. The Baseline scenario simulates pollutant loadings that would be generated under the current watershed characteristics and NPDES effluent flows if the climate of 1991-2011 were repeated. This means additional changes have to be incorporated in the model.

Crop production changes year to year. Each year market conditions, weather, and other factors affect the acreage planted to different crops. Agriculture practices may also change over a significant period of time. Figure 21 shows a change in the area planted as corn (shown as a percentage of total area in production) for counties in the Fox River watershed during the simulation period. The average for all counties is also shown. The percentage incorporated in the HSPF model during model development corresponds to the 1999/2000 land use. There has been an increase in percent area planted as corn since 2003 with the average increasing from 53% in 1999 to 65% in 2011. Crop areas were modified accordingly in the HSPF model files for the Baseline scenario.

Tillage practices in the watershed have also changed. Figure 22 and Figure 23 show corn and soy tillage practices, respectively, for DeKalb, LaSalle, Kane, and Kendall Counties as recorded in transect data (IDOA, 2013) for years 2004, 2006, 2009, and 2011. A transect survey

was not conducted in Kane County in 2011.Most counties show a decrease in conventional and reduced tillage from 2004 to 2011 in favor of mulch or no-till practices. The model parameters were adjusted for the Baseline scenario to reflect increased soil cover due to increases in mulch and no-till acreage.

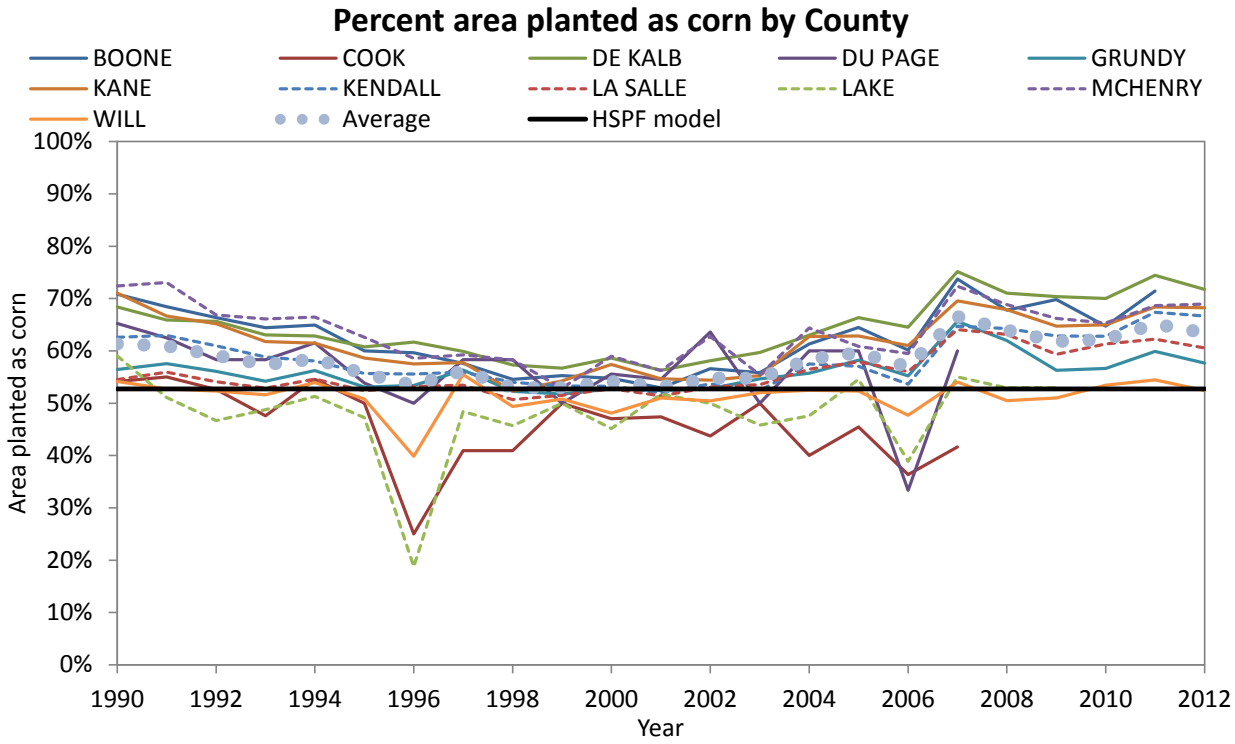


Figure 21. Percent agriculture area planted as corn by county

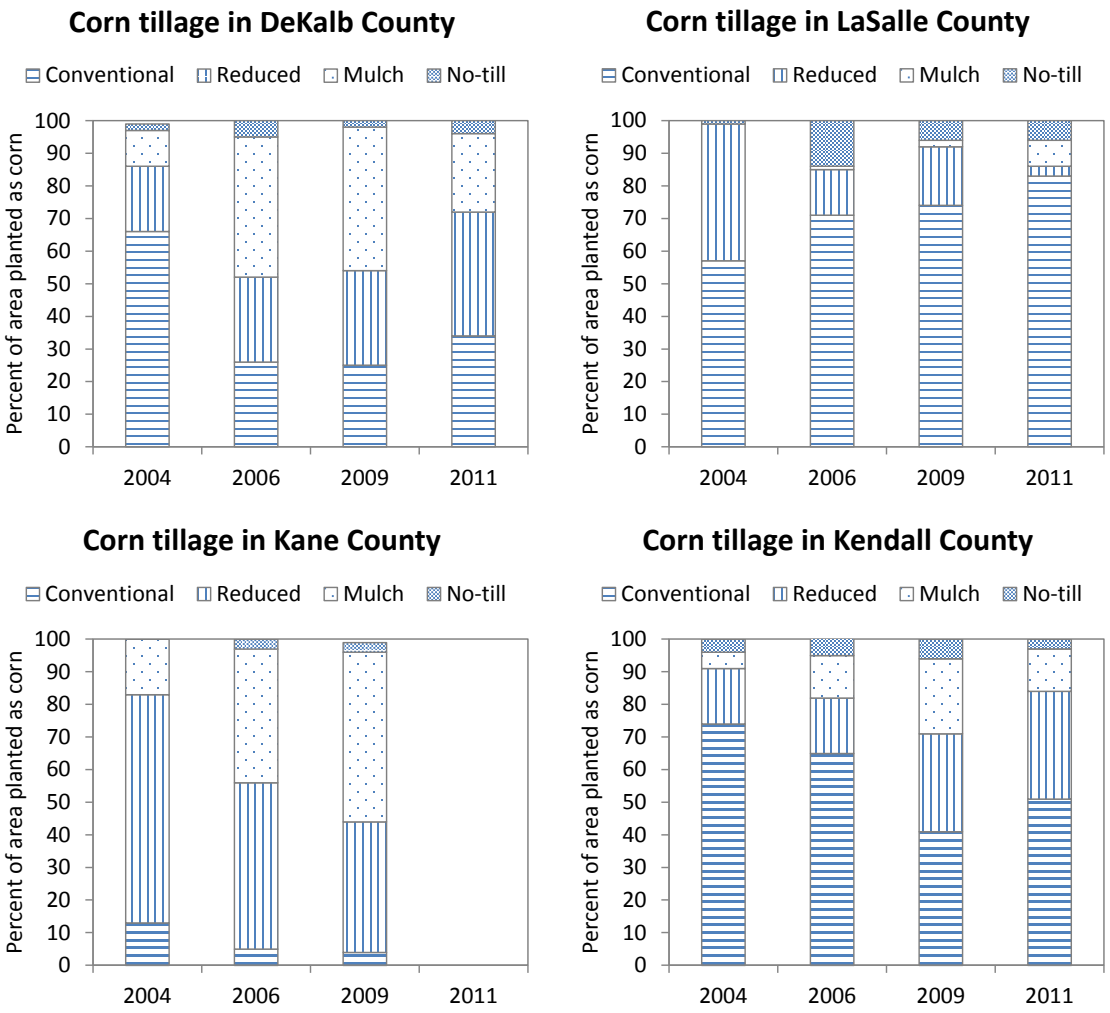


Figure 22. Corn tillage practices in DeKalb, LaSalle, Kane, and Kendall Counties

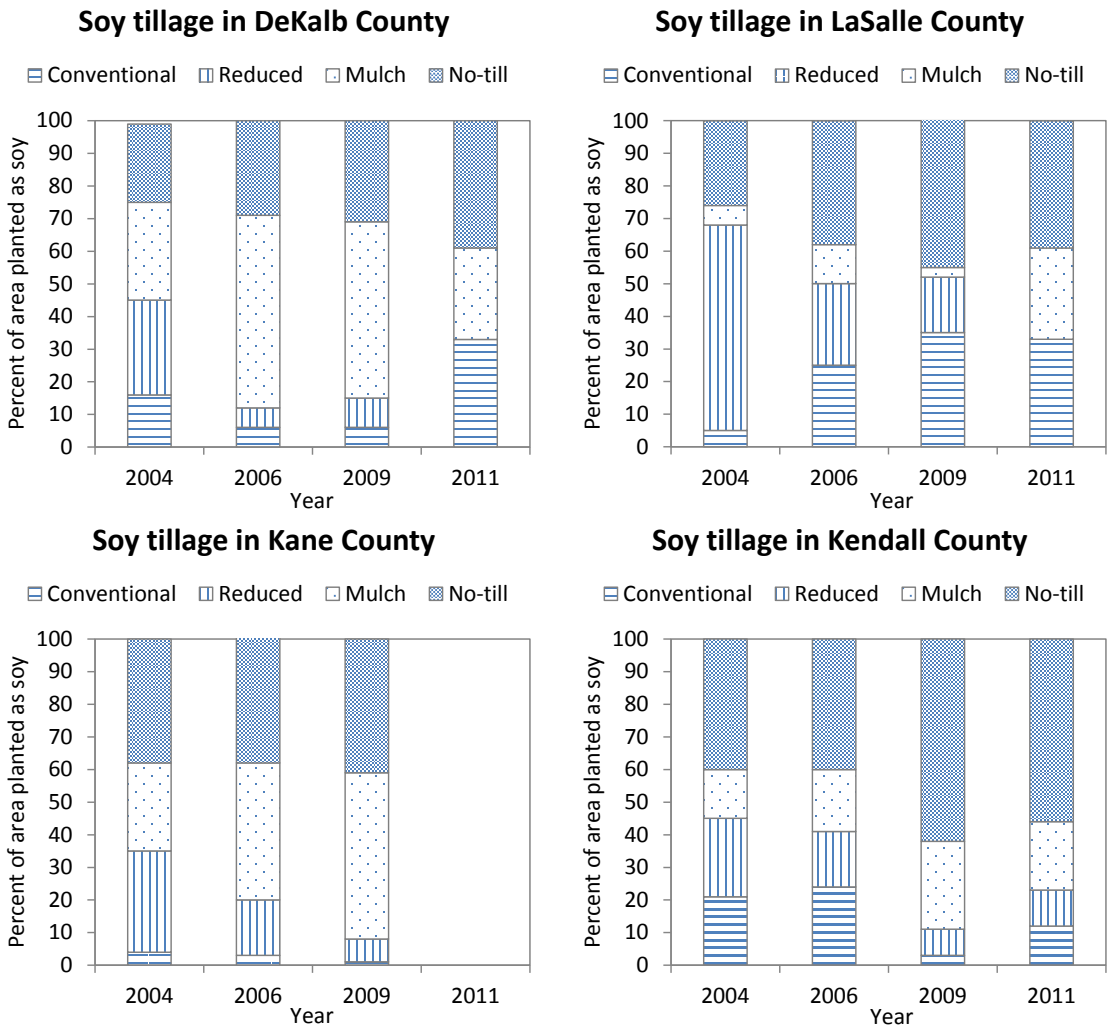


Figure 23. Soy tillage practices in DeKalb, LaSalle, Kane, and Kendall Counties

Discharge from NPDES facilities also had to be adjusted to reflect the current levels of treatment. In this focus area, the actual discharges were used in scenario simulations rather than as a permitted value. This approach allows comparing the individual impacts of the three pollution source types (urban runoff, agriculture runoff, and point sources) at the same level.

First, currently active NPDES facilities were identified. The inactive facilities were set to zero effluent flow. Both effluent flow and effluent concentrations at major NPDES facilities (DAF at or above 1 mgd) were analyzed in detail for trends to isolate the latest stationary period, i.e., the period without a significant increasing or decreasing trend. The effect of past precipitation on effluent flow values was analyzed using the precipitation totals for the same day, last 5 days, last 10 days, and last 30 days. For facilities where a significant relationship was detected, Baseline effluent flow time series were calculated from precipitation. For all other facilities, monthly average effluent flows determined from the stationary period were used. Table 16 shows the methods selected to calculate Baseline effluent flow along with the totaling period for precipitation where applicable, and the beginning of the stationary period for major municipal NPDES facilities.

Ammonia nitrogen and fecal coliform concentrations were determined as monthly averages from the latest stationary period common between observed effluent flow and effluent concentrations. The effluent concentrations for all other constituents were tested for a relationship with effluent flow. For facilities where a significant relationship was detected, Baseline effluent concentration time series were calculated from Baseline effluent flow determined in the previous step. Most facilities and constituents did not exhibit any significant relationship with effluent flow. Subsequently, the average effluent concentrations determined from the latest stationary period common between observed effluent flow and effluent concentrations were used in most cases.

Table 16. Baseline effluent flow calculations for major NPDES facilities

Facility Name	*NPDES ID*	*Formula to determine effluent flow*	*Precipitation period (x)*	*Stationary period begins*
Algonquin	IL0023329	$2.8234e^{0.0818x}$	10-day	10/1/2003
Barrington WWTP	IL0021598	Monthly average	N/A	10/1/2003
Batavia	IL0022543	$3.0642e^{0.2182x}$	5-day	10/1/2003
Carpentersville STP	IL0027944	Monthly average	N/A	9/30/2005
Cary WWTP	IL0020516	2.3053x0.0455	30-day	9/30/2007
Crystal Lake WWTP 2	IL0028282	Monthly average	N/A	10/1/2003
Crystal Lake WWTP 3	IL0053457	Monthly average	N/A	10/1/2003
East Dundee WWTP	IL0028541	Monthly average	N/A	1/1/2008
Elburn WWTP	IL0062260	Monthly average	N/A	9/30/2006
Fox Metro	IL0020818	$27.763e^{0.0562x}$	30-day	10/1/2003
Fox River Grove WWTP	IL0020583	Monthly average	N/A	
Fox River WRD North	IL0028665	$5.039e^{0.06695x}$	10-day	10/1/2003
Fox River WRD South	IL0028657	$15.965e^{0.1515x}$	5-day	10/1/2003
Fox River WRD West	IL0035891	$2.4041e^{0.0963x}$	5-day	1/1/2008
Geneva STP	IL0020087	Monthly average	N/A	1/1/2007
Gilberts WWTP	IL0068764	Monthly average	N/A	9/30/2006
IL American Terra Cotta*	IL0038202	Monthly average	N/A	9/30/2006
Lake in the Hills	IL0021733	Monthly average	N/A	10/1/2003
Northern Moraine WWTP	IL0031933	Monthly average	N/A	10/1/2003
Plano STP	IL0020052	$1.1764e^{0.0242x}$	30-day	9/30/2007
Sandwich WWTP	IL0030970	0.0415x+0.8611	30-day	10/1/2003
St Charles WWTP	IL0022705	Monthly average	N/A	10/1/2003
Wauconda WWTP	IL0020109	Monthly average	N/A	10/1/2003
Yorkville Bristol	IL0036412	$2.0647e^{0.1078x}$	10-day	

Notes: * Existing facility has DAF of 0.1 mgd, new (proposed) facility has DAF of 1.0 mgd

Effluent flows, ammonia nitrogen concentrations, and fecal coliform concentrations were determined for all minor NPDES facilities (DAF less than 1 mgd) as monthly averages using data from water years 2004-2011. Long-term averages during the stationary period were used for all other constituents at these facilities.

Urban Runoff Management Scenario

Urban BMPs considered in this focus area are retrofit structures designed to control urban runoff. Urban BMP structures can be dry or wet detention ponds, grass swales, porous pavements, bioretention basins, catchbasin inserts, and many others. Urban BMPs applicable to each land use category were identified from the list of BMPs available in the HSPF.

Urban BMPs were applied to 5% of all urban areas with average removal efficiencies specified individually for each land use category to reflect the different types of BMPs applicable: urban high density development (UHD), urban medium/low density development (ULM), and urban open space (UOS). This level of implementation was selected as the most practical level that can be achieved in the selected implementation time frame of 20 to 30 years considering the costs of the urban BMPs and land availability. Table 17 lists ranges of efficiencies associated with the combinations of BMPs as selected for each land use. Averages of the range of averages were used in Scenarios 1, 4, and 5 to approximate an impact of a mixture of urban BMPs on runoff quality.

Table 17. Range of removal efficiencies for urban BMPs by land use

	UHD			*ULM/UOS*		
Constituent	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*
Sediment: Sand	15%	67%-72%	99%	0%	68%-78%	99%
Sediment: Silt	15%	67%-72%	99%	0%	68%-78%	99%
Sediment: Clay	15%	67%-72%	99%	0%	68%-78%	99%
Fecal Coliforms	77%	88%-88%	97%	50%	76%-89%	97%
BOD	20%	27%-37%	40%	0%	37%-48%	99%
NO_3	0%	43%-51%	85%	0%	42%-50%	99%
NO_2	0%	43%-51%	85%	0%	42%-50%	99%
TAM: Solution	0%	28%-53%	80%	0%	29%-49%	99%
NH_4: Sediment Adsorbed	0%	28%-53%	80%	0%	29%-49%	99%
Organic Nitrogen	0%	28%-53%	80%	0%	29%-49%	99%
Organic Phosphorus	5%	45%-47%	90%	5%	43%-48%	99%
PO_4: Solution	0%	0%-14%	20%	0%	20%-30%	99%
PO_4: Sediment Adsorbed	5%	45%-47%	90%	5%	43%-48%	99%

Agriculture Runoff Management Scenarios

Agricultural practices in the watershed were reviewed on a county level from state-wide datasets. The recommendations in this scenario are focused on tillage practices. Fertilizer sales data (IDOA, 2013b) show a slight increase in the amount of fertilizer sold. The fertilizer

application rate is kept at the current level. Personal communication with Mr. James Rospopo, District Conservationist at Kane County Natural Resources Conservation Service (NRCS), indicated that cover crops are used only sporadically (only four farmers have filed an application to receive funding to plant a cover crop on a small scale). Also, he was not aware of anybody doing drain tile management.

Tillage practices were determined based on the 2009 level of implementation. The following levels are simulated for corn: 100% increase in no-till from the 2009 average (8% of total area planted as corn), 40% decrease in conventional and reduced tillage (32% of total area planted as corn), and the remainder in mulch tillage (60% of total area planted as corn). The following levels are simulated for soy: 70% no-till, 25% mulch tillage, and 5% conventional and reduced tillage. The 2009 average values were 44% no-till, 23% mulch tillage, and 33% conventional and reduced tillage.

NPDES Facility Management Scenario

The impact of changing permit limits for major municipal NPDES facilities on nutrient loads was tested. Future scenario permit levels were assumed to be 12 mg/l, 10 mg/l, and 1 mg/l for total suspended solids, biochemical oxygen demand, and total phosphorus, respectively (Table 18).

If current permit levels are at or below the levels above, the constituents were simulated using the same values as the Baseline scenario. For facilities where the current permit levels are above those in Table 18, the average concentration is set to 80% of the future permit level (Table 19). In a limited number of cases where the average concentration for biochemical oxygen demand or total suspended solids was higher than the Baseline scenario concentration, future concentrations were assumed at 70% of Baseline concentrations. The Baseline scenario concentrations have a lower variability than actual discharged concentrations due to the averaging method of determination (the same concentration is always discharged under the same conditions, whether specified as a function of effluent flow, month, or as a long-term average). The fact that the Baseline concentration is at or below the tested concentration values does not imply that the facility's effluent currently satisfies requirements of the tested permit levels.

Only 12 NPDES facilities have current limits set above 12 mg/l and 10 mg/l for total suspended solids and biochemical oxygen demand, respectively. There are 24 municipal NPDES facilities classified as major (DAF at or above 1 mgd), 58 NPDES facilities reporting total suspended sediments, and 45 NPDES facilities reporting biochemical oxygen demand in their effluents in the study area.

Only 7 facilities in the watershed have currently a limit for total phosphorus (1 mg/l). Some of these facilities (e.g., Illinois American Water Company – Terra Cotta STP) have received a limit for total phosphorus only for the planned plant expansion, not for the current facility. This means the current plant does not remove phosphorus since the discharge does not have to comply with the limit. The NPDES discharges in those cases are simulated with current concentrations in the Baseline scenario and with concentrations from Table 18 in the NPDES Facility Management.

Only four tributary watersheds were affected by the future NPDES limits specified in Table 18: Sleepy Hollow (Terra Cotta STP), Flint Creek (Barrington WWTF), Little Rock (Sandwich STP), and Big Rock (Elburn WWTP). The remaining major municipal NPDES facilities discharge directly to the Fox River mainstem.

Table 18. NPDES permit limits for the future scenario

DAF	*TSS*	*BOD5*	*TP*
≥1 mgd	12 mg/l	10 mg/l	1 mg/l
<1 mgd	no change	no change	no change

Table 19. Average concentrations for facilities where the current permit is above future levels

DAF	*TSS*	*BOD5*	*TP*
≥1 mgd	9.6 mg/l	8 mg/l	0.8 mg/l
<1 mgd	no change	no change	no change

Impact of Management Scenarios on Fox River Water Quality

The management scenarios described in the previous section (Table 15) were simulated using the calibrated HSPF model. Table 20 presents the simulated annual average loads delivered by the Fox River to the Illinois River for all scenarios. Under the Baseline scenario the Fox River delivers approximately 9,000 tons of total phosphorus, 6,000,000 tons of sediment, 266,000 tons of total nitrogen, and 188,000 tons of organic matter expressed as biochemical oxygen demand during an average year. While loads for all scenarios are shown, it is easier to compare the scenarios by calculating the change from the Baseline scenario. Maps in Appendix C (page 75) show unit area loads simulated for the Baseline scenario for all constituents and watersheds. Maps in Appendix D (page 79) show a percent change in simulated load for all constituents and watersheds as compared to the Baseline scenario.

The percent change was calculated for each watershed separately, and the minimum, average, and maximum were calculated from the individual numbers. Figure 24 shows the range of percent change in the simulated load from the Baseline scenario for each management scenario as simulated for tributary watersheds. The range may start at 0% change, signifying that particular management scenario did not affect some of the watersheds. The average percent change is also shown.

The largest average change for all tributaries in total phosphorus load for individual management options (Scenarios 1-3) is found for Scenario 2, agriculture runoff management. However, the overall impact of the individual management options cannot be inferred from results for tributary watersheds only, due to the varying importance of the individual pollution sources in each tributary watershed. The impact of future NPDES limits on sediment load is negligible. This is due to the fact that effluent total suspended solids concentrations for the Baseline scenario are very close to the average concentrations assumed for the future NPDES limits. Percent reductions in total phosphorus load and sediment load achieved by the simulated management scenarios are significant: maximum reductions on a tributary watershed level are achieved with Scenario 5 (20% and 23% for total phosphorus and sediment, respectively). Changes in total nitrogen load and biochemical oxygen demand are negligible. Maximum reduction is less than 5% for either constituent.

The only reduction in total nitrogen load directly related to management scenarios is associated with removal efficiencies at urban BMPs. The increase in total nitrogen load simulated for some tributaries is related purely to in-stream nutrient transformation processes. Lower in-stream phosphorus concentrations lead to lower phytoplankton chlorophyll *a* concentrations. Consequently, less nitrogen is also used by phytoplankton to support its growth. The extra nitrogen incorporated in phytoplankton under the Baseline scenario is subject to settling when phytoplankton dies off. This leads to small increases in the simulated total nitrogen load for watersheds and scenarios that show a reduction in phosphorus sufficient to influence phytoplankton growth and where stream conditions support settling.

Table 20. Average total loads simulated at Fox River outlet, tons/year

Constituent	*Baseline*	*1URB*	*2AG*	*3PS*	*4AGUR*	*5AUP*
Total phosphorus	9,041	9,029	8,549	5,999	8,549	5,550
Sediment	6,029,834	5,999,578	5,147,638	6,028,304	5,146,677	5,145,147
Total nitrogen	265,953	265,536	266,540	278,676	266,102	278,492
BOD	188,445	188,228	187,757	168,830	187,572	168,689

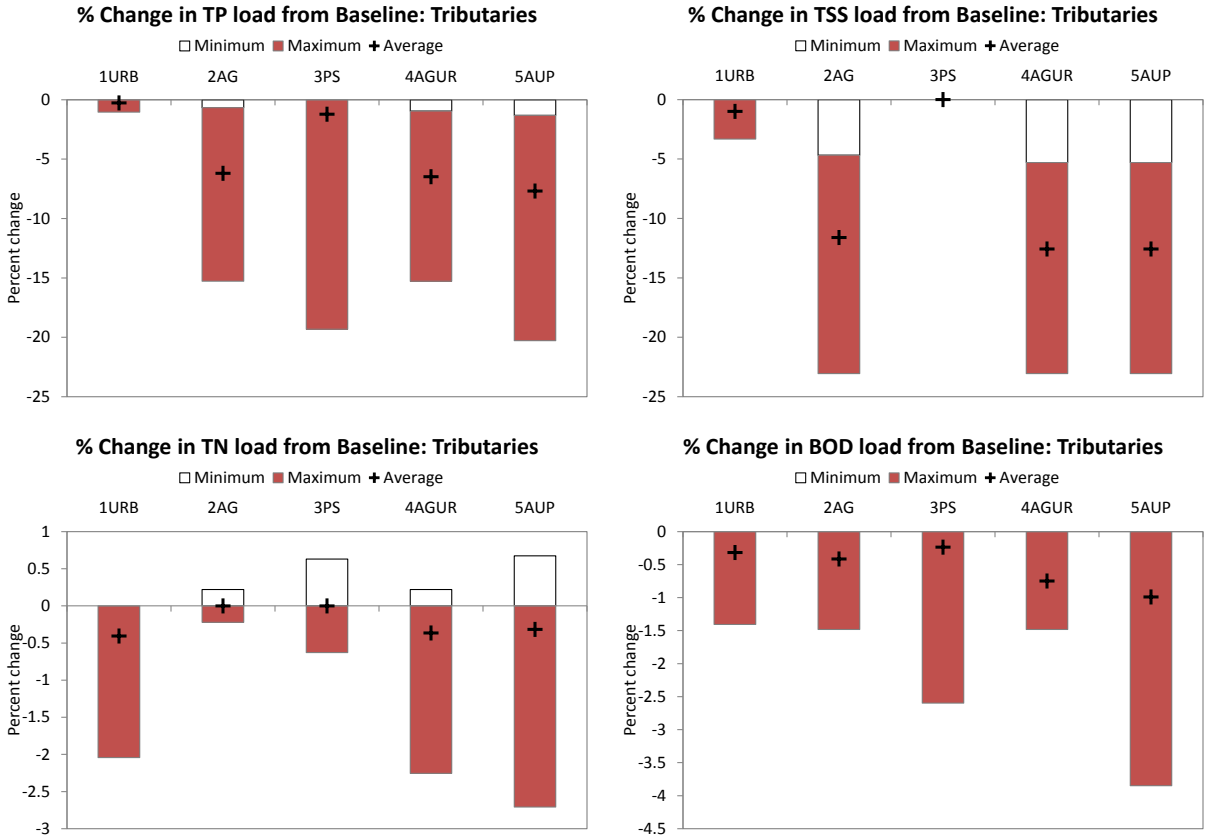


Figure 24. Percent change in simulated load from Baseline for tributaries

Figure 25 shows the percent change in the five different scenario simulated loads from the Baseline scenario at seven mainstem locations (Burtons Bridge, Route 62 in Algonquin, State Street in Elgin, Fabyan Park in Geneva, Mill Street in Montgomery, Route 47 in Yorkville, and the most downstream segment) for total phosphorus and sediment. The largest reduction in total phosphorus among the simulated management scenarios is achieved through point source control (Scenarios 3 and 5). Limiting total phosphorus at major municipal NPDES facilities to 1 mg/l results in a 33% overall reduction in the total phosphorus load delivered to the Illinois River. The maximum simulated reduction of 40% was achieved assuming all simulated measures are combined to control urban and agriculture runoff as well as NPDES facilities. Urban BMPs result in less than 1% reduction in total phosphorus load at the Fox River outlet.

Agricultural practices have a significant impact on the simulated sediment load. Changing tillage practices to the level specified in Scenario 2 results in a 15% reduction of sediment load at the Fox River outlet. Scenarios 1 and 3 result in less than a 1% reduction of total sediment load at the Fox River outlet.

Figure 26 shows the percent change in the five different scenario simulated loads from the Baseline scenario at seven mainstem locations (Burtons Bridge, Route 62 in Algonquin, State Street in Elgin, Fabyan Park in Geneva, Mill Street in Montgomery, Route 47 in Yorkville, and the most downstream segment) for total nitrogen and biochemical oxygen demand. Total nitrogen remains mostly unaffected by the simulated measures. Only a negligible reduction (less than 1%) is simulated for Scenario 1. An overall increase in total nitrogen load is simulated for the remaining scenarios due to in-stream processes as discussed above. Scenarios 1 and 2 result in a negligible reduction of biochemical oxygen demand (less than 1%). Scenario 3 results in a 10% reduction of biochemical oxygen demand at the Fox River outlet.

Figure 27 shows the percent change in the five different scenario simulated loads from the Baseline scenario at seven mainstem locations (Burtons Bridge, Route 62 in Algonquin, State Street in Elgin, Fabyan Park in Geneva, Mill Street in Montgomery, Route 47 in Yorkville, and the most downstream segment) for fecal coliforms. Only urban BMPs (Scenario 2) affect fecal coliform loads; less than 1% reduction is achieved at the Fox River outlet. However, reductions of 2.3% to 3.5% are achieved for urbanized areas between Algonquin and Yorkville.

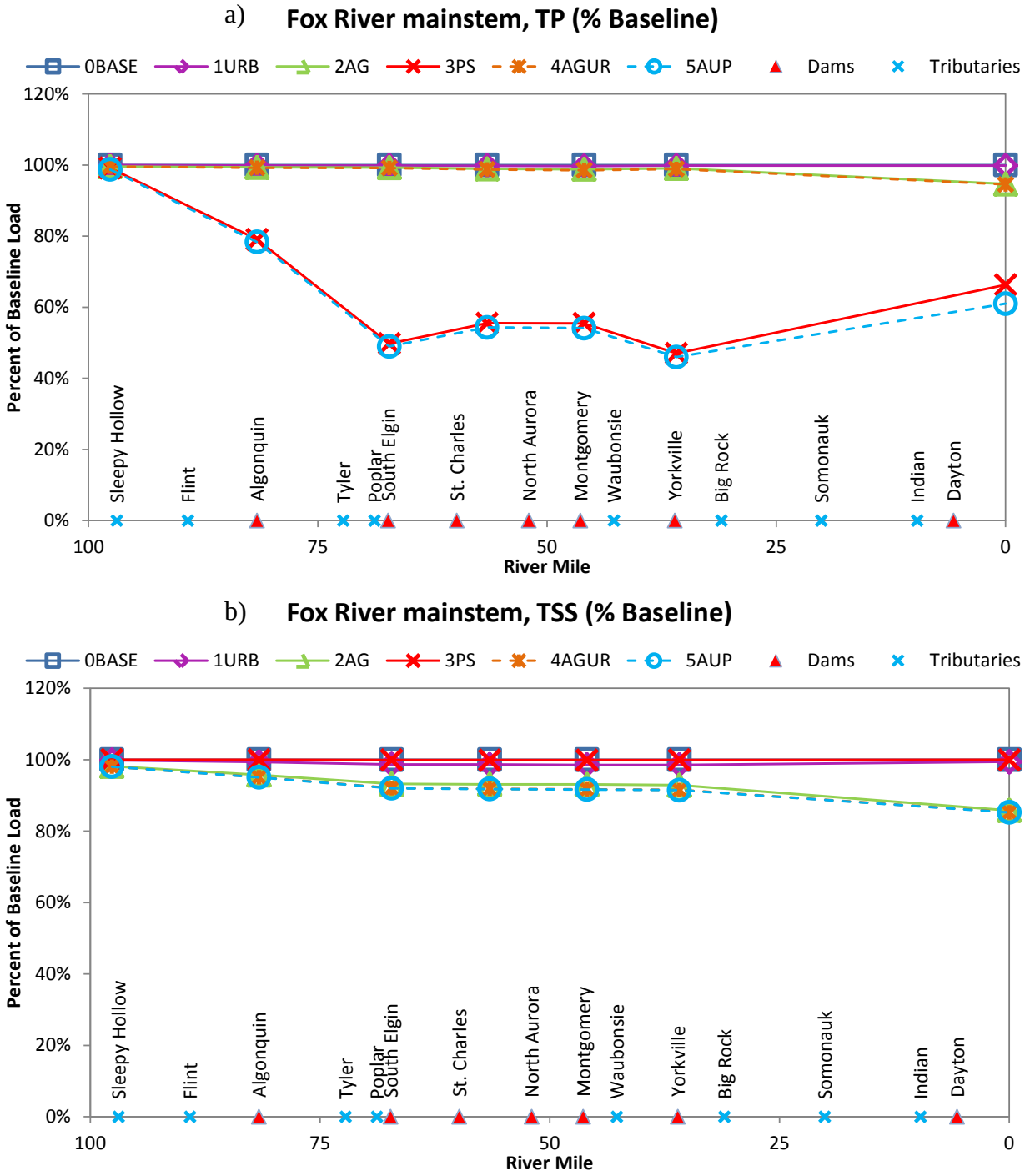
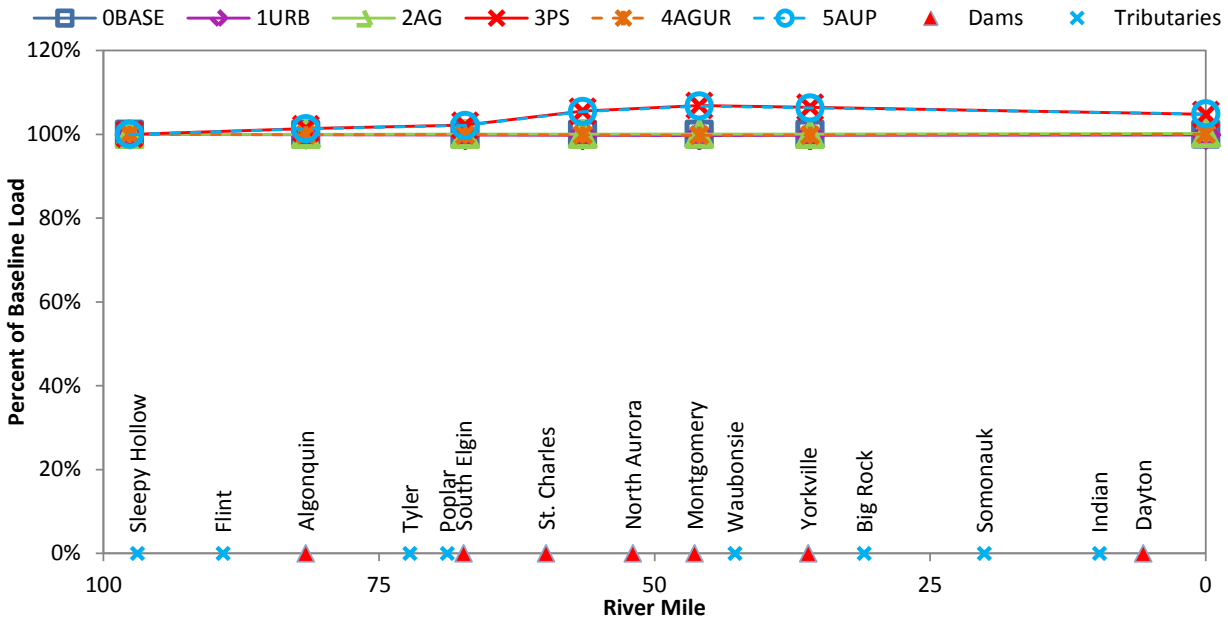


Figure 25. Simulated load as percent of Baseline load for mainstem: a) total phosphorus, b) sediment

a) **Fox River mainstem, TN (% Baseline)**



b) **Fox River mainstem, BOD5 (% Baseline)**

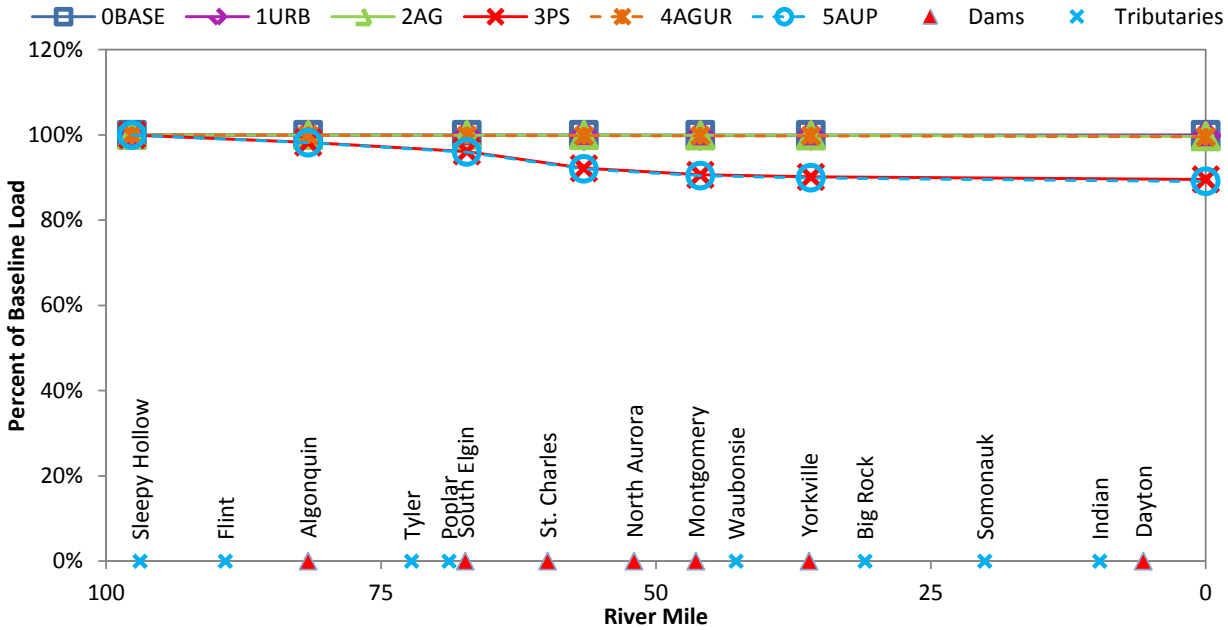


Figure 26. Simulated load as percent of Baseline load for mainstem: a) total nitrogen, b) biochemical oxygen demand

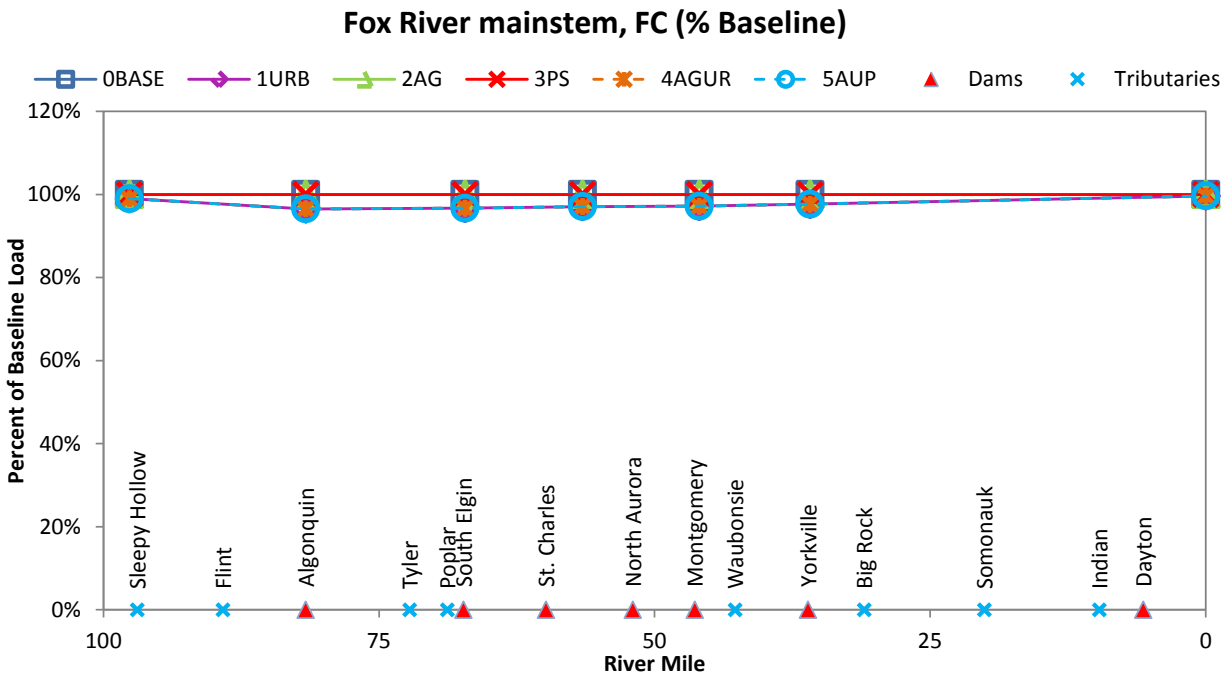


Figure 27. Simulated load as percent of Baseline load for mainstem: fecal coliforms

Figure 28 shows total and unit area total phosphorus loads at seven locations in the Fox River. Total phosphorus loads increase from upstream to downstream as the drainage area increases and additional sources contribute the constituent. A relatively low unit area total phosphorus load at the upstream boundary at Stratton Dam can be attributed to settling in the Fox Chain of Lakes. The unit area load also increases from upstream to downstream. The largest rate of increase (the steepest line) in the unit area load is found at the two locations immediately downstream of two major municipalities. Urban areas contribute total phosphorus not only through the urban runoff but also through municipal waste.

Figure 29 shows the total and unit area sediment load at seven locations in the Fox River. The increase in sediment load from upstream to downstream is more gradual than the increase in total phosphorus load for both total and unit area loads. The largest rate of increase (the steepest line) in the unit area load is found downstream of Yorkville where rural tributary watersheds predominate.

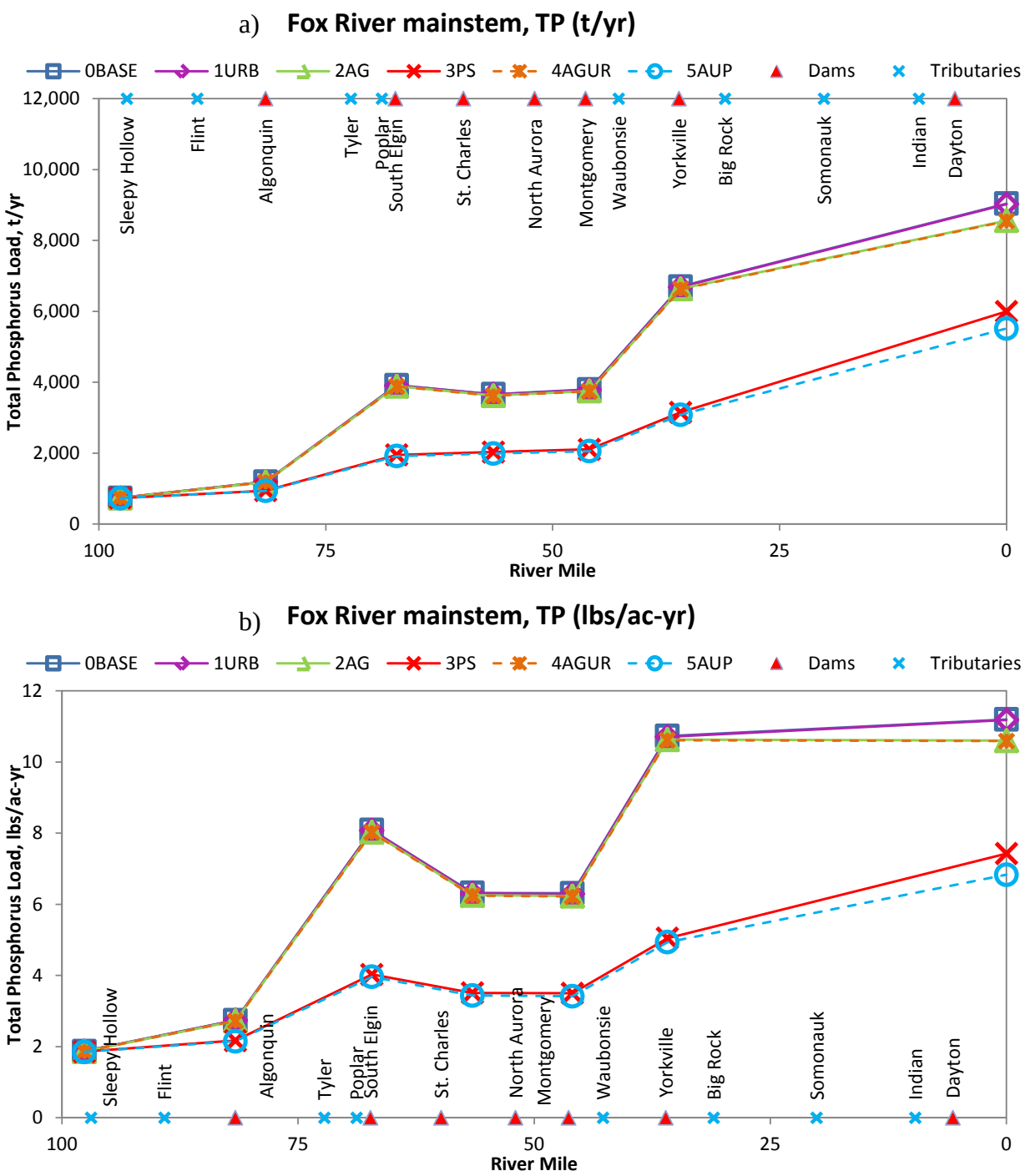
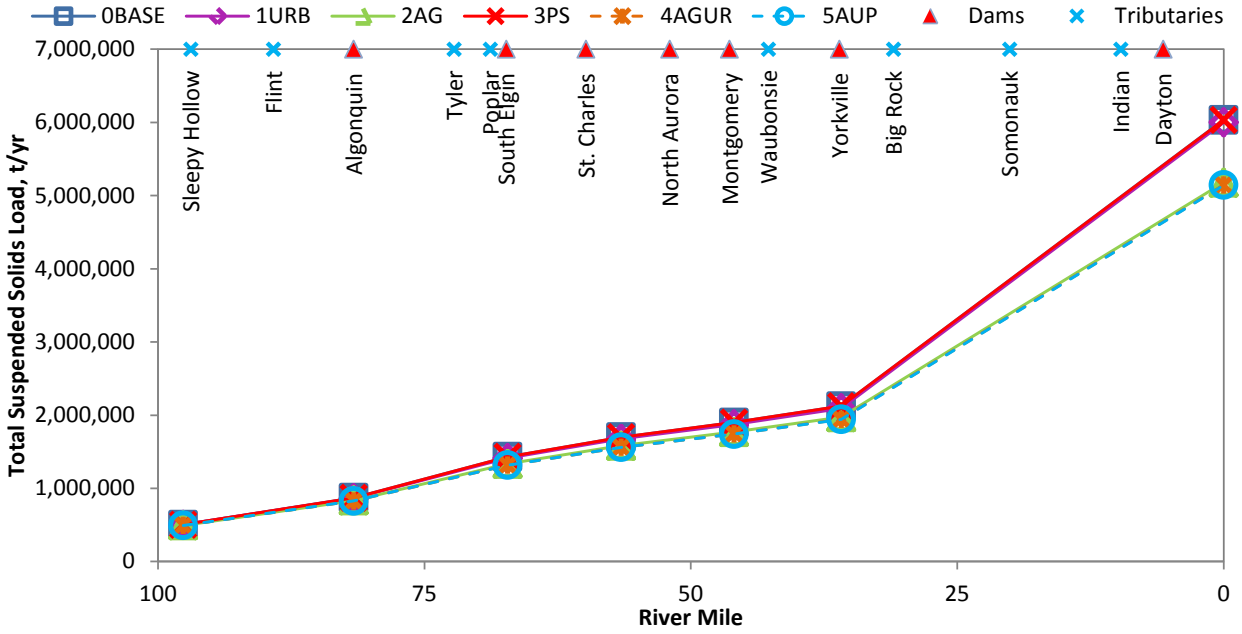


Figure 28. Total (a) and unit area (b) total phosphorus loads in the Fox River

a) **Fox River mainstem, TSS (t/yr)**



b) **Fox River mainstem, TSS (lbs/ac-yr)**

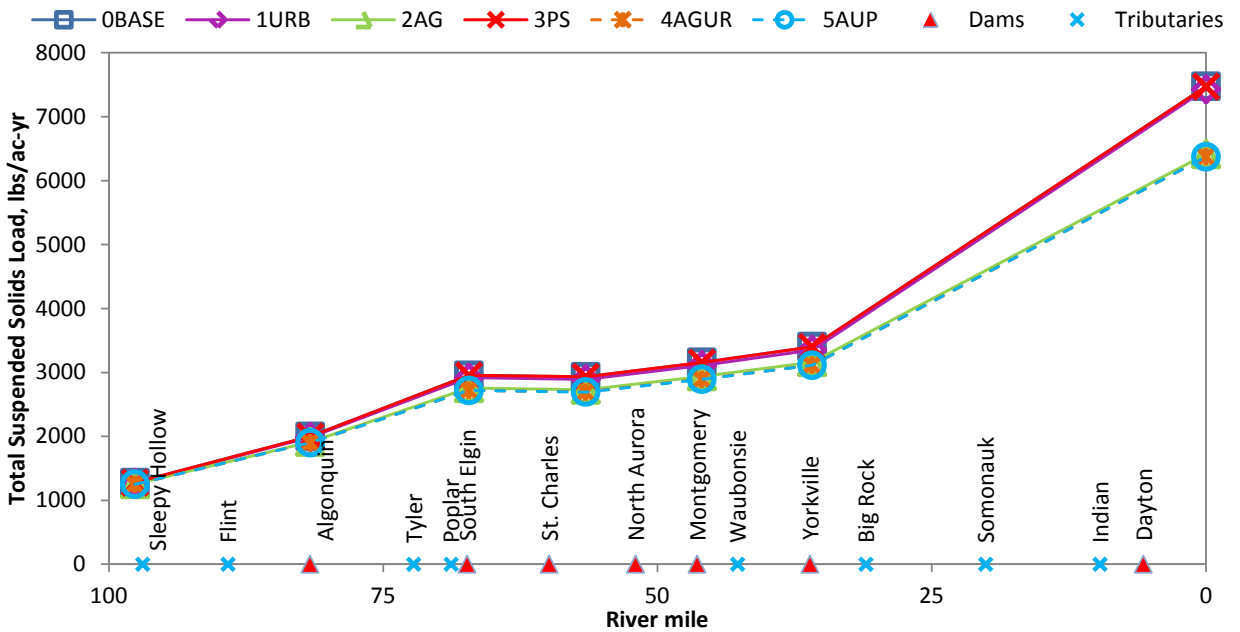


Figure 29. Total (a) and unit area (b) sediment loads in the Fox River

Summary and Conclusions

Two computer simulation models were calibrated to observed data: the HSPF model simulating annual loads for nutrients, sediment, and fecal coliforms, and the QUAL2K model simulating algae and dissolved oxygen concentrations under critical summer low flow conditions. Watershed management scenarios were specifically developed for each focus area represented by the simulation models and then tested. The QUAL2K model evaluated the impact of total phosphorus limits at municipal effluents and removal of dams. The HSPF model evaluated the impact of practices that control urban runoff, agriculture runoff, and stricter limits for municipal effluents.

The water quality impacts simulated as a result of urban BMPs are limited by the areas treated: BMPs were simulated at 5% of the area currently classified as one of the urban land uses (urban high density development, urban low and medium density development, and urban open space). Approximately 20% of the study area is classified as urban. However, the study area represents only about 50% of the Fox River watershed area. Ultimately, only approximately 0.5% of the total watershed area is being affected by urban BMPs as simulated. It is no surprise that this management scenario resulted in negligible reductions (less than 0.5% for all tested constituents) of average annual loads. If the treated area is kept at or below 5% urban area for practical reasons (financial and space requirements), large reductions in the average annual loads at the Fox River outlet cannot be expected. However, local improvements can be achieved for streams in urbanized areas with an optimized mixture of urban BMPs.

Agriculture land covers 58% of the study area, or 29% of the total watershed area. Tillage practices were modified on all agricultural land. Moving corn and soy production areas from conventional or reduced tillage to mulch tillage or no-till production limits erosion during the period between the harvest and seedlings emergence when fields would be otherwise left fallow. The lower erosion rates resulting from this change in simulated farm practices reduced average annual sediment loads at the Fox River outlet by 15% and average annual total phosphorus loads by 5%. Additional measures can be taken with respect to future agricultural practices to increase the impact on average annual loads, especially for sediment and sediment-related constituents such as total phosphorus.

Several different scenarios were tested for management of municipal point sources. Three numerical values for total phosphorus limits in municipal effluent were tested: 1.0 mg/l, 0.5 mg/l, and 0.1 mg/l. The scenario limiting total phosphorus concentration to 1 mg/l at major municipal point sources was simulated with both models. Additional changes to total suspended solids and biochemical oxygen demand limits were included in the HSPF simulations for facilities with current limits set above 12 mg/l and 10 mg/l, respectively.

The reduction in average annual biochemical oxygen demand load at the Fox River outlet was 10%. The reduction in average annual sediment load at the Fox River outlet was negligible (less than 1%). The difference in relative reductions for these two constituents is driven by the overall magnitude of the annual load. Biochemical oxygen demand concentrations in the Fox River are relatively low so even a small absolute reduction can be a significant portion of the total load. The average annual sediment load delivered by the Fox River is quite large with many sources contributing significant loads.

Limiting total phosphorus concentrations in municipal effluent results in a significant reduction of total phosphorus load delivered by the Fox River to the Illinois River as well as a

significant reduction in total phosphorus concentrations in the Fox River. Limiting total phosphorus effluent concentrations to 1 mg/l monthly average (0.8 mg/l as discharged) at major municipal point sources reduced the average annual total phosphorus load by 33%. However, even the most drastic scenario limiting total effluent concentration to 0.1 mg/l at all municipal point sources did not result in a drastic change in phytoplankton as measured by the chlorophyll *a* concentration under the critical summer low flow conditions, principally because the numerous impoundments along the Fox River are optimal habitats for phytoplankton growth.

Dams create obstacles to water flowing through the channel, artificially raising the depth, slowing the velocities, and increasing the residence time in the impounded reaches upstream of the dams. These conditions support algae growth similar to a reservoir. Significant reductions in phytoplankton chlorophyll *a* concentrations under critical summer low flow conditions were found only for scenarios that included removal of dams. Removing dams restores the natural flow regime, often resulting in lower sedimentation in the reach than above the dam that also leads to lower sediment oxygen demand. These changes improve average dissolved oxygen concentrations in the previously impounded reach. On the other hand, removing dams can create physical conditions that are more favorable for the growth of benthic algae. Any such increase in benthic algae may reduce or eliminate improvements in minimum dissolved oxygen concentrations that might have been otherwise associated with decreased phytoplankton chlorophyll *a* concentrations. Average dissolved oxygen concentrations are driven by concentrations of oxygen-demanding substances such as organic matter in water and sediment expressed as biochemical oxygen demand and sediment oxygen demand, respectively, or ammonia nitrogen. The diurnal fluctuation of dissolved oxygen concentrations and associated daily minima and maxima are driven by the phytoplankton and benthic algae activity.

It should be noted that there is a large uncertainty associated with estimating how the stream channel cross-sections will respond to dam removal and a change from impounded water to free flow with higher velocities. An established channel narrower than the existing channel would result in deeper waters where benthic algae could be limited by available light more than predicted by the model in this report. A detailed hydraulic study would be necessary to determine the future channel cross-sections with a higher accuracy. The procedure of dam removal itself may also affect the channel response to the removal; complete dam removal in a short time may lead to a significant washout of the sediments accumulated behind the existing dams while more gradual removal may result in partial stabilization of sediments behind the dam. Removing a dam restores fish movement and ecological processes in streams, reduces siltation of spawning and feeding habitat, and leads to more varieties of natural habitat.

The Fox River receives treated effluent from a number of point sources. Under very low flow conditions (Q7-10), the total sum of DAFs for all NPDES facilities discharging directly to the simulated reaches of Fox River represents almost 50% of the total increase in flow from Stratton Dam to the Fox River outlet. It is extremely difficult to improve phytoplankton and dissolved oxygen conditions in such an effluent-dominated river without taking significant measures involving the effluent being discharged to the river. The impact of effluent flows on Fox River water quality varies with stream flow, time of the year, and actual weather conditions. Additional simulations can help to determine optimum effluent requirements on a seasonal and/or flow basis. The economics and feasibility of treatment should be weighed against water quality improvements before recommendations can be made regarding the level to which total phosphorus should be reduced at limited in point source effluents.

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Appendix A
List of Facilities Voluntarily Providing Effluent Data to the FRSG

NPDES ID	*Permit Name*	*State Water Body Name*
IL0023329*	ALGONQUIN, VILLAGE OF	FOX RIVER
IL0022543*	BATAVIA STP	FOX RIVER
IL0027944	CARPENTERSVILLE, VILLAGE OF	FOX RIVER
IL0020516	CARY, VILLAGE OF	FOX RIVER
IL0053457	CRYSTAL LAKE, CITY OF	DRAIN DITCH TRIBUTARY TO SLEEPY HOLLOW CREEK
IL0028282	CRYSTAL LAKE, VILLAGE OF	CRYSTAL CREEK OUTLET
IL0028541	EAST DUNDEE, VILLAGE OF	FOX RIVER
ILG640231	ELGIN WTP, VILLAGE OF	FOX RIVER
IL0020818*	FOX METRO WRD STP	FOX RIVER
IL0028657*	FOX RIVER WRD	FOX RIVER
IL0028665*	FOX RIVER WRD	FOX RIVER
IL0035891*	FOX RIVER WRD	FOX RIVER
IL0020087	GENEVA, CITY OF	FOX RIVER
IL0038202	IL AMERICAN WATER-TERRA COTTA	SLEEPY HOLLOW CREEK
IL0024732	IL AMERICAN WATER-RIVER GRANGE	UNNAMED TRIBUTARY TO FOX RIVER
IL0031551	IL AMERICAN WATER-VALLEY MARINA	FOX RIVER
IL0021733	LAKE IN THE HILLS SD STP	CRYSTAL CREEK
IL0027260	MOOSEHEART CHILD CITY & SCHOOL	FOX RIVER
ILG580153	NEWARK SANITARY DISTRICT	CLEAR CREEK
ILG580213	PAW PAW, VILLAGE OF	PAW PAW RUN
IL0020052	PLANO STP	BIG ROCK CREEK
IL0030970	SANDWICH, CITY OF	HARVEY CREEK
IL0020265	SOMONAUK STP	SOMONAUK CREEK
IL0022705	ST CHARLES. CITY OF	FOX RIVER
IL0020109	WAUCONDA STP	FIDDLE CREEK
IL0036412*	YORKVILLE-BRISTOL SANITARY DISTRICT	FOX RIVER

Notes: * The facility also provided long-term data for HSPF model development. Additional facilities not listed in the table that provided long-term data include McHenry STP (IL0021067, IL0066257), and Village of Fox Lake (IL0020958).

Appendix B
QUAL2K Calibration Results

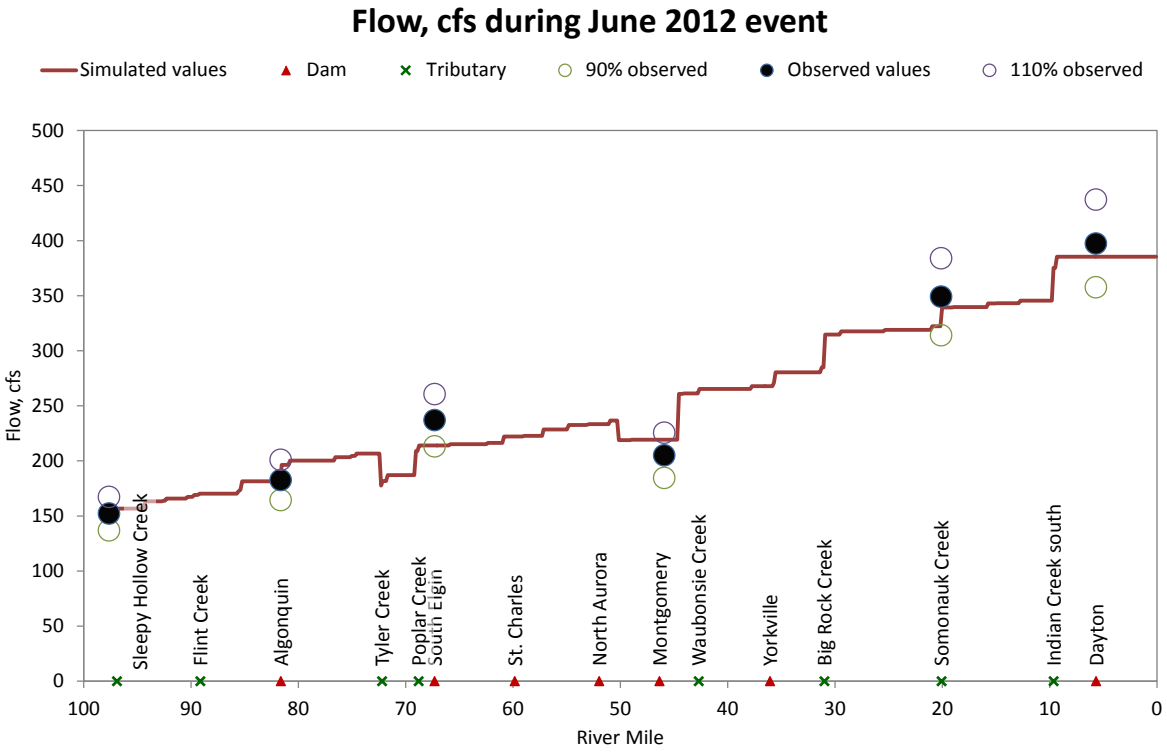


Figure 30. Simulated and observed flow during June 2012 event

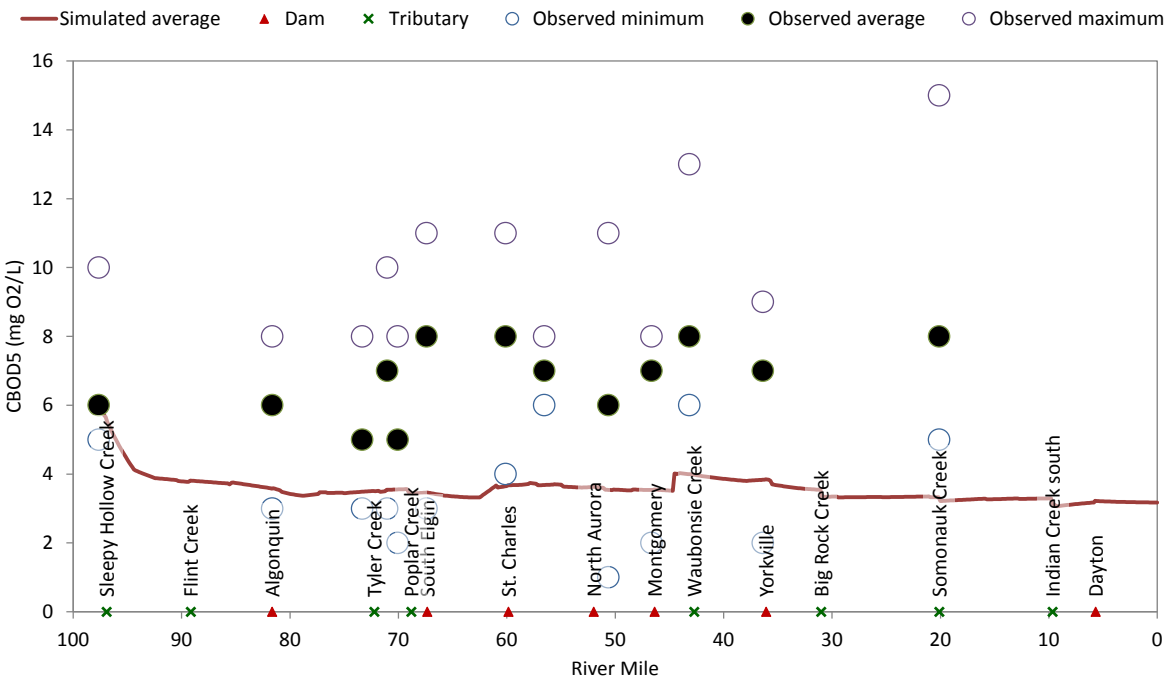


Figure 31. Simulated and observed BOD_5 during June 2012 event

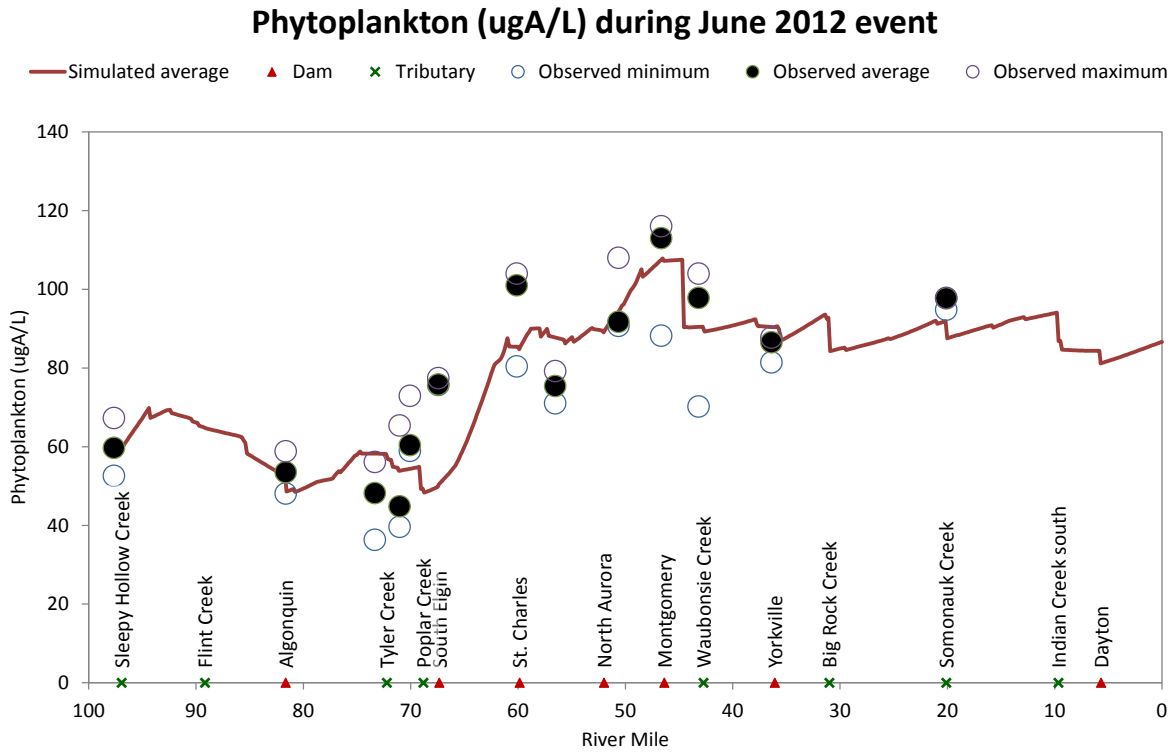


Figure 32. Simulated and observed phytoplankton chlorophyll *a* during June 2012 event

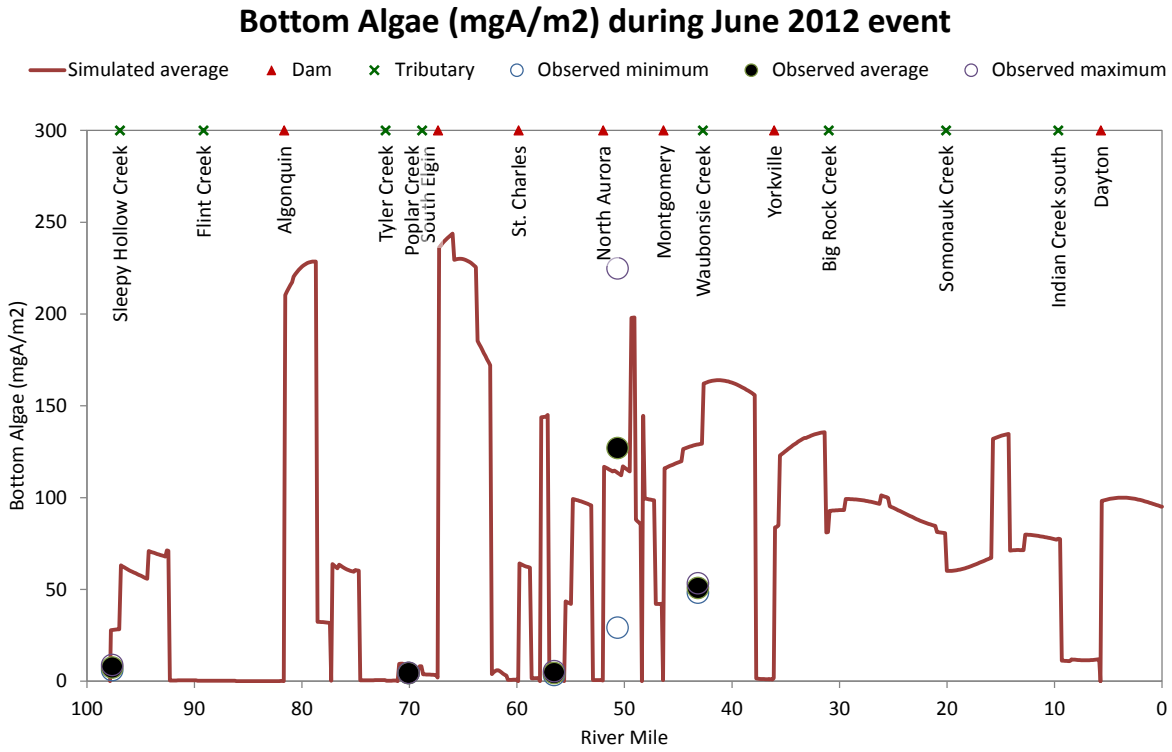


Figure 33. Simulated and observed benthic algae chlorophyll *a* during June 2012 event

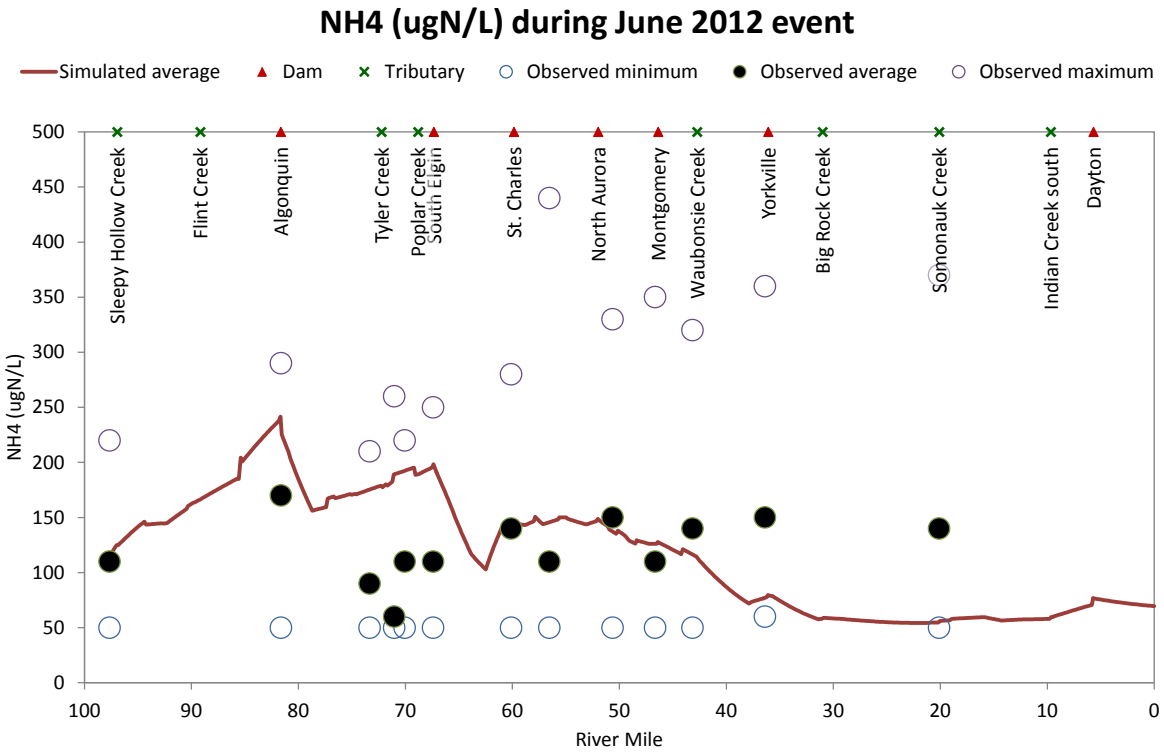


Figure 34. Simulated and observed ammonia nitrogen during June 2012 event

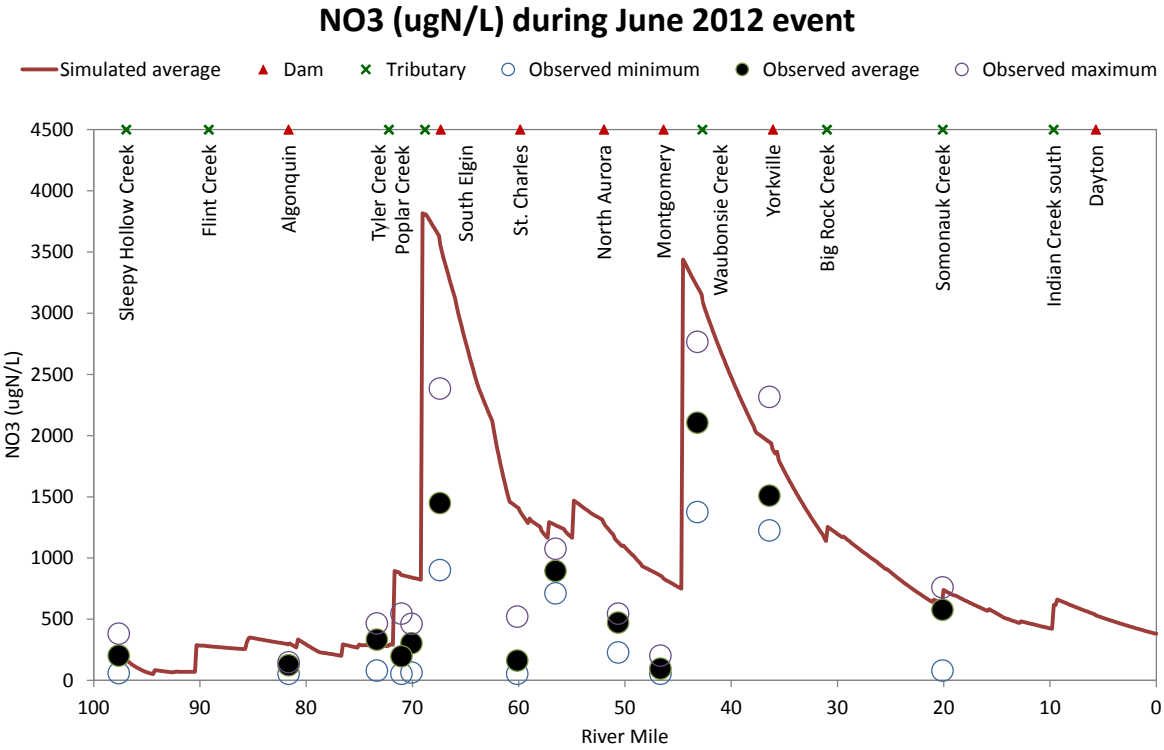


Figure 35. Simulated and observed nitrate nitrogen during June 2012 event

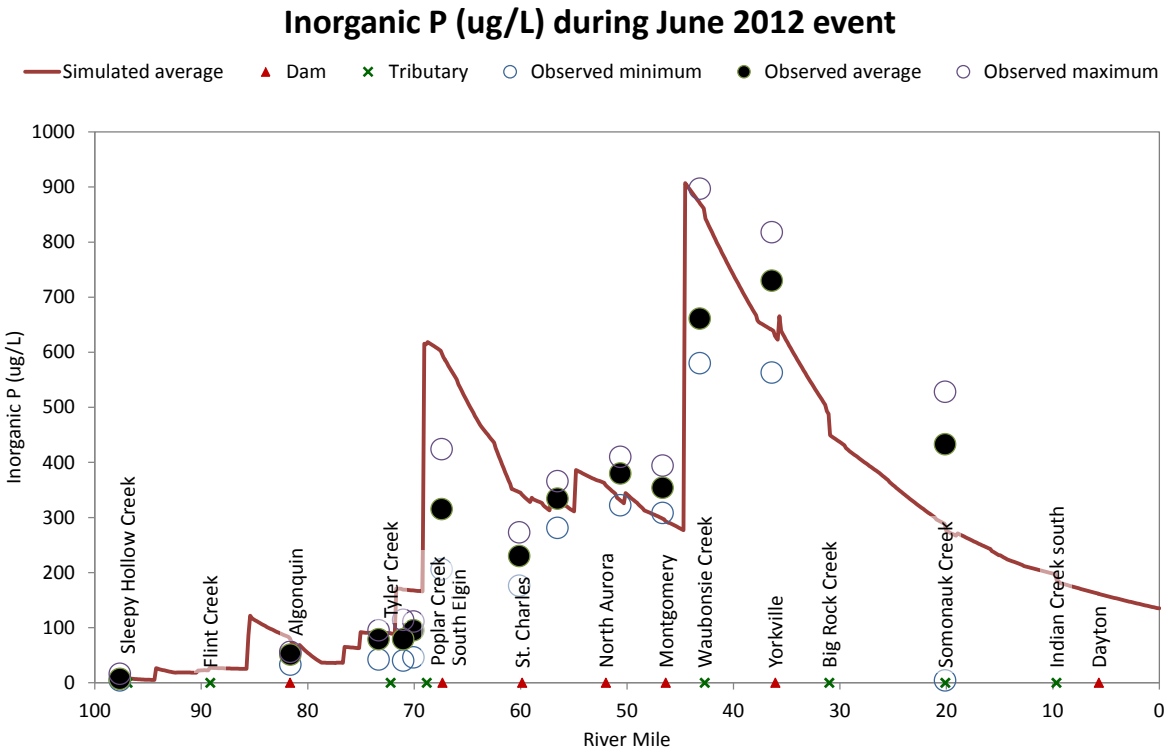


Figure 36. Simulated and observed inorganic phosphorus during June 2012 event

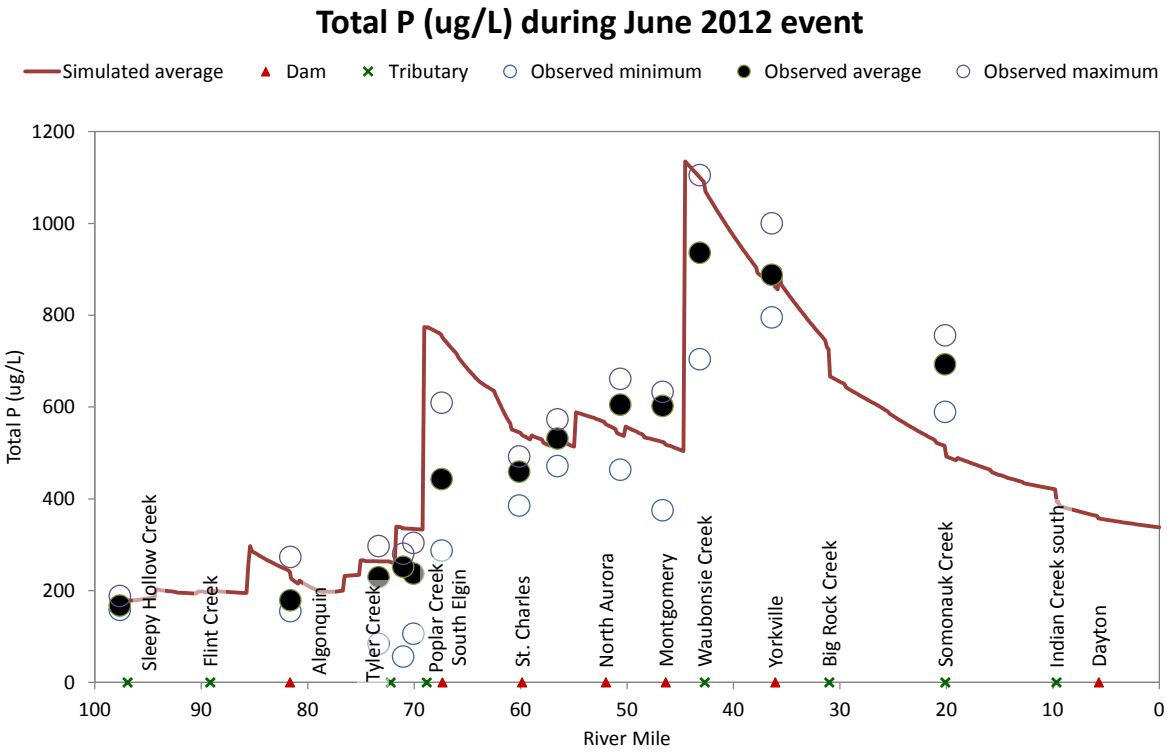


Figure 37. Simulated and observed total phosphorus during June 2012 event

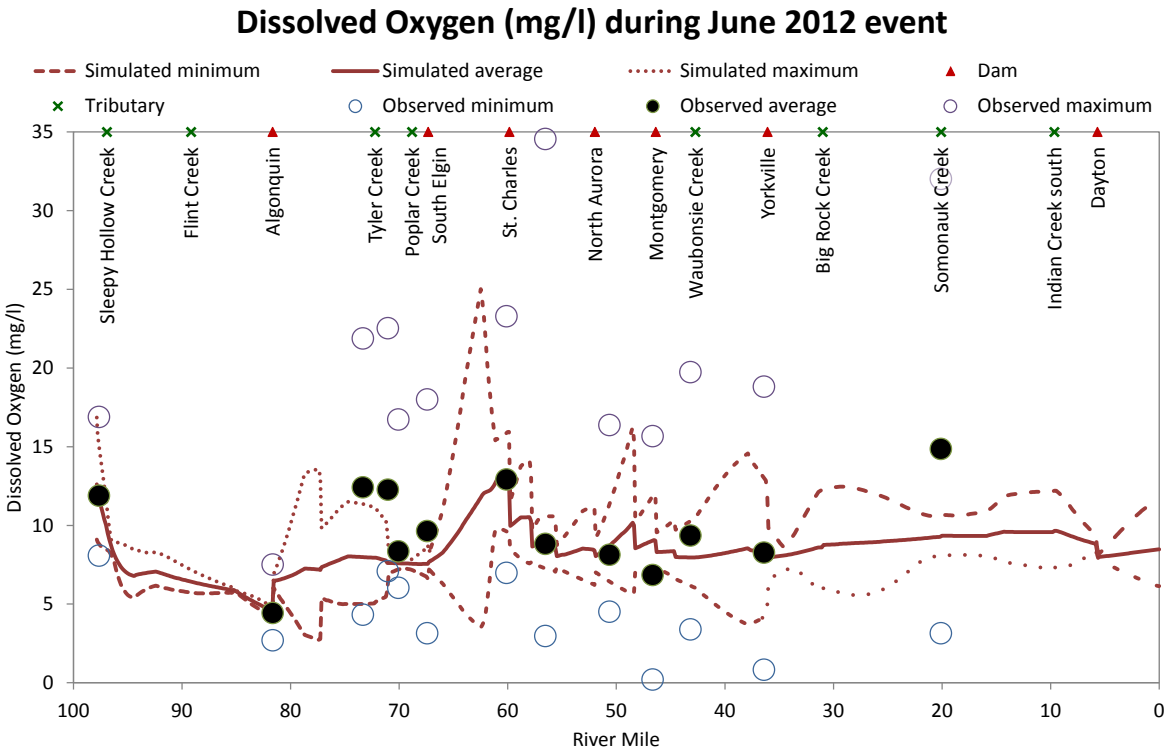


Figure 38. Simulated and observed dissolved oxygen during June 2012 event

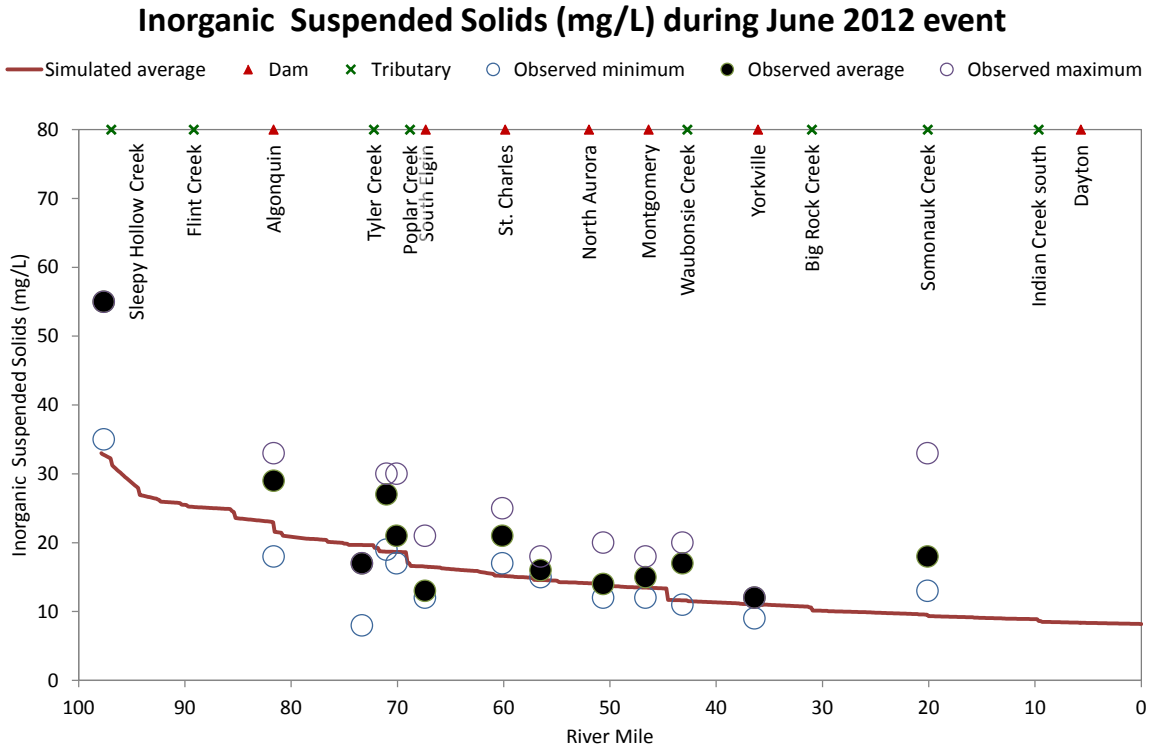
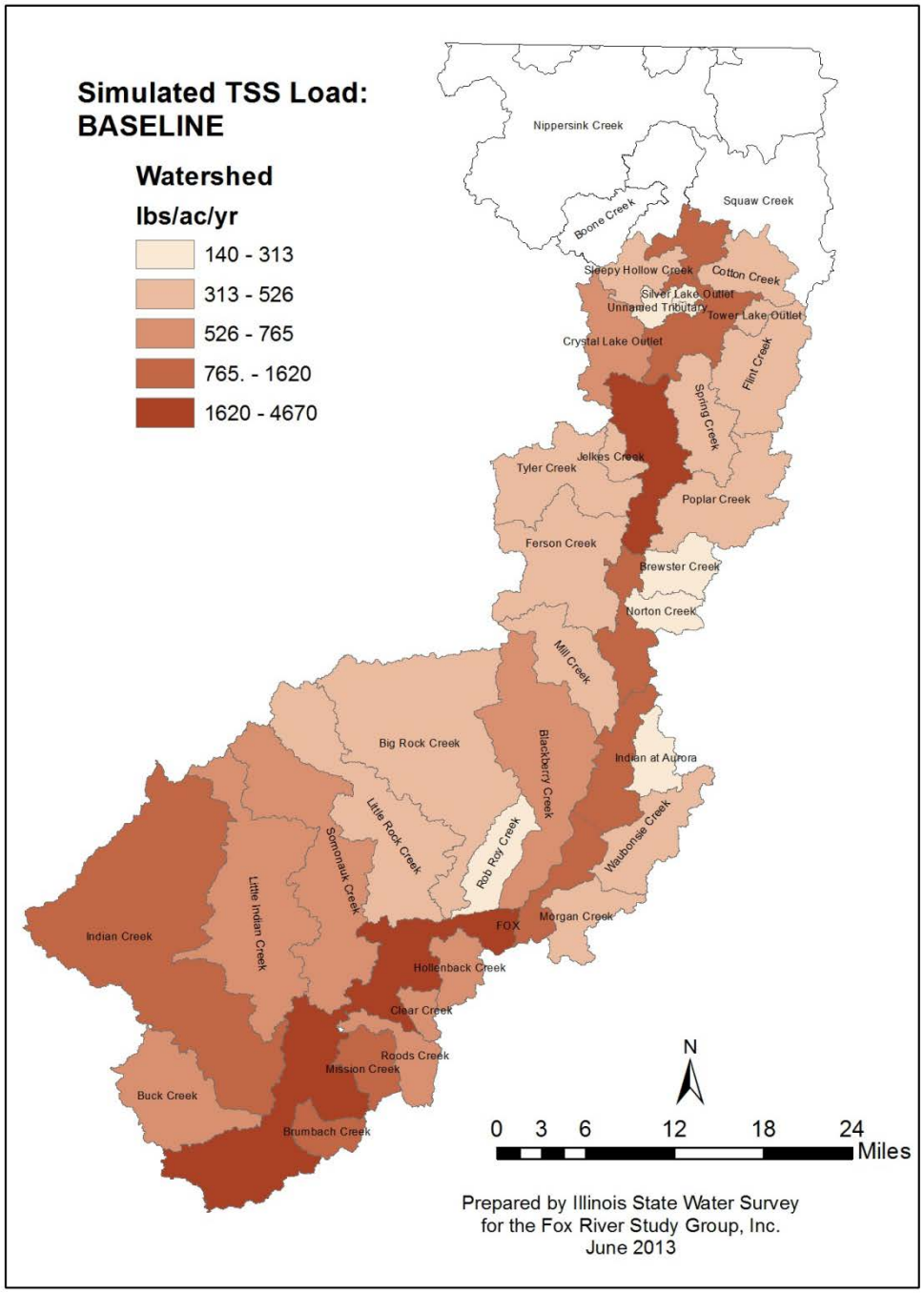


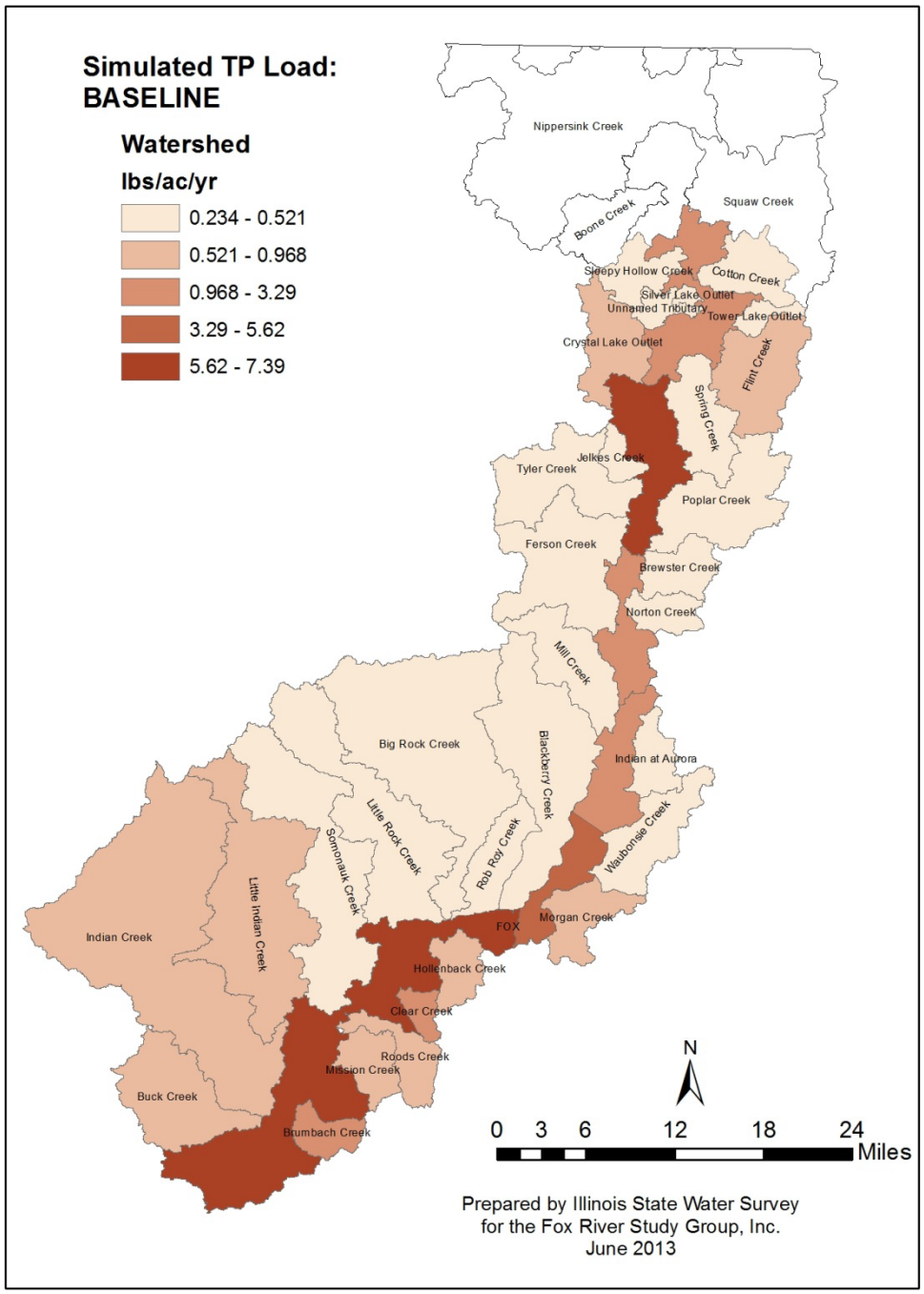
Figure 39. Simulated and observed inorganic suspended solids during June 2012 event

Appendix C
Unit Area Loads Simulated for Baseline

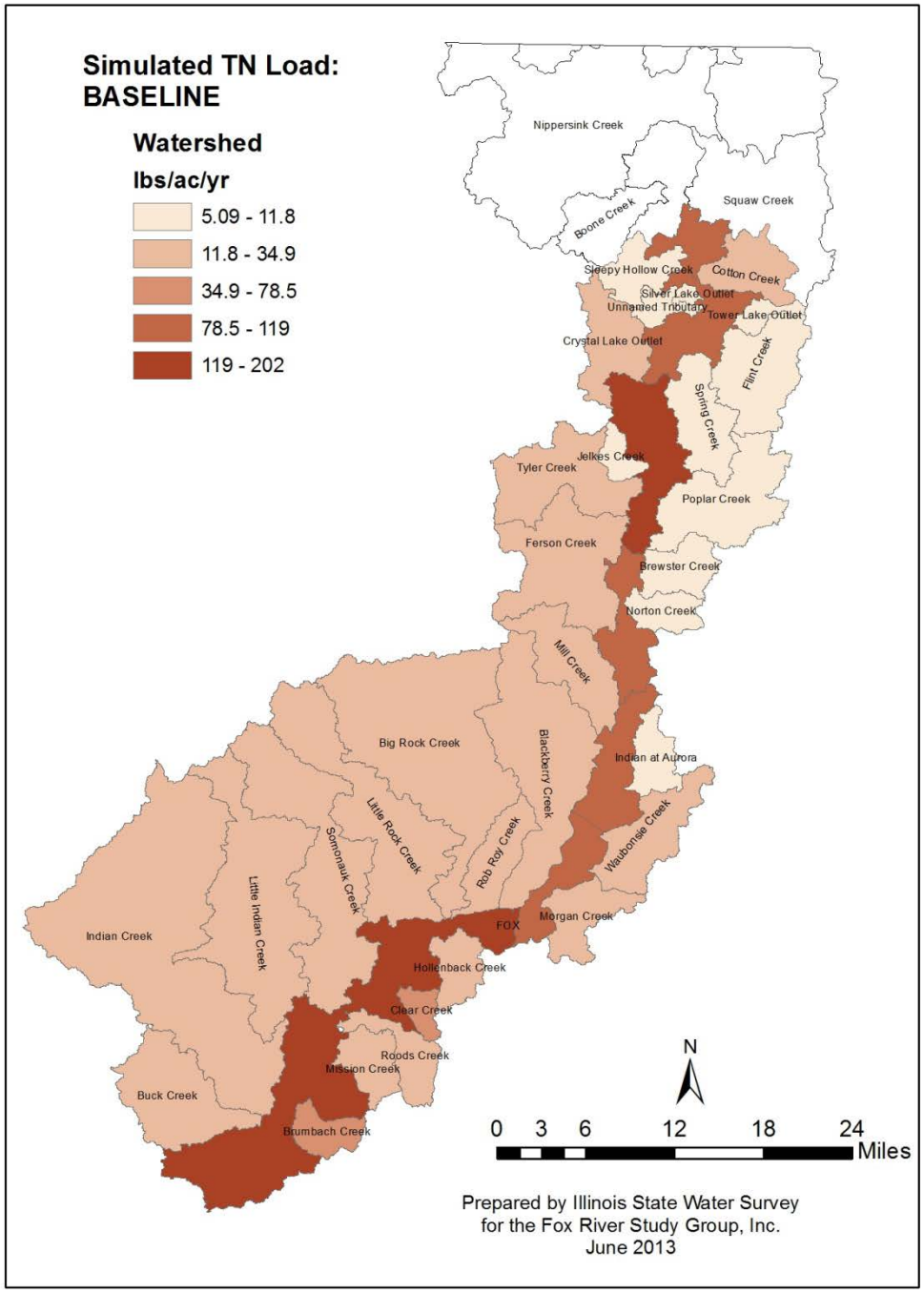
Map 1. Unit area total suspended solids load simulated for Baseline



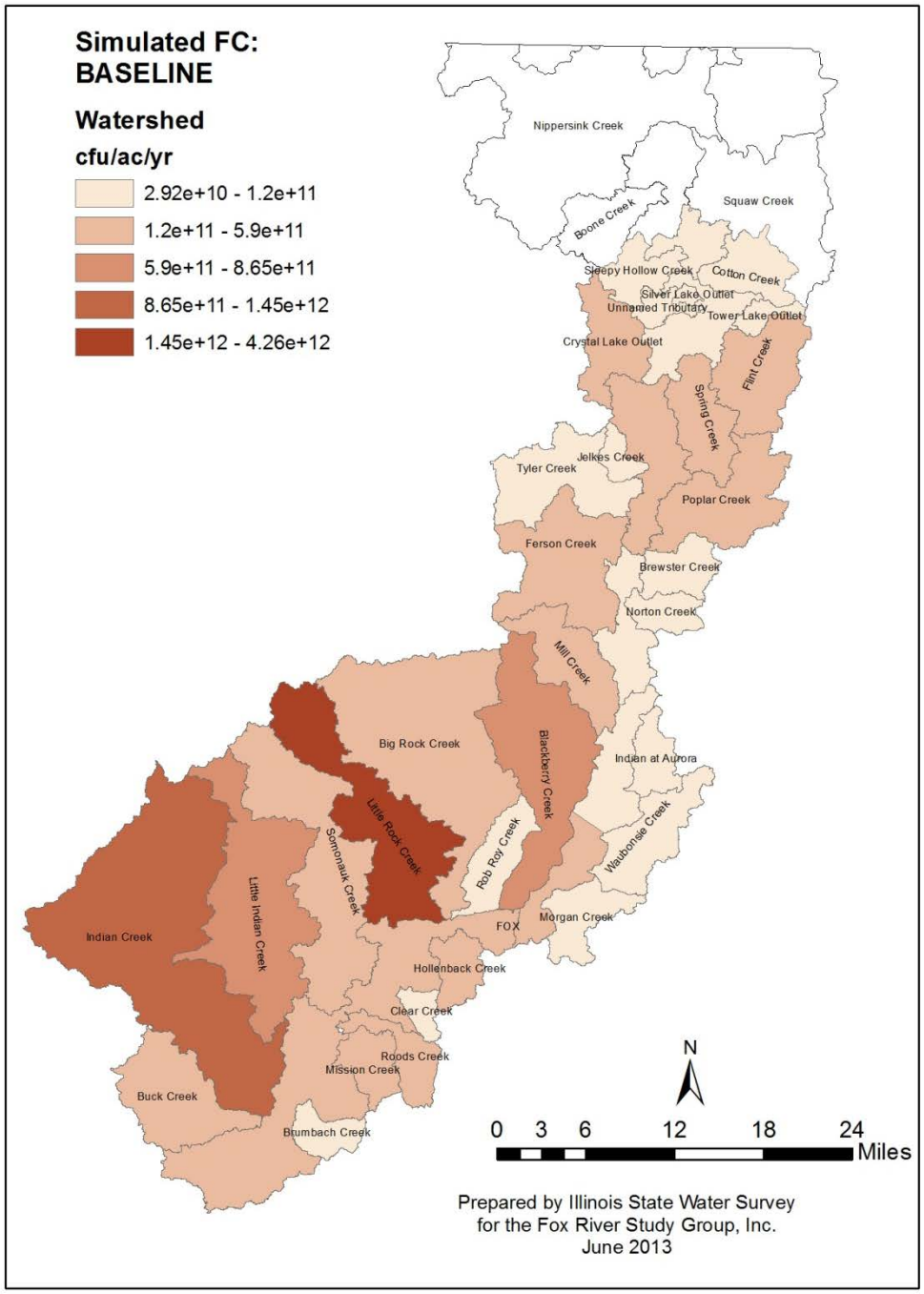
Map 2. Unit area total phosphorus load simulated for Baseline



Map 3. Unit area total nitrogen load simulated for Baseline



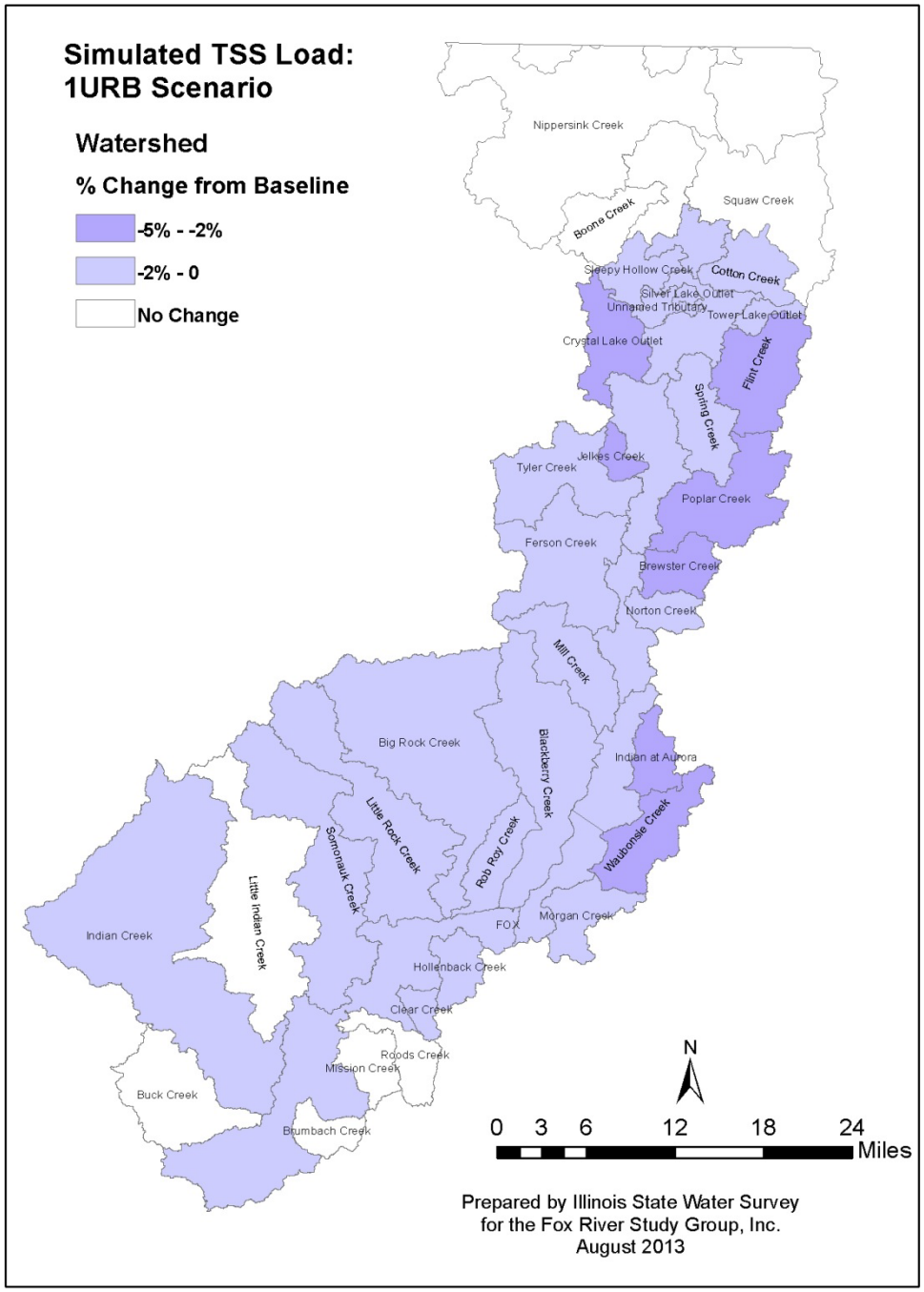
Map 4. Unit area fecal coliform load simulated for Baseline



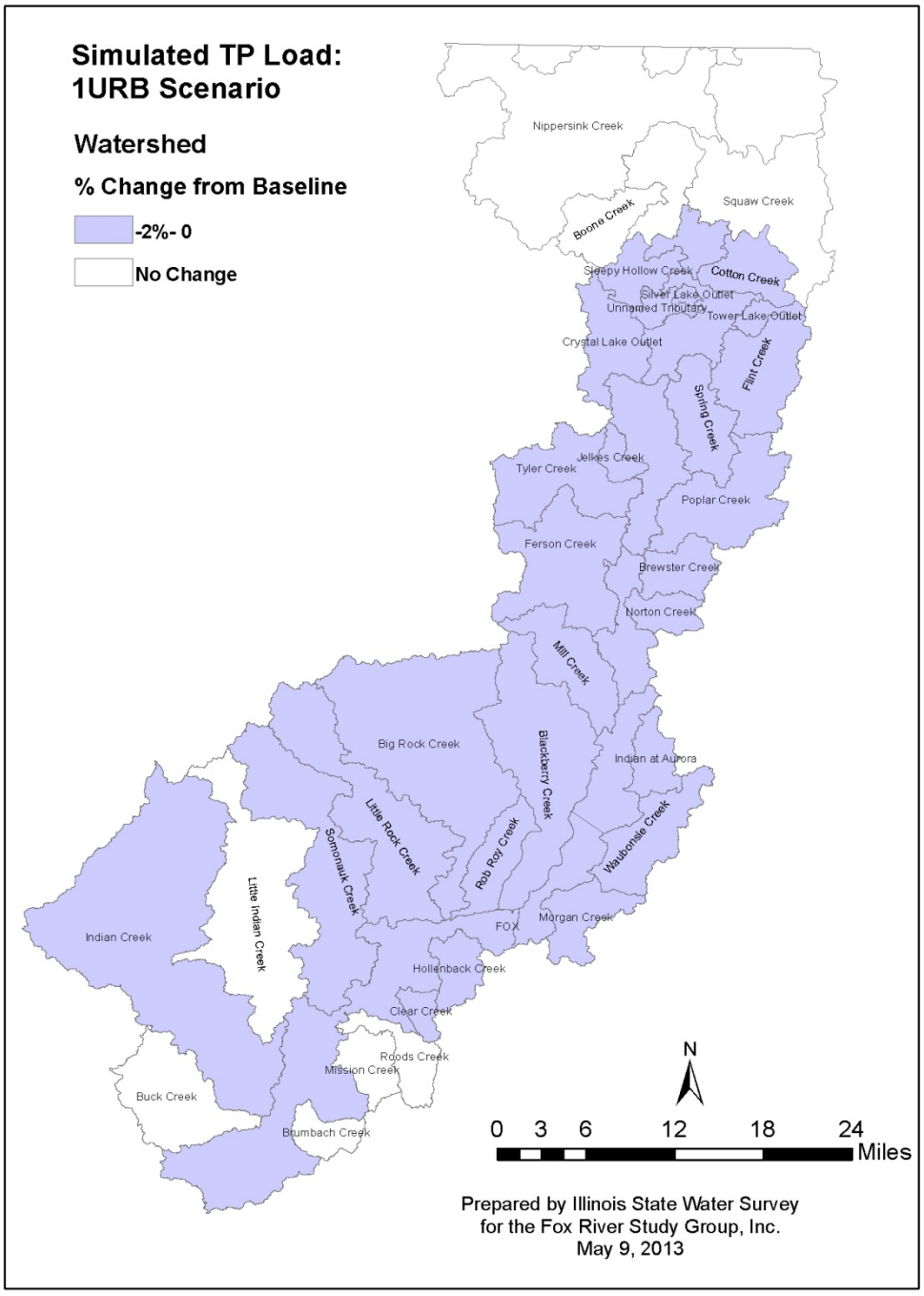
Appendix D
Percent Change in Simulated Load Comparing to Baseline Scenario

Scenario 1URB

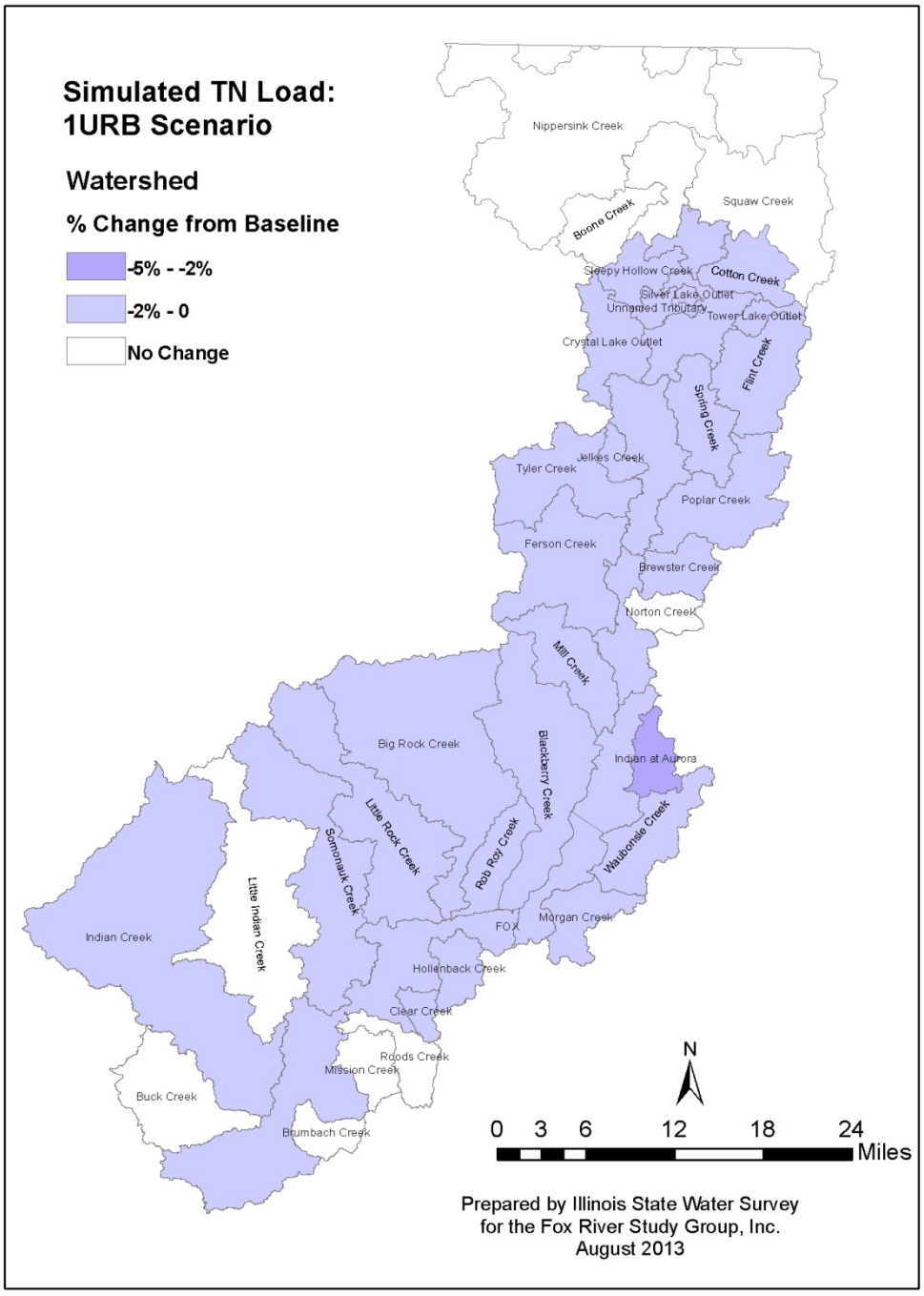
Map 5. Percent change in total suspended solids load simulated for 1URB compared to Baseline



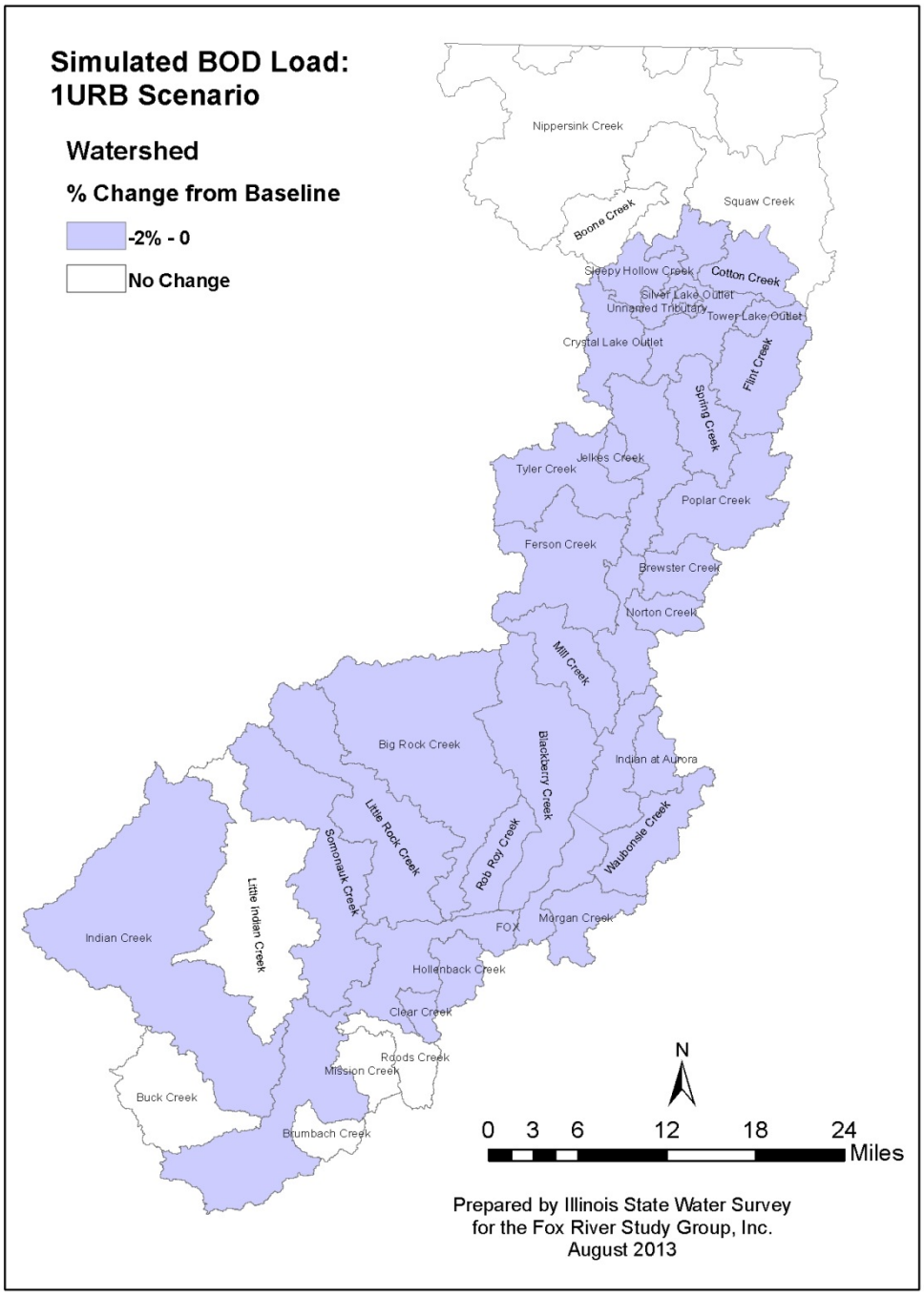
Map 6. Percent change in total phosphorus load simulated for 1URB compared to Baseline



Map 7. Percent change in total nitrogen load simulated for 1URB compared to Baseline

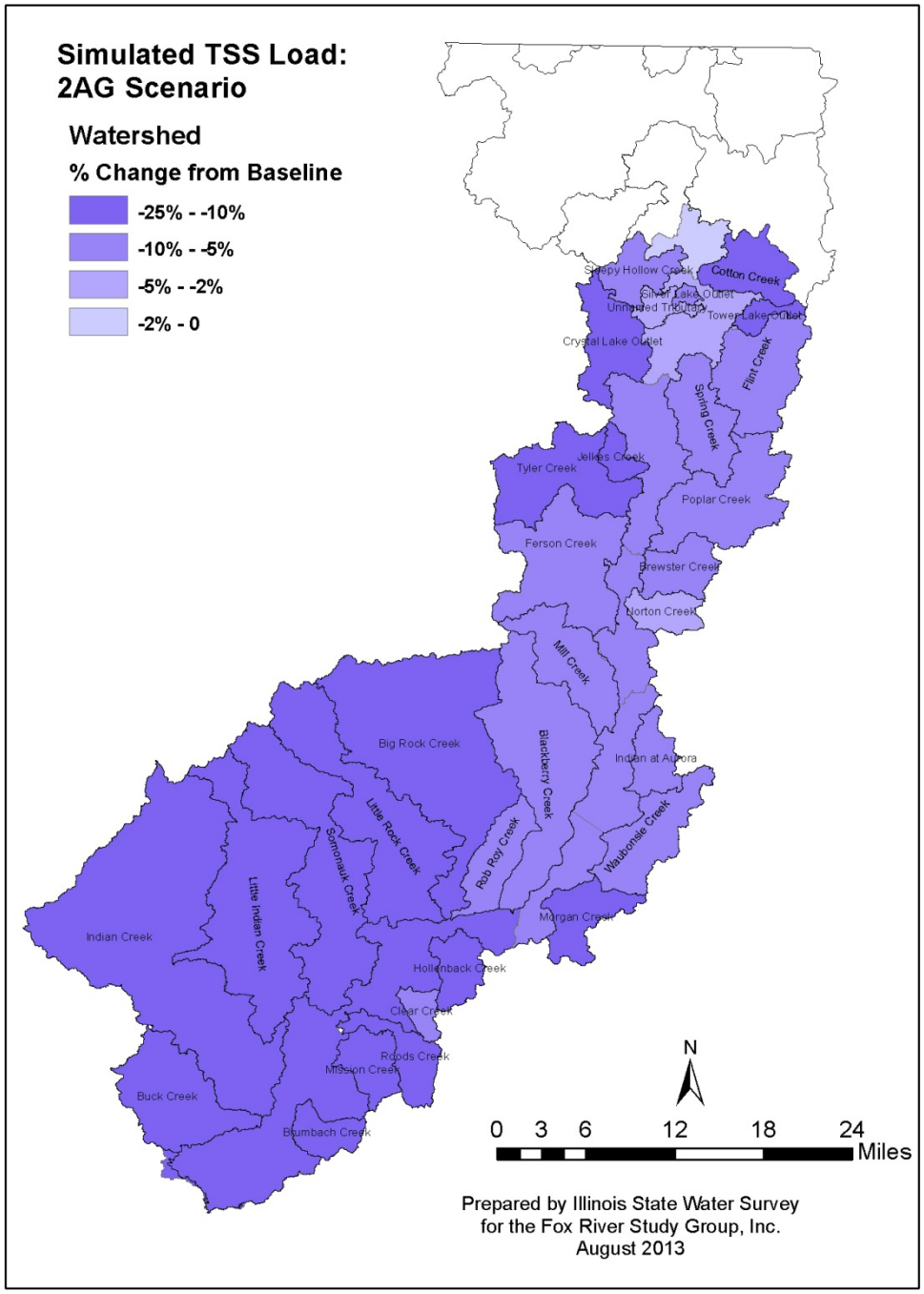


Map 8. Percent change in BOD_5 load simulated for 1URB compared to Baseline

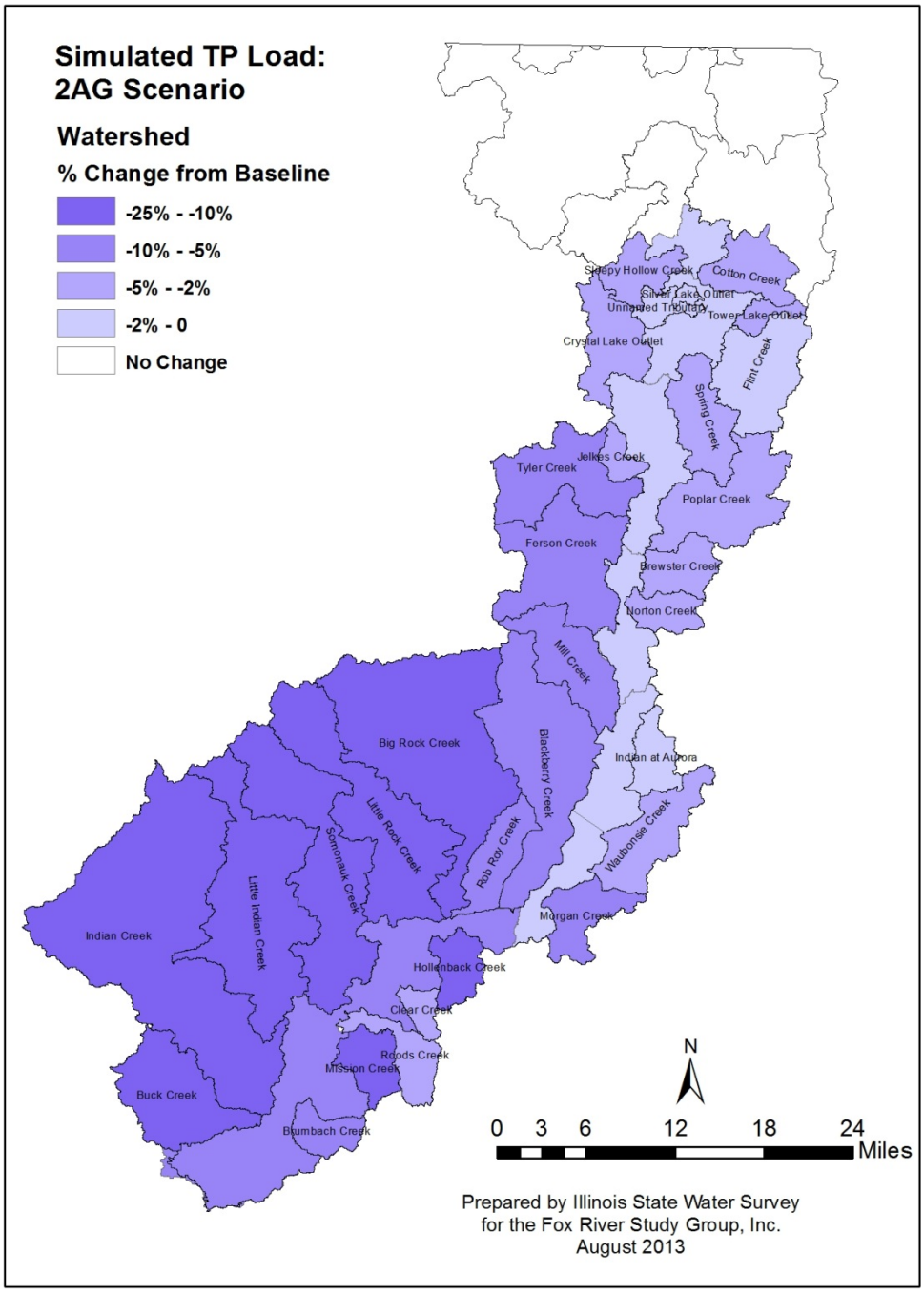


Scenario 2AG

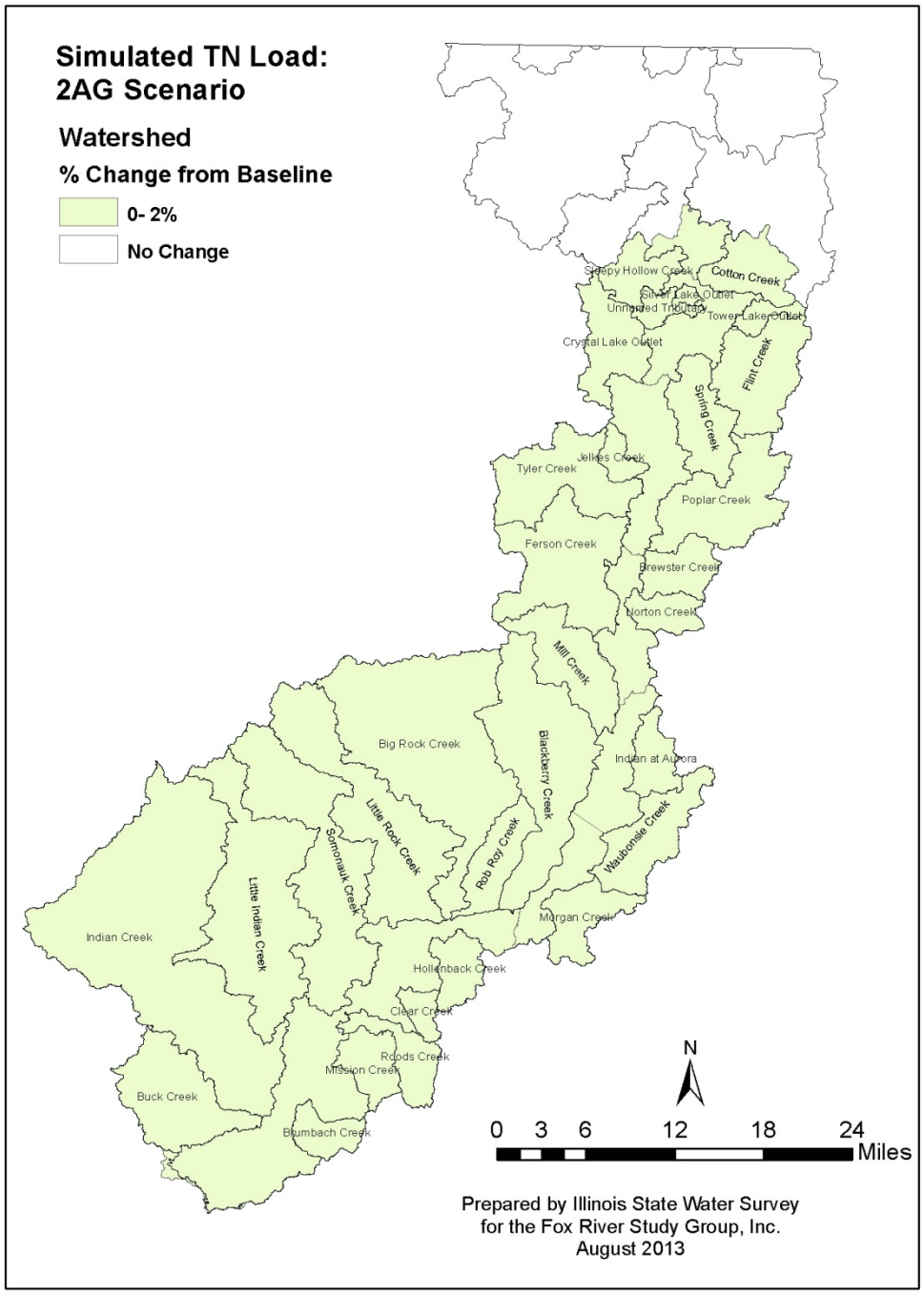
Map 9. Percent change in total suspended solids load simulated for 2AG compared to Baseline



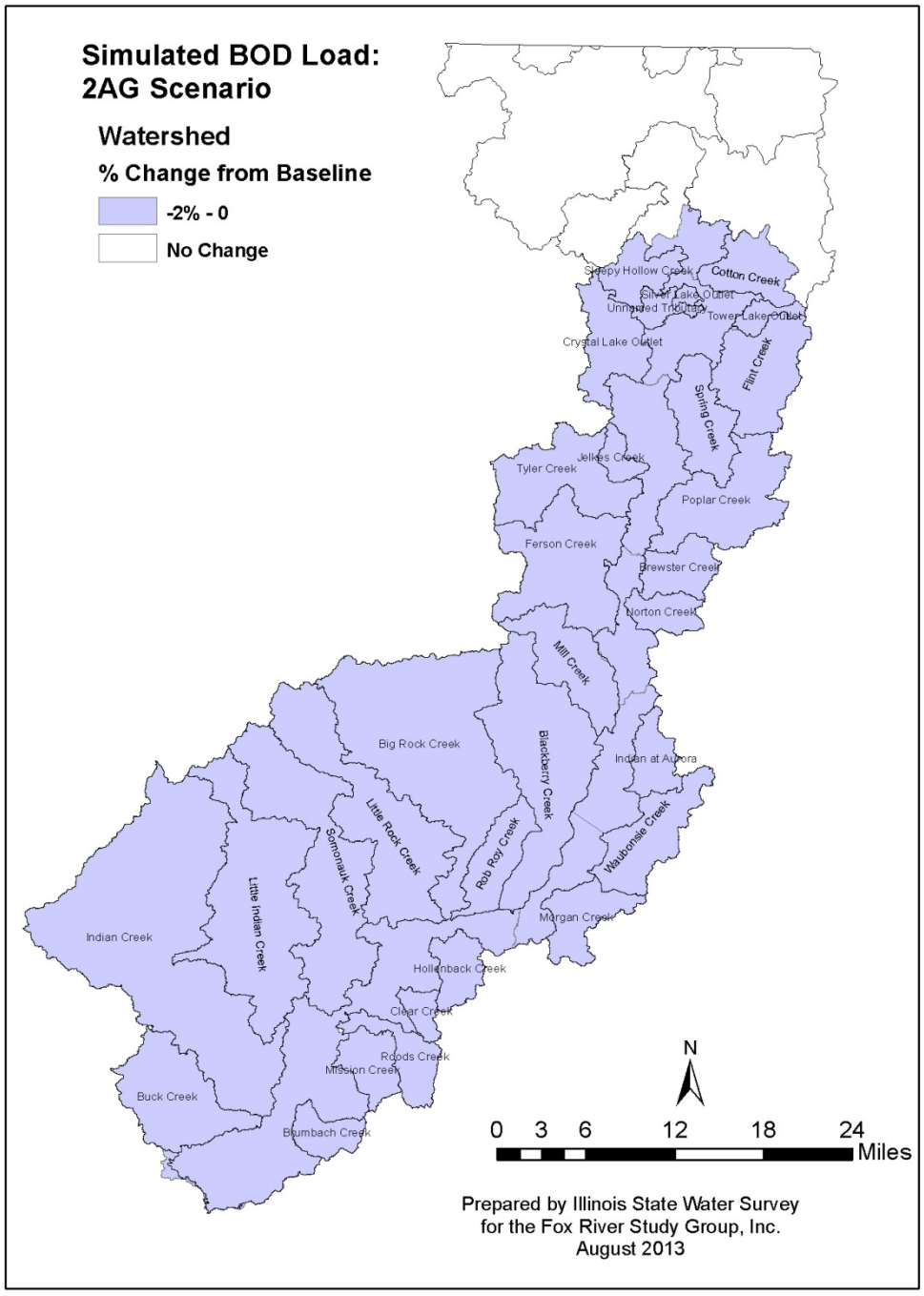
Map 10. Percent change in total phosphorus load simulated for 2AG compared to Baseline



Map 11. Percent change in total nitrogen load simulated for 2AG compared to Baseline

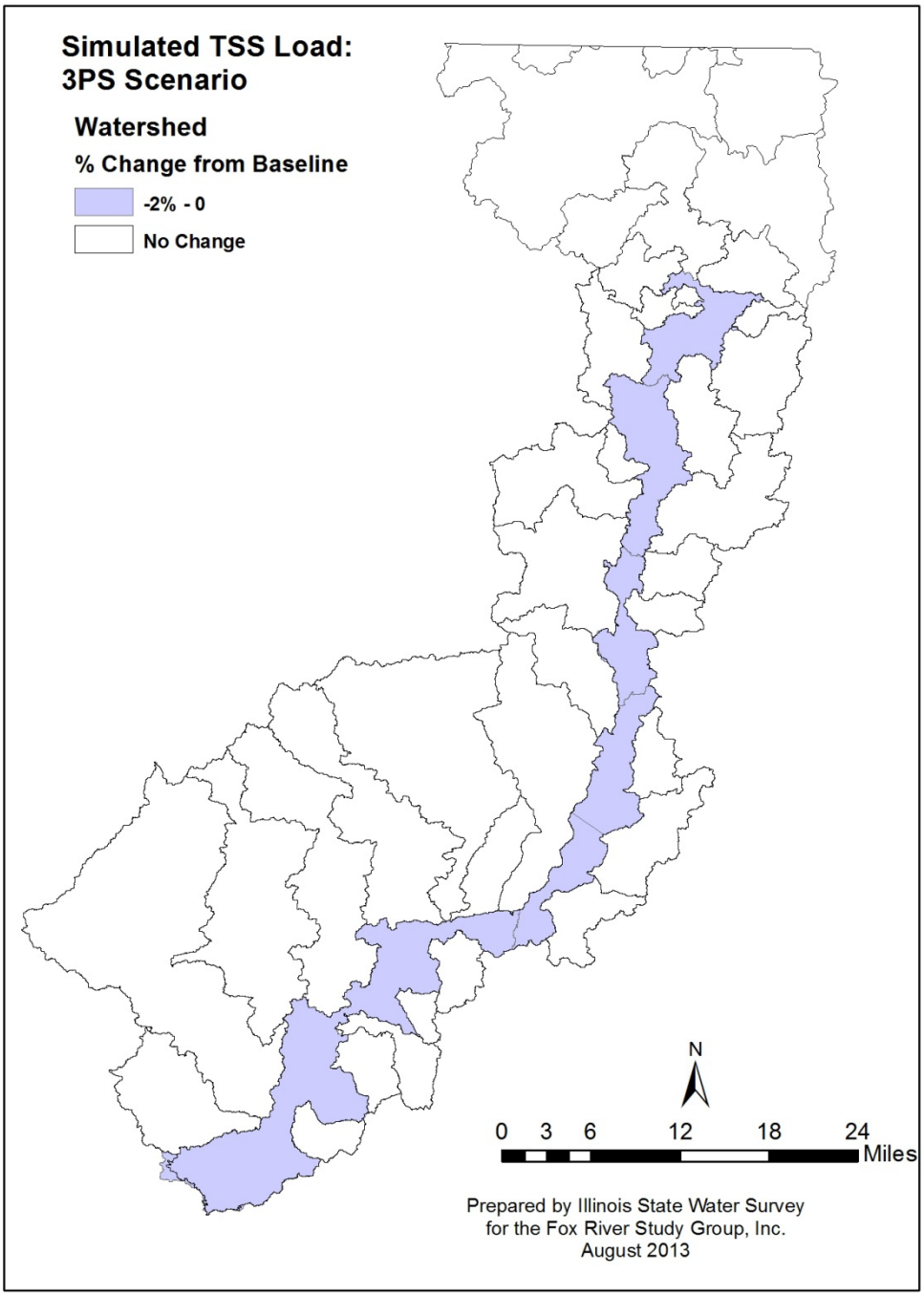


Map 12. Percent change in BOD_5 load simulated for 2AG compared to Baseline

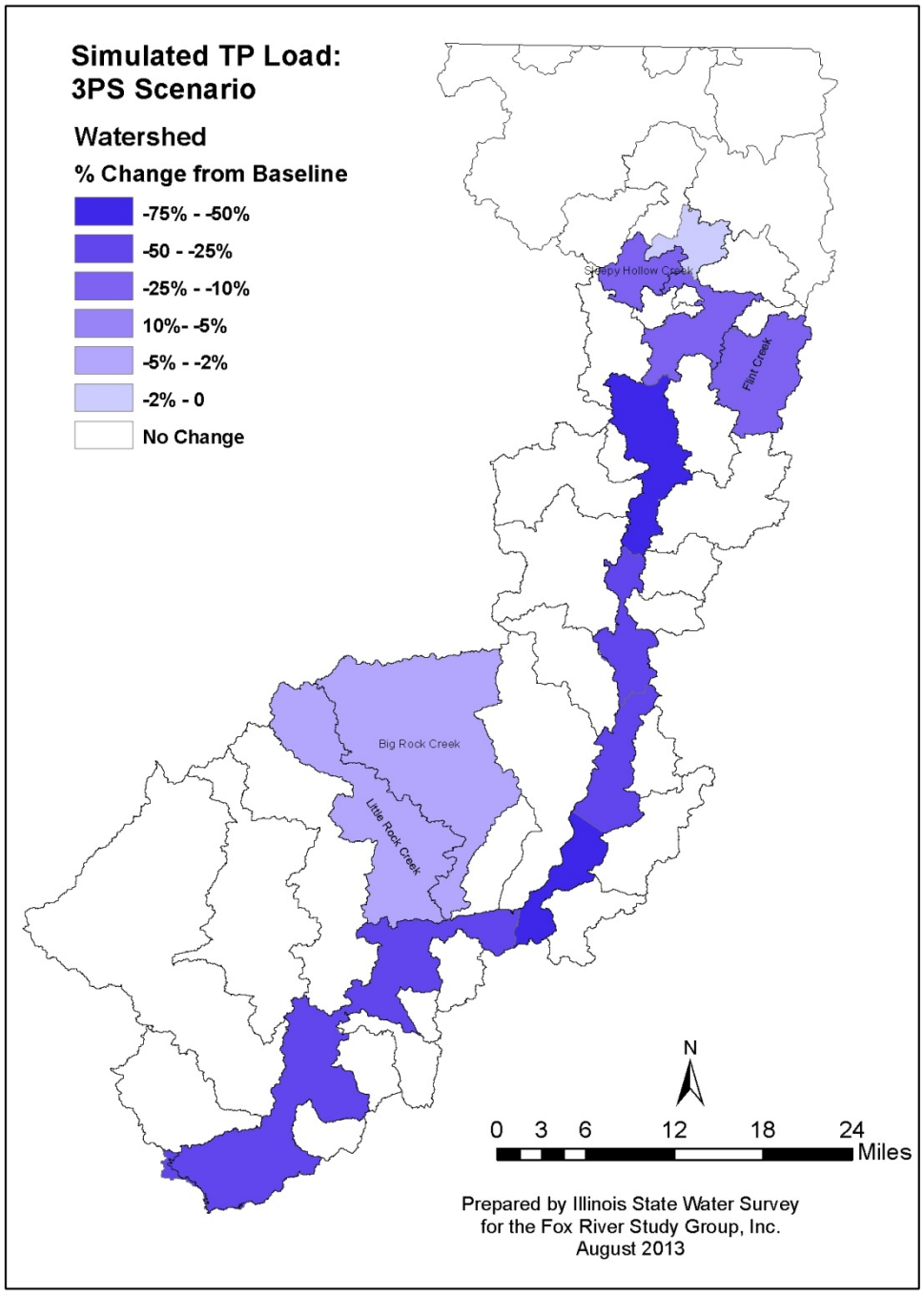


Scenario 3PS

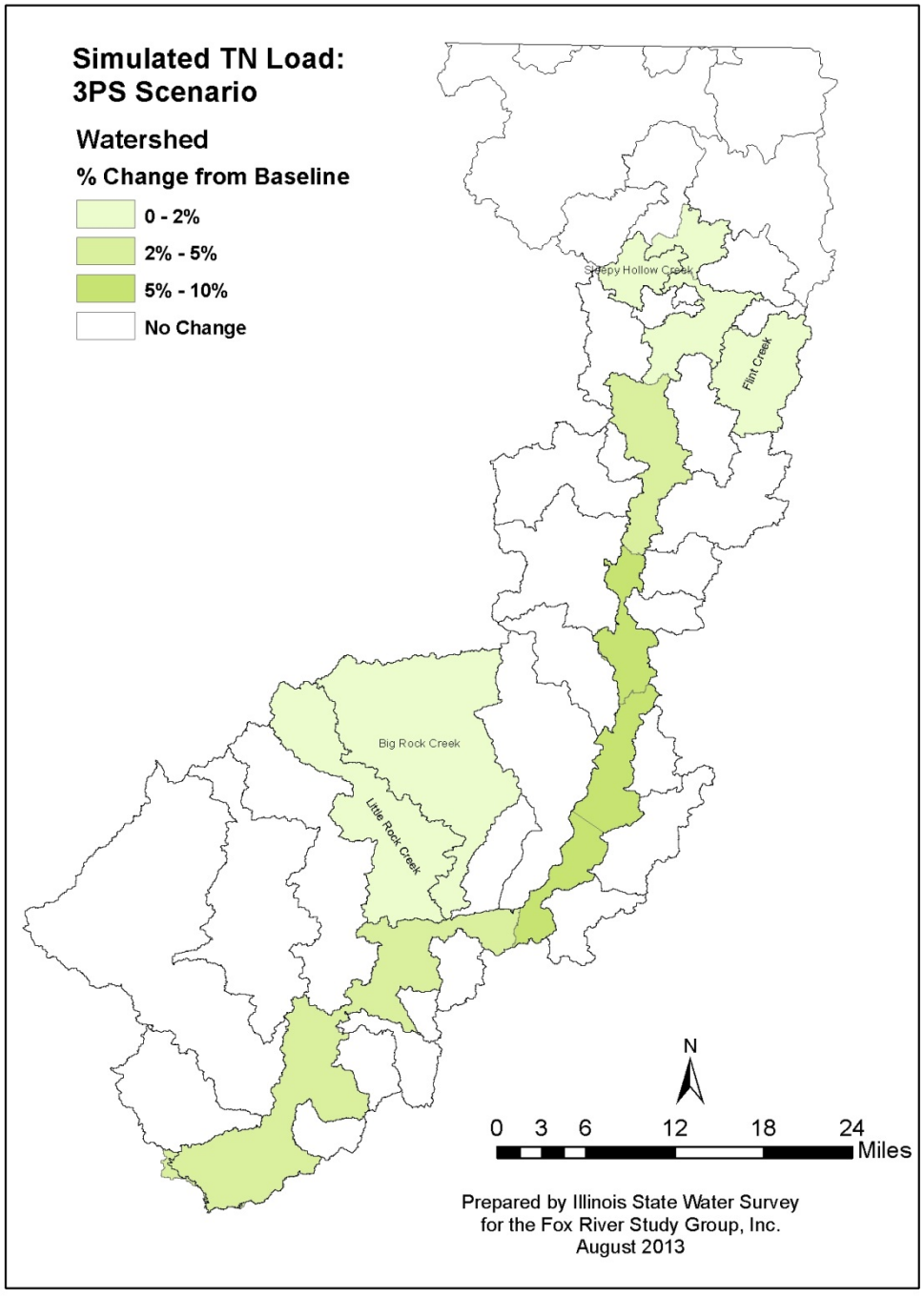
Map 13. Percent change in total suspended solids load simulated for 3PS compared to Baseline



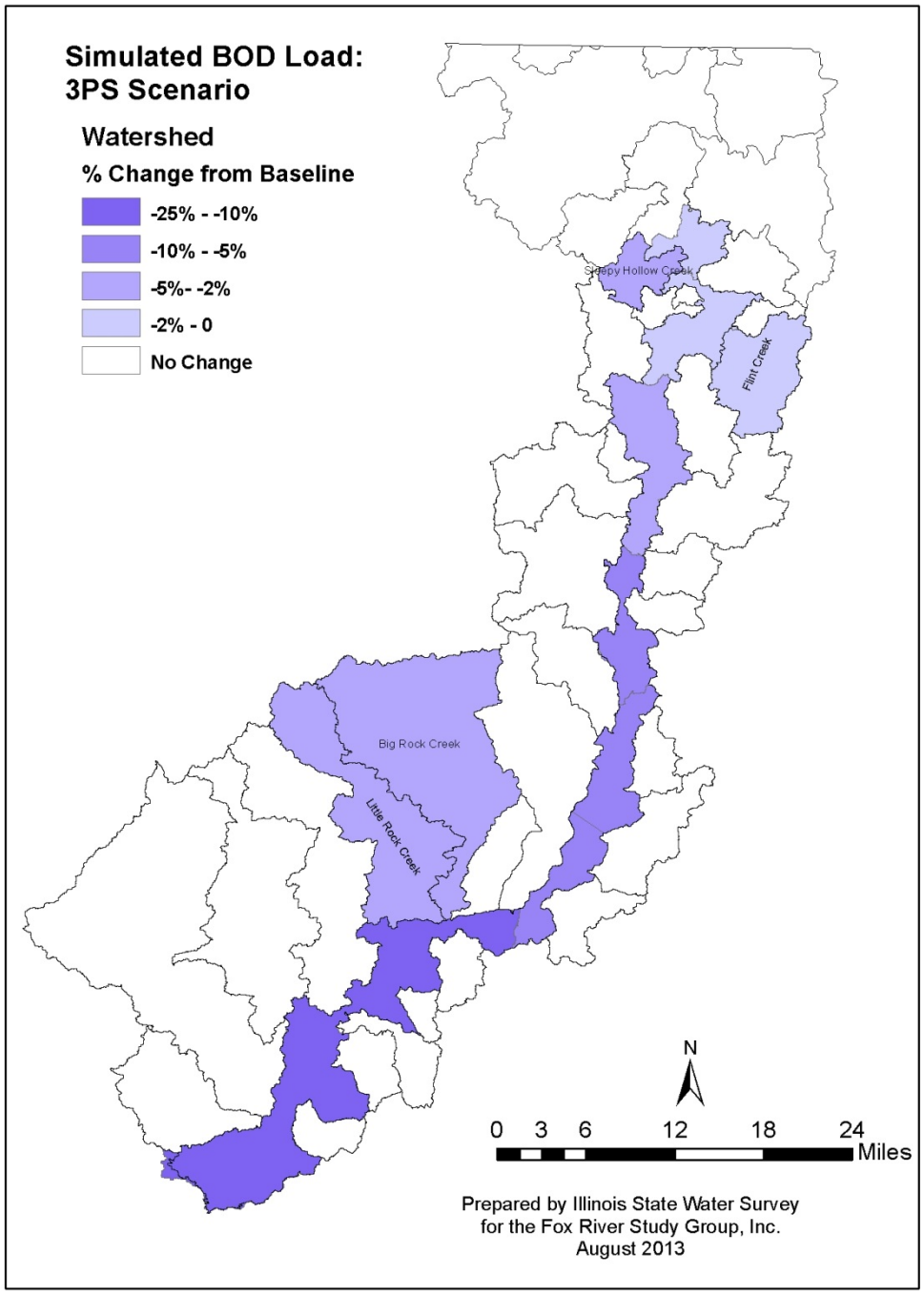
Map 14. Percent change in total phosphorus load simulated for 3PS compared to Baseline



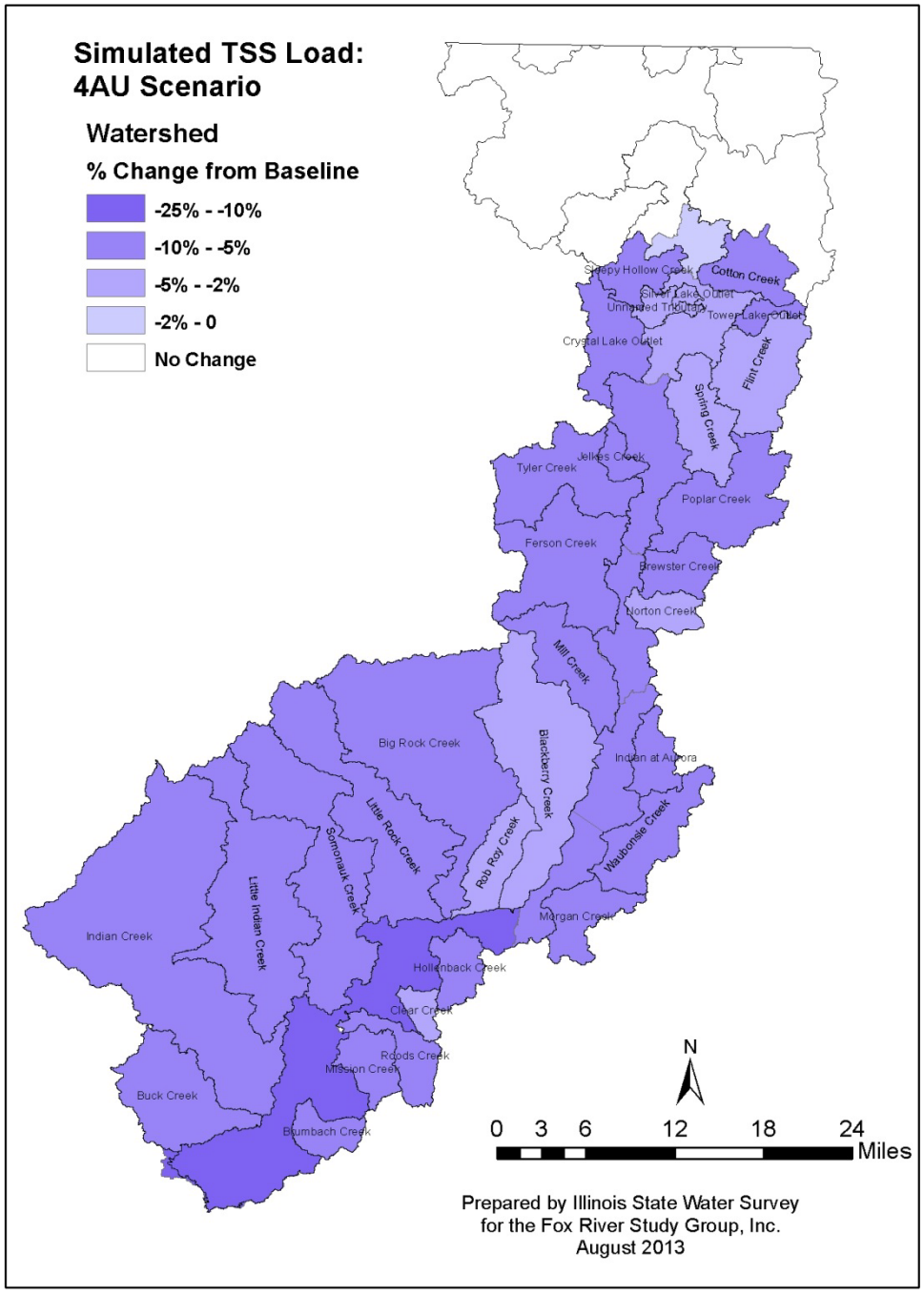
Map 15. Percent change in total nitrogen load simulated for 3PS compared to Baseline



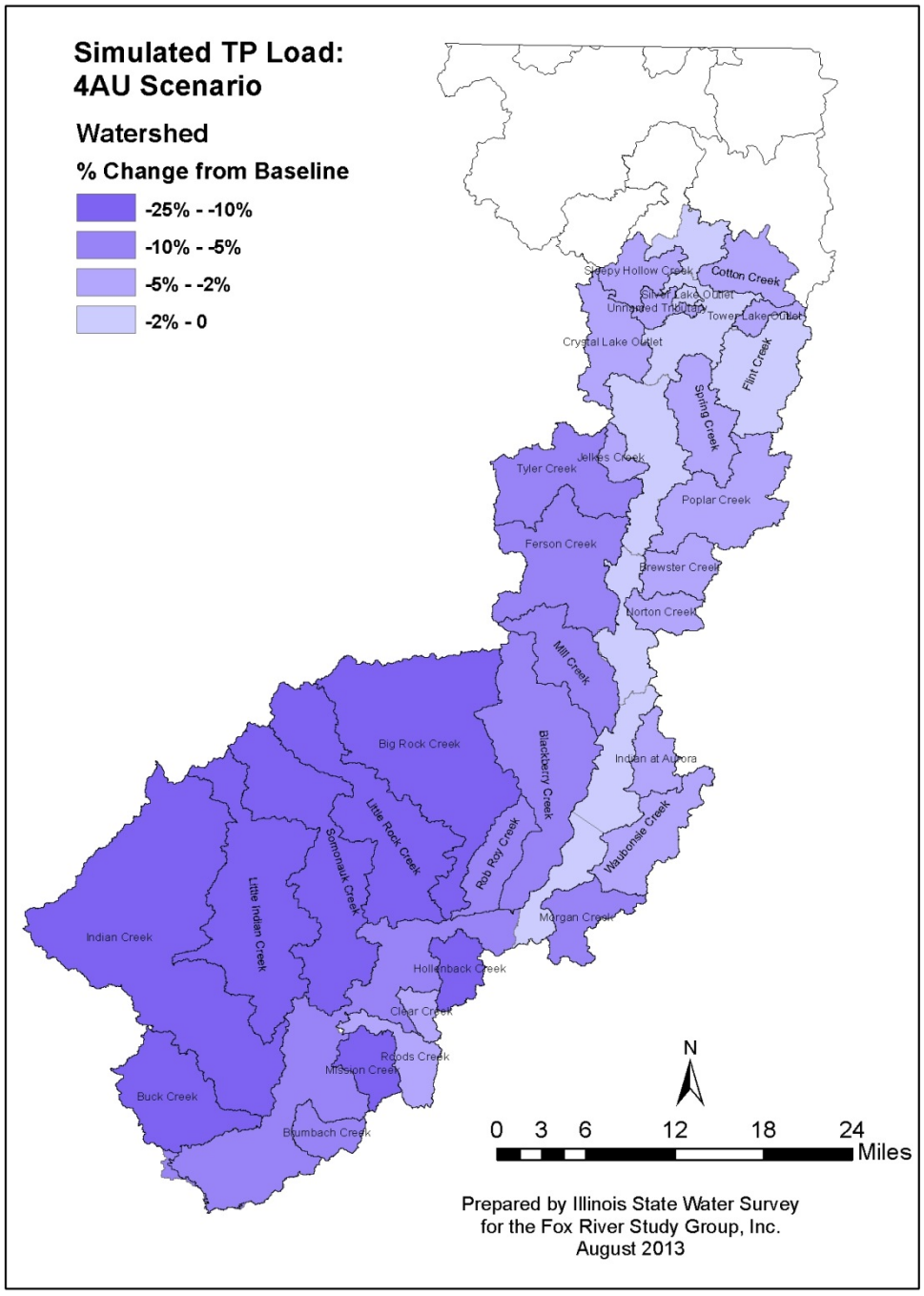
Map 16. Percent change in BOD_5 load simulated for 3PS compared to Baseline



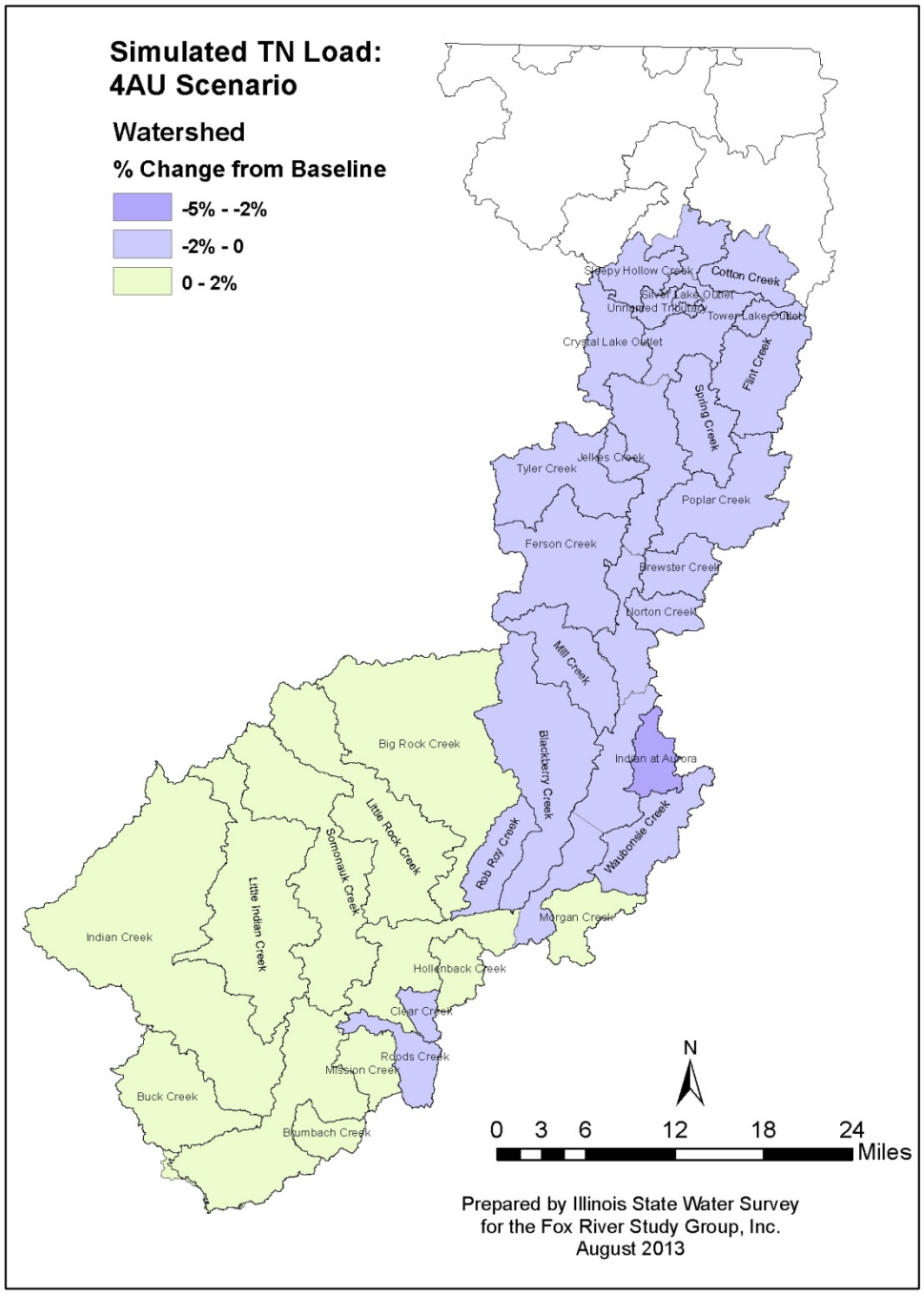
Map 17. Percent change in total suspended solids load simulated for 4AU compared to Baseline



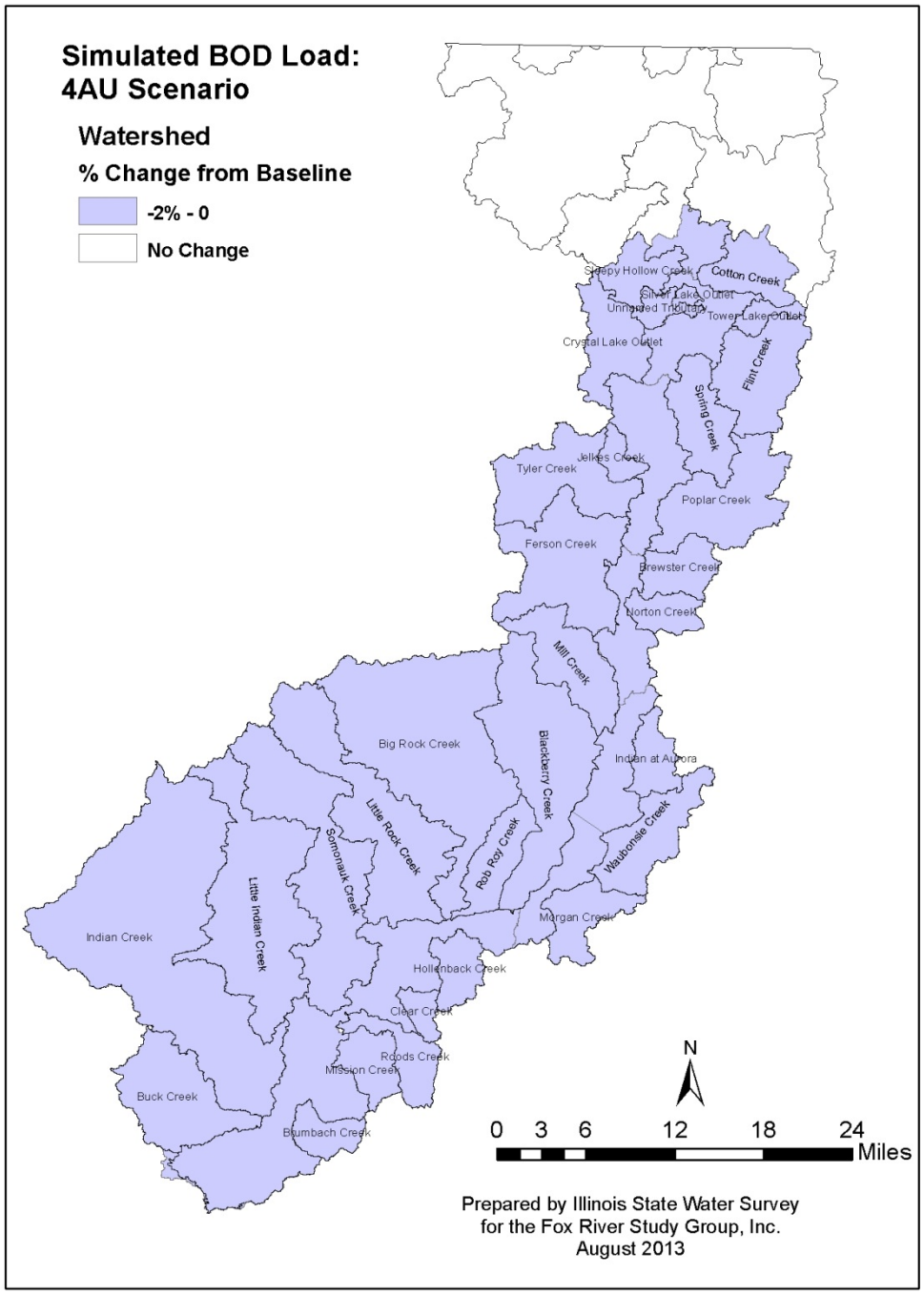
Map 18. Percent change in total phosphorus load simulated for 4AU compared to Baseline



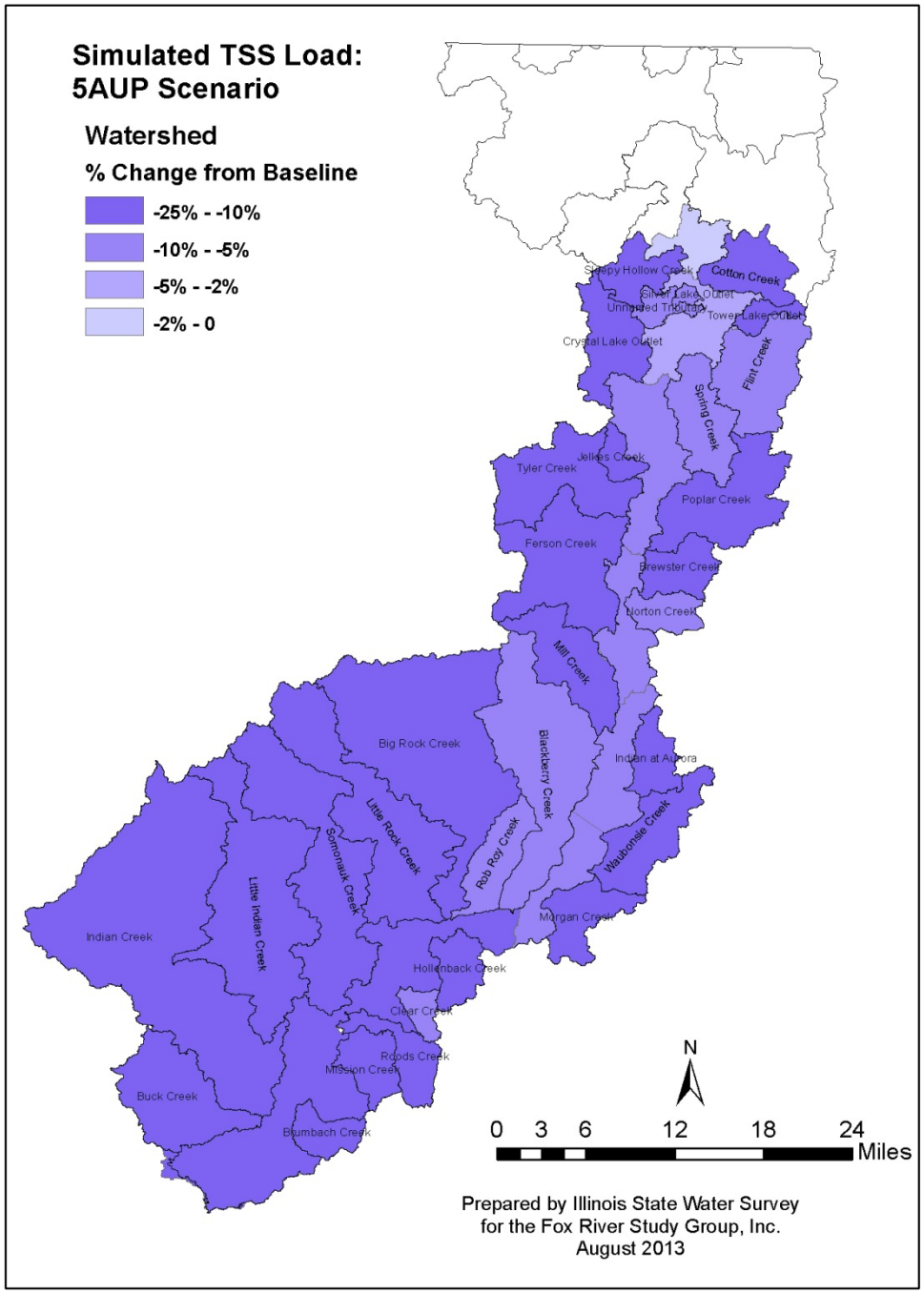
Map 19. Percent change in total nitrogen load simulated for 4AU compared to Baseline



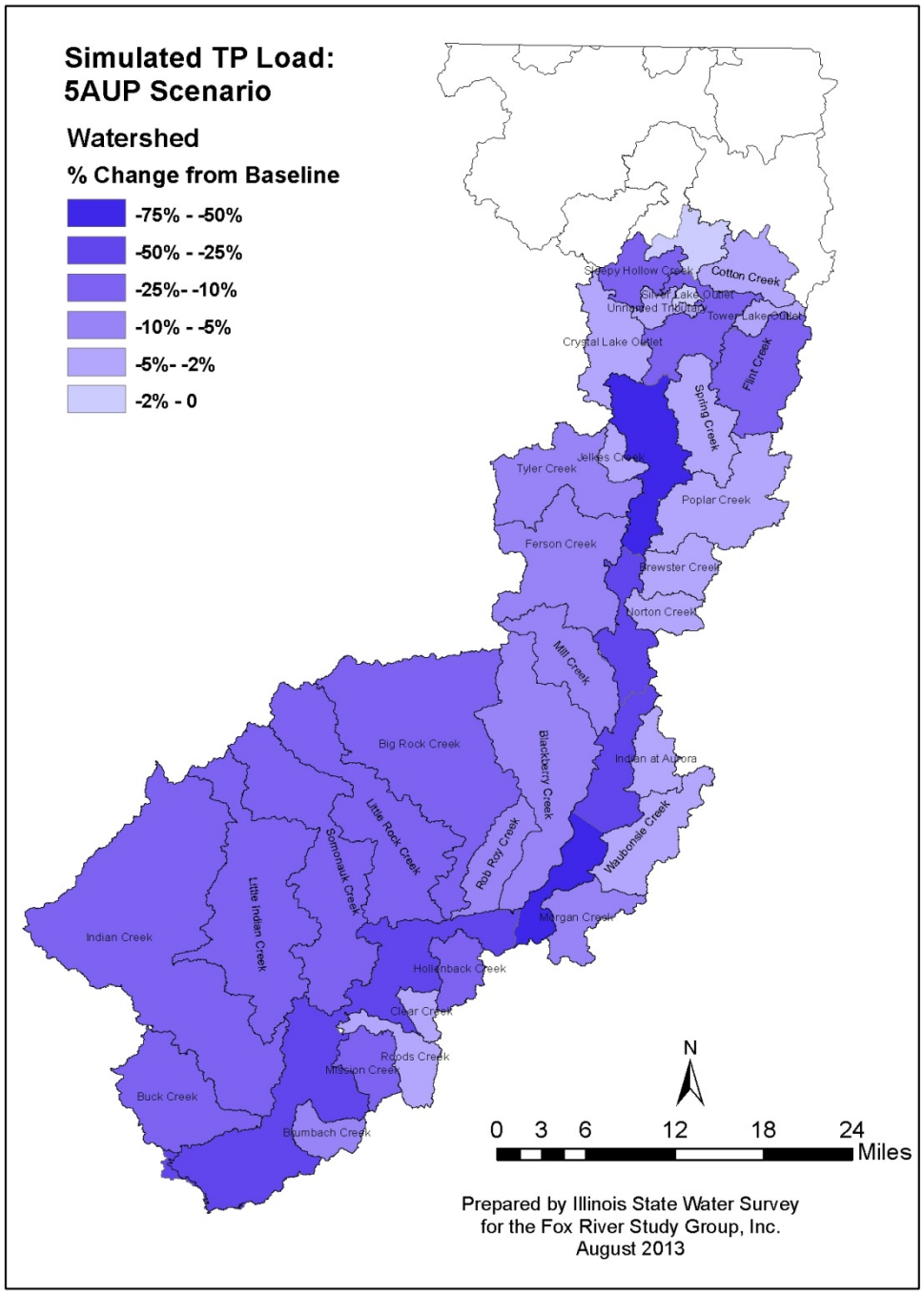
Map 20. Percent change in BOD_5 load simulated for 4AU compared to Baseline



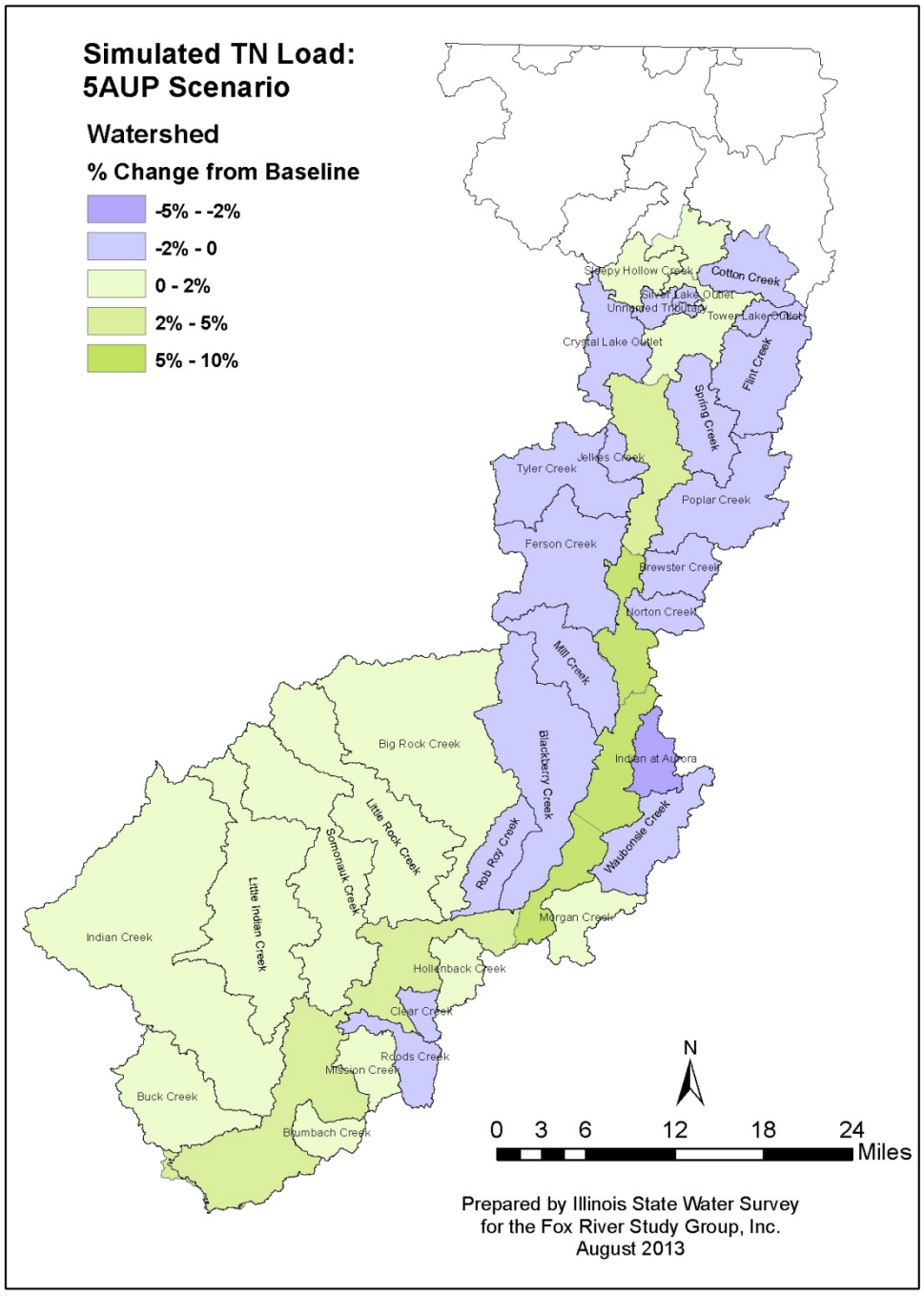
Map 21. Percent change in total suspended solids load simulated for 5AUP compared to Baseline



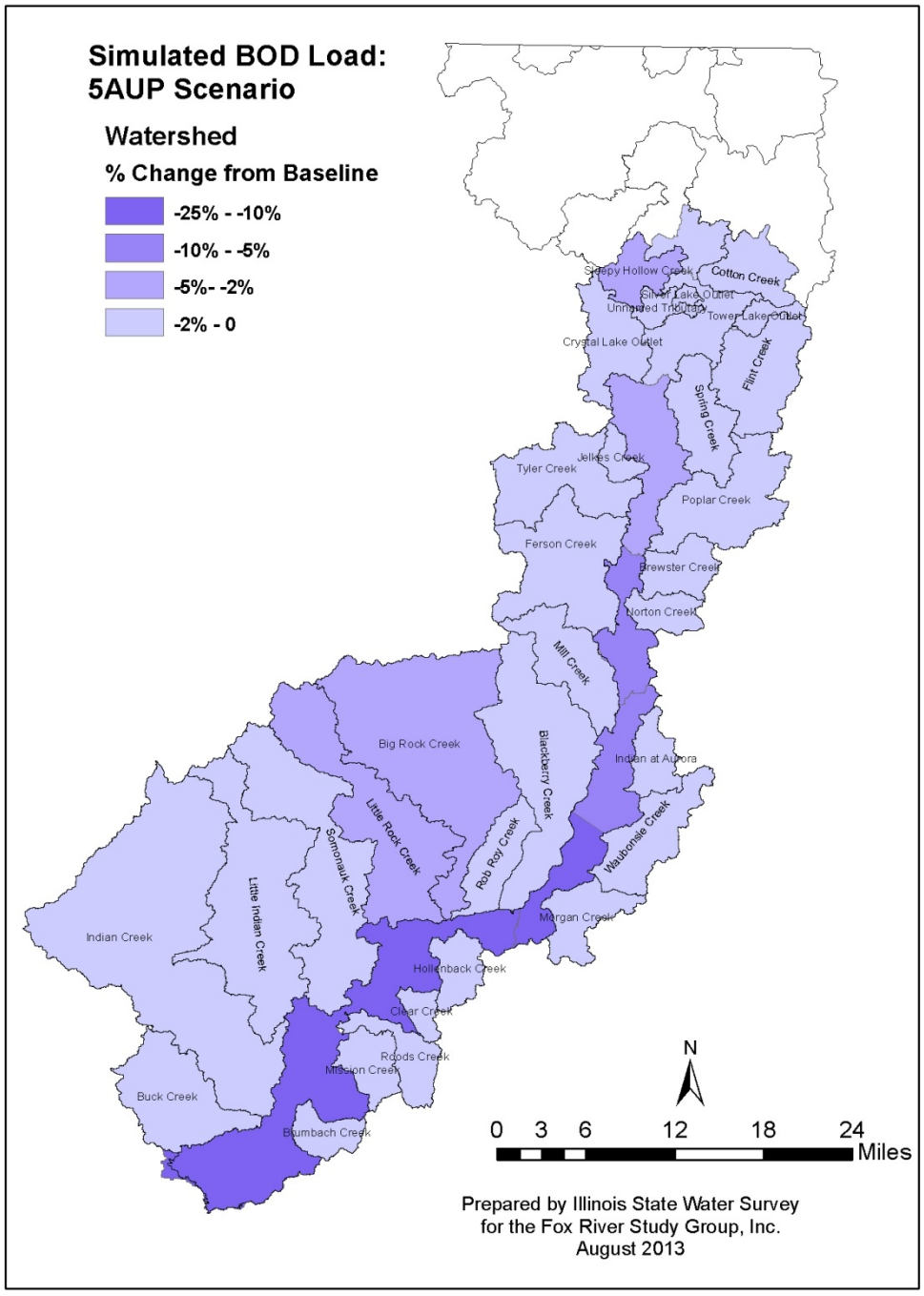
Map 22. Percent change in total phosphorus load simulated for 5AUP compared to Baseline



Map 23. Percent change in total nitrogen load simulated for 5AUP compared to Baseline

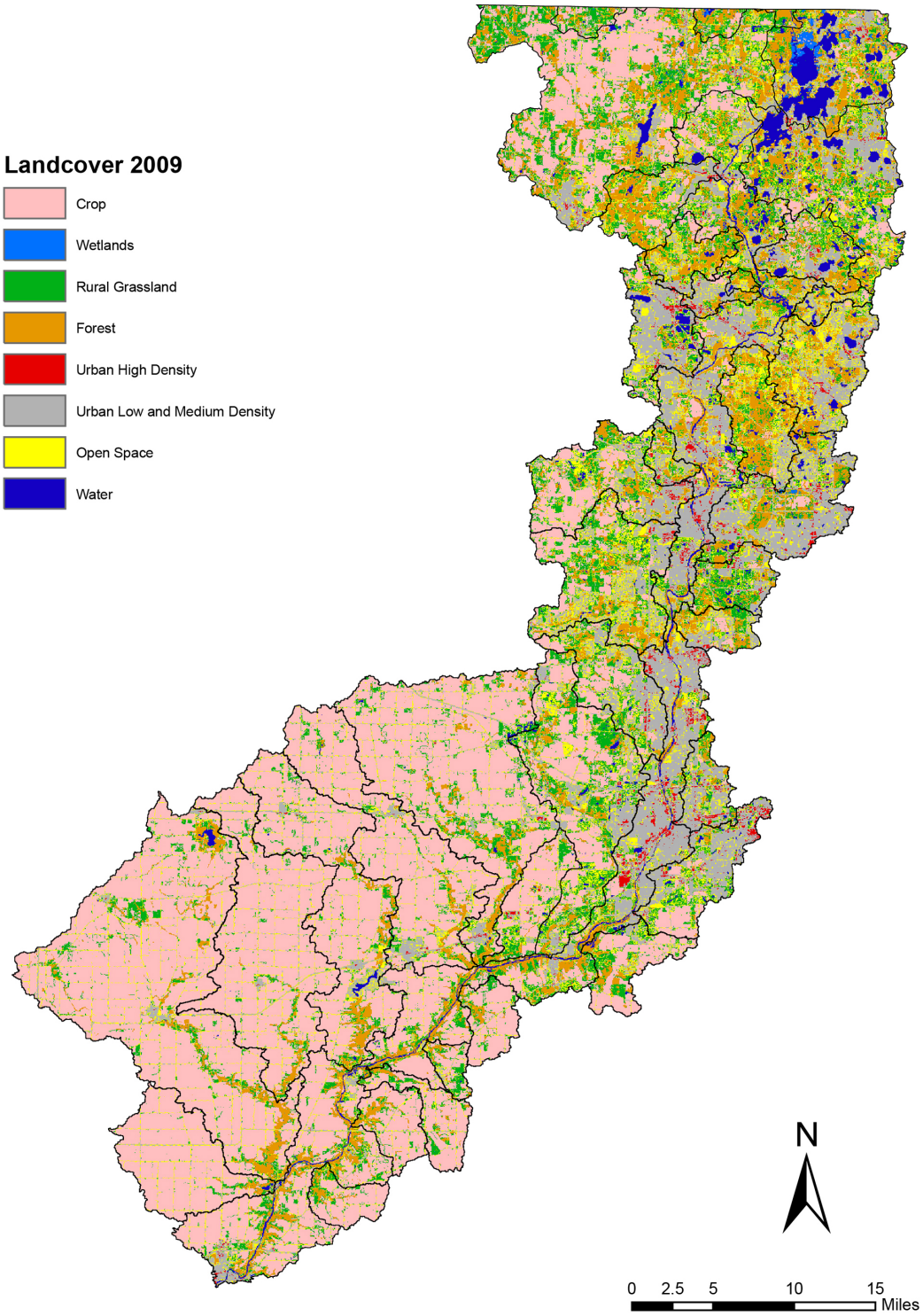


Map 24. Percent change in BOD_5 load simulated for 5AUP compared to Baseline

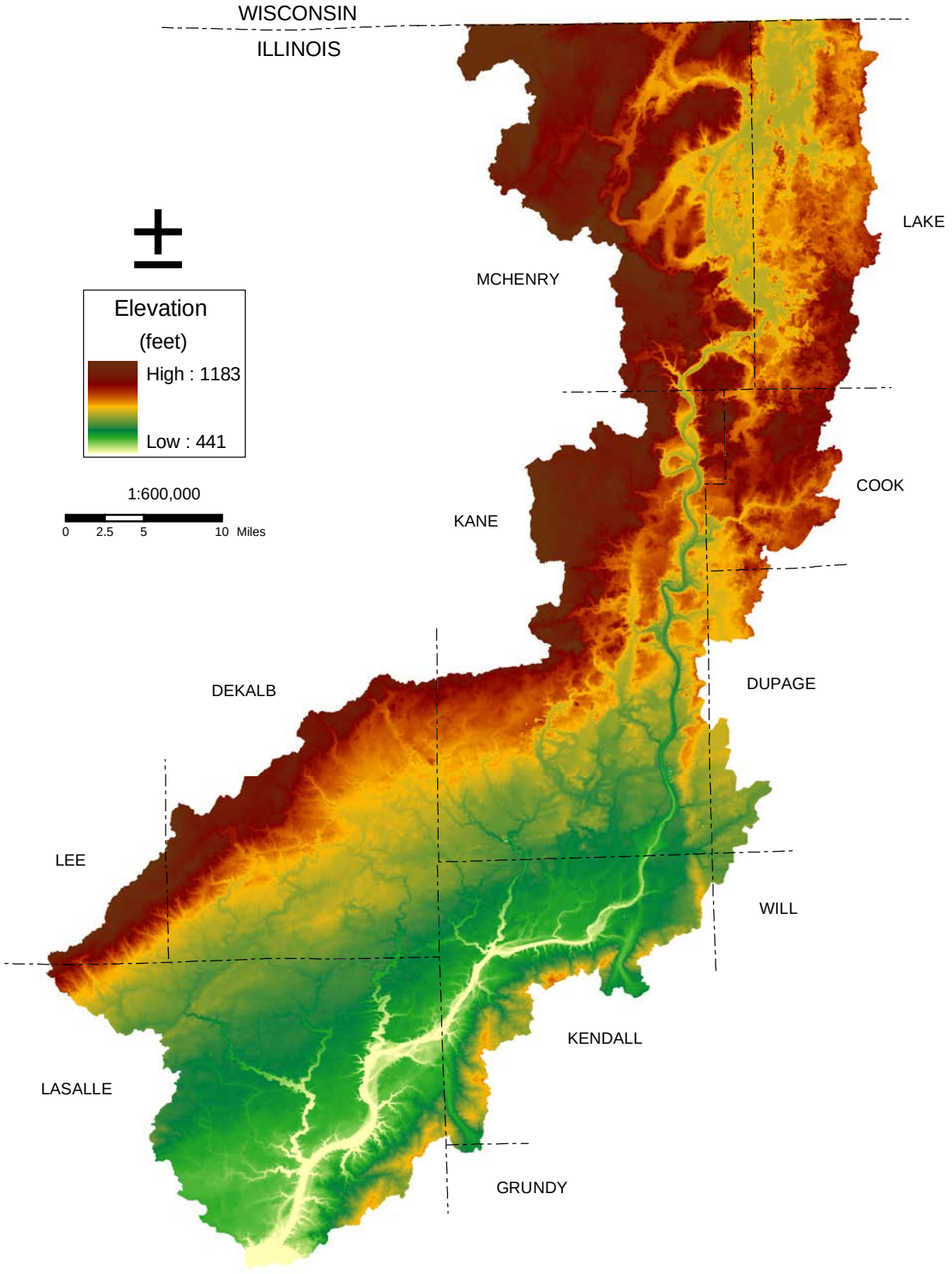


Appendix E
Fox River Watershed Maps

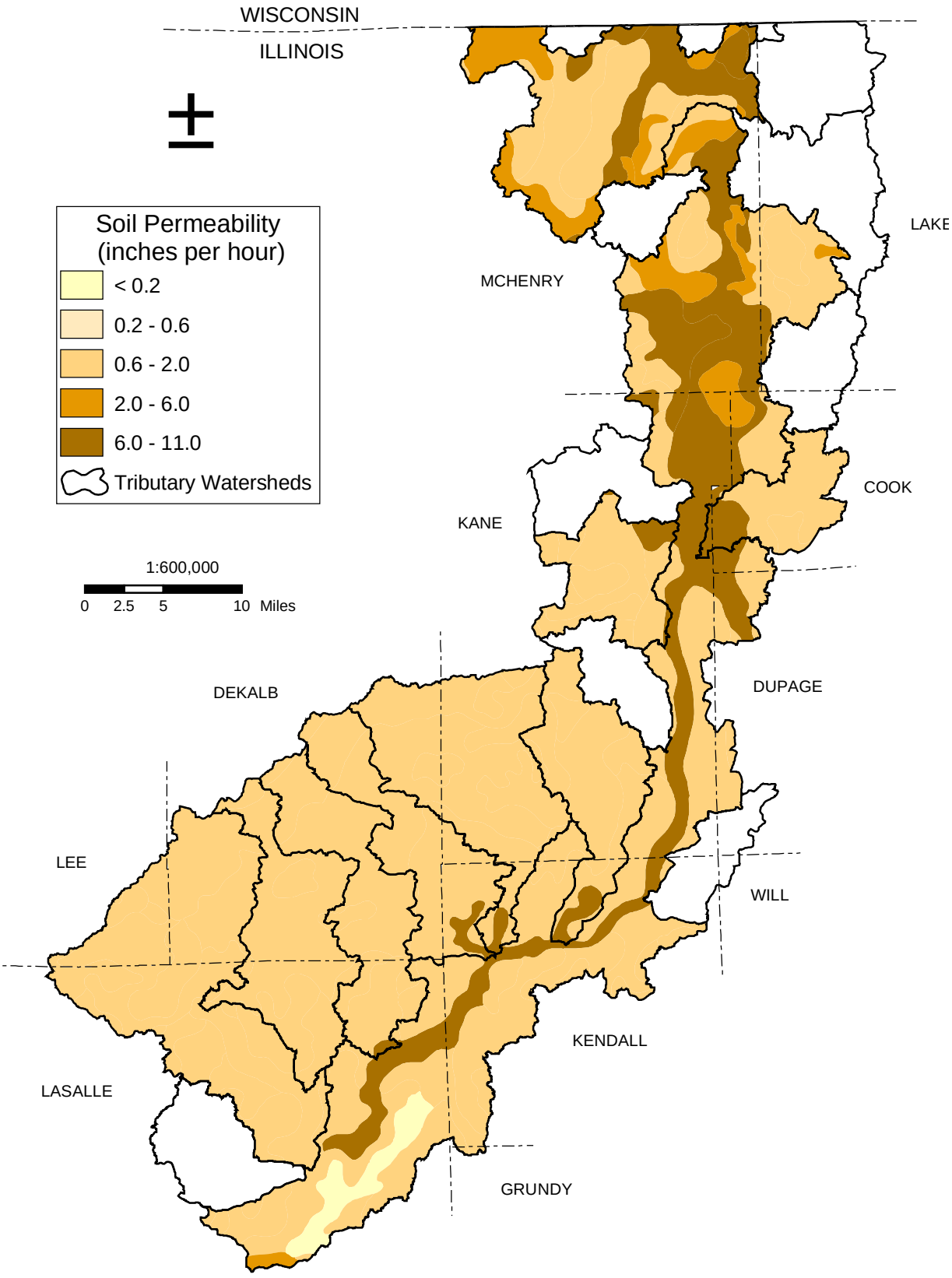
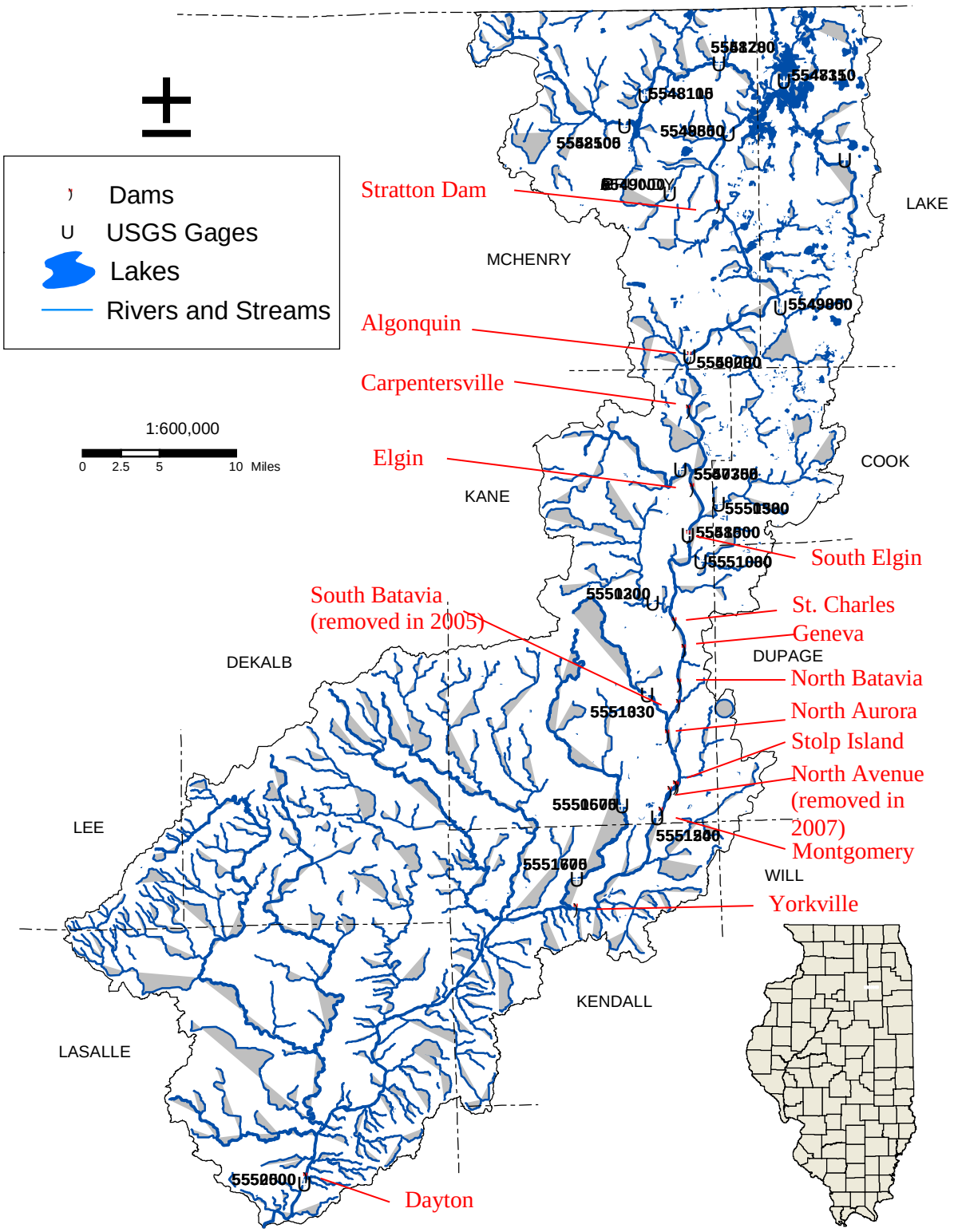
Map 25: Land Cover (2009)



Map 26: Elevation



Map 27: Soil Permeability



Map 28: Dams and USGS Gages